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ENVIRONMENTAL and EFFLUENT MONITORING at LUCAS HEIGHTS SCIENCE and TECHNOLOGY CENTRE, 1995

by

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AUSTRALIAN NUCLEAR SCIENCE
AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS SCIENCE and TECHNOLOGY CENTRE

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ABSTRACT

Results are presented of environmental and effluent monitoring conducted in the vicinity of the Lucas Heights Science and Technology Centre (LHS&TC) during 1995. 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 0.01 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.

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ANSTO; AIR; 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, 1995

EXECUTIVE SUMMARY

The environmental and effluent monitoring results for 1995 show that the Australian Nuclear Science and Technology Organisation (ANSTO) complied with existing 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 1995 was 0.22 representing 22% of the limit, with the individual monthly quotients ranging from 0.13 to 0.36.

The mean radionuclide concentration quotient (based upon the WHO *Guidelines for Drinking-Water Quality*) in liquid effluent for the period September to December 1995, was 0.30. This represents 30% of the limit. Individual monthly quotients ranged from 0.23 to 0.40.

Concentrations of the non-radioactive components of liquid effluent discharged to the Sydney Water Corporation 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 Lucas Heights Science and Technology Centre (LHS&TC) 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 HIFAR. 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 LHS&TC 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 LHS&TC.

Environmental monitoring at the Little Forest Burial Ground (LFBG) indicated similar trends to past years with the exception that traces of americium-241 may have been

detected in monitoring bore OS2, situated at the south-eastern margin of the disposal trenches at LFBG, and MB16 in the centre of the trenches. These results are yet to be confirmed by further analyses undertaken by the Australian Radiation Laboratory. 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 LHS&TC perimeter fence and at three private residences in the nearby suburbs of Lucas Heights, Engadine and Woronora. Measurements of absorbed dose in air at the three residential locations showed an average integrated absorbed dose of 1.0 mSv/year. This level is consistent with figures reported in a survey conducted by the Australian Radiation Laboratory, 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 2.4 mSv/year were registered at some locations in the south-western sector of the LHS&TC perimeter fence. These elevated readings are a result of gamma emissions from some nuclear material stored in the area, however this part of the site is not readily accessed by the general public. The maximum dose observed is well within the level considered typical for annual effective doses to adults from natural sources (UNSCEAR 1993). Nevertheless, ANSTO is in the process of relocating this nuclear material to a new shielded storage facility which has been constructed on site.

Regular seawater and biological sampling programs were established at Potter Point ocean outfall during 1995. Treated sewage effluent for the Sutherland Shire, including low-level effluent from the LHS&TC, passes through the Cronulla Sewage Treatment Plant and is discharged at Potter Point. The seawater and biological sampling programs aim to address public concern that members of the public recreating in the ocean off Potter Point may be exposed to radiation doses as a result of any radionuclides released at the Potter Point sewage outfall.

In 1995, monitoring of shoreline seawater samples (collected along the shoreline 200m south of Potter Point) for tritium and gamma emitting radionuclides, showed tritium levels within the range of the very low levels normally found in the upper layer of seawater. The only gamma emitter detected was potassium-40 which occurs naturally in seawater at about the measured concentrations.

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. Four types of sample were collected from Potter Point: fish, macrophytic algae, barnacles and particulates > 37 μm (including plankton). Some samples of fish, green algae and barnacles were also collected from a reference site, approximately 5.5 km south of Potter Point, at the Royal National Park.

Based on the maximum amounts of cobalt-60 and caesium-137 detected in fish from Potter Point in 1995, a person would have to consume about 77 000 kg of fish per year to reach the recommended Annual Limits of Intake derived from the 1996

International Basic Safety Standards (jointly sponsored by the FAO, IAEA, ILO, OECD/NEA, PAHO and WHO)[1].

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.

[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 (UN).
PAHO: Pan-American Health Organisation.
WHO: World Health Organisation (UN).

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 (LHS&TC), 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 programs is to determine whether the operations at LHS&TC 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 LHS&TC 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 1995 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 LHS&TC in relation to local roads, waterways and residential areas.

2.0 ENVIRONMENTAL PATHWAYS

The main environmental pathways by which radionuclides from LHS&TC 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 sewer system;
- radionuclide transport by surface/ground water and/or contaminated airborne particulate dispersion from the Little Forest low-level radioactive waste Burial Ground (LFBG);
- accidental releases or spillages.

2.1 Atmospheric Discharges

Atmospheric discharges from LHS&TC 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 LHS&TC 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 LHS&TC is at Glenfield, approximately 13 km away (NSW Dairy 8 Corporation, 1995). In previous years, milk samples have been obtained from a cow belonging to a family living at Lucas Heights. However, as the cow was no longer available after February 1993 and ANSTO is not aware of any other local milk supplies, no further milk sampling was undertaken since that time and this pathway is no longer considered applicable.

A hypothetical critical group for inhalation of airborne activity is assumed to consist of people living close to the LHS&TC 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 likely sources of exposure since there is little or no food production or processing in the neighbourhood of LHS&TC and small creeks receiving runoff from the site are not used as sources of drinking water.

Levels of integrated external radiation at the LHS&TC and in nearby suburban locations, were also measured during 1995 using dosimeters issued by the Australian Radiation Laboratory.

2.2 The Discharge of Low-level Liquid Effluent

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

Low-level liquid effluent discharged at ANSTO passes through the Cronulla Sewage Treatment Plant (CSTP) and along with other effluent from that plant is discharged to the ocean at the Potter Point outfall. Potential exposure scenarios for members of the public would include ingestion of contaminated fish caught around the Potter Point outfall and ingestion of contaminated seawater by swimmers and surfers recreating in

the ocean near the outfall. The large dilution effects in both the sewer system and the ocean, ensure that levels of radioactivity from ANSTO in the ocean are at negligible levels and of no radiological consequence for members of the public and employees of Sydney Water Corporation.

Studies to confirm the negligible level of radionuclides from LHS&TC in seawater a short distance from the Potter Point outfall were undertaken during 1993 and reported in *Environmental and Effluent Monitoring at LHRL, 1994 (ANSTO/E-717).* The results of further studies on liquid effluent released to the sewer, undertaken in 1995, are presented in **Section 5.3** of this report. Routine seawater monitoring commenced during 1994 and a biological monitoring program 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 LHS&TC.

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

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

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

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

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

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

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

The radiation levels over the disposal trench area are close to background levels. Direct exposure to external radiation from buried waste would only become a consideration if the waste was exposed through erosion or subsidence of the cover, or 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 LHS&TC 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 announced in November 1993 its intention to form a new regulatory body, the Australian Institute for Radiation Protection (AIRP). The AIRP was to be an amalgamation of the Australian Radiation Laboratory 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 LHS&TC are resented 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 directed to the Sydney Water Corporation Ltd sewer, all liquid effluent discharges are required to comply with the Sydney Water Corporation's requirements for acceptance of liquid trade waste, including the radioactivity concentration limits specified in the NSW Radioactive Substances Regulations (1959) as amended. In September 1993 the NSW Radiation Control Regulation (1993) came into force, however this regulation does not specify generic radioactivity concentration limits for liquid discharges to the sewer.

In lieu of the proposed regulatory arrangements involving the AIRP, during 1995 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).

In 1995 a revised Trade Wastewater Agreement: *Consent to Discharge Trade Wastewater;* was negotiated with the Sydney Water Corporation under the *Water Board (Corporatisation Act) 1994*. Under the terms of this Agreement ANSTO has agreed to 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_i) defined for that radionuclide. Where more than one radionuclide is present, the sum of the average concentrations of all radionuclides (expressed as a fraction of the relevant MPC), termed the *concentration quotient,* must be no greater than one: *ie*

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

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

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

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

Where α = average gross alpha concentration in effluent discharged;
β = average gross beta concentration in effluent discharged;
^3H = average tritium concentration in effluent discharged;
MPC = Maximum Permissible activity 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)	
Ra-226	1×10^4
Sr-90	1×10^5
^3H	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. 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.

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 Corporation Ltd 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 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[2].

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}	40.3
iodine-131	2.2×10^{-5}	6.2
radium-226	2.8×10^{-4}	0.49
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).
2) The WHO (1993) quotes a rounded up drinking water reference concentration of 7800 Bq/L, which is quoted throughout this report.

The WHO Guidelines are deemed to apply at the 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.

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

Activity Concentration Equivalents (Bq/m^3)	
Ra-226	1.25×10^4
Sr-90	1.25×10^5
^{3}H	1.95×10^8

[2] 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 (UN).
PAHO: Pan-American Health Organisation.
WHO: World Health Organisation (UN).

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

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

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

3.2 Gaseous Emissions

From 1968, radioactive emissions from AAEC/ANSTO were subject to a discharge authorisation approved by the NSW RAC. This specified the maximum amount of radioactivity which could be discharged from each of the stacks at LHS&TC at the time.

In 1988, ANSTO proposed to the NSW RAC a revised site-wide airborne radioactive effluent discharge limit for LHS&TC. The revision was proposed because 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 LHS&TC.

The proposal for a revised authorisation was based on limiting the total amount of radioactivity discharged to the atmosphere from LHS&TC, 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[3]) which requires stack discharge monitoring information as well as local meteorological data and internationally accepted dosimetry parameters.

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

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

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

Appendix B lists the various types of radioactive airborne effluent releases from LHS&TC 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, Barden and MDP Creeks. These creeks, shown on **Figure 2,** receive most of the stormwater running off the LHS&TC area.

4.0 MEASURED RADIOACTIVITY

This section gives brief explanations of the types of radioactivity analyses performed and the radionuclides commonly found in the surveys, and some information on natural radioactivity in environmental samples. 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 unspecified alpha particle-emitting 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: similar to gross alpha, but concerned with the measurement of unspecified beta particle-emitting nuclides in a sample.

Gamma activity: Gamma photons emitted from radionuclides are detected by a semi-conductor detector made of a high purity germanium crystal. A spectrum of counts for each sample is accumulated in an energy range from 1 to 2000 keV. The gamma photopeaks in the spectrum are then analysed for significant nuclides and the specific activity calculated. Nuclides detected by this method include cobalt-60 (half-life 5.26 years), caesium-137 (half-life 30.2 years), and iodine-131 (half-life 8.02 days).

Caesium-137: is a fission product which was widely dispersed around the world by atmospheric nuclear weapons testing in the early 1960's. Because of its 30.2 year half-life, bomb-generated caesium-137 is still found in the environment. Caesium-137 is deposited in precipitation or 'dry' fallout, and adsorbs strongly onto fine clays, so that it is mostly contained within the top few centimetres of soil. The caesium-137 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). Concentrations of caesium-137 in food range from 0.04 to 0.074 Bq/kg in fruits and vegetables, to around 10 times this concentration in meats, dairy products and grain products (in the northern hemisphere). 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 (H-3) is a heavy 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 may also be 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.

