ANSTO/E-730

ENVIRONMENTAL and EFFLUENT MONITORING at LUCAS HEIGHTS SCIENCE and TECHNOLOGY CENTRE, 1996

by

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JUNE 1997

ISSN 1030-7745
ISBN 0 642 599 688

REPORT E

ANSTO/ E-730

AUSTRALIAN NUCLEAR SCIENCE
AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS SCIENCE and TECHNOLOGY CENTRE

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ABSTRACT

Results are presented of environmental and effluent monitoring conducted in the vicinity of the Lucas Heights Science and Technology Centre (LHS&TC) during 1996. 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 during this period, were estimated to be less than 0.010 mSv/year for receptor locations on the 1.6 km buffer zone boundary around HIFAR. 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 adopted by ANSTO.

ISSN 1030-7745

ISBN 0 642 599 688

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.

ANSTO; AIR; AMERICIUM 241; AUSTRALIA; BERYLLIUM 7; CESIUM 137; COBALT 60; CONTAMINATION; DOSE LIMITS; ENVIRONMENT; ENVIRONMENTAL EXPOSURE PATHWAY; EVALUATED DATA; EXPERIMENTAL DATA; FRESH WATER; GAMMA RADIATION; GASEOUS WASTES; GROUND WATER; IODINE 131; LIQUID WASTES; PARTICULATES; PLUTONIUM 239; PUBLIC HEALTH; RADIATION DOSES; RADIATION MONITORING; RADIOACTIVE EFFLUENTS; RADIOACTIVITY; SOILS; THERMOLUMINESCENT DOSIMETRY; TRACER TECHNIQUES; TRITIUM.

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ENVIRONMENTAL AND EFFLUENT MONITORING AT LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE, 1996

EXECUTIVE SUMMARY

The environmental and effluent monitoring results for 1996 show that the Australian Nuclear Science and Technology Organisation (ANSTO) complied with effluent discharge authorisations and relevant environmental regulations.

In September 1995 a revised Trade Wastewater Agreement was negotiated with Sydney Water Corporation. This Agreement required ANSTO discharges to comply with:

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

Radionuclide concentrations in liquid effluent discharged to the sewer were well below the limits specified for the most restrictive alpha and beta emitters and tritium prescribed in the former NSW Radioactive Substances Regulations (1959). The mean monthly radionuclide concentration quotient for liquid effluent discharged to the sewer during 1996 was 0.20 representing 20% of the limit, with the individual monthly quotients ranging from 0.11 to 0.37.

The mean radionuclide concentration quotient (based upon the WHO *Guidelines for Drinking-Water Quality*) in liquid effluent for 1996, was 0.21. This represents 21% of the limit. Individual monthly quotients ranged from 0.12 to 0.33.

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

Potential effective doses to local members of the public from controlled airborne discharges from the Lucas Heights Science and Technology Centre (LHSTC) stacks were all estimated to be less than 0.010 mSv per year for receptor locations on the 1.6 km radius buffer zone boundary around the HIFAR research reactor. This value represents 1.0% of the annual dose limit of 1 mSv for members of the public recommended by the National Health and Medical Research Council (NH&MRC) and 3.3% of the dose constraint of 0.3 mSv per year adopted by ANSTO.

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

Environmental monitoring at the Little Forest Burial Ground (LFBG) indicated similar trends to past years. The low levels of americium-241 detected in monitoring bores OS2 and MB16 in 1995 were confirmed by further analyses undertaken by the Australian Radiation Laboratory. Investigations into the source of the americium-241

have shown that it is associated with the sediments in the bores, which are disturbed and suspended when the water is sampled. When filtered samples from the same bores were analysed, no americium-241 was detected. The sampling and analysis techniques were modified to achieve more representative samples and avoid contamination of the water samples with sediment.

The routine monitoring for airborne particulates at LFBG was disrupted during 1996 by incidents of vandalism and theft of the on-site sampling equipment. The sample for the first quarter of 1996 showed no detectable levels of beryllium, and was insufficient to be analysed for plutonium. No further samples were collected. A new sampling procedure based on a portable high-volume air sampler is being implemented. The LFBG site has been a stable and well-grassed area for many years, which makes it less likely that potentially contaminated airborne particulates could be transported off-site. Radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

During the year, thermoluminescent dosimeters measured ambient gamma radiation at various locations around the LHSTC perimeter fence and at three private residences in the nearby suburbs of Barden Ridge, Engadine and Woronora. Measurements of absorbed dose in air at the three residential locations showed an average integrated absorbed dose of 0.7 mSv/year. This level is consistent with figures reported in a survey conducted by the Australian Radiation Laboratory (1990), of ambient levels in the various State or Territory capitals around Australia due to radiation from naturally occurring terrestrial gamma emitting radionuclides in the environment.

Absorbed dose levels of up to 3.2 mSv/year were registered at some locations in the south-western sector of the LHSTC perimeter fence. These elevated readings are a result of gamma emissions from some drums containing nuclear material which had temporarily been stored in the area. This part of the site is not readily accessed by the general public. The maximum dose observed is just above the level considered typical for annual effective doses to adults from natural sources (UNSCEAR 1993). This material has since been relocated to the building 59 storage facility extension, further away from the site perimeter. Subsequent dose rate meter readings indicate a 30% reduction in the dose rates at the perimeter fence closest to building 59. The dosimeter readings for 1997 should also reflect a similar reduction.

Biological and seawater monitoring continued at Potter Point ocean outfall during 1996. Treated sewage effluent for the Sutherland Shire, including low-level effluent from the LHSTC, passes through the Cronulla Sewage Treatment Plant and is discharged at Potter Point. The seawater and biological sampling programs are aimed at assessing potential doses to members of the public who may recreate in the ocean off Potter Point and/or ingest fish caught in the vicinity of the outfall.

The biological monitoring program at Potter Point was designed to maximise the chances of detecting radionuclides in the marine environment. Three types of sample were collected: fish, macrophytic algae and barnacles. Similar samples were also collected from a reference site, approximately 5.5 km south of Potter Point, at The Royal National Park. No activity which could be directly attributed to ANSTO was found in any biological samples taken from Potter Point in 1996.

The tritium levels offshore in the immediate vicinity of Potter Point were investigated in April and November 1996. The tritium levels are normally below the limit of detection (5 Bq/L), however on 14 November 1996 low tritium levels were detected. Due to the calm conditions, the effluent plume rose to the surface and could be sampled as close as 100 metres from the cliff outfall. The maximum tritium level observed was 251 Bq/L which is 3.2% of the WHO reference value for tritium in drinking water. In an associated investigation, the transit time for wastewater flow from Lucas Heights to the Cronulla Sewage Treatment Plant was 10 hours and the minimum in-line dilution factor 21.5. These results are consistent with results in 1994 and 1995.

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, and well below the NH&MRC recommended dose limits for members of the public and the lower dose constraint level adopted by ANSTO.

ENVIRONMENTAL AND EFFLUENT MONITORING AT LUCAS HEIGHTS

1.0 INTRODUCTION

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

The environmental and effluent monitoring programs are aimed at detecting and quantifying any radioactive contaminants, released from LHSTC either routinely as authorised discharges or as a result of accidental release, and to verify that such releases do not result in radiation exposure to the general public in excess of the limits recommended by the International Commission on Radiological Protection (ICRP) and adopted by the National Health and Medical Research Council of Australia (NH&MRC).

This report summarises the results from the environmental and effluent surveys during 1996 and assesses the effects of radioactive discharges on both the local population and the environment. The results obtained in earlier surveys have been published regularly and are listed in **Appendix A.**

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

2.0 ENVIRONMENTAL PATHWAYS

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

- atmospheric discharges from stacks (including tritium, fission products, activation products and noble gases released from isotope production facilities, research laboratories and the HIFAR research reactor);

- discharge of low-level liquid effluent, via the Sydney Water Corporation Ltd (hereafter referred to as Sydney Water) sewer system, and hence to the ocean at the Potter Point outfall;

- radionuclide transport by surface/ground water and/or contaminated airborne particulate dispersion from the Little Forest low-level radioactive waste Burial Ground (Little Forest Burial Ground);

- accidental airborne releases or spillages which enter the stormwater system.

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 iodine-131. Iodine-131, strontium-90 and caesium-137 have the potential to concentrate in milk after deposition onto grazing land. Thus, milk consumption is a potentially significant pathway for the transfer of airborne radioactivity to people.

The critical group for the milk consumption pathway is assumed to be one year old infants living adjacent to LHSTC at Steven's Hall Motel (shown on **Figure 2**) who are given all their milk requirements (0.7 L per day) from a hypothetical local dairy. The closest registered dairy herd to LHSTC is at Glenfield, approximately 13 km away (NSW Dairy Corporation, 1995). Since 1993, ANSTO has not been aware of any milk supplies in the neighbourhood. Hence this pathway is no longer considered significant.

A hypothetical critical group for inhalation of airborne activity is assumed to consist of people living close to the LHSTC perimeter at Steven's Hall Motel. Accordingly, continuous air samplers are located close to the site perimeter fence at sites nearest to suburban residences and Steven's Hall.

Other potential pathways for the transfer of airborne radioactivity to members of the public usually include such dietary items as drinking water and vegetable produce. However, these are not considered significant sources of exposure since there is little or no commercial food production or processing in the neighbourhood of LHSTC and small creeks receiving runoff from the site are not used as sources of drinking water.

Levels of integrated external radiation at the LHSTC and in nearby suburban locations, were also measured during 1996 using dosimeters issued by the Australian Radiation Laboratory.

2.2 The Discharge of Low-level Liquid Effluent

Since June 1980 the low-level liquid effluent generated from various operations at the LHSTC has been chemically treated and analysed to verify compliance with authorised discharge limits before discharge to the Sydney Water sewer. In accordance with the Trade Waste Agreement **(Section 3.1)** the authorised discharge limits were those specified in the NSW Radioactive Substances Regulations (1959).

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

Studies to confirm the negligible level of radionuclides from LHSTC in seawater a short distance from the Potter Point outfall have been undertaken since 1993 and published in ANSTO's *Environmental and Effluent Monitoring at LHSTC* reports (listed in Appendix A). The results of further studies on liquid effluent released to the sewer, undertaken in 1996, are presented in **Section 5.3** of this report. A biological monitoring program at Potter Point was established in 1995.

2.3 The Little Forest Burial Ground (LFBG)

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

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

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

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

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

Ground water and surface water associated with the LFBG and surrounding area is not currently utilised as a potable water supply, and the ephemeral nature of the streams excludes their use for any large scale irrigation of crops. The hydrogeological conditions at LFBG ensure that groundwater movement in the immediate area of the low-level wastes is very slow and most radionuclides, with the exception of tritium, are readily adsorbed onto the clay subsoil of the LFBG site.

Airborne contamination at LFBG could potentially occur through wind suspension 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 as soon as possible.

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

3.0 DISCHARGE AUTHORISATIONS

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

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

In 1993, the NSW Environment Protection Authority (EPA) withdrew from its role of regulating ANSTO's compliance with NSW legislation. Until the AIRP is established, the Australian Radiation Laboratory has agreed to independently audit and verify ANSTO's effluent and environmental monitoring programs.

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

Summaries of 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

Since mid-1980 when the then AAEC's liquid effluent discharges were re-directed to the Sydney Water sewer, all liquid effluent discharges are required to comply with the Sydney Water requirements for acceptance of liquid trade waste as set out in the Trade Waste Agreement (see below). In September 1993 the NSW Radiation Control Regulation (1993) came into force. However, this regulation does not specify generic radioactivity concentration limits for liquid discharges to the sewer.

During 1996 ANSTO continued its policy of ensuring that all liquid effluent discharges conform with the concentration limits specified in the former NSW Radioactive Substances Regulations (1959), pending the establishment of the AIRP.

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

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

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

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

$$\sum_i \frac{C_i}{\mathrm{MPC}_i} \leq 1$$

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

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

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

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

The activity concentration limits for the presumed most restrictive alpha or beta emitting radionuclides and tritium, are shown in the following table.

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

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

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

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

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

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

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

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

This equation involves the following assumptions:
Committed effective dose - The committed effective dose limit for an individual nuclide in drinking water is set at 0.1 mSv/year, which is approximately one twentieth of the average background radiation dose from all sources (UNSCEAR 1993);

Volume of water consumed - The volume of water consumed by an adult each day is assumed to be 2 litres. This figure is used by the World Health Organisation and is believed to be appropriate for Australian conditions. Annual consumption is then 730 litres;

Dose conversion factor - Once a radionuclide is inside the body, its metabolic behaviour and internal dosimetry (*ie.* the effect of a given dose on specific organs) must be considered. This yields the dose conversion factor, which is the committed effective dose (in mSv) received as a result of ingesting one becquerel of the radionuclide.

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

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

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

The WHO Guidelines are deemed to apply at the Cronulla Sewage Treatment Plant (CSTP). A conservative dilution factor of 25 is assumed between the ANSTO discharge point and the CSTP (**Section 5.3**).

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

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

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

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

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

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

Compliance with the Regulations

Compliance with the discharge authorisations was routinely monitored by ANSTO. Prior to the establishment of the AIRP, the Australian Radiation Laboratory within the Commonwealth Department of Health and Community Services has agreed to independently audit and verify ANSTO's effluent and environmental monitoring programs. Sydney Water also collects random liquid effluent samples from the ANSTO discharge pipeline, to assess compliance with their requirements for the acceptance of liquid trade waste.

3.2 Gaseous Emissions

From 1968 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 which could be discharged from each of the stacks at LHSTC during a given time period.

In 1988, ANSTO proposed to the NSW RAC a revised site-wide airborne radioactive effluent discharge limit for LHSTC. The proposed revision arose out of changes to ICRP and NH&MRC recommendations occurring in the intervening 20 years, site operational changes, advances in radiation dosimetry and increased knowledge of the local meteorology at LHSTC. It was based on limiting the total amount of radioactivity discharged to the atmosphere from LHSTC, such that the sum of the effective dose to any member of the public from all stack discharges would not exceed 0.5 mSv. This is half of the annual effective dose limit for members of the general public recommended by the NH&MRC and specified in the NSW Radiation Control Regulation (1993).

The basis of the proposed new discharge authorisation is the demonstration of compliance by the use of an independently-reviewed, ANSTO-developed, computer-based, atmospheric dispersion, transport and dosimetry model (ADDCOR[2]) which requires stack discharge monitoring information as well as local meteorological data and internationally accepted dosimetry parameters.

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[2] Atmospheric Dispersion and Dosimetry Code for Operators and Regulators.

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

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

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

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

3.3 Surface Waters

The NSW Clean Waters Regulations (1972) as amended, limit the gross alpha and gross beta activity in class C waters to 1.1 and 11.1 Bq/L, respectively. In order to assess ANSTO's compliance with these regulations, sampling points were selected by the State Pollution Control Commission (SPCC, now the NSW EPA) at Strassman, MDP and Bardens Creeks. These creeks, shown on **Figure 2,** receive most of the stormwater running off the LHSTC area.

4.0 MEASURED RADIOACTIVITY

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

4.1 Types of Radioactivity Measured

Gross alpha activity: refers to the measurement of total alpha activity from unspecified nuclides in a sample. Screening for gross alpha emitters is a rapid, semi-quantitative technique used to determine whether more complete analyses for specific radionuclides is 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: Gamma rays emitted from radionuclides are analysed on a high purity germanium solid state detector. A gamma spectrum for each sample is accumulated in an energy range from 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 which was widely dispersed around the world by atmospheric nuclear weapons testing. The isotope is deposited in precipitation or as 'dry' fallout, and adsorbs strongly onto fine clays, so that it is mostly contained within the top few centimetres of soil. It is subsequently redistributed by erosion and sedimentation processes. 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 bomb-casings or 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: This fission-product radionuclide has a half-life of only 8 days, but is biologically important because it can deposit onto pasture and be incorporated into milk. Human consumption of this milk can then lead to iodine-131 up-take by thyroid tissue. Further, inhalation of gaseous iodine-131 can also result in doses to the lung and thyroid. Iodine is more readily concentrated by marine biota than by freshwater organisms.

Tritium: Tritium (^{3}H) is a radioisotope of hydrogen, with a half-life of 12.26 years. It decays by the emission of a weak beta particle, with a maximum energy of 18.6 keV and an average energy of 5.69 keV (there is no corresponding gamma emission). The penetration of the tritium beta is consequently low (the stopping distance is about 7 mm in air, 0.01 mm thickness of paper, or the outer dead layer of human skin). Thus, only exposure through internal uptake needs to be considered in assessing radiation dose. The allowable limit of intake for tritium is relatively high in comparison with other more energetic radionuclides (see the table of Drinking Water Reference Concentrations in **Section 3.1.2**).

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

Tritium (as tritiated water) is chemically indistinguishable from normal water, and hence does not undergo geochemical processes such as ion exchange, adsorption or precipitation during transport through geologic media.