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

Potassium-40

Potassium-40 is a primordial radioisotope of potassium, and since potassium is an essential element 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 2g per kg of body weight, or about 60 Bq of potassium-40 per kg of body weight.

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

Most gross beta measurements of LHS&TC survey samples have the contribution from natural potassium-40 deducted.

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.

5.0 ENVIRONMENTAL & EFFLUENT MONITORING PROGRAMS AND RESULTS

The monitoring programs at LHS&TC 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 LHS&TC 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 LHS&TC site boundary, and performs the routine environmental surveys of the site and surrounding areas.

Samples of soil, sediment, groundwater, air, surface water, and seawater were collected during 1995 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, LHS&TC stormwater outlets, the creeks draining LHS&TC and Little Forest Burial Ground.

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

Environmental survey results for 1995 are presented in **Tables 2 to 18**.

Note: Tritium results in previous years have been quoted in units of Becquerels per millilitre (Bq/mL), however from this report onwards the units used are Becquerels per litre (Bq/L).

5.1.1 Woronora River

Routine water samples are collected weekly from the Woronora River, at the boat ramp in Jannali Reserve. These water samples are analysed for tritium as an indicator of possible pipeline leaks. No tritium was detected in these samples during 1995 (see **Table 2**).

Discharges of treated liquid effluent to the Woronora River from LHS&TC ceased on 1 July 1980. Residual levels of radioactivity in samples from the estuary were monitored until December 1983 when no significant radioactivity associated with discharges from LHS&TC could be measured. Further sampling of biological materials from the Woronora Estuary was undertaken in 1992. No radioactivity above background levels was found in any of these samples, except for a small amount of cobalt-60 in ribbon weed, *Zostera spp.*(see report ANSTO/ E-709).

5.1.2 Forbes Creek

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 LHS&TC origin. The samples are analysed for tritium, as it is the radionuclide most likely to be detectable under such circumstances.

No tritium was detected in any of the samples collected during 1995 (see **Table 3**).

5.1.3 Potter Point Ocean Outfall

Seawater

Samples of sea-water were collected from an accessible point at the shoreline, approximately 200m south of the Potter Point ocean outfall for the Cronulla Sewage Treatment Plant (CSTP). The samples were collected to determine whether any radioactivity of LHS&TC origin could be detected in an area close to the outfall and accessible to members of the public. The sampling location is shown on **Figure 5**.

Sampling was performed about 11.5 hours after discharge of treated liquid effluent into the Sydney Water sewer at LHS&TC. This is approximately the time it takes the effluent to reach and pass through the CSTP and discharge at the ocean outfall at Potter Point, therefore the sampling takes place when the possibility of detecting radionuclides from LHS&TC is greatest.

The seawater samples were analysed for tritium after concentration by electrolysis, and by direct gamma spectrometry of 0.5 litre samples counted for 23 hours. The results below show that no gamma-emitters other than natural potassium-40 were detected in either shoreline water sample during the year.

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

Date	Gamma emitters (Bq/L)	Tritium * (Bq/L)
7.6.95	$^{40}K = 8.0$	0.24
26.8.95	$^{40}K = 14$	0.24

*Low-level tritium analysis by electrolysis method, see **Appendix D**.

These tritium levels are within the range of tritium values measured in the top layer of seawater off Sydney in studies conducted in 1979 (Harries *et al.*). The environmental levels of tritium found 200 metres south of Potter Point have no health significance for persons using this area.

A special investigation conducted on 10-11 October 1995, aimed at providing further information on transit times and dilution factors at the Cronulla STP and off Potter Point, resulted in tritium being readily detected in the sewage plume off Potter Point (see **Section 5.3**).

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 1995, and four types of sample were collected within a 10-20m radius of the outfall: fish; macrophytic algae; barnacles; and particulates >37 μm (including plankton).

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

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

The green alga (seaweed which grows luxuriantly in the nutrient-enriched environment near to the outfall) and phytoplankton, represent the primary producers of the food chain. Barnacles (filter feeders which live very close to the outfall) and zooplankton represent the primary consumers, and the fishes (being those most commonly caught off the rocks near the outfall) are tertiary consumers.

A reference coastal sampling site was also 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 collected.

Approximate quantities of biological material collected are tabulated below:

Location	Mass of Material Collected* (kg FW)		
	Fish	**Green Algae**	**Barnacles**
Potter Point	2.45	1.4	1.12
Royal National Park	0.73	0.26	0.38

*Mass of Biological Material Collected in 1995 from Potter Point and Royal National Park.

Blackfish were caught using a fishing line baited with weed, while the green algae and barnacles were scraped off the rocks. Particulate samples were obtained from a boat situated in the visible sewage plume, by pumping approximately 200 to 600 litres of water through a 37 μm nylon mesh plankton net. The particulates >37μm (including plankton) were then rinsed onto GF-C laboratory filter papers, and dried. Fish were filleted and skinned, while the algae and barnacle samples were left whole. 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**. Samples were analysed for gamma-emitting radioisotopes.

Results

No significant gamma emitters (apart from potassium-40) were detected in any of the 8 particulate samples collected from the Potter Point ocean outfall in 1995. This could be due to the small sample yield, which was generally less than 1 gram of dried material per sample.

Gamma spectrometry of the dried samples revealed traces of cobalt-60 in 3 out of 5 fish, 4 of 6 green algae and 1 of 4 barnacle samples collected from Potter Point. Cobalt-60 was also detected in 1 out of 5 analyses of similar samples obtained from the

Royal National Park. The cobalt-60 levels were at, or just above, the limits of detection, which vary slightly with each sample.

No caesium-137 was found in algae or barnacle samples from Potter Point, or in any samples from the Royal National Park. Traces of caesium-137 at or just above the limit of detection, were found in 2 out of 5 fish samples from Potter Point. The levels are within the range of caesium-137 levels found in fish around Australia (IAEA-TECDOC-838), shown in the following table.

FISH	LOCATION	RADIOACTIVITY (Bq/ kg fresh weight)	
		Caesium-137	Potassium-40
Flathead	Sydney	0.04 ± 0.01	4.4 ± 0.5
Flathead	Perth	-	9.3 ± 1.4
Cobbler	Perth	-	11.4 ± 1.5
Mullet	Sydney	0.03 ± 0.01	8.4 ± 0.9
Mullet 1	Perth	0.33 ± 0.03	8.8 ± 0.9
Mullet 2	Perth	0.18 ± 0.02	8.6 ± 0.9
Mackerel	Cairns	0.58 ± 0.05	17.2 ± 1.8
Shark	Perth	0.16 ± 0.02	9.0 ± 1.0
AVERAGE and Standard Deviation		**0.22 ± 0.21**	**9.6 ± 3.6**

*Caesium-137 and potassium-40 in Australian Fish (IAEA-TECDOC-838, & Personal Communication with J. Twining)

Bearing in mind the normal variability found between environmental samples, and the smaller amounts of material collected from the Royal National Park (about 70% less), it is too early to make comparisons between the Potter Point and Royal National Park data.

The short-lived isotope iodine-131 was detected in duplicate algal samples 1A and 1B from Potter Point (collected on 2.11.95), at 24 Bq/kg fresh weight (corrected for decay from sampling date). This algae is only a few cell layers thick and is therefore thoroughly exposed to any radionuclides dissolved in the sewage plume.

All of the other 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 isotopes were not quantitatively determined considering the extra effort required and their natural origin.

Concentration factors for caesium-137, cobalt-60 and iodine-132 (similar chemically to iodine-131) in marine organisms are listed below.

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 are detectable, especially in the algal samples.

Based on the maximum amounts of cobalt-60 or caesium-137 detected in fish from Potter Point in 1995, a person would have to consume about 77 000 kg of fish per year to reach the recommended Annual Limits of Intake derived from the 1996 International Basic Safety Standards.

These results clearly demonstrate that 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

Water samples are usually collected from the stormwater outlets every three months, after rain if possible, and analysed for tritium (results in **Table 7**). Stormwater Outlet No.1 however, is sampled and analysed for tritium on a weekly basis. The remaining sample (approx. 3 litres) is combined each week to make a monthly composite for gross alpha, gross beta and gamma spectrometry analyses (**Table 8**). 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.

Tritium in stormwater

Tritium results for the stormwater samples collected up to October 1995 are shown in **Table 7.**

Tritium was usually detected in stormwater drains, but always 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 LHS&TC, since tritiated water vapour released to air from HIFAR operation, will exchange with rain water and other free water surfaces.

Tritium levels in the weekly samples from Stormwater Outlet No.1 varied from <50 to 869 Bq/L. The average tritium level here in 1995 was 317 Bq/L. This is 4.1% 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 for most of the year (**Table 8**). The average caesium-137 for 1995 was 0.070 Bq/L. In the September composite sample however, a relatively elevated caesium-137 value (0.52 Bq/L) was observed along with chromium-51 at 1.8 Bq/L. This combination of results tends to indicate that an unplanned release of a small volume of treated liquid effluent may have occurred in September, although the weekly water samples which made up the composite sample for September show no corresponding elevated tritium or gross alpha/beta activity levels.

When compared with the WHO guidelines, the average caesium-137 and the single chromium-51 activities measured during 1995 represent less than 0.7% and 0.1 % respectively of the WHO drinking water reference concentrations.

Gross alpha/ beta (Stormwater Outlet No.1 monthly composite samples)
Monthly gross alpha radioactivity results for stormwater outlet No.1 were at background levels throughout the year. The gross beta results however, while showing some elevated levels, never exceeded the NSW Clean Waters Regulations (1972) limit for gross beta activity (11.1 Bq/L).

New retention systems and changes to stormwater sampling points
During 1994, small capacity concrete stormwater retention dams (or bunds) were constructed on the three main stormwater outlet points for the LHS&TC site. The dams 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 to be used as environmental monitoring points.

The locations of the dams are shown on **Figure 2**. They are inspected regularly and discharged when necessary in order to leave capacity for any spills that may occur. The dams are allowed to discharge freely during rain periods.

On 31 October 1995 the newly-operational stormwater retention dams were sampled, and replaced the previous stormwater outlet sampling regime. Analysis results for these samples were as follows:

Radioactivity in Water from Stormwater Retention Dams, 1995

	Radioactivity (Bq/L)			
31 Oct. 1995	Gross alpha	Gross beta	Gamma emitters	Tritium
Dam A	<0.10	0.24	ND	75
Dam B	<0.10	<0.10	ND	<50
Dam C	<0.10	1.45	ND	210

ND = no statistically significant activity detected

The construction of the dams has eliminated the necessity for stormwater sampling at the majority of the previous sampling points, because many of the existing stormwater pipes were re-routed to ensure that most of the LHS&TC stormwater passes through one of the three dams.

Conclusion
The levels of tritium, chromium-51 and caesium-137 found in stormwater at LHS&TC 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 LHS&TC.

Vegetation & Sediment from Stormwater Drains
No 'Crofton Weed' vegetation samples were collected from stormwater drains during 1995 due to the fact that the new stormwater retention dams do not support the growth of vegetation.