4.2 Natural Radioactivity in Environmental Samples

Uranium and thorium series

The uranium-238 and thorium-232 chains are two of the primordial radioactive decay series found in nature. The extremely long half-lives of the parent nuclides (4.5×10^9 and 1.4×10^{10} years respectively) mean that the various daughter radionuclides produced by their decay are ubiquitous in nature, occurring to varying degrees in soils, water, vegetation and air. When present in environmental samples, the daughter products of the uranium and thorium series can contribute significantly to the levels of gross alpha, gross beta and gamma radioactivity of such samples. Levels of the uranium-238 and thorium-232 series in LHSTC environmental survey samples have not been quantified, considering the natural origin of such activity, and the extensive and costly procedures required. If daughters of the uranium-238 and thorium-232 decay series are detected during gamma spectroscopy of samples, their presence is reported in the relevant tables simply as "U & Th series". Typical activities of uranium and thorium and each of their 24 radioactive daughters range from 0.001 to 0.520 Bq/g in different soil types (adapted from UNSCEAR 1993: Table 5, p 65).

Potassium-40

Potassium-40 (half-life 1.28×10^9 years) is a primordial radioisotope of potassium, and since potassium is an essential element, it is found in all living and formerly living things. Potassium-40 occurs naturally in a fixed ratio to stable potassium, and decays by beta/gamma emission with a specific activity of 27.6 Bq/g of stable potassium (NH&MRC 1987). Potassium-40 does not accumulate in the body but is maintained at a constant level. The average concentration of potassium in an adult male is about 2 g per kg of body weight, or about 60 Bq of potassium-40 per kg of body weight.

For crustal rock, the mean potassium-40 activity is 0.63 Bq/g, while some granites may have concentrations exceeding 1.85 Bq/g (Kathren 1984). Soils are lower, with a mean of around 0.44 Bq/g. Concentrations in seawater are approximately 10 Bq/litre.

Beryllium-7: Beryllium-7 is a cosmic spallation product, with a relatively short half-life of 53.3 days. Sometimes found in soils, plants and marine biota, ^{7}Be is of little, if any, biological significance.

4.3 Counting Statistics

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

Most of the results from the Environmental Monitoring programme 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.

They have established the following definitions of statistically determined decision levels in terms of the following questions:

- **Critical limit** (L_C) - a decision level: 'Is the net count significant?'
- **Upper Limit** (L_U) - 'Given that this count is not statistically significant, what is the maximum statistically reasonable count?'
- **Minimum Detectable Activity** (MDA) - 'What is the least amount of activity measurable?'

In practice, these decision limits were applied as follows:

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

- The critical limit, L_C, is defined as that count at which there was only a 5% chance that a count would be judged to be present when in reality it was not. L_C was calculated from the formula $2.33B^{1/2}$ (equation 5.54, page 120 of Gilmore and Hemingway), and compared with the net sample count or peak area.

- If the sample's net count (or peak area) is greater than L_C we can say with 95% certainty that the activity has been detected, and a result with an associated uncertainty is quoted. Otherwise, the sample is judged to be inactive and an *upper count limit,* L_U, is calculated. The L_U value is passed through the normal activity calculation to produce an *upper activity limit* which can be equated with the MDA.

The Minimum Detectable Activity (MDA) is the minimum amount of radioactivity which can be determined given the particular conditions of measurement. The calculation procedure is presented in Section 5.6.7 (page 123) of Gilmore and Hemingway.

Throughout this report, results have been rounded off to the appropriate number of significant figures. Where given, uncertainties are quoted at one standard deviation (counting error only).

5.0 ENVIRONMENTAL & EFFLUENT MONITORING

The monitoring programs at LHSTC involve measurements of the radioactivity in local environmental samples, and in liquid and airborne effluents discharged from the site. The annual external gamma radiation levels around LHSTC have been measured since 1994. The on-site meteorological station collects data all year round.

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

5.1 ENVIRONMENTAL MONITORING

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

Samples of soil, sediment, groundwater, air and surface water were collected during 1996 at the sites shown in **Figures 1, 2, 3 & 5** and analysed for radioactivity. Sampling locations included the Woronora River, Mill Creek, Bardens Creek, Forbes Creek, Potter Point ocean outfall, LHSTC stormwater outlets, the creeks draining LHSTC and the Little Forest Burial Ground.

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

Environmental survey results for 1996 are presented in **Tables 2 to 18a**.

5.1.1 Woronora River

Routine water samples were collected weekly from the Woronora River at the boat ramp in Jannali Reserve, until June 1996. These water samples were analysed for tritium as an indicator of possible pipeline leaks. No tritium has been detected in weekly samples since discharges of treated liquid effluent from LHSTC to the Woronora River ceased on 1 July 1980. Sampling at this location is now performed monthly. No tritium was detected in the monthly samples during 1996 (see **Table 2**).

5.1.2 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, the location is shown on **Figure 1**.

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

No tritium was detected in any of the samples collected during 1996 (see **Table 3**).

5.1.3 Potter Point Ocean Outfall

Seawater

In 1996 no seawater was collected from the 1995 sampling point on the shore at Potter Point (200 metres south of the ocean outfall). However, the samples collected during the offshore investigations reported in **Section 5.3** were considered to be more representative than the shoreline sampling point, since they were collected directly from the sewage plume.

Biological Monitoring

The biological monitoring program at Potter Point was designed to maximise the chances of detecting radionuclides in the marine environment across a range of trophic levels in the food chain. Two sampling trips were made during 1996, and three types of sample were collected within a 10-20 metre radius of the outfall: fish; macrophytic algae and barnacles.

A reference coastal sampling site was selected for comparison purposes at The Royal National Park, approximately 5.5 km south of Potter Point, where specimens of fish, green algae and barnacles were also collected.

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

Common Name	Scientific Name
blackfish	*Girella sp.*
green algae	*Enteromorpha sp.* and *Cladophora sp.*
surf barnacles	mainly *Tesseropera rosea*

The approximate quantities of biological material collected were:

Location	Total Mass of Material Collected (kg FW)		
	Fish	Green Algae	Barnacles
Potter Point	1.3	3.9	1.3
Royal National Park	0.5	0.9	0.4

Blackfish were caught using a fishing line baited with weed, while the green algae and barnacles were scraped off the rocks. Fish were filleted and skinned, the algae and barnacle samples were left whole. Samples were dried and analysed for gamma-emitting radioisotopes. See **Appendix D** for further details of sample preparation and analysis.

The sampling location at Potter Point is shown on **Figure 5**, and the results for fish, algae and barnacles are presented in **Tables 4, 5 & 6**.

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 macroalgae. No fission-product activity was found in any samples obtained from The Royal National Park. Isotopes which are considered to be of natural origin were found at similar levels in samples from Potter Point and The Royal National Park.

Apart from iodine-131 all of the gamma-emitters detected at significant levels in the biological samples are considered to be natural radioisotopes which are expected in marine specimens. Such radioisotopes included beryllium-7, potassium-40 (ubiquitous in biological samples) and daughter products of the uranium-238 and thorium-232 decay series, such as lead-210, thorium-224 and thallium-208. The uranium/thorium-series daughter isotopes were not quantitatively determined considering the extra effort required and their natural origin.

The short-lived isotope iodine-131 was detected in algal samples from Potter Point, in concentrations of 8 to 22 Bq/kg fresh weight (corrected for decay from sampling date). Algae are extremely efficient in scavenging iodine isotopes in the marine environment and have high concentration factors (see the table below).

Concentration Factors for Caesium-137, Cobalt-60 and Iodine-132 (similar to Iodine-131) in Marine Organisms

Marine Organism	Recommended Concentration Factors*		
	Cobalt-60	**Caesium-137**	**Iodine-132**
Fish	1 000	100	10
Molluscs	5 000	30	10
Macroalgae	10 000	50	1 000
Zooplankton	2 000	20	3 000
Phytoplankton	5 000	30	2 000

*Recommended Elemental Concentration Factors for Radionuclides in the Marine Environment, from IAEA Technical Reports Series No. 247, 1985.

Considering these concentration factors it is not unexpected that low levels of radionuclides may be detectable, especially in algal samples. The levels of iodine-131 found in macroalgae from Potter Point are of no health significance to humans.

The potential radiation dose to members of the general public as a result of ANSTO's discharges to the sewer is very low.

Note that ANSTO is not the only source of radionuclides entering the sewer system in the Sutherland Shire.

5.1.4 Stormwater Outlets

Stormwater retention bunds

During 1994, small capacity concrete stormwater retention dams (or 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 which enter the site stormwater system. They are also used as environmental monitoring points.

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

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

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

Tritium in Stormwater

Tritium results for water from the stormwater retention bunds are shown in **Table 9.**

Tritium was detected at levels well below the WHO drinking water reference concentration of 7800 Bq/L (**Section 3.1.2**). 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.

Sediment from Stormwater Bunds

Results for samples of sediment collected in the three stormwater bunds are shown in **Table 9a.**

Measurable amounts of radioactivity were detected in sediment samples collected. The low-level activities found at this location do not have any health consequences for humans.

Stormwater Outlet No.1

Stormwater Outlet No.1 drains the south-east corner of the site into MDP creek (**Figure 2**), and has experienced some low-level radioactivity contamination of sediment and vegetation in the past. Historically, it has been sampled in a small pool about 60 metres below the actual stormwater outlet itself. However, the concrete retention bund now collects any run-off from this sector of the site, and has become the most appropriate sampling point. Accordingly, in 1997, sampling of the MDP bund will replace the Stormwater Outlet No.1 location (MDP+60m).

In 1996, Stormwater Outlet No.1 was sampled and analysed for tritium on a weekly basis. Some of the weekly sample was combined each month to make a composite sample for gross alpha, gross beta and gamma spectrometry analyses.

Tritium

Tritium results for Stormwater Outlet No.1 are shown in **Table 7**. Tritium levels in the weekly samples from Stormwater Outlet No.1 varied from 60 to 3830 Bq/L. The average tritium level here in 1996 was 350 Bq/L. This is 4.5% of the WHO drinking water reference concentration.

Gamma spectrometry (Stormwater Outlet No.1 monthly composite samples)

Caesium-137 at low levels was identified by gamma spectrometry in water samples from Stormwater Outlet No.1 (**Table 8**). The average caesium-137 concentration for 1996 was 0.022 Bq/L, which represents less than 0.2% of the WHO drinking water reference concentration.

Gross alpha/beta (Stormwater Outlet No.1 monthly composite samples)

Monthly gross alpha and gross beta radioactivity results for stormwater outlet No.1 were at background levels throughout the year.

Conclusion

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

5.1.5 Creeks Draining LHSTC

SPCC weir sampling points
The stormwater which drains from the LHSTC flows into three small local streams which are classified as class 'C' waters under the NSW Clean Waters Regulations (1972). In 1975, the then SPCC required that the stormwater be sampled periodically at selected locations, in order to demonstrate compliance with the activity limits specified in the NSW Clean Waters Regulations (1972). Sampling points on Strassman Creek, Bardens Creek and MDP Creek (**Figure 2**) are sampled and analysed for gross alpha and gross beta activity. This data is 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 of 1.1 Bq/L for gross alpha activity, and 11.1 Bq/L for gross beta activity.

Samples of water were also collected from the SPCC sampling weir on Bardens Creek at weekly intervals during 1996 for tritium analysis. The results are shown in **Table 11**. The highest value recorded during the year was 140 Bq/L, which is 2% of the reference concentration for tritium in drinking water (**Section 3.1.2**). The average weekly concentration at this location was 80 Bq/L, which is 1% of the reference value. It should be noted that water from Bardens Creek is not part of any known drinking water supply.

5.1.6 Effluent Discharge Pipeline

The ANSTO liquid effluent disposal pipeline, which runs above ground for much of its length, is shown on **Figure 2**. Surveys of the dose rates along this pipeline were carried out in 1996, and the results are summarised in **Table 12**. These surveys were performed as part of the regular program of inspection and maintenance of the pipeline.

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

5.1.7 Little Forest Burial Ground (LFBG)

Results of sampling at the LFBG are given in **Tables 13, 14a, 14b, 14c** and **15**. The locations of the sampling points and the burial trenches are shown in **Figure 3**.

Radiation survey
Annual surveys of the burial trenches are carried out using field dose rate monitors to check for surface contamination (**Table 13**). Dose rates over the trenches ranged from 0.05 to 0.15 µSv/hour, consistent with normal background readings. Of the two localised points #5 and #6, which have shown elevated readings in the past, only point

#6 is now slightly above background levels. Results for this year are in the same range as those previously measured at these locations.

Soil

The 1996 gamma radiation survey did not indicate any areas which were greater than three times the background, therefore no soil samples were collected.

Groundwater Monitoring

Groundwaters from monitoring bores located inside the LFBG and outside the fenced area were collected in May and December 1996 and analysed for tritium, gross alpha, gross beta and gamma activities. Results are listed in **Tables 14a, 14b & 14c.**

Changes in Sampling & Analysis Methods for Groundwaters

A decision was made during the year to replace the traditional AAEC/ANSTO sampling and analysis methods (for gross alpha/beta and gamma activity) of the groundwater with those used by the Australian Radiation Laboratory. The procedures are outlined in **Appendix D**. The essential difference is that the AAEC/ANSTO sampling method disturbed sediments at the bottom of the bores, and the preparation method included any suspended matter present. The unacidified samples were evaporated, the dried residues collected and compressed into 50 mm x 3 mm tablets. These tablets were then counted for gross alpha/beta and gamma activity. The data therefore reflected the level of activity adsorbed on the fine sediments sampled with the groundwater and were reported as Bq/g of sediment.

The sampling procedure has been modified to reduce disturbance of sediments in the bores when pumping out the samples.

In the ARL sample preparation procedures, separate sources are prepared for gamma and gross alpha/beta counting. The groundwater is acidified, allowed to settle, and two volumes of clear sample decanted and evaporated. One sample is incorporated into an agar gel matrix for gamma spectrometry in the usual manner. For gross alpha/beta determinations the International Organization for Standardization (ISO) standard methods 9696:1990 & 9697:1990 are used. These involve sulphating the evaporated sample, then drying and igniting the residue which is spread and fixed onto a planchette for counting. The results are in Bq/L.

Tritium analysis of all samples remains unaffected, and is performed using the International Organization for Standardization method 9698:1989(E).

The May 1996 samples were prepared using the former ANSTO methods for gamma spectrometry and gross alpha/beta determinations. The December samples were prepared using the new ARL methods. **Tables 14a & 14b** show all the gamma, gross alpha/beta & tritium results in terms of Bq/L for easy comparison of the ANSTO & ARL methods. **Table 14c** shows the May 1996 results in units of Bq/g sediment, for contrast with results obtained in previous years.

Gamma Results

Analyses undertaken by the ARL (at ANSTO's request) confirmed the presence of low levels of americium-241, caesium-137 and cobalt-60 in the 1995 December water sample from MB16, and of americium-241 in the OS2 monitoring bore. The initial ANSTO results were published in report ANSTO/E-725 in 1996 (see **Appendix A**).

In May 1996 further very low levels of americium-241, caesium-137 and cobalt-60 were variously detected in the OS2, OS3, MB13 and MB16 bores. Subsequent studies on the distribution of the activity between the solution and sediment phases, have shown that the majority of activity is associated with the fine sediment suspended in the groundwater samples.

None of the concentrations of americium-241, caesium-137 or cobalt-60 were above the adult drinking water reference concentrations tabulated in **Section 3.1.2.**

When the December 1996 borewaters were analysed for gamma activity using the new ARL method, most of the sediment was visibly excluded from the decanted solutions and consequently, no fission products were detected in any bores other than MB16 which contained some cobalt-60. The activity expressed in MB16 is not unexpected since it is in the centre of the burial trench area. Significant reductions in the activity of uranium & thorium series daughters were also noted in most of the samples.

In contrast to tritium, most other radionuclides dissolved in groundwater are subject to various physical and chemical reactions (including adsorption) when passing through geological media, and clay-rich soil or rock in particular. These reactions retard the movement of radionuclides and consequently they migrate at a slower rate than the groundwater. Although some of the sediments (associated with bores inside the fenced area only) contained fission products, when the sediments were largely excluded from the water samples, little or no activity was detectable.

Gross alpha/beta activity

The levels of gross alpha and gross beta activity in groundwater from LFBG comply with the Clean Waters Act requirements for class C waters, and in the May samples, were mainly due to the contribution from the uranium and thorium series as well as potassium-40, in the sediments. The results for the December samples generally showed reduced gross alpha/beta activity when compared to the May samples, which were analysed using the ANSTO tablet method.

Stream Sediment and Surface Water Sampling

Samples of surface water and sediment were collected from creeks just above the confluence of Mill Creek and Bardens Creek (station T2, **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.

Monitoring Airborne Particulates

No aerosol filters from the Little Forest Burial Ground were collected after March 1996 due to the theft of the sampling equipment and several incidents of vandalism. The filter exposure period was 8/12/96 to 27/3/96. The beryllium result was < 0.005 μg (total). The sample obtained was insufficient to perform the plutonium analysis.

A new sampling procedure based on high-volume air sampling is being implemented.

The LFBG is now a stable and well-grassed area, which makes it less likely that contaminated airborne particulates could be transported off-site.

5.1.8 Ambient Iodine-131 in Air

Four (4) continuous air sampling stations are situated along the eastern fence boundary of the site (where suburban residences are closest) to monitor concentrations of ambient iodine-131 in air. The locations of these samplers are shown on **Figure 2**.

At each station the air is sampled by means of a vacuum pump drawing air through a pair of Maypacks (activated charcoal filter cartridges), so that duplicate samples are available. Air is sampled at a rate of approximately 35 m^3 per day. Filters are replaced and analysed weekly, with air flow rates through the filters being checked at the same time.

No measurable iodine-131 was recorded in the air samplers during 1996 **(Table 16).** The minimum detectable activity was 0.0025 Bq/m^3. The estimated effective dose to a hypothetical member of the critical group living at Stevens Hall Motel, and receiving continuous exposure to iodine-131 at a maximum concentration of 0.0025 Bq/m^3, would be less than 0.01 mSv per year[3].

5.1.9 Meteorological Monitoring

In common with many other nuclear facilities, ANSTO undertakes an extensive program of meteorological measurements. The prime reason for such a program is to allow estimates to be made of the downwind concentration of any airborne pollutants, particularly radionuclides, released from the site through routine operations or under accident conditions. The data collected from this program provide the necessary input to the atmospheric dispersion model called ADDCOR (ANSTO 1989) which can be used to compute the effective dose to an individual due to the routine airborne or accidental release of radionuclides from the LHSTC.

The location of monitoring stations used for the collection of local meteorological data are shown in **Figure 1**. The meteorological tower and associated laboratory are shown in **Figure 4**.

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

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

Prevailing Winds at Lucas Heights

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

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

Rainfall

The total rainfall at Lucas Heights in 1996 was 916 mm, recorded on 113 rainy days. The wettest month was May, with 143.5 mm of rainfall. The maximum evaporation in a 24 hour period was 8.2 mm.

Temperature

The temperature extremes were: minimum 2.8 °C recorded in July & August; maximum 34.9 °C (November). The coldest month was July with average temperatures ranging from 6.8 to 16 °C, whilst the warmest month was January with an average temperature range of 17.9 to 25.1 °C.

5.1.10 External Gamma Radiation at Lucas Heights

Levels of ambient external gamma radiation at and in the vicinity of the Lucas Heights Research Laboratories were measured during 1996 using two different types of thermoluminescent dosimeters (TLD's) as used by the Australian Radiation Laboratory (ARL) and ANSTO.

The TLD's 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 TLD's used by ANSTO were obtained from Harshaw (England) and contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters. They were analysed at ANSTO.

Figure 6 shows the locations of dosimeters 1 to 15.

Table 17 shows the integrated annual absorbed dose to air, in millisieverts, as monitored by the ARL dosimeters for the calendar year 1996, and compares these figures with results for 1995. Measurements were made over four consecutive exposure periods, the TLD's 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 1.

The data in **Table 17** indicate that the annual absorbed dose to air due to external radiation measured outside several homes in the vicinity of the LHSTC, was around

0.7 mSv. The annual environmental doses measured at or within the LHSTC perimeter fence, had a minimum of 0.5 mSv and a maximum of 3.0 mSv. The maximum value observed was slightly above the level considered typical for annual effective doses to adults from natural sources (see **Table 26**). The enhanced doses on the southern and western sides of the HIFAR security fence were due mainly to nuclear materials which were temporarily stored in this area from mid-July to September. By mid-October these nuclear materials were relocated to the newly-constructed shielded storage facility in building 59. Subsequent dose rate meter readings indicate a 30% reduction in the dose rates at the perimeter fence closest to building 59. Data to be collected in 1997 should show reduced perimeter doses. There is no public occupancy in this area.

Table 17a compares the ARL data with that obtained from the same locations using the ANSTO environmental dosimeters. The results from the two types of TLD are analogous.

When the annual environmental absorbed doses in air around homes in the vicinity of LHSTC (from **Tables 17 & 17a**) are converted to hourly rates, they correspond with the average hourly absorbed dose rate in air from terrestrial gamma radiation reported for capital cities around Australia (UNSCEAR 1993).

5.2 EFFLUENT MONITORING

The routine monitoring of the airborne effluent released from LHSTC stacks is performed by ANSTO's Safety Division.

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

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

5.2.1 Airborne Effluent Stack Discharges

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

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

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

Stack Sampling

During 1996, 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).

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

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

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

Results

Authorised airborne release data are given in **Tables 18 & 19**.

'Working levels' are set for individual stack discharges at ANSTO and are used for operational purposes to assess trends in the discharges. **Table 18** presents the quarterly airborne emissions for the individual stack release points, and **Table 19** lists the same figures expressed as percentages of the quarterly operational working levels.

Discharge records for the period 1977 to 1996 show that the majority of airborne emissions from LHSTC have been well below the quarterly working levels and, in most instances, can be regarded as negligible. During 1996, discharges of noble gases from HIFAR exceeded the quarterly working levels in all four quarters, and emissions of noble gases from the Bld 54 hotcells were just above the working level in the fourth quarter. This is due mainly to the increase in silicon semi-conductor material irradiation in HIFAR and subsequent release of argon-41.

Studies are currently under way to reduce the argon emissions by reducing the time air is resident within the reactor's neutron field.

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

It should be noted that the public doses due to the discharges of argon-41 are very low (well below the 0.3 mSv dose constraint adopted by ANSTO) and much smaller than natural background.

5.2.2 Low-Level Liquid Effluent Discharges

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

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

Liquid effluent treatment and discharge

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

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

The sewage waste is passed through an on-site sewage treatment plant before temporary storage in holding tanks. The active liquid effluent goes through an alum-based chemical treatment process for removal of radionuclides. The trade waste is tested and chemically treated if necessary. Finally, water seeping into the sump in the vicinity of Building 27 (the intermediate waste and spent fuel storage facility) is pumped into the holding tanks. The levels of gamma emitting isotopes and tritium in the groundwater seepage are monitored monthly (**Table 20**).

The treated effluent is transferred to holding tanks where levels of radioactivity are checked prior to discharge to the sewer. Proportional samples from the discharge pipeline are collected during the release of the treated effluent to the sewer, and are analysed for gross alpha and gross beta radioactivity, pH, ammonia and total chromium. A volume weighted monthly composite sample is produced from all discharge samples for the month. This monthly composite sample is analysed for gross alpha/beta, tritium and gamma activity and assessed for compliance with the Sydney Water Trade Waste Agreement (as are the individual pipeline samples).

Results

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

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

Former NSW Radioactive Substances Regulations (1959)

The average concentration quotient for monthly effluent composite samples in 1996 was 0.20, and all of the monthly radionuclide concentration quotients were less than unity, demonstrating compliance with the former NSW Radioactive Substances Regulations (1959).

World Health Organisation Guidelines for Drinking-Water Quality
The average monthly quotient term (based on the WHO Activity Concentration Equivalents at the ANSTO discharge point) for 1996 was 0.21. All of the individual monthly quotient terms were also less than unity, demonstrating compliance with the WHO *Guidelines for Drinking-Water Quality* at the CSTP.

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

5.3 POTTER POINT OFFSHORE MONITORING

During the Commonwealth Government Research Reactor Review (1992), public interest groups such as the Sutherland Shire Council and the Surfriders Association expressed concern that ANSTO's aqueous effluent may be a radiation hazard to swimmers and surfers in the vicinity of the Potter Point outfall. Biannual investigations were commenced with the following technical objectives:

1. to measure the transit times and dilution factors between Lucas Heights and the Cronulla Sewage Treatment Plant (CSTP);
2. to study the dispersion of tritium in the vicinity of the outfall; and
3. to implement a program of biological monitoring (**Section 5.1.3**).

Two routine authorised effluent releases were monitored during 1996, the first on the 23rd April and the second on the 14th November.

5.3.1 April 1996 Effluent Monitoring

The contents of three holding tanks at Lucas Heights were released between 19:00 hours on 22 April 1996 and 04:00 hours on the following morning. A composite sample was taken from the pipeline during the release and the tritium concentration determined. The total volume of release was 550 kilolitres and the average tritium concentration 1360 Bq/L.

Offshore sampling
Consistent with previous offshore monitoring of effluent releases, the Environment Division research vessel *Imara* conducted an hourly sampling program throughout the daylight hours of 23rd April, taking 2 litre samples of water from the ocean at depths of 1 metre and 3 metres. These samples were taken at six stations which 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 as close as practical in the prevailing sea conditions to the Potter Point outfall which was approximately 100 metres on this occasion. The positions of the remaining five stations ranged up to 500 metres from the outfall. They were positioned in the middle of the sewage plume as it spread out from Potter Point.

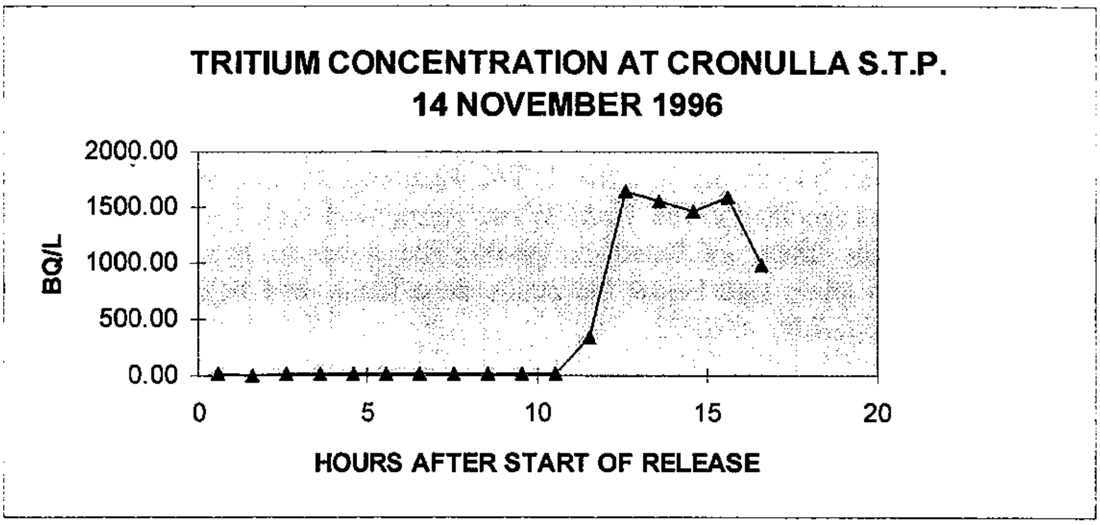
These samples were analysed for tritium concentration by liquid scintillation counting. The limit of detection is 5 Bq/L.

Results

The data are listed in **Table 22.** Some tritium was detected at both the 1 metre and the three metre depths. The maximum concentration was 9 Bq/L which occurred at the first station 16 hours after the release. This concentration is to be compared with the WHO drinking water reference concentration of 7800 Bq/L.

5.3.2 November 1996 Effluent Monitoring

On 13 November 1996, 536 kilolitres of effluent were discharged between 21:00 hours and 07:30 hours on the following day. A composite sample was taken from the release at the LHSTC and the resulting tritium pulse monitored as it passed through the CSTP. As in the April trial, a line of 6 sampling stations were set up offshore from Potter Point. Although the conditions were calm during the morning, the offshore sampling had to be abandoned after the midday sample run due to the arrival of a gale force southerly change.



The variation of the tritium concentration with time at the CSTP is shown in the above figure. The time difference between the centre of the effluent release from Lucas Heights and the centre of the peak of the pulse as it passed out of the CSTP was 10 hours. This is consistent with transit times obtained in previous trials.

The minimum in-line dilution was 21.5. The composite sample from Lucas Heights contained 52 250 Bq/L of tritium and the maximum concentration in hourly samples taken at the outlet of the CSTP was 1650 Bq/L.

Offshore Sampling

For previous trials, samples had been taken at depths of 1 and 3 metres in the sewage plume. On this occasion, samples were taken at depths of 0.5, 1.0 and 2.0 metres to see whether there was evidence of a shallow surface-trapped plume during the calm sea conditions which prevailed during the morning of the trial.

Sample station 1 was within 10 metres of the shore directly above the sewage outfall while station 2 was approximately 50 metres further offshore. Station 3 was approximately 200 metres due south of the outfall. Stations 4 to 6 were located in the plume at separations of about 100 metres. The data are listed in **Table 23.**

The samples from stations 1, 2 & 3 were the only samples to contain readily measurable tritium concentrations. The tritium concentrations in samples taken at stations 4, 5 and 6 were very close to or below detectable levels. The samples taken at stations 1, 2 and 3 had no detectable tritium at 2 metres. Under calm sea conditions there was a tendency for the tritium to be found within 1 metre of the surface. The maximum observed value was 251 Bq/L which is 3.2% of the WHO drinking water guideline level. It should be noted that this sample was taken under very calm conditions close to the surface and within 10 metres of the outfall. At station 3 located 200 metres from the outfall, the maximum tritium level had dropped to 21 Bq/L. The onset of the heavy weather in the afternoon would have resulted in further very large dilution.

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

The principal sources of potential radiation exposure to members of the public from routine operations at LHSTC are from airborne emissions and low level liquid effluent discharges to the sewer. These sources are controlled in compliance 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 dose constraint adopted by ANSTO.

6.1 Airborne Emissions

As indicated in **Section 3.2**, the ADDCOR atmospheric transport, dispersion and dosimetry computer code is used to evaluate potential doses to members of the public at various receptor locations, based on measured stack discharges and local meteorological data. Effective doses to ANSTO staff from stack discharges are also calculated by the same method. **Tables 24 and 25** give a summary of the estimated public and occupational effective doses due to airborne discharges at specified locations and distances from the HIFAR reactor.

The results show that the potential effective doses to critical group members of the public within the 1.6 km radius ANSTO buffer zone, were estimated to be less than 0.010 mSv per year; *ie* 1% of the NH&MRC recommended annual dose limit of 1 mSv and less than 3.3% of the dose constraint of 0.3 mSv adopted by ANSTO. For members of the general public residing at the 1.6 km radius ANSTO Buffer Zone boundary and beyond, the most exposed individual was also estimated to receive less than 0.010 mSv/year.

Iodine-131 emissions from the LHSTC were monitored at the perimeter fence, all results for the weekly composite of 4 samples were less than the minimum detectable concentration of 0.0025 Bq/m^3. Using 0.0025 Bq/m^3 as the yearly average iodine-131 concentration, it was calculated that critical group members of the public would potentially receive an effective dose of less than 0.01 mSv from iodine-131 releases from ANSTO. This figure represents 1% of the NH&MRC recommended annual dose limit and about 3% of the dose constraint adopted by ANSTO, and was calculated in an extremely conservative manner. This is consistent with the results obtained from the ADDCOR model.

Table 26, 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.

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 1%, of the radiation dose received by every member of the public each year from naturally occurring sources of radiation.

6.2 Low-Level Liquid Effluent

Low-level liquid effluent is chemically treated and analysed before controlled discharge to the Sydney Water sewer. Prior to 1980, discharges were routinely made to the Woronora River. Dose estimates based on actual radioactive concentrations measured in environmental samples from 1969 to 1979 were given in the relevant environmental survey reports (**Appendix A**). These dose estimates confirmed the negligible impact on public health of low level liquid effluent discharges to the Woronora Estuary.

The recent studies conducted by ANSTO at the CSTP and the Potter Point ocean outfall area (**Section 5.3**) confirm the expected dilution effects on any radionuclide contained in the treated effluent discharged by ANSTO to the sewer. The levels of iodine-131 found in fish, algae and barnacles collected near the outfall, as well as tritium measured in the ocean a short distance from the outfall, are negligible and do not pose any health risk to members of the public recreating in the ocean in the vicinity of the outfall or ingesting sea foods from the area.

6.3 External Radiation

The levels of external gamma radiation measured by thermoluminescent dosimeters located at private residences in Barden Ridge, Engadine and Woronora (see **Tables 17 & 17a**) all indicate annual absorbed doses in air consistent with annualised levels recorded by similar dosimeters sited at capital cities around Australia for surveys carried out by the Australian Radiation Laboratory and reported by UNSCEAR (1993).

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

The highest levels of external gamma radiation at LHSTC were registered in the western sector of the perimeter fence. These locations are not readily accessible to the general public and, due to the lack of occupancy, any incremental dose resulting from proximity to the fence will be negligible. The maximum value observed was similar to the level considered typical for annual effective doses to adults from natural sources (see **Table 26**). However, as indicated in **Section 5.1.10**, ANSTO has relocated the nuclear material to a shielded storage facility to reduce the doses at these locations.

6.4 Little Forest Burial Ground

The environmental survey results for the LFBG show elevated levels of tritium in the groundwater in the centre of the burial trenches area and lower levels at some other monitoring bores inside the fenced area. Very low levels of cobalt-60, caesium-137 and americium-241 were found in sediment suspended in groundwater from the centre of the burial trench area. Traces of caesium-137 and americium-241 were also found in two other monitoring bores adjacent to the trenches. However with improved sampling and analysis techniques, it was shown that the only bore which contained radioactivity which could possibly have been dissolved in the groundwater, was MB16.

All groundwater monitoring bores outside the LFBG fenced area show background levels of radioactivity and surface water sampling 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, make the groundwater unsuitable for human consumption.

Sampling of airborne particulates at LFBG was only conducted in the first quarter of the year, after which no further samples were collected due to theft of the equipment. The sample for the first quarter showed no detectable levels of beryllium. Based on past results it is deemed that possible radiation exposure to members of the general public via the inhalation pathway is negligible.

External radiation readings over the trenches are consistent with normal background levels except for one small localised area in the middle of the trenches. Radiation readings around the LFBG site boundary fence are all at background levels, ensuring that possible doses to members of the public from external radiation can also be regarded as negligible.

7.0 ACKNOWLEDGMENTS

For critical review of this document the authors thank Dr Peter Airey, Alex Camilleri and Frank Harris.