Results for samples of sediment collected in stormwater drains are shown in **Table 9**. Measurable amounts of radioactivity were detected in sediment samples collected at Stormwater Outlet No.1. The low levels of activities found at this location do not have any health consequences.

5.1.5 Creeks Draining LHS&TC

SPCC weir sampling points
The stormwater which drains from the LHS&TC flows into three small local streams which are classified as class 'C' waters under the NSW Clean Waters Regulations (1972). In 1975, the then SPCC required that the stormwater be sampled periodically at selected locations, in order to demonstrate compliance with the activity limits specified in the NSW Clean Waters Regulations (1972). Sampling points on Strassman Creek, Bardens Creek and MDP Creek (**Figure 2**) are sampled and analysed for gross alpha and beta activity. This data is presented in **Table 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 1995 for tritium analysis. The results are shown in **Table 11**. The highest value recorded during the year was 1940 Bq/, which is 25% of the reference concentration for tritium in drinking water (**Section 3.1.2**). The average weekly concentration at this location was 125 Bq/L, which is less than 2% 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 1995, 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 during 1995 on an Eberline PRM-7 field dose-rate meter were less than 0.12 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, 14, 15** and **16**. The locations of the sampling points and the burial trenches are shown in **Figure 3**.

Radiation survey
Annual surveys of the burial trenches are carried out using field dose rate monitors to check for surface contamination (**Table 13**). Dose rates over the trenches ranged from 0.07 to 0.10 μSv/hour, consistent with normal background readings. Of the two localised points, #5 and #6, which have shown elevated readings in the past, only point #6 is now slightly above background levels. Results for this year are in the same range as those previously measured at these locations.

Soil
In 1993, the general area encompassing points #5 & #6 was top-dressed with a clay/shale mixture to replace cover material removed during regular sampling. The 1995 gamma radiation survey did not indicate any areas which were greater than three times the background, therefore no soil samples were collected.

Groundwater Monitoring
Groundwaters from monitoring bores located inside the LFBG and outside the fenced area were analysed for tritium, gross alpha, gross beta and gamma activities. Results are given in **Table 14**.

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

Tritium is readily detectable inside the burial ground with higher values adjacent to the disposal trenches. Levels of tritium found in the fenced bores were similar to those measured in the past, ranging from <50 Bq/L to 11600 Bq/L in MB16, which is located in the centre of the burial trench area. Note that the WHO reference concentration for tritium in drinking water is 7800 Bq/L. Tritium levels in monitoring bores outside the fenced area were less than the limit of detection (50 Bq/L). The groundwater at LFBG is not used for any purpose, and the general quality of groundwater in the area is affected by the presence of nearby sites used for the disposal of night soil, industrial liquid wastes and municipal wastes. The tritium concentrations present are of no health significance.

The levels of gross alpha and beta activity in groundwater are similar to those found in the past, and are mainly due to the contribution from natural uranium and thorium series, as well as potassium-40.

Due to the high levels of suspended solids (silt) in many of the bore waters, radionuclides of the naturally occurring uranium and thorium series are routinely detected by gamma spectrometry at environmental levels. *Note: Gamma and gross alpha/beta results are in units of Bq/g sediment.*

The only bores which contained gamma activity possibly associated with the buried waste were MB16 and OS2. The activity expressed in bore MB16 is not unexpected since it is in the centre of the burial trench area.

There is some evidence of low levels of americium-241 in MB16, and in the OS2 monitoring bore which is located close to the south-eastern corner of the disposal trenches, within the fenced area. ANSTO has requested further testing of these two samples to be carried out by the Australian Radiation Laboratory.

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.

In 1994, a trace of cobalt-60 was reported in the December OS2 groundwater sample. A statistical analysis of this result revealed that the activity was not significantly greater than background and should not have been reported. Furthermore, no cobalt-60 above the limit of detection (0.010 Bq/g sediment) was detected in any OS2 bore samples collected in 1995.

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 and beta, tritium and gamma analyses on these samples are given in **Table 15**. No radioactivity above background levels was found.

Air Sampling

No beryllium (Be) or plutonium-239 was detected on aerosol filters from the air sampling station near the burial trenches (**Table 16**). The minimum detectable level for Be is 0.0025 mg (total per filter) and for plutonium-239 is 0.0001 Bq (total per filter).

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.

Measurable quantities of iodine-131 were occasionally recorded in the air samplers on the site perimeter, during 1995 (**Table 17**). The highest reading, registered for the week ending 27 February 1995, was 5.8 x 10^{-2} Bq/m^3. The average iodine-131 concentration in air for the year was 5.4 x 10^{-3} Bq/m^3. The effective dose to a hypothetical member of the critical group living at Stevens Hall Motel, and receiving continuous exposure to iodine-131 at the average concentration recorded, would be less than 0.01 mSv per year[5].

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 opertions 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 LHS&TC.

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

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

Prevailing Winds at Lucas Heights

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

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.

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

Rainfall
The total rainfall at Lucas Heights in 1995 was 1144 mm, recorded on 121 rainy days. The wettest month was September, with 249 mm of rainfall.

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 1995 using thermoluminescent dosimeters (TLD's) issued by the Australian Radiation Laboratory (ARL). The dosimeters issued by ARL for environmental monitoring are the same as those issued for personal monitoring, and consist of calcium sulphate thermoluminescent material with three filtered areas and an open window.

Figure 6 shows the locations of dosimeters 1 to 15.

Table 18 shows the integrated annual absorbed dose to air, in millisieverts, for the calendar year 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 18** indicate that the annual absorbed dose to air due to external radiation measured outside several homes in the vicinity of the LHS&TC, is between 0.9 and 1.1 mSv. The annual environmental doses measured at or within the LHS&TC perimeter fence, have a minimum of 0.9 mSv and a maximum of 2.4 mSv. The maximum value observed was around the level considered typical for annual effective doses to adults from natural sources (see **Table 24**). The enhanced doses on the southern and western sides of the HIFAR security fence are due mainly to nuclear materials stored in this area. Although there is no public occupancy in this area, a newly-constructed shielded storage facility will be used to store these nuclear materials.

When the annual environmental absorbed doses in air around homes in the vicinity of LHS&TC 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 LHS&TC 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 LHS&TC.

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

5.2.1 Airborne Effluent Stack Discharges

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

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

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

Stack Sampling
During 1995, 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 that any particulate activity previously measured was principally due to short-lived radioisotopes.

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

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

Results
Authorised airborne release data are given in **Tables 19 & 20.**

'Working levels' are set for individual stack discharges at ANSTO and are used for operational purposes to assess trends in the discharges. **Table 19** presents the quarterly airborne emissions for the individual stack release points, and **Table 20** lists the same figures expressed as percentages of the quarterly operational working levels.

Discharge records for the period 1977 to 1995 show that the majority of airborne emissions from LHS&TC have been well below the quarterly working levels and, in most instances, can be regarded as negligible. During 1995, discharges of noble gases from HIFAR exceeded the quarterly working levels in the second 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 underway 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 LHS&TC, by utilisation of the ADDCOR atmospheric dispersion and dosimetry computer model (see **Section 6.1**).

It should be noted that the resultant doses from the discharge of argon-41 are very low and well below the 0.3 mSv dose constraint adopted by ANSTO.

5.2.2 Low-level Liquid Effluent Discharges

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

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.

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 then analysed for gross alpha, gross beta, tritium and gamma activity and assessed for compliance with the Sydney Water Trade Waste Agreement.

Results

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 1995 was 0.22, 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 the period September to December 1995 was 0.30. 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.

It should be noted that the calculated quotients are very conservative because the assumption is made that all alpha and beta activity is due to radium-226 and strontium-90 respectively.

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

5.3 DILUTION STUDIES OF LIQUID EFFLUENT DISCHARGED TO SEWER

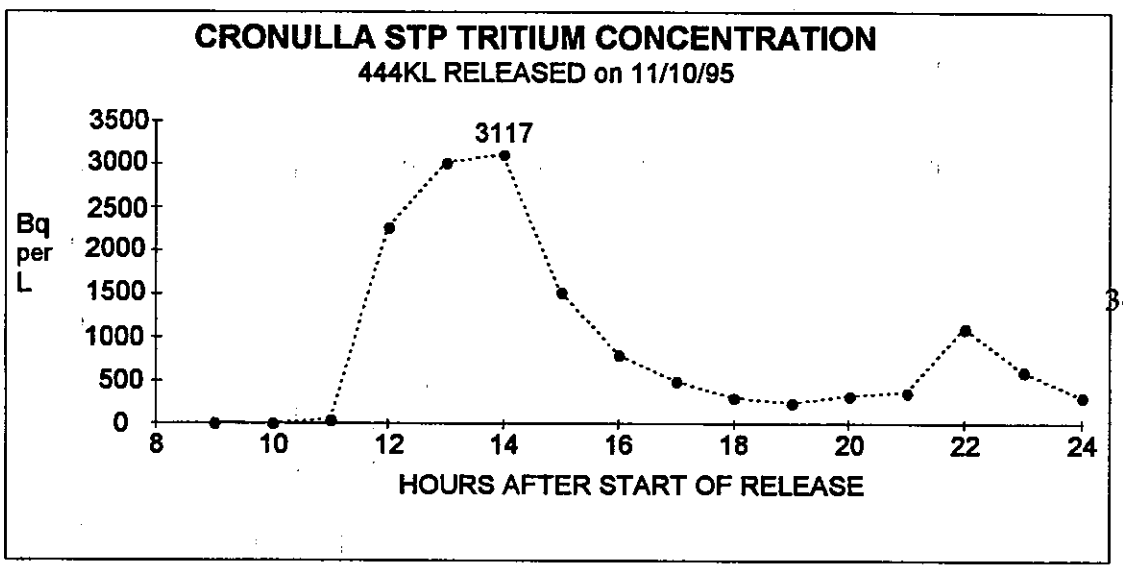
As an extension of the studies reported in *Environmental and Effluent Monitoring at Lucas Heights Research Laboratories, 1994* (ANSTO/E-717), further investigations of dilution factors for the discharge of treated effluent from LHS&TC to the Cronulla STP and thence to the ocean outfall at Potter Point were carried out during 1995. Similar to earlier investigations, tritium was used as a tracer, since it is usually present in the ANSTO discharges and is widely used in environmental tracer studies.

The previous work indicated that a relatively high concentration of tritium was required in the effluent, to enable the tritium to be readily measured in the seawater samples off Potter Point. A planned release of such effluent was conducted on 11 October 1995. Measurements were made of the tritium concentrations in the holding tanks at LHS&TC, in the outflow from the Cronulla STP, at the Potter Point outfall and away from the outfall in the sewage plume. The measurements allowed the estimation of in-line dilution and transit time of the effluent between Lucas Heights and the Cronulla STP, the initial off-shore dilution at the outfall as well as off-shore dilution and dispersion.