Thanks to Graham Spelman & Phillip Thornton of Environment Division for their contributions in relation to the Potter Point sampling program (**Sections 5.1.3 & 5.3**).

Beryllium levels on the LFBG air filters were determined by the Environmental Chemistry group (Environment Division) using ICPAES techniques.

Iodine-131 levels in air samples were determined by Safety Division.

Details of airborne effluent sampling and analysis procedures were supplied by Safety Division.

Dosimeter readings for external gamma radiation at LHSTC (**Tables 17 & 17a**) and airborne effluent release data (**Table 18**) were supplied by Safety Division.

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

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TABLE 1

ENVIRONMENTAL MONITORING SAMPLE COLLECTION AND PREPARATION SCHEDULE, 1996

SAMPLE	STATION	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION AND ANALYSIS
Stormwater.	MDP+60m (60m down-stream of stormwater outlet No.1, on MDP Creek).	Weekly.	3 litres, sampled with polyethylene bottle.	Weekly samples evaporated to dryness, the residue combined into a monthly composite tablet for α,β,γ counting. 250 mL collected weekly and distilled for tritium analysis.
	3 Stormwater Bunds (see Figure 2).	Monthly.	1 litre sampled with polyethylene bottle.	Distilled for tritium analysis.
Estuary water (Woronora River).	E5.9 (Jannali Park boat ramp).	Weekly until end of May 1996. Monthly thereafter.	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.
	3 SPCC Weirs: on Bardens Ck; MDP Ck; and Strassman Ck.	Monthly.	1 litre sampled after rain.	Gross α,β according to Clean Waters Act Regulations: AS 3550.0 (1990).
	Forbes Creek.	Monthly.	1 litre sampled after rain.	Distilled for tritium analysis.
	Bardens & Mill Creeks (above junction - station T2).	Yearly.	5 litres of surface water.	Evaporated to dryness and residue counted for α,β,γ. 250 mL distilled for tritium analysis.
Groundwater.	Little Forest Burial Ground (LFBG).	Twice yearly.	MB series bore holes; pumped dry, allowed to refill and sampled from the bottom of the bore.	Tablet method: 10 L sample evaporated to dryness & the residue counted for α,β,γ. Also by ISO method (**App.D**). 250 mL distilled for tritium analysis.
Marine Biological Samples.	Potter Point Ocean Outfall.	Twice yearly.	Barnacles, algae & fish, near the outfall.	Gamma spectrometry of dried, homogenised samples.

Continued next page...

TABLE 1 Continued...

SAMPLE	STATION	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION AND ANALYSIS
Dust on air filters.	Little Forest Burial Ground.	Quarterly.	Duplicate samples collected on 0.8 μm aerosol filters, triggered by wind speeds of 3 $m.s^{-1}$ or greater.	A yearly composite made up of 4 quarterly samples is analysed for ^{239}Pu. The duplicate sample is analysed for Beryllium each quarter.
Ambient iodine-131 in air.	Stations 1,2,3,4 along the eastern boundary of site.	Weekly.	Collected on Maypacks (activated charcoal filters).	Gamma spectrometry of Maypacks.
Soil / sediment.	Stormwater bunds.	Yearly, or whenever bunds are emptied.	Bund is drained. 1kg 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 pipeline.	If indicated by six-monthly dose rate survey.	1 kg, from surface.	As above.
	T2: Bardens and Mill Creeks.	Yearly.	From creek bed (above junction of the two creeks).	As above.
Gamma Dose Rate Survey.	Effluent Pipeline.	Twice yearly.	Pipe joints and ground surveyed. Soil is sampled if indicated by dose rate survey.	If collected, soils are sieved and ashed, then counted for α,β,γ activity.
	Little Forest Burial Ground.	Yearly.	Burial trench system surveyed in 1m wide sweeps. Soil is sampled if indicated by dose rate survey.	As above.
External Gamma Radiation.	Sites 1-15 at LHSTC, sites 16-18 in local suburbs (see Figure 6).	Quarterly.	Personal & Environmental Thermoluminescent Dosimeter (TLD) badges, exposed to ambient gamma radiation.	Personal TLD's sent to ARL for analysis, Environmental TLD's analysed at ANSTO. Results reported as absorbed dose in mSv/year.

TABLE 2

TRITIUM IN WORONORA ESTUARY WATER STATION E5.9, 1996

Date	Tritium (Bq/L)
2.1.96	< 30
9.1.96	< 30
16.1.96	< 70
23.1.96	< 60
30.1.96	< 40
6.2.96	< 100
13.2.96	< 20
20.2.96	< 30
27.2.96	< 70
5.3.96	< 30
12.3.96	< 50
19.3.96	< 60
26.3.96	< 60
2.4.96	< 60
9.4.96	< 60
16.4.96	< 60
23.4.96	< 60
1.5.96	< 70
7.5.96	< 70
14.5.96	< 60
21.5.96	< 60
28.5.96	< 60
4.6.96	< 80
2.7.96	< 50
6.8.96	< 70
3.9.96	< 50
1.10.96	< 80
6.11.96	< 50
3.12.96	< 70

Notes:

i) The Reference Activity Concentration for tritium in drinking water is 7800 Bq/L (WHO, 1993).

ii) Values which are quoted as "less than" figures were below the stated minimum detectable activity (calculated with 95 % confidence).

TABLE 3

TRITIUM IN FORBES CREEK WATER SAMPLES, 1996

Date	Tritium (Bq/L)
3.1.96	< 40
20.2.96	< 30
19.3.96	< 60
2.4.96	< 60
7.5.96	< 70
11.6.96	< 60
23.7.96	< 60
6.8.96	< 60
5.9.96	< 60
1.10.96	< 60
6.11.96	< 50
10.12.96	< 80

Notes:

i) See Figure 1 for the location of this sampling point.

ii) Where no significant tritium is detected, the minimum detectable activity is quoted as a "less than" figure, with 95 % confidence.

TABLE 4

RADIOACTIVITY IN FISH FROM POTTER POINT OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1996

Location	Date Sampled	Sample	GAMMA EMITTERS (Bq/kg FW)				
			U&Th series	**^{7}Be**	**^{40}K**	^{60}Co	^{137}Cs
POTTER POINT Ocean Outfall	30.4.96	A	-	-	160 ± 20	-	-
	"	B	-	-	170 ±20	-	-
	3.10.96	A	✓	-	720 ± 90	-	-
	"	B	✓	140 ± 30	150 ± 40	-	-
The Royal National Park (reference site)	25.9.96	A	✓	-	220 ± 60	-	-

Notes: As for **Tables 5 & 6.**

TABLE 5

RADIOACTIVITY IN **GREEN ALGAE** FROM POTTER POINT OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1996

Sampling Location	Date Sampled	Sample	GAMMA EMITTERS (Bq/kg FW)					
			U&Th series	**^{7}Be**	**^{40}K**	^{60}Co	^{137}Cs	^{131}I
POTTER POINT Ocean Outfall	1.5.96	A	✓	40 ± 10	140 ± 10	-	-	10 ± 4
	"	B	✓	40 ± 10	130 ± 10	-	-	20 ± 8
	3.10.96	A	✓	-	130 ± 30	-	-	10 ± 2
	"	B	✓	-	170 ± 30	-	-	10 ± 2
The Royal National Park (reference site)	9.10.96	A	✓	-	170 ± 30	-	-	-
	"	B	✓	-	420 ± 50	-	-	-

TABLE 6

RADIOACTIVITY IN **BARNACLES** FROM POTTER POINT OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1996

Sampling Location	Date Sampled	Sample	GAMMA EMITTERS (Bq/kg FW)				
			U&Th series	**^{7}Be**	**^{40}K**	^{60}Co	^{137}Cs
POTTER POINT Ocean Outfall	1.5.96	A	✓	-	40 ± 10	-	-
	"	B	✓	-	40 ± 10	-	-
	3.10.96	A	✓	-	-	-	-
The Royal National Park (reference site)	9.10.96	A	✓	-	10 ± 7	-	-

Notes For Tables 4, 5 & 6:

i) Bq/kg FW refers to the radioactivity per kilogram of fresh (wet) sample.

ii) "U & Th series" refers to the unquantified presence of daughter products from either of the natural uranium-238 or thorium-232 decay series.

iii) A dash "-" indicates that the nuclide was not detected.

iv) **U&Th, ^{7}Be, ^{40}K** are all of natural origin.

TABLE 7

TRITIUM IN WATER SAMPLES FROM STORMWATER OUTLET NO.1 (MDP+60 metres), 1996

Date	Tritium Bq/L	Date	Tritium Bq/L
2.1.96	280 ± 40	2.7.96	200 ± 50
9.1.96	260 ± 10	8.7.96	260 ± 40
16.1.96	250 ± 30	16.7.96	290 ± 30
23.1.96	280 ± 20	23.7.96	300 ± 40
30.1.96	210 ± 60	31.7.96	130 ± 40
6.2.96	290 ± 60	6.8.96	300 ± 40
13.2.96	330 ± 50	13.8.96	280 ± 40
20.2.96	260 ± 30	20.8.96	300 ± 40
27.2.96	340 ± 80	27.8.96	420 ± 30
5.3.96	250 ± 20	3.9.96	80 ± 20
12.3.96	240 ± 20	12.9.96	200 ± 30
19.3.96	340 ± 30	17.9.96	280 ± 40
26.3.96	340 ± 40	24.9.96	340 ± 40
2.4.96	430 ± 40	1.10.96	190 ± 50
9.4.96	420 ± 60	8.10.96	300 ± 40
16.4.96	360 ± 40	15.10.96	370 ± 40
23.4.96	3830 ± 60	23.10.96	440 ± 30
26.4.96	260 ± 60	29.10.96	300 ± 90
1.5.96	310 ± 80	6.11.96	300 ± 20
7.5.96	70 ± 40	13.11.96	380 ± 40
14.5.96	190 ± 20	20.11.96	520 ± 50
21.5.96	290 ± 30	27.11.96	340 ± 30
28.5.96	340 ± 40	3.12.96	340 ± 50
4.6.96	310 ± 20	10.12.96	480 ± 30
11.6.96	230 ± 40	17.12.96	60 ± 50
18.6.96	200 ± 40	23.12.96	290 ± 70
25.6.96	260 ± 30	31.12.96	270 ± 20

Notes:

i) Refer to **Figure 2** for the location of these sampling points.

ii) The reference activity concentration for tritium in drinking water is 7800 Bq/L (WHO, 1993).

iii) The average tritium level 60m downstream from Stormwater Outlet No.1 during 1996 was 350 Bq/L, which is 4.5 % of the WHO reference activity.

iv) The weekly water samples above are combined into monthly composite samples and analysed for gross alpha/beta and gamma activity. See **Table 8** for these results.

TABLE 8

RADIOACTIVITY IN WATER SAMPLES, 60m FROM STORMWATER OUTLET No.1, 1996

Sample Location	Date	RADIOACTIVITY (Bq/L)			
		Gross α	Gross β	**Gamma emitters** ^{137}Cs	^{40}K
60m from Stormwater Outlet No. 1	January	0.22 ± 0.04	1.00 ± 0.02	0.028 ± 0.002	0.04 ± 0.01
	February	0.26 ± 0.05	0.88 ± 0.01	0.015 ± 0.002	0.04 ± 0.01
	March	0.14 ± 0.02	0.90 ± 0.01	0.019 ± 0.002	0.04 ± 0.01
	April	0.16 ± 0.03	1.05 ± 0.03	0.076 ± 0.008	0.10 ± 0.02
	May	0.19 ± 0.01	0.72 ± 0.02	0.024 ± 0.003	0.05 ± 0.03
	June	0.18 ± 0.03	0.56 ± 0.01	0.013 ± 0.002	< 0.07
	July	0.19 ± 0.05	0.81 ± 0.01	0.013 ± 0.001	0.04 ± 0.01
	August	0.10 ± 0.01	0.61 ± 0.01	0.009 ± 0.002	0.09 ± 0.01
	September	0.07 ± 0.02	0.70 ± 0.01	0.007 ± 0.002	0.04 ± 0.02
	October	0.09 ± 0.03	0.64 ± 0.01	0.018 ± 0.002	< 0.04
	November	0.32 ± 0.06	1.06 ± 0.01	0.019 ± 0.003	0.06 ± 0.02
	December	0.22 ± 0.09	0.77 ± 0.01	0.019 ± 0.002	0.06 ± 0.02

Notes:

i) This location is sampled weekly for tritium (see **Table 7**), with the remainder of the weekly samples being combined to make a monthly composite water sample for gross alpha, beta and gamma analysis.

ii) "Radioactivity (Bq/L)" refers to the radioactivity per litre of water sample (suspended & dissolved).

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

iv) The average ^{137}Cs level in 1996 was 0.022 Bq/L, which is 0.2 % of the WHO reference value for ^{137}Cs in drinking water, see **Section 3.1.2.**

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

TABLE 9

RADIOACTIVITY IN WATER FROM STORMWATER RETENTION BUNDS, 1996

Bund Location	Date	RADIOACTIVITY in WATER (Bq/litre)		
		Gross α	Gross β	Tritium
A	18.2.96	< 0.03	0.30 ± 0.05	160 ± 30
(Bld 1)	2.4.96	0.13 ± 0.07	0.56 ± 0.06	< 60
	22.4.96	< 0.04	0.26 ± 0.06	110 ± 40
	22.5.96	-	-	140 ± 30
	25.6.96	-	-	130 ± 30
	24.7.96	-	-	< 60
	27.8.96	-	-	140 ± 40
	18.9.96	-	-	80 ± 30
	29.10.96	-	-	< 50
	28.11.96	-	-	150 ± 30
	31.12.96	-	-	< 60
B	18.2.96	< 0.03	0.27 ± 0.05	< 30
(opposite Met. tower)	2.4.96	< 0.10	0.20 ± 0.05	90 ± 20
	22.4.96	< 0.04	0.38 ± 0.06	< 60
	22.5.96	-	-	80 ± 10
	25.6.96	-	-	170 ± 30
	24.7.96	-	-	60 ± 30
	27.8.96	-	-	< 70
	18.9.96	-	-	< 60
	29.10.96	-	-	< 50
	28.11.96	-	-	80 ± 20
	31.12.96	-	-	4470 ± 110
C	18.2.96	0.07 ± 0.04	1.40 ± 0.07	190 ± 30
(MDP)	2.4.96	< 0.10	1.40 ± 0.07	360 ± 20
	22.4.96	0.06 ± 0.04	1.30 ± 0.07	120 ± 40
	22.5.96	-	-	210 ± 40
	25.6.96	-	-	240 ± 20
	24.7.96	-	-	140 ± 50
	27.8.96	-	-	540 ± 40
	18.9.96	-	-	140 ± 30
	29.10.96	-	-	270 ± 20
	28.11.96	-	-	280 ± 40
	31.12.96	-	-	160 ± 50

i) See **Figure 2** for the location of these sampling points.

TABLE 9a

RADIOACTIVITY IN SEDIMENT FROM STORMWATER RETENTION BUNDS, 1996

Bund Location	Date	RADIOACTIVITY in SEDIMENT (Bq/g Dry Wt.)			
		Gross α	Gross β*	γ-emitters	^{40}K
A Behind Building 1	18.2.96	0.50	0.39	^{7}Be = 0.11 ± 0.01 ^{137}Cs = 0.005 ± 0.001	0.36 ± 0.01
"	18.9.96	0.25	0.18	^{7}Be = 0.11 ± 0.02	0.011 ± 0.003
B Opposite Meteorological Tower	18.2.96	0.36	0.21	^{7}Be = 0.024 ± 0.003 ^{60}Co = 0.087 ± 0.002	0.17 ± 0.01
"	18.9.96	0.32	0.34	^{7}Be = 0.45 ± 0.05 ^{137}Cs = 0.007 ± 0.001	0.37 ± 0.04
C MDP	18.2.96	0.50	0.69	^{7}Be = 0.14 ± 0.006 ^{137}Cs = 0.186 ± 0.002 ^{134}Cs = 0.009 ± 0.001 ^{60}Co = 0.003 ± 0.001	0.20 ± 0.01
"	18.9.96	0.43	0.36	^{137}Cs = 0.076 ± 0.007 ^{134}Cs = 0.010 ± 0.001 ^{241}Am =0.003 ± 0.001	0.18 ± 0.02

Notes:
i) See **Figure 2** for the location of the stormwater bunds.

TABLE 10

RADIOACTIVITY IN WATER FROM SPCC SAMPLING POINTS, 1996

Date	RADIOACTIVITY (Bq/L)					
	Strassman Creek		**Bardens Creek Weir**		**MDP Creek Weir**	
	Gross alpha	Gross beta	Gross alpha	Gross beta	Gross alpha	Gross beta
10.1.96	< 0.08	< 0.10	< 0.06	< 0.18	< 0.06	0.79 ± 0.06
27.2.96	< 0.10	< 0. 13	< 0.07	< 0.15	< 0.07	0.76 ± 0.06
20.3.96	< 0.07	0.15 ± 0.06	< 0.07	0.24 ± 0.06	< 0.11	0.98 ± 0.07
26.4.96	0.04 ± 0.02	0.11 ± 0.05	< 0.06	< 0.16	< 0.05	0.86 ± 0.06
22.5.96	< 0.08	0.18 ± 0.07	< 0.12	< 0.23	< 0.06	0.85 ± 0.07
26.6.96	< 0.04	< 0.15	< 0.04	< 0.14	< 0.06	0.61 ±0.06
24.7.96	< 0.07	< 0.25	< 0.07	0.19 ± 0.08	< 0.09	0.57 ± 0.09
30.8.96	< 0.06	< 0.23	< 0.12	0.14 ± 0.06	< 0.07	0.67 ± 0.06
24.9.96	< 0.03	0.54 ± 0.06	0.04 ± 0.04	0.10 ± 0.06	< 0.03	0.03 ± 0.05
16.10.96	0.06 ± 0.04	0.48 ± 0.06	0.03 ± 0.04	0.11 ± 0.05	0.01 ± 0.04	0.17 ± 0.06
8.11.96	0.09 ± 0.03	< 0.16	< 0.12	< 0.22	< 0.11	0.67 ± 0.08
31.12.96	< 0.07	0.56 ± 0.07	< 0.07	0.12 ± 0.06	< 0.07	0.28 ± 0.06

Notes:
i) See **Figure 2** for the location of the SPCC sampling points.
ii) All gross beta results include the contribution from natural potassium-40 (a beta-gamma emitter).
iii) The NSW Clean Waters Regulations (1972) specify limits for radioactivity in class C waters as follows: gross α = 1.1 Bq/L
gross β = 11.1 Bq/L.

TABLE 11

TRITIUM IN WATER FROM BARDENS CREEK WEIR
(at SPCC sampling point)
1996

Date	Tritium Bq/L	Date	Tritium Bq/L
2.1.96	70 ± 20	2.7.96	< 50
9.1.96	40 ± 10	8.7.96	70 ± 30
16.1.96	< 70	16.7.96	< 60
23.1.96	90 ± 30	23.7.96	< 60
30.1.96	40 ± 40	30.7.96	100 ± 40
6.2.96	< 100	6.8.96	90 ± 40
13.2.96	70 ± 30	13.8.96	< 70
20.2.96	50 ± 20	20.8.96	80 ± 40
27.2.96	< 70	27.8.96	90 ± 40
5.3.96	110 ± 30	3.9.96	< 50
12.3.96	60 ± 20	12.9.96	< 60
19.3.96	60 ± 40	17.9.96	< 60
26.3.96	< 60	24.9.96	100 ± 50
2.4.96	140 ± 20	1.10.96	80 ± 30
9.4.96	80 ± 40	8.10.96	< 70
16.4.96	70 ± 10	15.10.96	< 80
23.4.96	70 ± 20	23.10.96	100 ± 20
1.5.96	100 ± 70	29.10.96	< 50
7.5.96	< 70	6.11.96	80 ± 30
14.5.96	< 60	13.11.96	< 60
21.5.96	70 ± 20	20.11.96	130 ± 30
28.5.96	90 ± 30	27.11.96	90 ± 40
4.6.96	90 ± 50	3.12.96	100 ± 40
11.6.96	140 ± 20	10.12.96	100 ± 40
18.6.96	100 ± 10	17.12.96	70 ± 40
25.6.96	110 ± 20	23.12.96	< 70
		31.12.96	< 60

Notes:
i) The average weekly tritium concentration at Bardens creek weir during 1996 was 80 Bq/L, which is 1% of the WHO drinking water reference activity concentration.
ii) 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, 1996

Survey of exposed portions of pipeline between LHSTC and the Sydney Water sewer connection, using an Eberline PRM-7 field rate meter.

Date	Location	Dose Rate (μSv/hour)		Background Dose Range (μSv/hour)
		ground below joint	pipe joint	
22-5-96	Joints #1-22*	0.05 - 0.08	0.05 - 0.09	0.05 - 0.10
8-11-96	Joints #1-22*	0.05 - 0.09	0.05 - 0.09	0.05 - 0.10

* Excluding joints # 18 & 19 which are inaccessible.

TABLE 13

GAMMA SURVEY - BURIAL TRENCHES LITTLE FOREST BURIAL GROUND, 1996

Date	Location	Dose Range (μSv/hour)
13 December 1996	Background (outside LFBG fence)	0.09
	Readings over all trenches	0.05 - 0.10
	Point #5	0.08
	Point #6	0.15

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

TABLE 14 a

GAMMA EMITTERS IN GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1996
(AAEC/ANSTO and ARL Methods)

Bore	Date Sampled	GAMMA RADIOACTIVITY				
		Bq/litre (AAEC/ANSTO tablet method*)				
		U&Th	^{60}Co	^{137}Cs	^{241}Am	^{40}K
BHF	17.5.96	✓	-	-	-	< 0.06
BH10	"	✓	-	-	-	< 0.06
OS2	"	✓	-	-	0.038 ± 0.003	0.23 ± 0.04
OS3	"	✓	-	0.020 ± 0.003	0.37 ± 0.04	0.31 ± 0.04
MB11	"	✓	-	-	-	< 0.07
MB12	"	✓	-	-	-	< 0.06
MB13	"	✓	-	< 0.008	0.005 ± 0.002	0.08 ± 0.03
MB14	"	✓	-	-	-	0.25 ± 0.04
MB15	"	✓	-	-	-	< 0.08
MB16	"	✓	0.22 ± 0.02	0.020 ± 0.003	< 0.006	< 0.20
MB17	"	✓	-	-	-	< 0.20
MB18	"	✓	-	-	-	0.11 ± 0.03
MB19	"	✓	-	-	-	0.26 ± 0.07
MB20	"	✓	-	-	-	0.95 ± 0.10
MB21	28.5.96	✓	-	-	-	0.18 ± 0.04
BHD	"	✓	-	< 0.007	-	0.22 ± 0.04
			Bq/litre (ARL method #)			
BHF	16.12.96	✓	-	-	-	0.23 ± 0.16
BH10	"	✓	-	-	-	0.42 ± 0.15
OS2	"	✓	-	-	-	0.25 ± 0.14
OS3	"	-	-	-	-	0.15 ± 0.12
MB11	"	-	-	-	-	0.45 ± 0.15
MB12	"	-	-	-	-	0.17 ± 0.19
MB13	"	-	-	-	-	0.28 ± 0.07
MB14	"	✓	-	-	-	0.76 ± 0.16
MB15	"	-	-	-	-	0.22 ± 0.13
MB16	"	✓	0.38 ± 0.04	-	-	0.10 ± 0.14
MB17	"	✓	-	-	-	< 0.40
MB18	"	✓	-	-	-	< 0.50
MB19	"	-	-	-	-	0.24 ± 0.15
MB20	"	-	-	-	-	0.42 ± 0.20
MB21	"	-	-	-	-	0.44 ± 0.20

i) See **Figure 3** for the location of the sampling bores and **Appendix D** for analysis methods.
ii) * Analysed using the AAEC/ANSTO tablet method. Results were originally in terms of Bq per gram of sediment, but have been converted to Bq/L for ease of comparing the two methods.
iii) # Analysed with the method used by the Australian Radiation Laboratory (ARL). Results in Bq/L.
iv) "U & Th" refers to the presence of daughter products from the natural uranium-238 and thorium-232 decay series.
v) "<" indicates the result was less than the stated minimum detectable activity (95% confidence).
vi) Light shading indicates the bores which are outside the fenced area at the LFBG.

TABLE 14 b

GROSS ALPHA/BETA & TRITIUM RADIOACTIVITY IN GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1996

(AAEC/ANSTO and ISO Methods)

Bore	Date	Gross α	Gross β	Tritium Bq/L
		Bq/litre (AAEC/ANSTO method)*		
BHF	17.5.96	0.24 ± 0.04	0.49 ± 0.01	140 ± 20
BH10	"	0.18 ± 0.03	0.30 ± 0.01	530 ± 30
OS2	"	1.1 ± 0.1	0.42 ± 0.02	1800 ± 20
OS3	"	0.45 ± 0.03	0.51 ± 0.02	1360 ± 80
MB11	"	0.35 ± 0.05	0.09 ± 0.01	< 60
MB12	"	0.10 ± 0.02	0.06 ± 0.01	80 ± 40
MB13	"	0.28 ± 0.1	0.25 ± 0.01	2520 ± 100
MB14	"	1.0 ± 0.1	0.34 ± 0.02	< 60
MB15	"	0.24 ± 0.02	0.11 ± 0.01	< 60
MB16	"	1.2 ± 0.1	2.5 ± 0.1	8720 ± 160
MB17	"	0.7 ± 0.1	0.29 ± 0.02	940 ± 30
MB18	"	0.69 ± 0.06	0.22 ± 0.01	< 60
MB19	"	1.0 ± 0.1	0.55 ± 0.02	70 ± 30
MB20	"	0.34 ± 0.06	0.34 ± 0.01	60 ± 30
MB21	28.5.96	0.69 ± 0.04	0.21 ± 0.01	< 60
BHD	"	0.35 ± 0.05	0.28 ± 0.01	90 ± 40
		Bq/litre (ISO METHOD)#		
BHF	16.12.96	0.12 ± 0.02	0.51 ± 0.03	300 ± 60
BH10	"	0.06 ± 0.03	0.24 ± 0.03	550 ± 30
OS2	"	0.30 ± 0.03	0.83 ± 0.03	1790 ± 100
OS3	"	0.13 ± 0.02	0.83 ± 0.02	1630 ± 80
MB11	"	0.06 ± 0.02	0.29 ± 0.03	< 60
MB12	"	0.07 ± 0.02	0.23 ± 0.02	< 60
MB13	"	0.09 ± 0.01	0.23 ± 0.02	4350 ± 110
MB14	"	0.30 ± 0.07	1.0 ± 0.1	< 60
MB15	"	< 0.03	0.09 ± 0.01	< 60
MB16	"	0.22 ± 0.02	0.75 ± 0.02	8880 ± 230
MB17	"	0.14 ± 0.02	0.39 ± 0.02	1290 ± 30
MB18	"	0.16 ± 0.03	0.45 ± 0.03	< 60
MB19	"	0.28 ± 0.09	0.81 ± 0.09	< 60
MB20	"	0.07 ± 0.02	0.32 ± 0.02	< 60
MB21	"	0.13 ± 0.04	0.57 ± 0.05	< 60

i) See **Figure 3** for the location of the sampling bores, and **Appendix D** for analysis methods.
ii) * Analysed using the AAEC/ANSTO tablet method. Results were originally in terms of Bq per gram of sediment, but have been converted to Bq/L for ease of comparing the two methods.
iii) # Analysed using the ISO 9696 & 9697 standard methods. Results in Bq/L.
iv) "<": the result was less than the stated minimum detectable activity (95% confidence level).
v) Light shading indicates the bores which are outside the fenced area at the LFBG.

TABLE 14 c

RADIOACTIVITY IN GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1996
(AAEC/ANSTO Tablet Method)

Bore	Date	Gross α	Gross β	γ-emitters
		Bq/g sediment*		
BHF	17.5.96	1.6	3.2	^{40}K < 0.4
BH10	"	0.8	1.3	^{40}K < 0.3
OS2	"	3.3	1.2	^{241}Am = 0.11 ± 0.01 ^{40}K = 0.7 ± 0.1
OS3	"	3.2	3.6	^{137}Cs = 0.14 ± 0.02 ^{241}Am = 2.6 ± 0.3 ^{40}K = 2.2 ± 0.3
MB11	"	1.9	0.5	^{40}K < 0.4
MB12	"	0.6	0.4	^{40}K < 0.4
MB13	"	1.8	1.6	^{137}Cs < 0.05 ^{241}Am = 0.03 ± 0.01 ^{40}K < 0.7
MB14	"	1.8	0.6	^{40}K < 0.5
MB15	"	0.9	0.4	^{40}K < 0.3
MB16	"	4.3	9.4	^{60}Co = 0.82 ± 0.08 ^{137}Cs = 0.074 ± 0.010 ^{241}Am = 0.013 ± 0.006 ^{40}K < 0.7
MB17	"	2.7	1.1	^{40}K < 0.8
MB18	"	1.9	0.6	^{40}K < 0.4
MB19	"	0.6	0.3	^{40}K < 0.3
MB20	"	0.7	0.7	^{40}K = 2.0 ± 0.3
MB21	28.5.96	1.3	0.4	^{40}K < 0.4
BHD	"	0.5	0.4	^{40}K < 0.4

i) See **Figure 3** for the location of the sampling bores.
ii) * Analysed using the AAEC/ANSTO tablet method, which includes any suspended sediments in the sample. Results are in terms of Bq per gram of sediment.
iii) "<" indicates that the activity was less than the stated limit of detection (95% confidence level).
iv) Light shading indicates the bores which are outside the fenced area at LFBG.

TABLE 15

RADIOACTIVITY IN CREEKS RECEIVING RUNOFF FROM THE LITTLE FOREST BURIAL GROUND AREA, 1996

Sample Location	Date	RADIOACTIVITY in **SEDIMENT** (Bq/g DW)			
		Gross α	Gross β	γ-emitters	
Mill Creek	5.7.96	1.03	0.84	U & Th series ^{40}K = 0.28 ± 0.03	
Bardens Creek	5.7.96	0.53	0.23	U & Th series ^{40}K = 0.09 ± 0.01	
		RADIOACTIVITY in **WATER** (Bq/L)			
		Gross α	Gross β	γ-emitters	Tritium
Mill Creek	5.7.96	< 0.38	0.20 ± 0.01	^{40}K = 0.39 ± 0.04	< 60
Bardens Creek	5.7.96	< 0.26	0.07 ± 0.01	^{40}K = 0.06 ± 0.03	< 60

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

TABLE 16

AMBIENT IODINE-131 IN AIR, 1996

Sampled during the week ending :	Iodine-131 Air Concentration (Bq / m^3)	Sampled during the week ending :	Iodine-131 Air Concentration (Bq / m^3)
2.1.96	< 0.0025	8.7.96	< 0.0025
9.1.96	< 0.0025	16.7.96	< 0.0025
16.1.96	< 0.0025	23.7.96	< 0.0025
23.1.96	< 0.0025	30.7.96	< 0.0025
30.1.96	< 0.0025	6.8.96	< 0.0025
6.2.96	< 0.0025	13.8.96	< 0.0025
13.2.96	< 0.0025	20.8.96	< 0.0025
20.2.96	< 0.0025	27.8.96	< 0.0025
27.2.96	< 0.0025	3.9.96	< 0.0025
5.3.96	< 0.0025	12.9.96	< 0.0025
12.3.96	< 0.0025	17.9.96	< 0.0025
19.3.96	< 0.0025	24.9.96	< 0.0025
26.3.96	< 0.0025	1.10.96	< 0.0025
2.4.96	< 0.0025	8.10.96	< 0.0025
9.4.96	< 0.0025	15.10.96	< 0.0025
16.4.96	< 0.0025	23.10.96	< 0.0025
23.4.96	< 0.0025	29.10.96	< 0.0025
1.5.96	< 0.0025	6.11.96	< 0.0025
7.5.96	< 0.0025	13.11.96	< 0.0025
14.5.96	< 0.0025	20.11.96	< 0.0025
21.5.96	< 0.0025	27.11.96	< 0.0025
28.5.96	< 0.0025	3.12.96	< 0.0025
4.6.96	< 0.0025	10.12.96	< 0.0025
11.6.96	< 0.0025	17.12.96	< 0.0025
18.6.96	< 0.0025	23.12.96	< 0.0025
25.6.96	< 0.0025	31.12.96	< 0.0025
2.7.96	< 0.0025		

i) Four air samplers are located along the eastern boundary of the site, where suburban residences are closest (**Figure 2**). Results are calculated making the conservative assumptions that:

(a) all iodine-131 activity was released during the first day of the sampling period; and
(b) all the activity was concentrated at one sampling point.

ii) A person receiving continuous exposure to iodine-131 at the average concentration recorded (< 0.0025 Bq/m3), would receive an effective dose of less than 0.01 mSv per year (IAEA, 1994).