The *dilution ratio* is defined as the ratio of the effluent tritium concentration released to the sewer at LHS&TC, to the maximum concentration detected at the point of interest.

5.3.1 In-Line Dilution

The volume of the release on 10 October 1995 was 444 kL, containing 98 920 Bq/L tritium (approximately half the maximum concentration of tritium allowed in effluent discharges from Lucas Heights), commencing at 21:56 and finishing at 03:45 on 11 October 1995 (5.82 hours duration). The following graph shows the tritium concentrations of effluent leaving the Cronulla STP from 10 to 24 hours after the effluent release began at Lucas Heights.



The maximum tritium value of 3117 Bq/L was observed 14 hours after the start of the effluent release at Lucas Heights. This leads to an estimated minimum in-line *dilution ratio* of 32. This result is consistent with previous results for in line *dilution ratios* for special effluent discharges made outside normal daytime discharge hours as part of the effluent dilution studies at Cronulla STP and Potter Point. (**see Section 5.3.5** for in-line *dilution ratios* for normal daytime effluent discharges from LHS&TC)

5.3.2 Effluent Transit Time to Cronulla STP

The *transit time* is defined as the interval from the mid-point of an effluent release until the time at which the maximum tritium concentration was observed at Cronulla STP. On 11 October 1995 the *transit time* was approximately 11 hours. This transit time is consistent with transit times measured in previous studies at Cronulla STP, which were in the range of 9.6 to 11.8 hours.

5.3.3 Initial Off-shore Dilution at Outfall

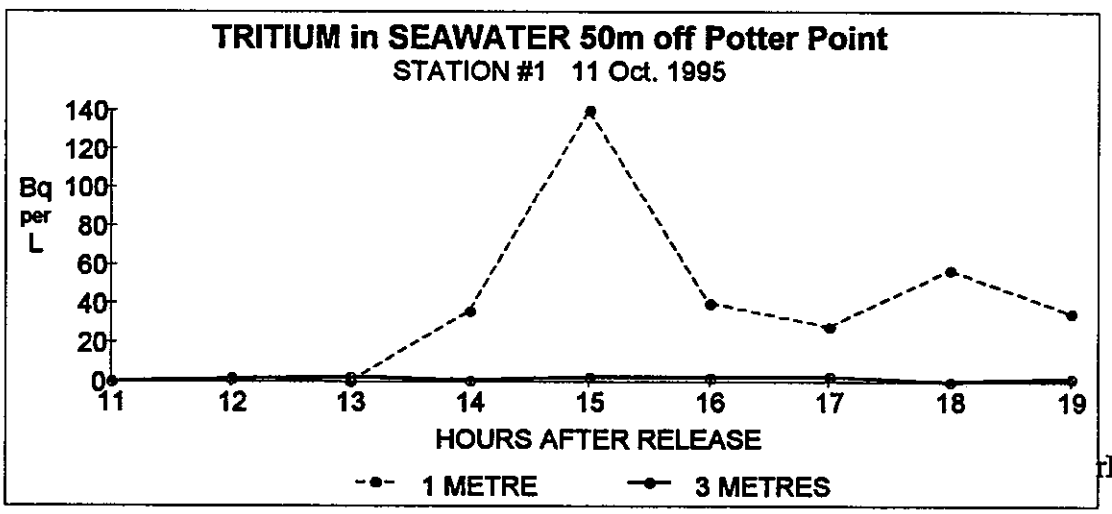
On exit from the Cronulla STP the treated sewage from all the Sutherland Shire travels via a pipeline to the Potter Point outfall where it enters the ocean (this takes approximately 1 hour). Seven sampling stations were positioned in a grid pattern over the visible effluent plume moving away from the outfall. Sampling station #1 was

located 50 metres from the outfall, while station #7 was the most distant at approximately 550 metres to the south.

A marker buoy was laid at each station and their positions were fixed using a Garmin Global Positioning system. Two-litre samples were taken hourly at depths of 1 and 3 metres, using a Jabsco pump.

Very calm conditions prevailed on 11 October 1995 and consequently samples were able to be taken in a safe manner closer to the outfall than on previous occasions. The highest tritium concentration detected was in one of the close outfall samples which contained a concentration of 156 Bq/L. Since the highest concentration in the samples taken at the outflow of the Cronulla STP was 3117 Bq/L, this gives an estimated initial minimum *dilution ratio* at the outfall of 20.

The highest concentration detected at station #1 (50 metres from outfall) was 140 Bq/L. The following graph shows the tritium concentratios observed at station #1 plotted against time after start of discharge from LHS&TC.



5.3.4 Off-Shore Dilution and Dispersion

The off-shore sampling station located the greatest distance from the outfall *ie* #7, showed a maximum tritium concentration of 55.1 Bq/L at 1 metre depth, recorded 17 hours after the effluent started to be released from LHS&TC. Given the maximum concentration at the outfall was 156 Bq/L, this indicates a further *dilution ratio* of 2.8 applied at a distance of 550 metres from the outfall in the plume for the very calm sea conditions prevailing at the time.

This value for the off-shore *dilution ratio* is approximately a factor of 8 less than the value reported for the August 1993 investigation, when sea conditions were much more turbulent due to a strong north-east seabreeze and a long-shore current of 1 metre per second prevalent at the time of the study.

All the samples taken at the seven off-shore stations at a depth of 3 metres contained less than 5 Bq/L of tritium except for station #6 which contained 6 Bq/L. The fact that

no significant tritium concentrations were found in any of the 3m depth samples indicates that the sewage plume off Potter Point is a surface trapped plume and as such is greatly influenced by wind and sea conditions.

5.3.5 In-Line Dilution During Normal Discharge Times

Because of the long transit time for effluent between LHS&TC and Potter Point, the major studies conducted at Cronulla STP and Potter Point have required the release of effluent from LHS&TC outside the normal daytime discharge times, in order that sampling in the ocean off Potter Point could be optimised in terms of detecting radionuclides from ANSTO discharges to the sewer. Effluent discharges to the sewer from ANSTO's waste treatment plant are normally restricted to week days during the hours of 8 am and 5 pm.

Information provided by Sydney Water shows that the effluent flow-rate through the Cronulla STP is variable, with flow-rates during normal business hours on working days being higher than night time hours when industrial premises are closed. On this basis it could be expected that there is more in-line dilution for ANSTO effluent discharges made during normal operating hours compared with the special discharges made outside normal discharge times for purposes of the effluent investigations off Potter Point.

In order to confirm the in-line dilution ratio previously estimated at the Cronulla STP for normal daytime effluent discharges from LHS&TC, some further sampling was undertaken at Cronulla STP to coincide with the release of several effluent batches of differing volumes, from LHS&TC during normal operating times.

A summary of these investigations is given in the following table.

EFFLUENT DISCHARGES from LHS&TC in DAYLIGHT HOURS*

DATE	VOLUME (Kilolitres)	DISCHARGE PERIOD (hours)	TRITIUM (Bq/L)	IN-LINE DILUTION RATIO
22.2.96	210	2.75	4901	35.1
14.12.95	369	5.1	369	37.3
13.12.95	414	5.7	7914	35.5
18.12.95	621	9.3	10680	31.5
20.12.95	628	8.6	1755	30.8
20.2.95	630	7.5	5242	27.3
			AVERAGE	**32.9**

*It was assumed that there was no substantial variation in the flow through the treatment plant for the days that the sampling took place.

5.3.6 Modelling of the Potter Point Outfall by AWACS

The dispersion of tritium from the outfall under the conditions met on 11 October 1995 was modelled by Australian Water And Coastal Studies Pty Ltd (AWACS) at ANSTO's request (AWACS Report 95/46, December 1995). The model has been

designed so that pollutant sources may be defined at any location within the model domain and the impacts monitored both graphically and in terms of pollutant dilutions or concentrations at nominated target sites.

The Potter Point plume was modelled at hourly intervals between 06:00 and 18:00 hours on the day of the investigation. The output at 13:00 hours on 11 October 1995 is depicted in **Figure 7**. This example was chosen as it corresponds to the time at which the tritium maximum would be at the cliff outfall.

The general findings of the model were as follows:

- rapid initial dilution of the plume was followed by moderate subsequent dilution;
- the plume was transported close to the surface.

These findings are consistent with the tritium data tabulated below:

MAXIMUM OFF-SHORE TRITIUM CONCENTRATIONS, POTTER POINT 11 OCTOBER 1995

STATION	DISTANCE FROM OUTFALL (Metres)	TRITIUM Bq/L	
		1 Metre Depth	3 Metre Depth
#1	<50	139.5	< 5
#2	125	55.0	< 5
#3	80	45.4	< 5
#4	100	31.5	< 5
#5	175	84.4	< 5
#6	400	57.2	6
#7	425	55.1	< 5

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 LHS&TC are from airborne emissions and low level liquid effluent discharges to sewer. These sources are controlled in compliance with discharge authorisations given previously by the NSW Radiological Advisory Council or concentration limits specified in the Trade Waste Agreement with Sydney Water Corporation. 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 22 and 23** 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.

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

Table 24, taken from UNSCEAR, 1993, shows the average annual effective doses to adults from the various natural sources of radiation which result in an estimated total annual dose of 2.4 mSv. This figure will vary with local geological conditions and with height above sea level.

It can be readily shown that the potential dose estimates to members of the general public from airborne discharges at LHS&TC 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 Corporation 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 various levels of caesium-137, cobalt-60 and 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 Lucas Heights, Engadine and Woronora (see **Table 18**) all indicated 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 LHS&TC are not noticeably affected by the operations at LHS&TC.

The highest levels of external gamma radiation at LHS&TC 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 24**). However, as indicated in **Section 5.1.10**, ANSTO is taking steps to place the nuclear material in shielded storage 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. The tritium levels are generally less than those seen in recent years and may be due to the dry weather conditions. Cobalt-60 and caesium-137 were found in sediment suspended in groundwater in the centre of the burial trenches and traces of caesium-137 and possibly americium-241 were also found in two other monitoring bores adjacent to the trenches area.

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

These results confirm that potential radiation exposure to members of the public from groundwater and surface water in the vicinity of LFBG is negligible. It should be noted that contaminants from other non-radioactive wastes (disposed of by other agencies) in the areas adjacent to LFBG, make the groundwater unsuitable for human consumption.

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

External radiation readings over the trenches are consistent with normal background levels except for one small localised area 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

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Thanks to Graham Spelman, Phil Thornton and Dr John Ferris (all of Environment Division) for their contributions in relation to the Potter Point sampling program.

Thanks are due to Graeme Jay and staff of the Waste management group for their cooperation in arranging effluent releases at times to suit the sampling program.

Beryllium levels on the LFBG air filters were determined by the Environmental Chemistry project (of Environment Division) using ICPES 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.

Alpha spectrometry (for plutonium-239) on the composite air filter sample from the LFBG was performed by the Radiochemistry group (of Environment Division).