TABLE 17

EXTERNAL GAMMA RADIATION AT LHSTC
(ARL Dosimeter Results), 1995 and 1996

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

Notes:

i) Refer to **Figure 6** for the location of dosimeters (as used by the ARL) 1 to 15.

ii) * The data were recorded as mGy/year and converted to mSv/year using a conservative conversion factor of 1.

iii) 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 17a

EXTERNAL GAMMA RADIATION AT LHSTC, Comparison of ARL and ANSTO Dosimeter Results, 1996

	Dosimeter Location: on-site	**1996 Effective Dose** (mSv* / year)	
		ARL TLD's	**ANSTO** TLD's
1	Hifar fence - south east	0.8 ± 0.3	0.7 ± 0.1
2	Hifar fence - south	2.2 ± 0.3	2.0 ± 0.1
3	Perimeter fence - west	1.0 ± 0.4	1.0 ± 0.1
4	Hifar fence - west	2.1 ± 0.3	2.1 ± 0.1
5	Hifar fence - north west	3.0 ± 0.5	3.2 ± 0.2
6	Perimeter fence - north A	0.8 ± 0.3	0.8 ± 0.1
7	Internal fence - north	0.8 ± 0.3	0.7 ± 0.1
8	Perimeter fence - north B	0.7 ± 0.3	0.7 ± 0.1
9	Perimeter fence - north east	0.7 ± 0.3	0.7 ± 0.1
10	Perimeter fence - east	0.7 ± 0.3	0.7 ± 0.1
11	Perimeter fence - south east	0.5 ± 0.2	0.5 ± 0.1
12	Corner of Curie and Roentgen St	0.8 ± 0.3	0.9 ± 0.1
13	Perimeter fence - south	0.6 ± 0.2	0.6 ± 0.1
14	Hifar fence - east	0.8 ± 0.3	0.8 ± 0.1
15	Hifar fence - north east	0.9 ± 0.4	0.9 ± 0.1
	Dosimeter Location: off-site		
16	Private house - Barden Ridge	0.7 ± 0.3	0.6 ± 0.1
17	Private house - Engadine	0.8 ± 0.3	0.9 ± 0.1
18	Private house - Woronora	0.7 ± 0.3	0.7 ± 0.1

Notes:

i) Refer to **Figure 6** for the location of Thermoluminescent Dosimeters (TLD's) 1 to 15.

ii) * The data were recorded as mGy/year and converted to mSv/year using a conservative conversion factor of 1.

iii) The ARL dosimeters are the same as those 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.

iv) 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 18

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, 1996

Discharge stack Bld. No.	**Gross α** (kBq)	**^{131}I** (MBq)	**Gross β** (MBq)	**^{3}H** (GBq)	**Noble gases** (TBq)	**Other activity** (MBq)
1st Quarter (Jan - Mar) 1996						
Bld 54 (hotcells)	8	3152	0.30	-	131	21 667
3	9	1	0.18	-	-	-
15A (HIFAR)	2	2	0.46	1 493	42	64
19	3	0	0.10	-	-	-
20	10	0	0.30	45	-	-
21A	2	0.10	0.07	-	-	-
21B	0.25	0.28	0.01	-	-	-
23A	12	4 883	0.82	-	-	-
23B	0.74	0.74	0.04	-	-	-
41	10	1	0.29	-	-	-
56	12	3	0.45	-	-	-
57	2	1	0.09	141	-	-
2nd Quarter (Apr - Jun) 1996						
Bld 54 (hotcells)	8	2562	0.29	-	140	20 325
3	7	1	0.17	-	-	-
15A (HIFAR)	3	2	0.49	1 275	50	89
19	1	0	0.04	-	-	-
20	10	1	0.02	322	-	-
21A	2	0	0.07	-	-	-
21B	0	0	0.01	-	-	-
23A	13	2 186	1.00	-	-	-
23B	1	0	0.04	-	-	-
41	8	5	0.29	-	-	-
56	13	2	0.43	-	-	-
57	3	0	0.09	280	-	-

continued next page...

TABLE 18 continued ...

Discharge stack Bld. No.	**Gross α** (kBq)	**^{131}I** (MBq)	**Gross β** (MBq)	**^{3}H** (GBq)	**Noble gases** (TBq)	**Other activity** (MBq)
3rd Quarter (Jul - Sep) 1996						
Bld 54 (hotcells)	7	2 429	0.16	-	138	22 648
3	7	1.80	0.10	-	-	-
15A (HIFAR)	1	2	0.42	1 072	35	57
19	1	0	0.02	-	-	-
20	9	3	0.41	9	-	-
21A	1	0.67	0.41	-	-	-
21B	0.13	0.07	0	-	-	-
23A	7	3 570	0.89	-	-	-
23B	1	1	0.02	-	-	-
41	4	4	0.16	-	-	-
56	7	4	0.25	-	-	-
57	1	0.73	0.04	98	-	-
4th Quarter (Oct - Dec) 1996						
Bld 54 (hotcells)	5	4 204	0.17	-	180	29 015
3	8	2	0.10	-	-	-
15A (HIFAR)	1	2	0.72	1 490	34	88
19	1	0	0.02	-	-	-
20	7	2	0.30	97	-	-
21A	1	1	0.04	-	-	-
21B	0.13	0.06	0	-	-	-
23A	7	3 982	0.56	-	-	-
23B	1	0.43	0.02	-	-	-
41	5	3	0.16	-	-	-
56	7	4	0.26	-	-	-
57	1	2	0.04	12	-	-

i) See **Figure 4** for the location of the discharge stacks.
ii) See **Appendix B** for a list of the different types of airborne discharges and their origins.

TABLE 19

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, EXPRESSED AS PERCENTAGES OF QUARTERLY WORKING LEVELS, 1996

Period & Bld. No.	**Gross α** % of working level	**^{131}I** % of working level	**Gross β** % of working level	**^{3}H** % of working level	**Noble gases** % of working level	**Other activity** % of working level
1st Quarter (Jan - Mar) 1996						
Bld. 54 (hotcells)	< 0.1	5	< 0.1	-	77	1.4
3	0.6	< 0.1	< 0.1	-	-	-
15A (HIFAR)	< 0.1	< 0.1	< 0.1	1.1	156	0.1
19	< 0.1	-	< 0.1	-	-	-
20	0.4	-	< 0.1	0.6	-	-
21A	0.2	< 0.1	< 0.1	-	-	-
21B	0.1	<0.1	< 0.1	-	-	-
23A	< 0.1	31	< 0.1	-	-	-
23B	< 0.1	< 0.1	< 0.1	-	-	-
41	< 0.1	< 0.1	< 0.1	-	-	-
56	0.2	< 0.1	< 0.1	-	-	-
57	0.3	< 0.1	0.1	7.8	-	-
2nd Quarter (Apr - Jun) 1996						
Bld. 54 (hotcells)	< 0.1	4	< 0.1	-	82	1.3
3	0.4	< 0.1	< 0.1	-	-	-
15A (HIFAR)	< 0.1	< 0.1	< 0.1	1.0	185	0.1
19	< 0.1	-	< 0.1	-	-	-
20	0.4	< 0.1	< 0.1	4.0	-	-
21A	0.2	-	< 0.1	-	-	-
21B	-	-	< 0.1	-	-	-
23A	< 0.1	14	< 0.1	-	-	-
23B	< 0.1	-	< 0.1	-	-	-
41	< 0.1	< 0.1	< 0.1	-	-	-
56	0.2	< 0.1	< 0.1	-	-	-
57	0.5	-	0.1	16	-	-

continued next page...

TABLE 19 continued ...

Period & Bld. No.	**Gross α** % of working level	**^{131}I** % of working level	**Gross β** % of working level	**^{3}H** % of working level	**Noble gases** % of working level	**Other activity** % of working level
3rd Quarter (Jul - Sep) 1996						
Bld. 54 (hotcells)	< 0.1	4	< 0.1	-	81	1.4
3	0.4	< 0.1	< 0.1	-	-	-
15A (HIFAR)	< 0.1	< 0.1	< 0.1	0.8	130	0.1
19	< 0.1	-	< 0.1	-	-	-
20	0.3	< 0.1	0.1	0.1	-	-
21A	0.1	< 0.1	0.3	-	-	-
21B	< 0.1	< 0.1	-	-	-	-
23A	< 0.1	22	< 0.1	-	-	-
23B	< 0.1	< 0.1	< 0.1	-	-	-
41	< 0.1	< 0.1	< 0.1	-	-	-
56	< 0.1	< 0.1	< 0.1	-	-	-
57	0.2	< 0.1	< 0.1	5.4	-	-
4th Quarter (Oct - Dec) 1996						
Bld. 54 (hotcells)	< 0.1	6.4	< 0.1	-	106	1.8
3	0.5	< 0.1	< 0.1	-	-	-
15A (HIFAR)	< 0.1	< 0.1	< 0.1	1.2	126	0.1
19	< 0.1	-	< 0.1	-	-	-
20	0.3	< 0.1	< 0.1	1.2	-	-
21A	0.1	< 0.1	< 0.1	-	-	-
21B	< 0.1	< 0.1	-	-	-	-
23A	< 0.1	25	< 0.1	-	-	-
23B	< 0.1	< 0.1	< 0.1	-	-	-
41	< 0.1	< 0.1	< 0.1	-	-	-
56	< 0.1	< 0.1	< 0.1	-	-	-
57	0.2	< 0.1	< 0.1	0.7	-	-

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

TABLE 20

RADIOACTIVITY IN GROUNDWATER IN THE VICINITY OF BUILDING 27, 1996

Date Sampled	RADIOACTIVITY (Bq/L)	
	Gamma-emitters	Tritium
16.1.96	ND	360 ± 40
20.2.96	ND	370 ± 20
26.3.96	ND	460 ± 80
24.4.96	ND	520 ± 40
14.5.96	ND	300 ± 20
18.6.96	ND	460 ± 20
17.7.96	ND	400 ± 50
14.8.96	ND	350 ± 30
17.9.96	ND	410 ± 40
15.10.96	ND	420 ± 60
7.11.96	ND	320 ± 40
10.12.96	ND	440 ± 40

Notes:

i) Building 27 is the intermediate waste and spent fuel storage facility.

ii) See **Figure 2** for the location of the sampling sump which collects groundwater from the vicinity of Building 27.

iii) "ND" indicates that no significant levels of gamma-emitters were detected.

TABLE 21

LIQUID RADIOACTIVE EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, 1996

MONTH	VOLUME Discharged m^3	ALPHA [a] Bq/m^3	BETA [b] Bq/m^3	TRITIUM Bq/m^3	Average MONTHLY Concentration QUOTIENT*	
					Former 1959 Radioactive Substances Regulations	WHO Guidelines for Drinking Water
January	8939	5.17×10^2	5.80×10^3	1.1×10^7	0.11	0.15
February	5914	5.17×10^2	9.45×10^3	8.5×10^6	0.15	0.17
March	10 327	6.67×10^2	6.96×10^3	5.8×10^6	0.14	0.15
April	5562	7.89×10^2	1.85×10^4	1.0×10^7	0.27	0.28
May	7873	6.49×10^2	3.06×10^4	3.6×10^6	0.37	0.33
June	5600	5.28×10^2	1.02×10^4	4.8×10^6	0.16	0.16
July	6502	4.71×10^2	2.28×10^4	2.5×10^6	0.28	0.24
August	6789	6.48×10^2	5.60×10^4	2.3×10^6	0.12	0.12
September	6231	6.18×10^2	4.41×10^3	1.3×10^6	0.11	0.16
October	6653	8.10×10^2	9.40×10^3	4.4×10^6	0.18	0.18
November	6861	5.86×10^2	1.69×10^4	8.6×10^6	0.23	0.24
December	6861	5.39×10^2	2.64×10^4	1.4×10^7	0.31	0.33
Maximum Permissible Concentration (Former 1959 Radioactive Substances Regulations)	-	1.0×10^4 (as ^{226}Ra)	1.0×10^5 (as ^{90}Sr)	4.0×10^9	1.00	-
Activity Concentration Equivalent at ANSTO (WHO Guidelines for Drinking Water)	-	1.25×10^4 (as ^{226}Ra)	1.25×10^5 (as ^{90}Sr)	1.95×10^8	-	1.00

Notes:

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

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

* Concentration Quotient: the sum of the average monthly concentrations of α, β and tritium radioactivity in the liquid effluent divided by the Maximum Permissible Concentration (MPC) or Activity Concentration Equivalent for that radionuclide. The relevant quotient term must be no greater than one (unity) to comply with the requirements of the former NSW Radioactive Substances Regulations (1959) or the WHO Guidelines for Drinking-Water Quality (1993). See **Section 3.1.**

All discharges for 1996 were well 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

TRITIUM LEVELS OFFSHORE OF POTTER POINT
17 APRIL 1996

TRITIUM (Bq/L)						
Hours after release	**Stations sampled 1 metre below the surface:**					
	#1	#2	#3	#4	#5	#6
14	< 5	< 5	< 5	< 5	7	< 5
15	< 5	< 5	< 5	< 5	8	< 5
16	9	< 5	< 5	< 5	< 5	< 5
17	8	< 5	< 5	< 5	< 5	< 5
18	< 5	< 5	< 5	< 5	8	< 5
19	< 5	< 5	< 5	< 5	< 5	< 5
20	< 5	5	< 5	< 5	< 5	< 5
21	< 5	< 5	< 5	< 5	< 5	< 5
Hours after release	**Stations sampled 3 metres below the surface:**					
	#1	#2	#3	#4	#5	#6
14	< 5	5	6	< 5	< 5	5
15	< 5	< 5	< 5	< 5	< 5	< 5
16	< 5	< 5	< 5	< 5	< 5	< 5
17	< 5	< 5	< 5	< 5	< 5	< 5
18	< 5	5	< 5	< 5	< 5	< 5
19	< 5	< 5	< 5	< 5	< 5	< 5
20	5	< 5	6	< 5	< 5	< 5
21	8	< 5	< 5	< 5	< 5	< 5

Note: Sample locations are discussed in the text, **Section 5.3.1.**

TABLE 23

TRITIUM LEVELS OFFSHORE OF POTTER POINT
14 NOVEMBER 1996

TRITIUM (Bq/L)						
Hours after release	**Sample Station # 1**			**Sample Station # 2**		
	0.5 m	1.0 m	2.0 m	0.5 m	1.0 m	2.0 m
9	<5	<5	<5	<5	<5	<5
10	< 5	<5	<5	<5	<5	<5
11	251	12	<5	<5		<5
12	28	<5	8	67	51	9
Hours after release	**Sample Station # 3**			**Sample Station # 4**		
	0.5 m	1.0 m	2.0 m	0.5 m	1.0 m	2.0 m
9	<5	<5	<5	<5	<5	<5
10	<5	<5	<5	<5	<5	<5
11	11	<5	<5	5	<5	<5
12	21	6	<5	<5	<5	<5
Hours after release	**Sample Station # 5**			**Sample Station # 6**		
	0.5 m	1.0 m	2.0 m	0.5 m	1.0 m	2.0 m
9	<5	<5	<5			
10	<5	<5	5	<5	<5	7
11	<5	<5	<5	<5	<5	<5
12	<5	<5	<5	<5	6	<5

Note: Sample locations are discussed in the text, **Section 5.3.2.**

TABLE 24

ESTIMATED EFFECTIVE DOSES FROM AIRBORNE DISCHARGES 1996

Receptor Location	Effective dose 1996[#] (mSv/yr)
Library	0.012
Outside HIFAR	0.0023
Building 9	0.017
Main gate	0.012
Stevens Hall	0.011
MWDA Depot *	0.0094
BMX track *	0.012
Woronora Valley *	0.0016

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

TABLE 25

ESTIMATED EFFECTIVE DOSES FROM AIRBORNE DISCHARGES at 1.6 km and 4.8 km radii around HIFAR, 1996

Receptor Locations	Effective dose 1996 (mSv/yr)[#]	
	at 1.6 k m radius from HIFAR	**at 4.8 km radius** from HIFAR
NORTH	0.0085	0.0023
NNE	0.010	0.0023
NE	0.0068	0.0020
ENE	0.0083	0.0025
EAST	0.0070	0.0021
ESE	0.0050	0.0016
SE	0.0041	0.0013
SSE	0.0036	0.0011
SOUTH	0.0035	0.0010
SSW	0.0033	0.0010
SW	0.0033	0.0011
WSW	0.0033	0.0010
WEST	0.0034	0.0010
WNW	0.0030	0.00093
NW	0.0049	0.0015
NNW	0.0065	0.0018

[#] Estimated airborne effective doses were calculated using the ADDCOR program, stack discharge figures and meteorological data for 1996.

TABLE 26

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:

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

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

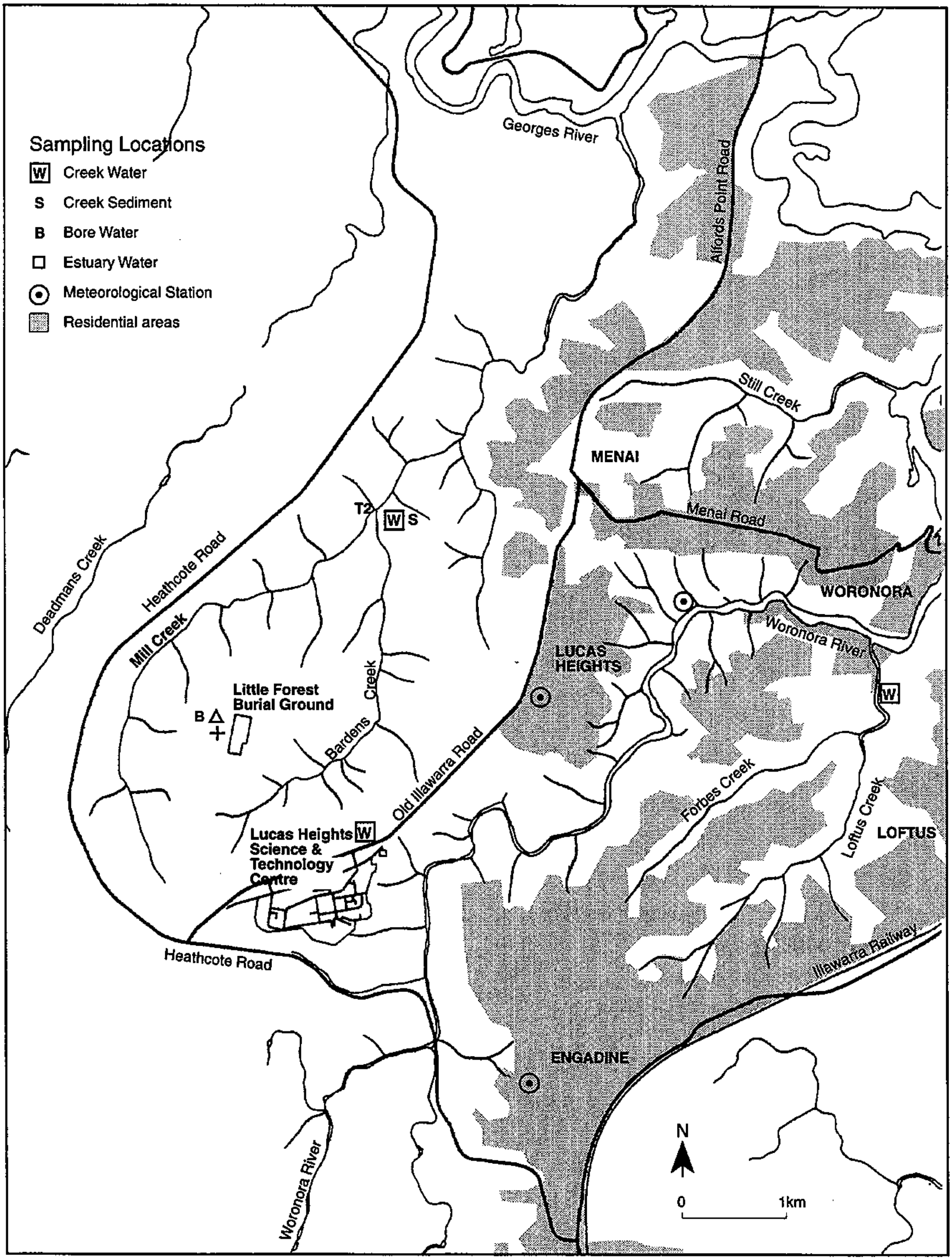

Figure 1: Location of LHSTC & Offsite Sampling Points

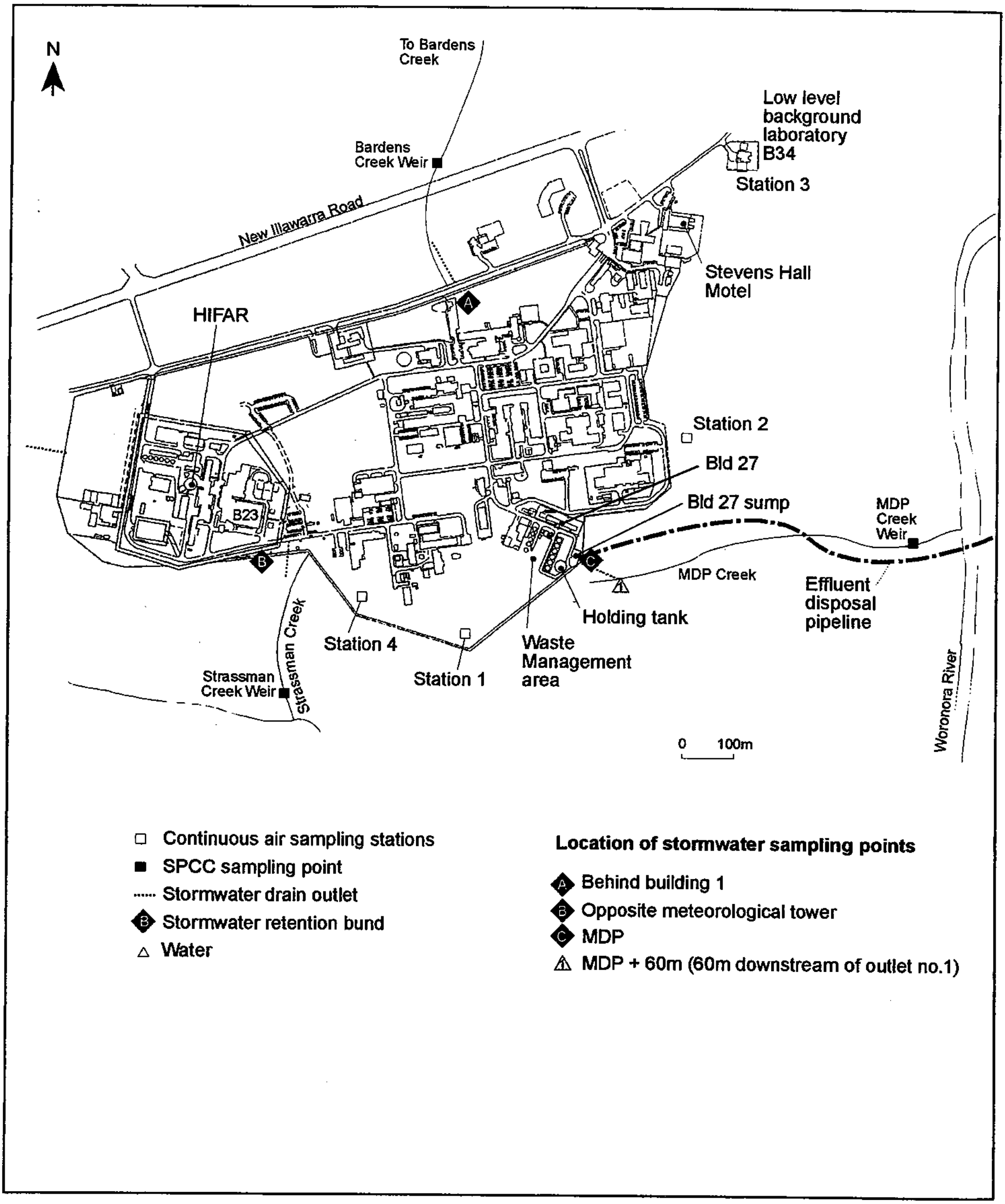

Figure 2: Location of Stormwater and Air Sampling Points at LHSTC

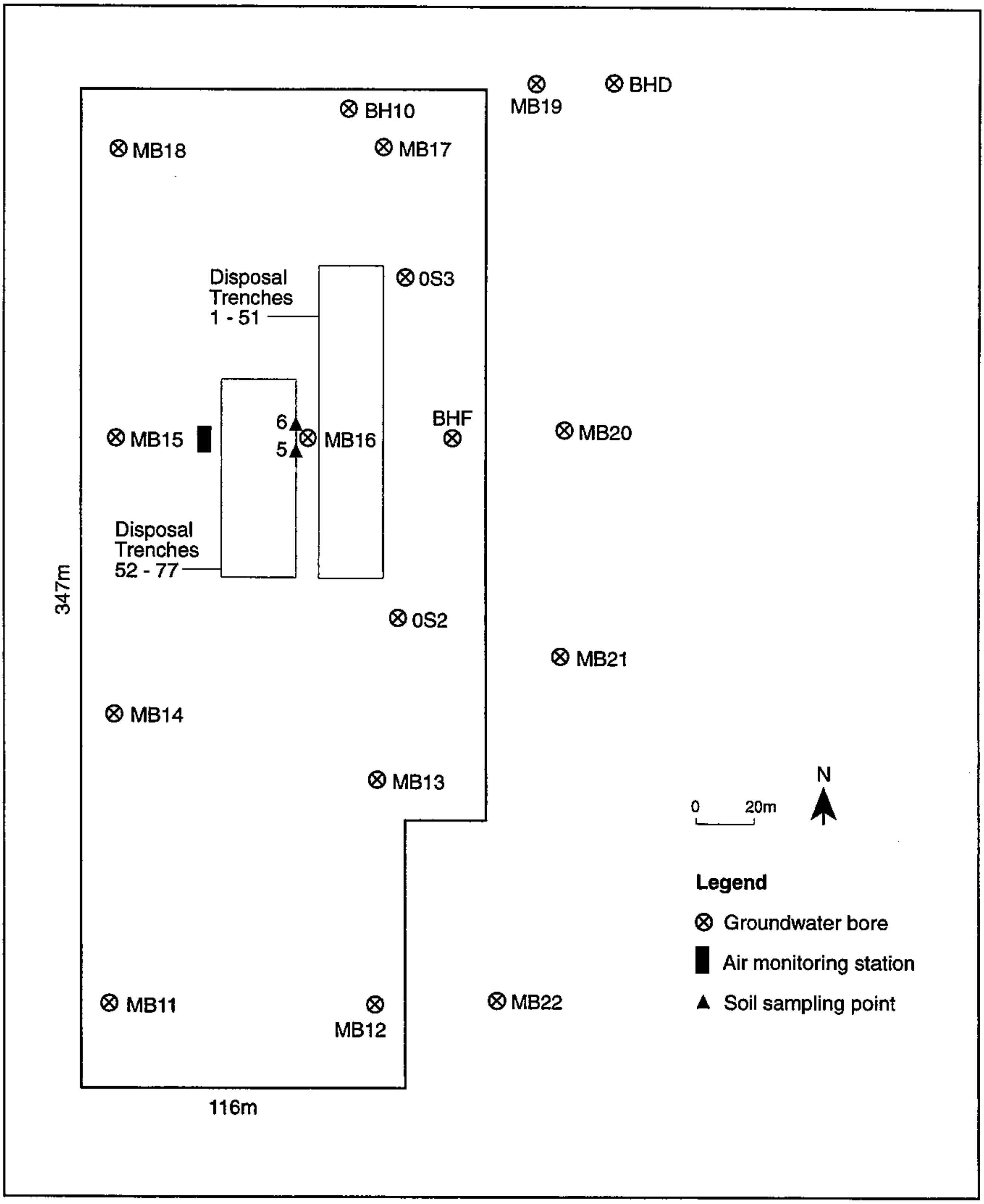

Figure 3: Little Forest Burial Ground - Location of Trenches, Groundwater Bores and Soil Sampling Points

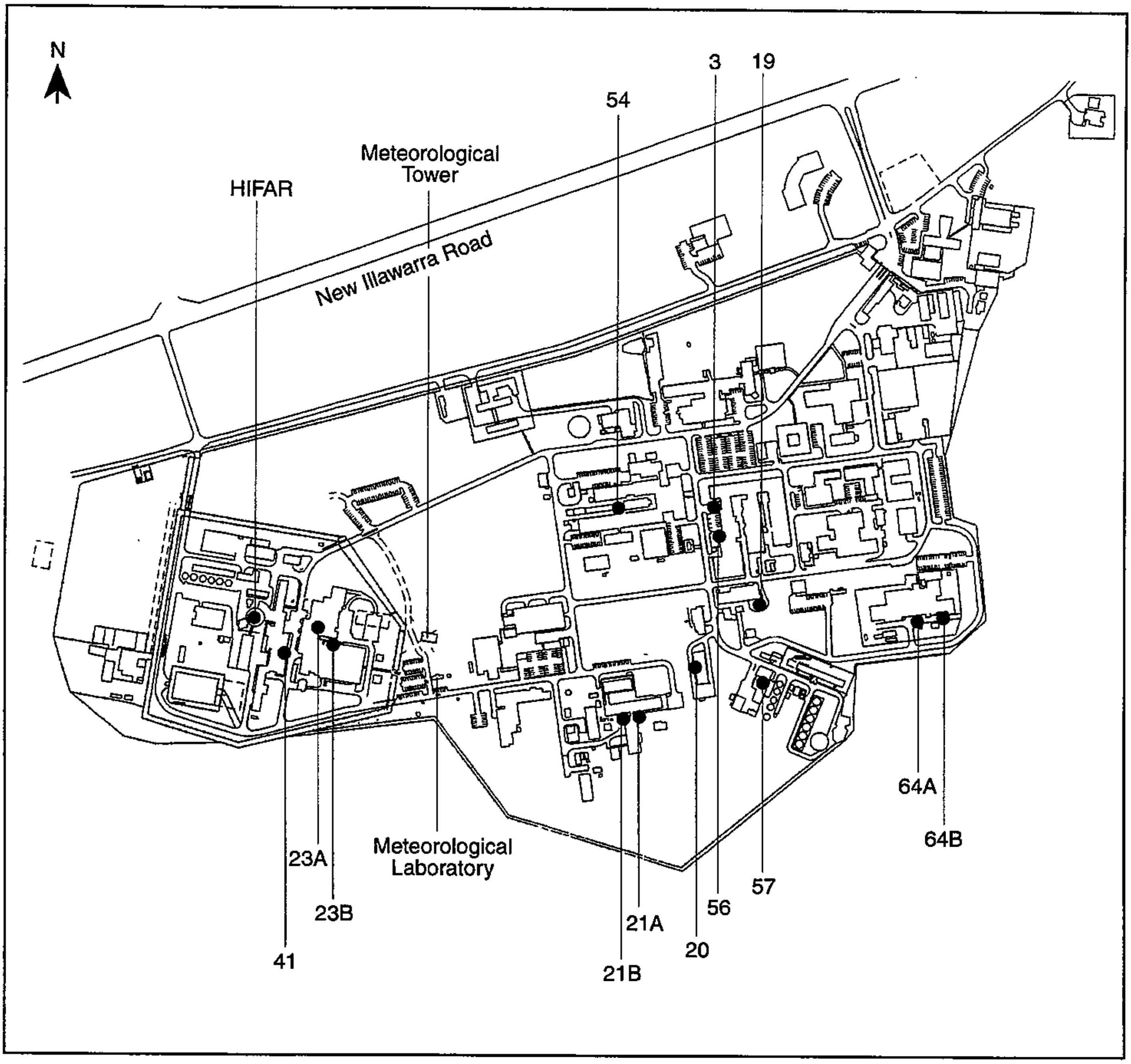

Figure 4: Location of Airborne Effluent Release Stacks and Meteorological Facilities at LHSTC

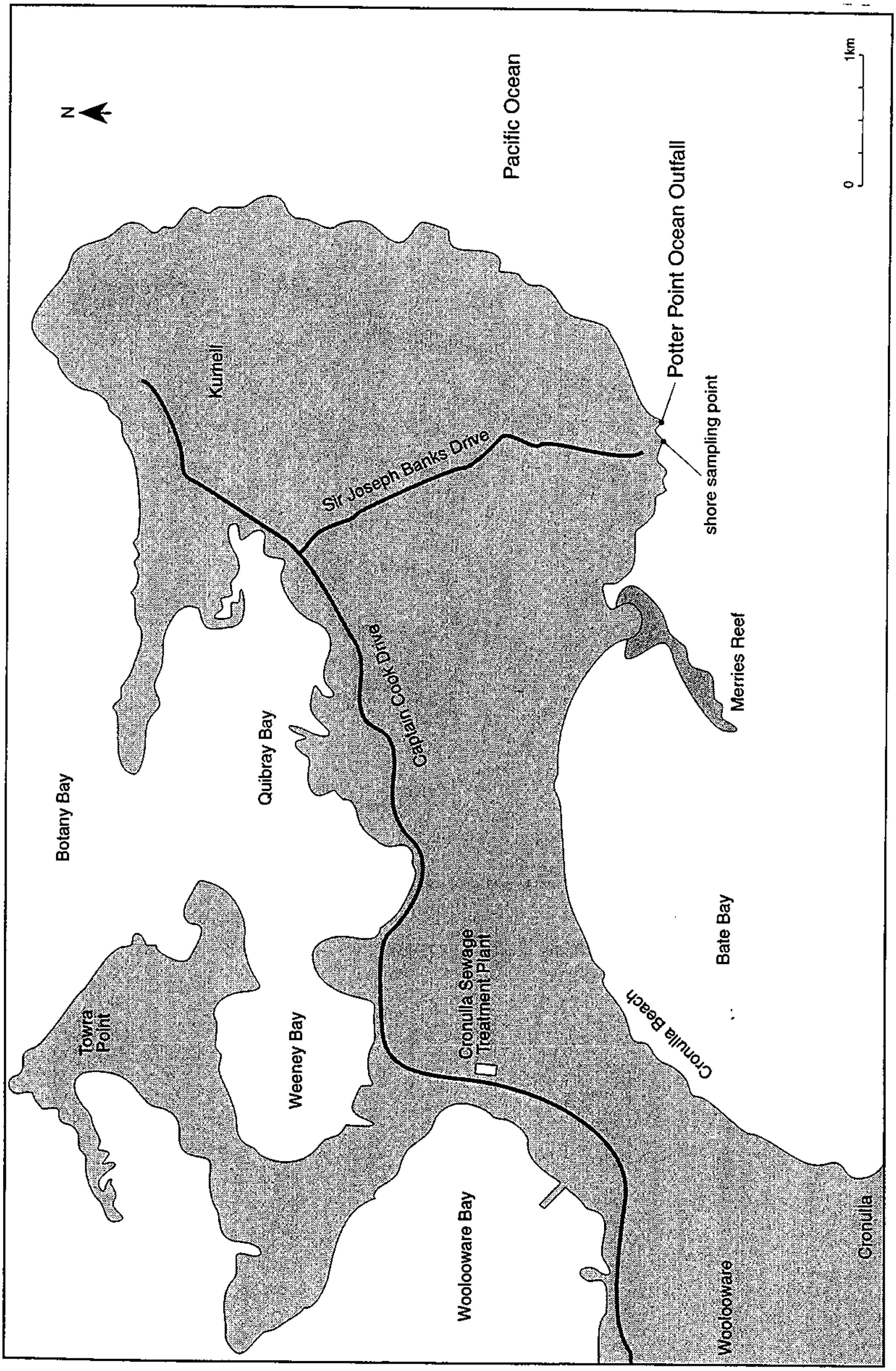

Figure 5: Location of Cronulla Sewage Treatment Plant and Potter Point Ocean Outfall