Dosimeter readings for external gamma radiation at LHS&TC (**Table 18**) and airborne effluent release data (**Table 19**) were supplied by Safety Division.

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

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TABLE 1

ENVIRONMENTAL MONITORING
SAMPLE COLLECTION AND PREPARATION SCHEDULE, 1995

Sample	Station	Frequency	Collection Details	Sample preparation and analysis
Stormwater	MDP Creek (60m from LHS&TC Outlet No.1)	Weekly	3L, sampled with polyethylene bottle	Weekly samples evaporated to dryness, the residue combined to form a monthly composite sample for α,β,γ counting. 250mL collected weekly and distilled for tritium
	Others (see Figure 2)	Quarterly (after rain)	250 mL, sampled by bottle at the drain outlet	Distilled for tritium
Estuary water (Woronora River)	E5.9	Weekly	250 mL, sampled by bottle at surface	Distilled for tritium
Sea water	200m south of Potter Point ocean outfall	Quarterly	1 Litre, collected 11 hours after effluent discharge from LHS&TC into the sewer	Gamma spectrometry on fresh sample. Low-level tritium analysis by electrolysis
Creek water	Bardens Creek Weir	Weekly	250 mL sampled from weir overflow	Distilled for tritium
	SPCC Weirs: - Bardens Ck - MDP Ck - Strassman Ck	Monthly	1 Litre sampled after rain	Gross α β according to Clean Waters Act Regulations: AS 3550.0 (1990)
	Forbes Creek	Monthly	1 Litre sampled after rain	Distilled for tritium analysis
	Bardens & Mill Creeks (above junction, station T2)	Yearly	5 Litres of surface water	Evaporated to dryness, and residue counted for α,β,γ. 250mL distilled for tritium analysis
Groundwater	Little Forest Burial Ground (LFBG)	Twice yearly	MB series bore holes; pumped dry, allowed to refill and sampled from the bottom of the bore	10L sample evaporated to dryness. The residue counted for α,β,γ. 250 mL distilled for tritium
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	Sub-sampled for Be analysis. Composite of quarterly samples for ^{239}Pu analysis by alpha spectrometry
Ambient iodine-131 in air	Along the eastern boundary of the site (stations 1,2,3,4)	Weekly	Collected on Maypacks (charcoal filters)	Gamma spectrometry of Maypacks
Sand / Soil	LHS&TC stormwater outlets	Quarterly	At drain outlet	Gamma spectrometry of sieved & ashed sample. Gross α β counting
	LFBG	If indicated by annual dose rate survey	1 kg, from surface	As above
	Effluent pipeline	If indicated by six-monthly dose rate survey	1 kg, from surface	As above
	T2: Bardens and Mill Creeks	Yearly	From creek bed (above junction of the two creeks)	As above
Gamma Survey (dose rate)*	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 (TLD)	Sites 1-15 at LHS&TC, sites 16-18 in local suburbs (see Figure 6)	Quarterly	Thermoluminescent Dosimeter (TLD) badges, exposed to ambient gamma radiation	Sent to ARL for analysis, reported as absorbed dose in mSv/year

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

TABLE 2

TRITIUM IN WORONORA ESTUARY WATER
STATION E5.9, 1995

Date	Tritium (Bq/L)	Date	Tritium (Bq/L)
3.1.95	LLD	4.7.95	LLD
10.1.95	LLD	11.7.95	LLD
17.1.95	LLD	18.7.95	LLD
24.1.95	LLD	25.7.95	LLD
31.1.95	LLD	2.8.95	LLD
7.2.95	LLD	8.8.95	LLD
14.2.95	LLD	15.8.95	LLD
21.2.95	LLD	22.8.95	LLD
28.2.95	LLD	29.8.95	LLD
7.3.95	LLD	5.9.95	LLD
14.3.95	LLD	12.9.95	LLD
22.3.95	LLD	19.9.95	LLD
28.3.95	LLD	26.9.95	LLD
4.4.95	LLD	4.10.95	LLD
12.4.95	LLD	10.10.95	LLD
18.4.95	LLD	17.10.95	LLD
26.4.95	LLD	24.10.95	LLD
2.5.95	LLD	31.10.95	LLD
9.5.95	LLD	7.11.95	LLD
16.5.95	LLD	14.11.95	LLD
23.5.95	LLD	21.11.95	LLD
30.5.95	LLD	28.11.95	LLD
7.6.95	LLD	5.12.95	LLD
14.6.95	LLD	12.12.95	LLD
20.6.95	LLD	20.12.95	LLD
26.6.95	LLD	28.12.95	LLD

Notes:
Tritium results are now in Bq/L, in previous years the units were Bq/mL.
'LLD' = less than the average limit of detection for tritium which was 50 Bq/L.
The Reference Activity Concentration for tritium in drinking water is 7800 Bq/L (WHO, 1993).

TABLE 3

TRITIUM IN FORBES CREEK WATER SAMPLES
(a tributary of the Woronora River)
1995

Date	Tritium (Bq/L)
3.1.95	LLD
21.2.95	LLD
7.3.95	LLD
18.4.95	LLD
10.5.95	LLD
15.6.95	LLD
24.7.95	LLD
15.8.95	LLD
27.9.95	LLD
18.10.95	LLD
14.11.95	LLD
12.12.95	LLD

See **Figure 1** for the location of this sampling point.
Tritium results are now in Bq/L, in previous years the units were Bq/mL.
LLD = less than the average limit of detection for tritium, which was 50 Bq/L.
The reference activity concentration for tritium in drinking water is 7800 Bq/L (WHO, 1993).

TABLE 4

RADIOACTIVITY IN **FISH** FROM POTTER POINT
OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1995

Location	Date Sampled	Sample	GAMMA EMITTERS (Bq/kg FW)				
			U&Th series	**^{7}Be ***	**^{40}K**	**^{60}Co**	**^{137}Cs**
POTTER POINT Ocean outfall	16.2.95	Blackfish 2B	✓	-	144	-	-
	1.10.95	Blackfish A	✓	-	142	<0.90	-
	8.11.95	Blackfish B	✓	-	47	-	<0.25
	11.10.95	Flathead A	✓	-	144	<0.44	0.73
	11.10.95	Flathead B	✓	-	136	<0.87	-
Royal National Park (reference site)	29.10.95	Blackfish A	✓	-	147	-	-
	29.10.95	Blackfish B	✓	-	122	<0.42	-

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

TABLE 5

RADIOACTIVITY IN **GREEN ALGAE** FROM POTTER POINT OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1995

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	16.2.95	1	✓	8.6	83	-	-	-
	"	2	✓	5.6	72	-	-	-
	2.11.95	1A	✓	15.3	133	1.6	-	23.6
	"	1B	✓	12.8	143	1.4	-	23.5
	"	2A	✓	-	81	2.4	-	-
	"	2B	✓	-	370	1.7	-	-
Royal National Park (reference site)	29.10.95	A + B	✓	-	280	-	-	-

TABLE 6

RADIOACTIVITY IN **BARNACLES** FROM POTTER POINT OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1995

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	16.2.95	1A	✓	7.1	44	3.3	-
	"	1B	✓	-	46	-	-
	1.10.95	A	✓	-	41	-	-
	2.11.95	B	✓	-	34	-	-
Royal National Park (reference site)	29.10.95	A	✓	-	22	-	-
	"	B	✓	-	31	-	-

Notes For Tables 4, 5 & 6:

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

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

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

* ^{7}Be has a relatively short half-life of 53.3 days. Due to analysis demands some of these samples were not counted until several weeks after sampling, with the possibility that any ^{7}Be present may have decayed away by that time.

"<" indicates that the activity was less than the stated limit of detection, calculated with a 95% confidence level. The limit of detection for gamma spectrometry varies between samples.

TABLE 7

TRITIUM IN WATER SAMPLES FROM STORMWATER OUTLETS, 1995

Sample Location	Date	Tritium Bq/L
Drain behind Bld.1	3.1.95	93
	19.4.95	76
	17.7.95	Dry
Drain near road on West fence	3.1.95	LLD
	19.4.95	LLD
	17.7.95	LLD
Drain opposite meteorological tower	3.1.95	LLD
	19.4.95	124
	17.7.95	LLD
20m from Stormwater Outlet No.1	3.1.95	LLD
	19.4.95	Dry
	17.7.95	Dry
60m from Stormwater Outlet No.1	3.1.95	51
	10.1.95	380
	17.1.95	345
	24.1.95	869
	31.1.95	556
	7.2.95	327
	14.2.95	LLD
	16.2.95	161
	21.2.95	357
	28.2.95	394
	7.3.95	159
	14.3.95	229
	22.3.95	304
	28.3.95	190
	4.4.95	291
	11.4.95	324
	18.4.95	314
	26.4.95	377
continued...		
60m from Stormwater Outlet No.1	2.5.95	187
	9.5.95	190
	16.5.95	127
	23.5.95	110
	30.5.95	184
	7.6.95	242
	14.6.95	263
	20.6.95	265
	26.6.95	284
	4.7.95	290
	11.7.95	545
	18.7.95	424
	25.7.95	382
	2.8.95	436
	8.8.95	458
	15.8.95	406
	22.8.95	526
	29.8.95	555
	5.9.95	499
	12.9.95	447
	19.9.95	262
	26.9.95	66
	4.10.95	188
	10.10.95	213
	17.10.95	244
	24.10.95	327
	31.10.95	373
	7.11.95	451
	14.11.95	445
	21.11.95	134
	28.11.95	376
	5.12.95	136
	12.12.95	354
	20.12.95	311
	28.12.95	396

Notes:
Refer to **Figure 2** for the location of these sampling points.
Tritium results are now in Bq/L, in previous years the units were Bq/mL.
"LLD" = less than the average limit of detection for tritium, which was 50 Bq/L.
The reference activity concentration for tritium in drinkin water is 7800 Bq/L (WHO, 1993).
The average tritium level 60m from Stormwater Outlet No.1 during 1995 was 317 Bq/L, which is 4.1% of the WHO reference value for tritium in drinking water.

TABLE 8

RADIOACTIVITY IN WATER SAMPLES, 60m FROM STORMWATER OUTLET No. 1, 1995

Sample Location	Date	RADIOACTIVITY (Bq/L)						
				Gamma Emitters				
		Gross α	Gross β	U&Th series	^{7}Be	^{40}K	^{51}Cr	^{137}Cs
60m from Stormwater Outlet No. 1*	January	0.16	9.3	✓	-	0.034	-	0.017
	February	0.04	4.8	-	0.050	0.073	-	0.019
	March	0.08	5.3	-	-	0.050	-	0.023
	April	0.07	2.9	-	-	0.017	-	0.007
	May	0.12	2.0	-	-	0.025	-	0.017
	June	0.28	1.7	-	-	0.040	-	0.023
	July	0.15	1.6	-	-	0.035	-	0.014
	August	0.22	1.3	✓	-	0.033	-	0.024
	September	0.24	1.7	-	-	0.043	1.8	0.520
	October	0.25	1.7	✓	-	0.062	-	0.100
	November	0.14	1.0	✓	0.070	0.050	-	0.040
	December	0.14	0.77	✓	0.046	0.053	-	0.026

Notes:
* 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.