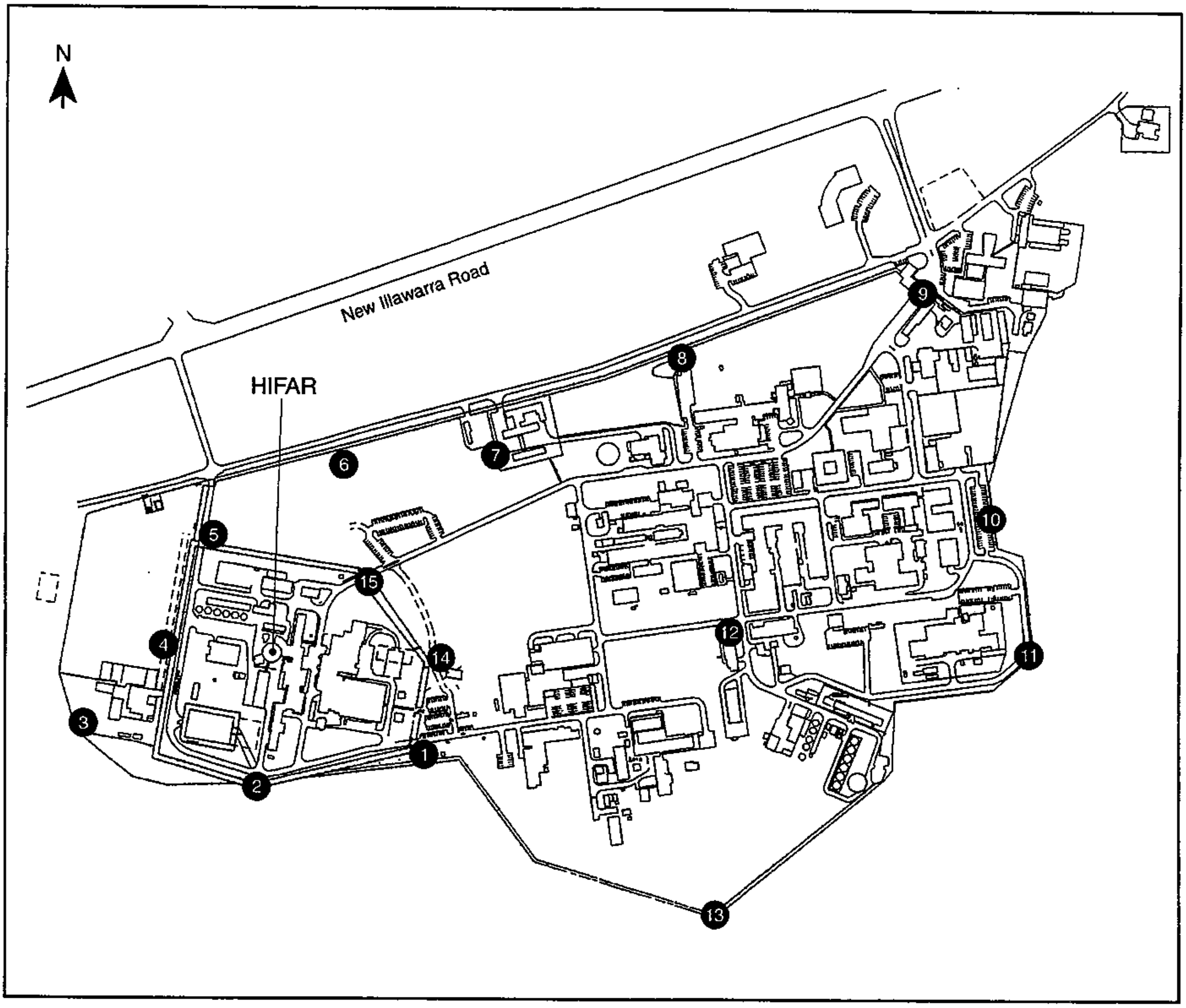

Figure 6: Location of External Radiation Dosimeters at LHSTC

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 beta are unable to penetrate the skin. Most beta particles can be stopped by a small thickness of light material, eg. aluminium or plastic sheeting.

beta radioactivity: Radioactive transformation of a nuclide in which high energy electrons are emitted and the mass number remains unchanged, but the atomic number changes by 1 with the emission of a beta particle.

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

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, or gamma radiation.

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

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 owned by ANSTO and located at Lucas Heights.

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

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

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

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

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

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

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

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 x 10^9 years. A major contributor to the internal part of radiation dose arising from natural background radiation. A beta/gamma emitter.

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

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

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

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

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

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

APPENDIX A

PREVIOUS ENVIRONMENTAL SURVEY REPORTS

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APPENDIX B

STACK DISCHARGES OF RADIOACTIVITY AT LUCAS HEIGHTS

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

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Tritium	12 years	Bld 20	Water Vapour	Bld 20 is the decontamination centre and occasionally handles coolant pumps removed from the reactor for maintenance.
Tritium	12 years	Bld 57	Water Vapour	Bld 57 is where the spent resin beds, used to purify the HIFAR coolant water, are regenerated or replaced. Most of the tritiated water on the resin beds is trapped before the drying gas is discharged to the stack.
Mercury-197 Mercury-203	64 hours 47 days	HIFAR	Vapour	Slight traces of mercury vapour in the air within the HIFAR containment are activated in passing through the HIFAR reactor. The mercury probably comes from a thermometer dropped at some time in the containment building.
Arsenic-76	26 hours	HIFAR	Arsene Vapour	Very slight traces of arsenic vapour in the air within the HIFAR containment are activated in passing through the HIFAR reactor. The arsenic vapour is being slowly emitted from wood, treated with preservative, which was used a few years ago, when renewing the thermal cladding of the containment building.
Iodine-131	8 days	HIFAR	Vapour	Even though there are only traces of iodine-131, if any, in the exhaust from HIFAR under normal operation, the effluent is continuously sampled for iodine, since it is the most important activity released in a serious accident to the reactor.
Xenon-133 Xenon-135 Xenon-135m Krypton-87 Krypton-85m Krypton-88	5.3 days 9.2 hours 15 mins 76 mins 4.5 hours 2.8 hours	Bld 54	Gas	These are all “fission product noble gases”. The radio-nuclide most often used as a diagnostic tracer in nuclear medicine is technetium-99m, extracted from fresh fission products. Small uranium targets are irradiated in HIFAR for a few days before they are dissolved in nitric acid in a fully enclosed apparatus in one of the heavily shielded “Hot Cells” in Bld 54. The noble gases which are released during dissolution are trapped on a large charcoal bed in the next cell. When the targets are completely dissolved the charcoal bed is isolated and the noble gases allowed to decay while trapped on the bed. However, additional noble gases are formed in the nitric acid solution, from radioactive gases released from the apparatus as the liquid is manipulated into different parts of the equipment by means of vacuum lines. The exhaust gases from the vacuum lines pass through small charcoal beds to trap most of the iodine-131. About 90% of the noble gases are trapped during dissolution leaving only 10% to be released during processing.

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Iodine-131	8 days	Bld 54	Organic Iodine Vapour	Iodine-131 is also released during technetium-99m extraction from fresh fission products. Iodine is very volatile even at room temperature and about 3% escapes from the enclosed apparatus, despite efforts to contain it. To prevent this quantity of iodine being released to the atmosphere, the exhaust from the hot cells passes through sixteen beds filled with a specially impregnated charcoal, which was developed in England to trap all forms of airborne iodine, even at high humidity. The beds are tested regularly and are replaced whenever the efficiency falls below 99.9%. The most penetrating form of airborne radio-iodine has been found to be the vapour of an organic compound, methyl iodide, formed when the extremely dilute radioactive iodine reacts with traces of organic vapours.
Iodine-131	8 days	Bld 23		Iodine-131 is an important medical isotope in its own right, being used in the treatment of thyroid cancer. It is produced by the irradiation of a tellurium target in HIFAR, before being processed in a small shielded hot cell in Bld 23. The exhaust from the group of cells passes through three charcoal beds similar to the ones in Bld 54.

APPENDIX C

SYMBOLS AND PREFIXES

Symbol	Name
α	alpha
β	beta
γ	gamma
^{241}Am	americium-241
^{7}Be	beryllium-7
^{137}Cs	caesium-137
^{134}Cs	caesium-134
^{144}Ce	cerium-144
^{51}Cr	chromium-51
^{60}Co	cobalt-60
^{131}I	iodine-131
K	potassium (stable)
^{40}K	potassium-40
^{239}Pu	plutonium-239
^{90}Sr	strontium-90
^{208}Tl	thallium-208
^{232}Th	thorium-232
^{3}H	tritium
^{238}U	uranium-238

PREFIXES

k (kilo) $= 10^{3} = 1\ 000$
M (mega) $= 10^{6} = 1\ 000\ 000$
G (giga) $= 10^{9} = 1\ 000\ 000\ 000$
T (tera) $= 10^{12} = 1\ 000\ 000\ 000\ 000$

m (milli) $= 10^{-3} = 0.001$
μ (micro) $= 10^{-6} = 0.000001$
n (nano) $= 10^{-9} = 0.000000001$
p (pico) $= 10^{-12} = 0.000000000001$

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 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.

All samples were oven-dried at 70 ^{0}C. Dried samples of fish and barnacles were ground to powder in a Retsch Ball-mill, while the algae were ground in a mortar and pestle. These ground samples were then packed into plastic petri dishes for gamma-counting.

Soils/Sediments

Soils were sampled with a scoop to take the first 4 cm from the surface. About 1 kg was collected. Samples were dried overnight at 100 ^{0}C, then passed through a coarse sieve to remove large stones and vegetative matter. The sample dry weight was obtained, then the sample was ignited at 450 ^{0}C in a muffle furnace, cooled and re-weighed. The whole, ashed sample was used for gamma spectrometry and gross beta counting. The remaining ash was sieved to yield a fraction with particle sizes ranging from 125 to 250 microns, which was used for alpha counting.

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

Waters

All water samples are collected in polyethylene bottles. Water samples for tritium or gross alpha/beta analysis are not acidified, but are prepared as soon as possible after arrival in the laboratory. The remaining samples are acidified to a pH of less than 2.

Ground Waters

Groundwaters from bores at Little Forest Burial Ground were collected by first pumping out the contents of each bore, then allowing all the bores to recharge with fresh groundwater over a period of at least two days. The samples for May 1996 were collected by pumping ten-litres from the bottom of each bore into a jerrycan, using a petrol-fuelled pump. This sampling method tends to disturb the bores and consequently increase the sediment loading of the samples, and has since been modified to reduce such disturbances. The December 1996 samples were collected using the modified technique.

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.

Dust on aerosol filters - LFBG

A solar-powered, remotely operating air sampler was located adjacent to the burial trenches at the Little Forest Burial Ground, to monitor possible aerial dust dispersion of contaminants from the site. The location of the air sampler is shown on **Figure 3**.

The system was triggered by wind speeds of 3 m s^{-1} or more. Below this speed, surface dusts would not be raised from this type of well-grassed landform. Air is drawn at approximately 8 litres per minute through a pair of Millipore (0.8 μm pore) aerosol filters. The Millipore filters are approved by the National Institute for Occupational Safety and Health (NIOSH) for monitoring airborne beryllium and other compounds (NIOSH 1977). The filters are replaced every three months.

The two air filters are sampled quarterly and analysed separately for beryllium and plutonium. One of the filters is digested using the US-Environment Protection Authority method 3050, and analysed for beryllium with an Inductively Coupled Plasma Atomic Emission Spectroscope (method 3120B of the American Public Health Authority). The duplicate sample is retained - together with the other 3 samples for the year - to form a composite sample for plutonium analysis by alpha spectrometry (performed by ANSTO's Environmental Radiochemistry Laboratory).

Environmental Radiation - ARL dosimeters

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

ANSTO also trialled environmental dosimeters from Harshaw (Bicron NE Technology) which contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters. They were analysed at ANSTO using an automatic reader.

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). One mL of distilled sample was then combined with 10 mL of Instagel scintillant in a polyethylene counting vial, refrigerated and stored in the dark for several hours prior to counting on a Canberra/Packard model 300c liquid scintillation counter. Standards (prepared monthly using a certified Amersham tritium solution) and distilled water blanks (prepared each week) were counted with the samples, to determine the counting efficiency and background radioactivity of the counter. Total counting time was 100 minutes per vial, comprising five 20-minute counts.

Alpha and beta activity in soils

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

Gross Alpha/Beta Activity in Waters

Water samples were screened for gross alpha/beta activities as a means of determining whether further tests for individual radionuclides were necessary. Samples were analysed using one of three methods: the Standards Association of Australia method AS 3550.5(1990); ISO methods 9696 & 9697(1992); or the AAEC/ANSTO tablet method.

A choice is made between the three gross alpha/beta methods depending upon the amount of sample available, whether the samples are acidified, the salinity of the samples or the levels of suspended or dissolved solids.

a) AS 3550.5(1990) - planchette thin source method

Samples analysed according to *Australian Standard - Waters - Part 5: Determination of gross alpha and gross beta activities.* A 'thin' source is prepared by evaporating the acidified sample in small aliquots onto an aluminium 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. For this method the source thickness should be no greater than 5 mg/cm^2 for alpha, or 10 mg/cm^2 for beta counting. The maximum volume used was 100 mL, which generally yielded sample residues below the specified thickness.

The method is not suitable for saline waters, or samples with high levels of suspended or dissolved solids.

The sources were counted in a Canberra 2400 thin-window gas-flow proportional alpha/beta counter and standardised against a range of sources of different thicknesses, prepared from americium-241 (for α) and caesium-137 (for β) solutions.

b) ISO 9696 & 9697 (1992) - planchette thick source method
In this method, the 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. Restrictions on the source thickness are similar in principle to those in the AS method in *a)* above, however the limits are slightly higher. The amount of sample residue dispensed onto the planchette was standardised at 100 mg. Standard sources of 100 mg thickness (americium-241 and potassium sulphate for alpha and beta respectively) were used to calibrate the Canberra 2400 counting system.

The method is not suitable for saline waters, but is usually applicable to samples with high levels of suspended or dissolved solids. Advantages are: improved accuracy and repeatability of results, ability to store dry residues for future reference, unfiltered samples can be used, samples can be acidified and stainless steel planchettes have lower backgrounds than aluminium planchettes. Disadvantages: long preparation times and high risk of losing samples by allowing them to evaporate to dryness on the hotplate.

c) AAEC/ANSTO tablet - thick source method
Water samples (≥ 10 L) were evaporated to dryness in porcelain dishes, the dried residue weighed, compressed into a 50 mm diameter tablet, and counted for gross alpha/beta activity in the Canberra 2400 alpha/beta counter. The tablet may also be counted for gamma activity.

A tablet of potassium chloride and a metal disc (an alloy of aluminium and natural uranium) were used to standardise the counter for beta and alpha activity, respectively. Advantages of this method are: large sample volumes can be used, long-term storage of dry tablets is possible, it is a non-destructive technique and uses a single source for alpha, beta and gamma counting. Disadvantages: non-acidified samples, if retention samples are required then large volumes are needed, long preparation times and this method is not used by other labs.

ARL gel method for preparation of gamma sources - alternative to tablet method
Two litres of supernatant was decanted from a settled acidified sample and evaporated down to 30 mL. The concentrated sample was then incorporated into an agar gel matrix, set in a 65 mm petri dish, sealed and counted for gamma-emitters. The method was obtained from the ARL. Results are expressed in Bq/litre. The advantages of this method are: the smaller sample volume required, the reduced sediment load, it uses an unfiltered sample, samples can be acidified & duplicate samples stored and results can be compared with the ARL if required.

Gamma spectrometry - water, soils, vegetation, fish, algae, barnacles
Gamma spectra are obtained by placing prepared samples onto the Ortec Gamma-X high-purity germanium (HPGe) low-background detector, and acquiring counts over a 23 hour period. A multi-channel analyser sorts the spectra according to the energy of the gamma photons. Peaks in the sample spectra are identified using an Ortec software package, *Maestro 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 errors.

The gamma energy spectrum is calibrated periodically using certified point sources. The efficiency of the detector is determined using a range of gamma sources, prepared from reference materials of known activity, of similar matrix and in the same geometry as the various types of samples. Background spectra are acquired monthly, and are counted for the same length of time as the samples (with no sample present).

Sample counting geometries include:

- tablets (water residues, ashed vegetation, biota);
- petri dishes (60 mm or 65 mm diameter filled with soil; sediment; powdered material; or agar gel);
- 450 mL Marinelli Beakers (for liquid samples).

Potassium-40 beta activity

In calculating the net beta activity in soils, the activity due to natural potassium-40 is subtracted. The potassium-40 activity can be calculated in two ways: either by direct calculation from its 1460 keV peak in the gamma spectrum of the sample, or by chemical analysis of the sample's potassium content and a subsequent calculation of the potassium-40 activity. The specific activity of potassium is 27.6 Bq of potassium-40 per gram of stable potassium. In many cases, the beta activity of a sample is almost entirely due to the potassium-40 contribution.

Air samples - Ambient Iodine-131

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

Results are reported in units of iodine-131 activity per volume of air sampled (Bq/m^3). The results are calculated in an extremely conservative manner, using the following assumptions:

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

APPENDIX E

AIRBORNE EFFLUENT SAMPLE COLLECTION AND ANALYSIS

Airborne Effluent
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 13 weeks when some of the particulate filters are measured again for gross alpha and beta activity. This is to confirm that any particulate activity previously measured was principally due to short-lived radioisotopes.

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

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

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