"Radioactivity (Bq/L)" refers to the radioactivity per litre of water sample (suspended & dissolved). The gross beta results include the contribution from potassium-40 (a natural beta-gamma emitter). "^{238}U & ^{232}Th series" refers to the presence of daughter products from the decay of the natural uranium-238 and thorium-232 series.

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

The average ^{137}Cs level in 1995 was 0.070 Bq/L, which is 0.7 % of the WHO reference value for ^{137}Cs in drinking water, see **Section 3.1.2.**

The single incidence of ^{51}Cr in the September composite sample was < 0.1 % of the WHO reference concentration for ^{51}Cr in drinking water.

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 SEDIMENT FROM STORMWATER OUTLETS, 1995

Sample Location	Date	RADIOACTIVITY in SEDIMENT (Bq/g Dry Wt.)			
		Gross α	Gross β *	γ-emitters	^{40}K
Drain on road at west fence	11-1-95	0.45	0.21	^{238}U & ^{232}Th series	0.01
	27-4-95	0.82	0.19	^{238}U & ^{232}Th series	0.06
	17-7-95	0.85	0.27	^{238}U & ^{232}Th series	0.06
20m from Stormwater Outlet No. 1	11-1-95	1.1	4.6	^{238}U & ^{232}Th series ^{241}Am = 0.26 ^{134}Cs = 0.057 ^{137}Cs = 3.7 ^{60}Co = 0.042 ^{144}Ce = 0.34	0.26
	27-4-95	0.43	0.45	^{238}U & ^{232}Th series ^{134}Cs = 0.021 ^{137}Cs = 0.29 ^{60}Co = 0.004 ^{144}Ce = 0.021 ^{7}Be = 0.58	0.21
	17-7-95	1.22	0.62	^{238}U & ^{232}Th series ^{241}Am = 0.28 ^{134}Cs = 0.012 ^{137}Cs = 0.82 ^{60}Co = 0.010 ^{144}Ce = 0.026	0.20

Notes:
See **Figure 2** for the location of these sampling points
* The gross beta results do not include the contribution from potassium-40 (a natural beta-gamma emitter), this has been deducted.
In the gamma-emitters column, "U & Th series" refers to the presence of daughter products from the decay of the natural uranium-238 and thorium-232 series.
^{7}**Be** is also of natural origin.

TABLE 10

RADIOACTIVITY IN WATER FROM SPCC SAMPLING POINTS, 1995

Date	Radioactivity (Bq/L)					
	Strassman Creek		Bardens Creek Weir		MDP Creek Weir	
	Gross α	Gross β*	Gross α	Gross β*	Gross α	Gross β*
10.1.95	LLD	LLD	LLD	0.13	LLD	1.1
22.2.95	LLD	LLD	LLD	0.14	LLD	1.0
15.3.95	LLD	LLD	LLD	0.23	LLD	2.4
20.4.95	LLD	0.18	LLD	LLD	LLD	1.1
24.5.95	LLD	0.17	LLD	0.17	LLD	1.5
28.6.95	LLD	0.13	LLD	0.18	LLD	1.7
27.7.95	LLD	0.10	0.11	0.13	LLD	1.2
17.8.95	LLD	0.18	LLD	LLD	LLD	1.2
27.9.95	LLD	LLD	LLD	0.17	LLD	0.6
25.10.95	LLD	0.18	LLD	0.17	LLD	0.9
7.12.95	LLD	0.18	LLD	0.13	LLD	1.0
22.12.95	LLD	LLD	LLD	LLD	LLD	1.0

Notes:
See **Figure 2** for the location of the SPCC sampling points.
* All gross beta results include the contribution from natural potassium-40 (a beta-gamma emitter).
"LLD" = Less than the limit of detection. The limit of detection is 0.10 Bq/L for gross α and gross β activity.
The NSW Clean Waters Regulations (1972) specify limits for radioactivity in class C waters as follows: gross α = 1.1 Bq/L
gross β = 11.1 Bq/L.

TABLE 11

TRITIUM IN WATER FROM BARDENS CREEK WEIR
(at SPCC sampling point)
1995

Date	Tritium Bq/L	Date	Tritium Bq/L
3.1.95	66	4.7.95	LLD
10.1.95	61	11.7.95	LLD
17.1.95	64	18.7.95	LLD
24.1.95	71	25.7.95	LLD
31.1.95	LLD	2.8.95	LLD
7.2.95	51	8.8.95	LLD
14.2.95	LLD	15.8.95	LLD
21.2.95	54	22.8.95	LLD
28.2.95	60	29.8.95	LLD
7.3.95	94	5.9.95	76
14.3.95	LLD	12.9.95	52
22.3.95	LLD	19.9.95	145
28.3.95	80	26.9.95	56
4.4.95	LLD	4.10.95	1940
11.4.95	LLD	10.10.95	204
18.4.95	110	17.10.95	64
26.4.95	LLD	24.10.95	188
2.5.95	LLD	31.10.95	90
9.5.95	190	7.11.95	269
16.5.95	LLD	14.11.95	345
23.5.95	LLD	21.11.95	393
30.5.95	LLD	28.11.95	130
7.6.95	LLD	5.12.95	218
16.6.95	LLD	12.12.95	LLD
20.6.95	LLD	20.12.95	94
26.6.95	LLD	28.12.95	69

Notes:
Tritium results are now in Bq/L, in previous years the units were Bq/mL.
"LLD" = Less than the average limit of detection for tritium, which was 50 Bq/L.
The average weekly tritium concentration at Bardens creek weir during 1995 was 125 Bq/L, which is <2% of the WHO drinking water reference activity concentration of 7800 Bq/L.

TABLE 12

GAMMA SURVEY - EFFLUENT DISCHARGE PIPELINE, 1995

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

Date	Location*	Dose Rate (μSv/hour)		Background range (μSv/hour)
		ground below joint	pipe joint	
30-5-95	Joints #1-17	0.04 - 0.07	0.05 - 0.08	0.04 - 0.10
	Joints # 20-22	0.05 - 0.06	0.06 - 0.07	0.04 - 0.05
8-11-95	Joints #1-17	0.05 - 0.07	0.05 - 0.08	0.05 - 0.09
	Joints #20 -22	0.05 - 0.06	0.05 - 0.06	0.05 - 0.07

* Joints # 18 & 19 are inaccessible.

TABLE 13

GAMMA SURVEY - BURIAL TRENCHES LITTLE FOREST BURIAL GROUND, 1995

Date	Location	Dose range (μSv/hour)
27 October 1995	Background outside fence	0.07
	Readings over all trenches	0.07 - 0.10
	Point #5	0.08 - 0.10
	Point #6	0.15 - 0.20

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

TABLE 14

RADIOACTIVITY IN GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1995

Bore	Date Sampled	RADIOACTIVITY (Bq/g Sediment*)							Tritium Bq/L
				Gamma Emitters					
		Gross α	Gross β	U&Th series	^{60}Co	^{137}Cs	^{241}Am	^{40}K	
BHF	6.7.95	1.1	0.21	-	-	-	-	0.36	240
BH10	"	0.99	0.01	-	-	-	-	0.09	450
OS2	"	2.2	0.01	✓	-	-	-	0.40	2100
OS3	"	1.4	0.17	✓	-	-	-	LLD	1250
MB11	"	1.3	0.05	-	-	-	-	0.10	LLD
MB12	"	0.89	0.37	-	-	-	-	0.09	LLD
MB13	"	1.7	1.6	-	-	-	-	0.30	3300
MB14	"	2.3	0.79	✓	-	-	-	0.03	LLD
MB15	"	1.3	0.53	✓	-	-	-	0.16	LLD
MB16	"	5.4	7.9	✓	0.98	0.07	-	0.33	11600
MB17	"	2.2	0.89	✓	-	-	-	0.50	1050
MB18	"	3.1	0.68	✓	-	-	-	0.22	LLD
MB19	"	0.46	0.33	✓	-	-	-	0.21	LLD
MB20	"	1.1	1.0	✓	-	-	-	0.81	LLD
MB21	"	1.2	0.63	✓	-	-	-	0.40	LLD
BHD	18.12.95	0.45	0.42	✓	-	-	-	0.36	LLD
BHF	"	2.1	4.2	✓	-	-	-	0.86	280
BH10	"	0.68	1.0	✓	-	-	-	0.24	500
OS2	"	3.6	1.0	✓	-	-	(0.08)	0.66	1830
OS3	"	1.8	3.2	✓	-	-	-	0.29	1270
MB11	"	1.4	0.54	✓	-	-	-	0.56	LLD
MB12	"	1.4	0.58	✓	-	-	-	0.62	LLD
MB13	"	2.8	1.4	✓	-	-	-	0.58	3040
MB14	"	0.74	0.58	✓	-	-	-	0.72	LLD
MB15	"	1.1	0.51	✓	-	-	-	0.49	LLD
MB16	"	17	9.5	✓	2.1	0.41	(0.06)	0.51	3540
MB17	"	2.2	0.94	✓	-	-	-	0.40	990
MB18	"	2.7	0.70	✓	-	-	-	0.60	LLD
MB19	"	1.6	0.86	✓	-	-	-	0.76	LLD
MB20	"	0.53	1.0	✓	-	-	-	0.98	LLD
MB21	"	1.4	0.80	✓	-	-	-	0.70	LLD

Notes: **Tritium results now in Bq/L**, in previous years the units were Bq/mL.
See **Figure 3** for the location of the sampling bores.
* Refers to the radioactivity of the unfiltered borewater, after evaporation of about 10 L of sample and counting the residue. The gross beta results include the contribution from natural potassium-40.
"U & Th series" refers to the presence of daughter products from the natural uranium-238 and thorium-232 decay series.
"LLD" = less than the average limit of detection for tritium, which was 50 Bq/L.
"<" indicates that the activity was less than the stated (95% confidence level) limit of detection.
^{241}Am results in brackets are preliminary only, pending further testing by the ARL.

TABLE 15

RADIOACTIVITY IN CREEKS RECEIVING RUNOFF FROM THE LITTLE FOREST BURIAL GROUND AREA, 1995

SAND					
Sample Location	Date	RADIOACTIVITY (Bq/g DW)			
		Gross α	Gross β * (less ^{40}K)	γ-emitters	^{40}K
Mill Creek (before it joins Bardens Creek)	11.12.95	0.28	0.06	U & Th series	0.02
Bardens Creek (before it joins Mill Creek)	11.12.95	0.23	0.08	U & Th series	0.04
WATER					
Sample Location	Date	RADIOACTIVITY (Bq/L)			
		Gross α	Gross β	γ-emitters	Tritium
Mill Creek (before it joins Bardens Creek)	11.12.95	1.5	0.37	ND	LLD
Bardens Creek (before it joins Mill Creek)	11.12.95	0.05	0.07	ND	LLD

Notes: See **Figure 1** for the location of these sampling points.
Tritium results are now in Bq/L, in previous years the units were Bq/mL.
* The gross beta results for SAND do not include the contribution from natural potassium-40, this has been deducted.
"ND" indicates that no gamma activity was detected above background levels.
"LLD" = less than the average limit of detection which was 50 Bq/L for tritium.
"U & Th series" refers to the presence of daughter products from the decay of uranium-238 and thorium-232, which occur naturally in the environment.

TABLE 16

RESULTS OF AIR SAMPLING AT LITTLE FOREST BURIAL GROUND
1995

Sampling period	Air volume sampled (m^3)	'B' filters Beryllium (μg / filter)	'A' filters ^{239}Pu * (Bq / m^3)
7.12.94 to 24.3.95	70.39	<0.05	-
24.3.95 to 23.6.95	50.35	<0.01	-
23.6.95 to 13.9.95	90.15	<0.01	-
13.9.95 to 8.12.95	221.6	<0.01	-
1995 Composite of 'A' filters	431.74 (total 'A' filters)	-	LLD

Notes:
Two Millipore aerosol filters, 'A' & 'B', sample the air simultaneously, in order to provide duplicate samples, one for the beryllium analysis and one for the plutonium analysis.

* The sample for plutonium analysis is a composite of all four 'A' air filters for 1995.
The beryllium analysis is performed on individual 'B' filters.

"LLD" = less than the limit of detection. The limit of detection for beryllium varied from 0.01 to 0.05μg Be / filter.

The limit of detection for ^{239}Pu is 0.0001 Bq (total).

See **Appendix D** for sample analysis procedures.

TABLE 17

AMBIENT IODINE-131 IN AIR, 1995

Sampled during the week ending :	Iodine-131 in air (Bq / m^3)	Sampled during the week ending :	Iodine-131 in air (Bq / m^3)
3.1.95	LLD	4.7.95	0.0094
10.1.95	LLD	11.7.95	LLD
17.1.95	LLD	18.7.95	LLD
24.1.95	LLD	25.7.95	0.0035
31.1.95	LLD	2.8.95	LLD
7.2.95	LLD	8.8.95	LLD
14.2.95	LLD	15.8.95	LLD
21.2.95	LLD	22.8.95	0.0035
28.2.95	LLD	29.8.95	LLD
7.3.95	LLD	5.9.95	0.025
14.3.95	LLD	12.9.95	LLD
22.3.95	LLD	19.9.95	LLD
28.3.95	LLD	26.9.95	LLD
4.4.95	LLD	4.10.95	0.026
12.4.95	0.0028	10.10.95	0.058
18.4.95	LLD	17.10.95	0.038
26.4.95	0.0041	24.10.95	0.0056
2.5.95	LLD	31.10.95	LLD
9.5.95	LLD	7.11.95	LLD
16.5.95	LLD	14.11.95	LLD
23.5.95	LLD	21.11.95	LLD
30.5.95	LLD	28.11.95	LLD
7.6.95	LLD	5.12.95	LLD
14.6.95	LLD	12.12.95	LLD
20.6.95	LLD	20.12.95	0.0036
26.6.95	LLD	28.12.95	LLD

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

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

The average iodine-131 concentration in air for the year was 0.0054 Bq/m^3 (assigning each LLD reading a value of 0.0025 Bq/ m^3). A person receiving continuous exposure to iodine - 131 at the average concentration recorded would receive an effective dose of less than 0.01 mSv per year (IAEA, 1994).

TABLE 18

EXTERNAL GAMMA RADIATION AT LHS&TC,
(ARL Dosimeter Results), 1995

	Dosimeter Location: on-site	Effective Dose (mSv* / year)
1	Hifar fence - South East	1.2 ± 0.3
2	Hifar fence - South	2.4 ± 0.5
3	Perimeter fence - West	1.4 ± 0.3
4	Hifar Fence - West	1.5 ± 0.5
5	Hifar fence - North west	1.2 ± 0.4
6	Perimeter fence - North A	1.0 ± 0.4
7	Internal fence - North	1.1 ± 0.5
8	Perimeter fence - North B	1.2 ± 0.7
9	Perimeter fence - North east	1.0 ± 0.4
10	Perimeter fence - East	1.2 ± 0.3
11	Perimeter fence - South East	1.0 ± 0.3
12	Corner of Curie and Roentgen St	1.2 ± 0.5
13	Perimeter fence - South	0.9 ± 0.4
14	Hifar fence - East	1.1 ± 0.4
15	Hifar fence - North east	1.2 ± 0.4
	Dosimeter Location: off-site	**Effective Dose (mSv / year)**
16	Private house - Lucas Heights	0.9 ± 0.3
17	Private house - Engadine	1.0 ± 0.4
18	Private house - Woronora	1.1 ± 0.5

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

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

TABLE 19

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, 1995

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) 1995						
Bld 54 (hotcells)	9	2156	0.29	-	118	16774
3	5	2	0.15	-	-	-
15A (HIFAR)	3	1	0.57	758	27	73
19	24	9	0.78	-	-	119
20	7	3	0.27	48	-	-
21A	2	0.45	0.05	-	-	-
21B	0.35	0.17	0.01	-	-	-
23A	14	2505	0.56	-	-	-
23B	0.15	0.15	0.03	-	-	-
41	79	76	0.29	-	-	-
56	13	5	0.39	-	-	-
57	3	1	0.09	631	-	-
2nd Quarter (Apr - Jun) 1995						
Bld 54 (hotcells)	9	1991	0.30	-	127	14967
3	7	1	0.17	-	-	-
15A (HIFAR)	3	2	0.68	1330	31	57
19	24	3	0.81	-	-	
20	8	1	0.36	582	-	-
21A	2	LLD	0.06	-	-	-
21B	LLD	LLD	0.01	-	-	-
23A	14	5715	0.78	-	-	-
23B	1	1	0.04	-	-	-
41	9	3	0.29	-	-	-
56	13	1	0.40	-	-	-
57	3	1	0.10	113	-	-

continued next page...

TABLE 19 continued ...

Discharge stack Bld No.	Gross α (kBq)	^{131}I (MBq)	Gross β (MBq)	^{3}H (GBq)	Noble gases (TBq)	Other activity (MBq)
3rd Quarter (Jul - Sep) 1995						
Bld 54 (hotcells)	13	1941	0.32	-	123	14707
3	6	2	0.18	-	-	-
15A (HIFAR)	2	2	0.44	1739	21	62
19	23	5	0.83	-	-	
20	10	4	0.35	1093	-	-
21A	2	1	0.35	-	-	-
21B	LLD	LLD	0.01	-	-	-
23A	14	15753	0.68	-	-	-
23B	1	2	0.04	-	-	-
41	8	10	0.31	-	-	-
56	13	3	0.46	-	-	-
57	3	8	0.10		-	-
4th Quarter (Oct - Dec) 1995						
Bld 54 (hotcells)	9	606	0.30	-	37	4702
3	6	3	0.18	-	-	-
15A (HIFAR)	2	3	0.47	9134	10	27
19	16	8	0.55	-	-	
20	8	3	0.39	129	-	-
21A	2	1	0.07	-	-	-
21B	0.27	0.04	0.01	-	-	-
23A	13	4247	1.03	-	-	-
23B	1	1	0.04	-	-	-
41	8	9	0.29	-	-	-
56	13	6	0.45	-	-	-
57	3	32	0.09	11	-	-

Notes:
All results are as supplied by ANSTO's Safety Division.

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

See **Figure 4** for the location of the discharge stacks.

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

TABLE 20

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, EXPRESSED AS PERCENTAGES OF QUARTERLY WORKING LEVELS, 1995

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) 1995						
Bld. 54 (hotcells)	0.0014	3.27	0.000045	-	69.4	1.05
3	0.3	0.01	0.01	-	-	-
15A (HIFAR)	0.009	0.006	0.002	0.58	100	0.11
19	0.007	0.027	0.003	-	-	0.02
20	0.25	0.02	0.07	0.59	-	-
21A	0.20	0.01	0.04	-	-	-
21B	0.15	0.01	0.03	-	-	-
23A	0.09	15.6	0.004	-	-	-
23B	0.002	0.0009	0.0005	-	-	-
41	0.024	0.475	0.001	-	-	-
56	0.17	0.01	0.035	-	-	-
57	0.48	0.028	0.10	35.0	-	-
2nd Quarter (Apr - Jun) 1995						
Bld. 54 (hotcells)	0.0014	3.02	0.00005	-	74.7	0.94
3	0.44	0.006	0.005	-	-	-
15A (HIFAR)	0.009	0.013	0.003	1.02	114.8	0.09
19	0.007	0.009	0.0003	-	-	0.10
20	0.28	0.006	0.09	7.2	-	-
21A	0.20	-	0.04	-	-	-
21B	-	-	0.03	-	-	-
23A	0.09	35.7	0.006	-	-	-
23B	0.015	0.006	0.0006	-	-	-
41	0.003	0.019	0.0001	-	-	-
56	0.17	0.002	0.04	-	-	-
57	0.48	0.028	0.11	6.3	-	-

continued next page...

TABLE 20 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) 1995						
Bld. 54 (hotcells)	0.002	2.9	0.00005	-	72.4	0.92
3	0.38	0.013	0.014	-	-	-
15A (HIFAR)	0.006	0.013	0.002	1.3	77.8	0.09
19	0.007	0.015	0.003	-	-	0.0008
20	0.36	0.025	0.085	13.5	-	-
21A	0.20	0.017	0.25	-	-	-
21B	-	-	0.03	-	-	-
23A	0.09	98.5	0.005	-	-	-
23B	0.015	0.013	0.0006	-	-	-
41	0.002	0.063	0.001	-	-	-
56	0.17	0.007	0.042	-	-	-
57	0.48	0.22	0.11	44	-	-
4th Quarter (Oct - Dec) 1995						
Bld. 54 (hotcells)	0.0014	0.92	0.00005	-	22	0.29
3	0.38	0.02	0.014	-	-	-
15A (HIFAR)	0.006	0.02	0.002	7	37	0.04
19	0.005	0.02	0.002	-	-	
20	0.29	0.02	0.10	1.6	-	-
21A	0.20	0.017	0.05	-	-	-
21B	0.12	0.003	0.03	-	-	-
23A	0.08	26.5	0.008	-	-	-
23B	0.015	0.006	0.0006	-	-	-
41	0.002	0.06	0.001	-	-	-
56	0.17	0.014	0.04	-	-	-
57	0.48	0.89	0.1	0.61	-	-

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 21

LIQUID RADIOACTIVE EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, 1995

MONTH	VOLUME Discharged m^3	ALPHA $^{\alpha}$ Bq/m^3	BETA $^{\beta}$ Bq/m^3	TRITIUM Bq/m^3	Average MONTHLY Concentration QUOTIENT*	
					Former 1959 Radioactive Substances Regulations	WHO Guidelines for Drinking Water
January	6743	6.5×10^2	2.6×10^4	5.4×10^6	0.32	-
February	5914	4.5×10^2	9.4×10^3	1.3×10^6	0.14	-
March	10327	5.9×10^2	7.0×10^3	3.5×10^6	0.13	-
April	5562	7.7×10^2	1.9×10^4	1.1×10^7	0.27	-
May	10375	6.8×10^2	8.0×10^3	5.9×10^6	0.15	-
June	7572	5.5×10^2	7.6×10^3	9.8×10^6	0.13	-
July	6459	8.8×10^2	7.4×10^3	2.5×10^7	0.17	-
August	6966	7.2×10^2	1.4×10^4	3.7×10^6	0.21	-
September	8778	7.1×10^2	1.8×10^4	3.9×10^6	0.25	0.23
October	9330	6.1×10^2	2.0×10^4	1.5×10^7	0.26	0.30
November	8217	5.2×10^2	2.1×10^4	1.0×10^7	0.26	0.27
December	8337	8.0×10^2	2.8×10^4	1.8×10^7	0.37	0.40
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:

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

β = 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).

All discharges for 1995 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

ESTIMATED EFFECTIVE DOSES FROM AIRBORNE DISCHARGES
1995

Receptor Location	Effective dose 1995# (mSv/yr)
Library	0.0069
Outside HIFAR	0.0013
Building 9	0.0095
Main gate	0.0072
Stevens Hall	0.0068
MWDA Depot *	0.0054
BMX track *	0.0070
Woronora Valley *	0.00095

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

TABLE 23

ESTIMATED EFFECTIVE DOSES FROM AIRBORNE DISCHARGES
at 1.6 km and 4.8 km radii around HIFAR, 1995

Receptor Locations	Effective dose 1995 (mSv/yr)#	
	1.6 km from HIFAR	**4.8 km** from HIFAR
NORTH	0.0049	0.0013
NNE	0.0058	0.0016
NE	0.0040	0.0012
ENE	0.0050	0.0015
EAST	0.0044	0.0013
ESE	0.0031	0.0010
SE	0.0024	0.00077
SSE	0.0022	0.00066
SOUTH	0.0020	0.00059
SSW	0.0019	0.00060
SW	0.0019	0.00060
WSW	0.0019	0.00056
WEST	0.0019	0.00056
WNW	0.0017	0.00054
NW	0.0029	0.00091
NNW	0.0038	0.0011

Estimated airborne effective doses were calculated using the ADDCOR program, stack discharge figures and meteorological data for 1995.

TABLE 24

ANNUAL EFFECTIVE DOSES TO ADULTS FROM NATURAL SOURCES[1]

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	-

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

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

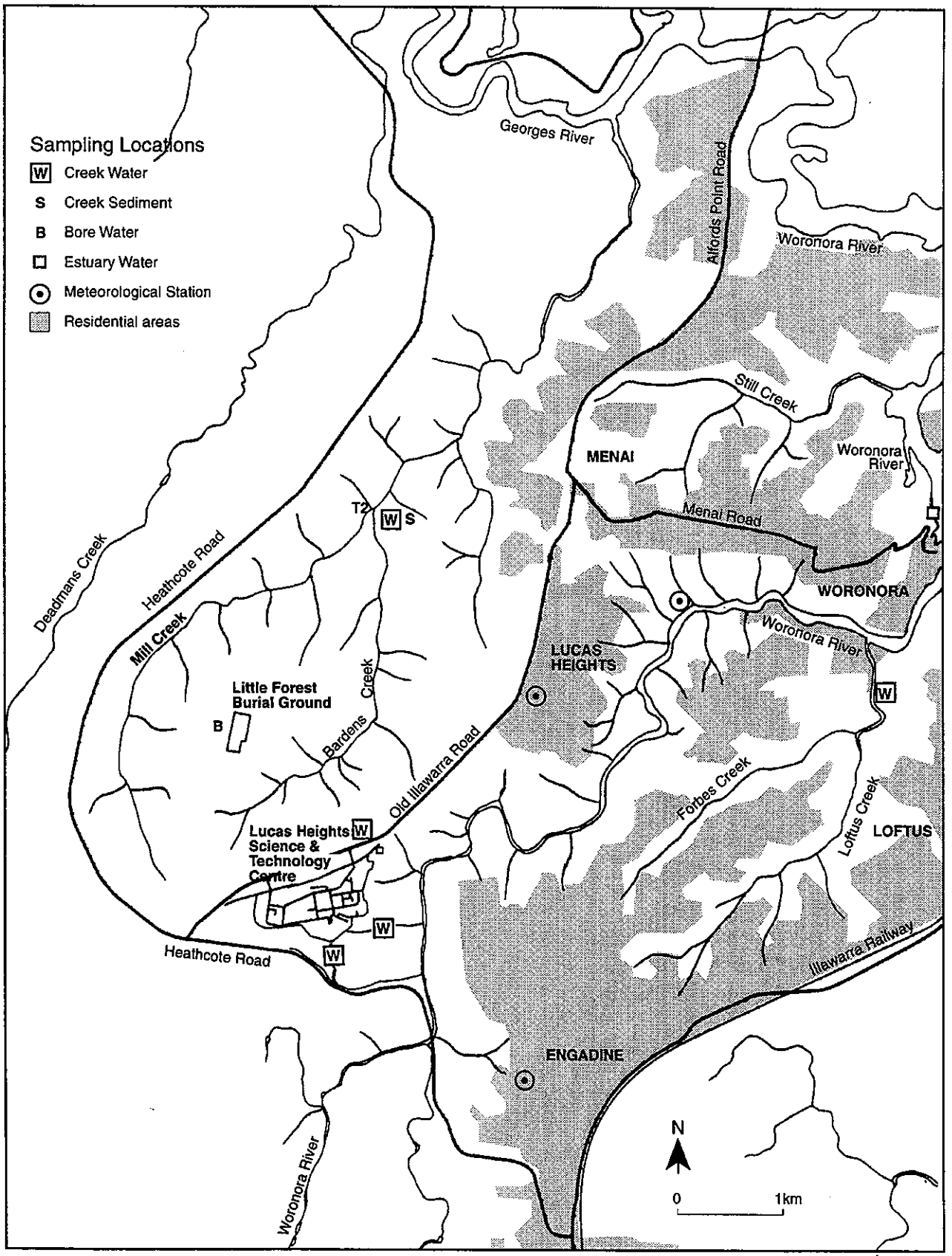
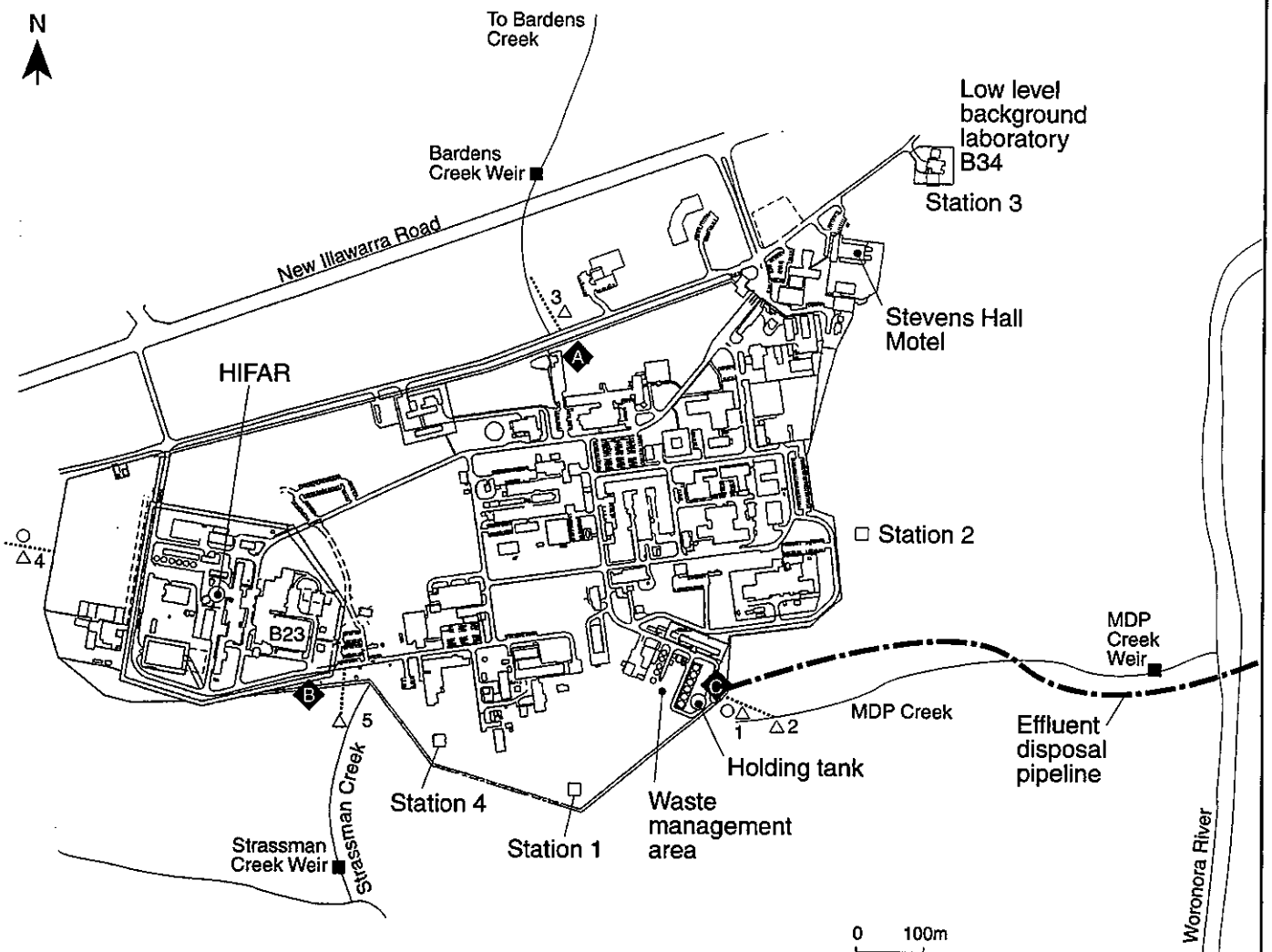


Figure 1: Location of off-site sampling points



□ Continuous air sampling stations
■ SPCC sampling point
····· Stormwater drain outlet

Stormwater drain sampling:
○ Sediment
△ Water

Stormwater retention dams:
A B C

Location of drain sampling points

1 20m downstream of outlet no.1
2 60m downstream of outlet no.1
3 Behind building 1 (water only)
4 On west fence road (water, sediment)
5 Opposite meteorological tower (no sediment)

Figure 2: Location of stormwater and air sampling points at LHS&TC, 1995

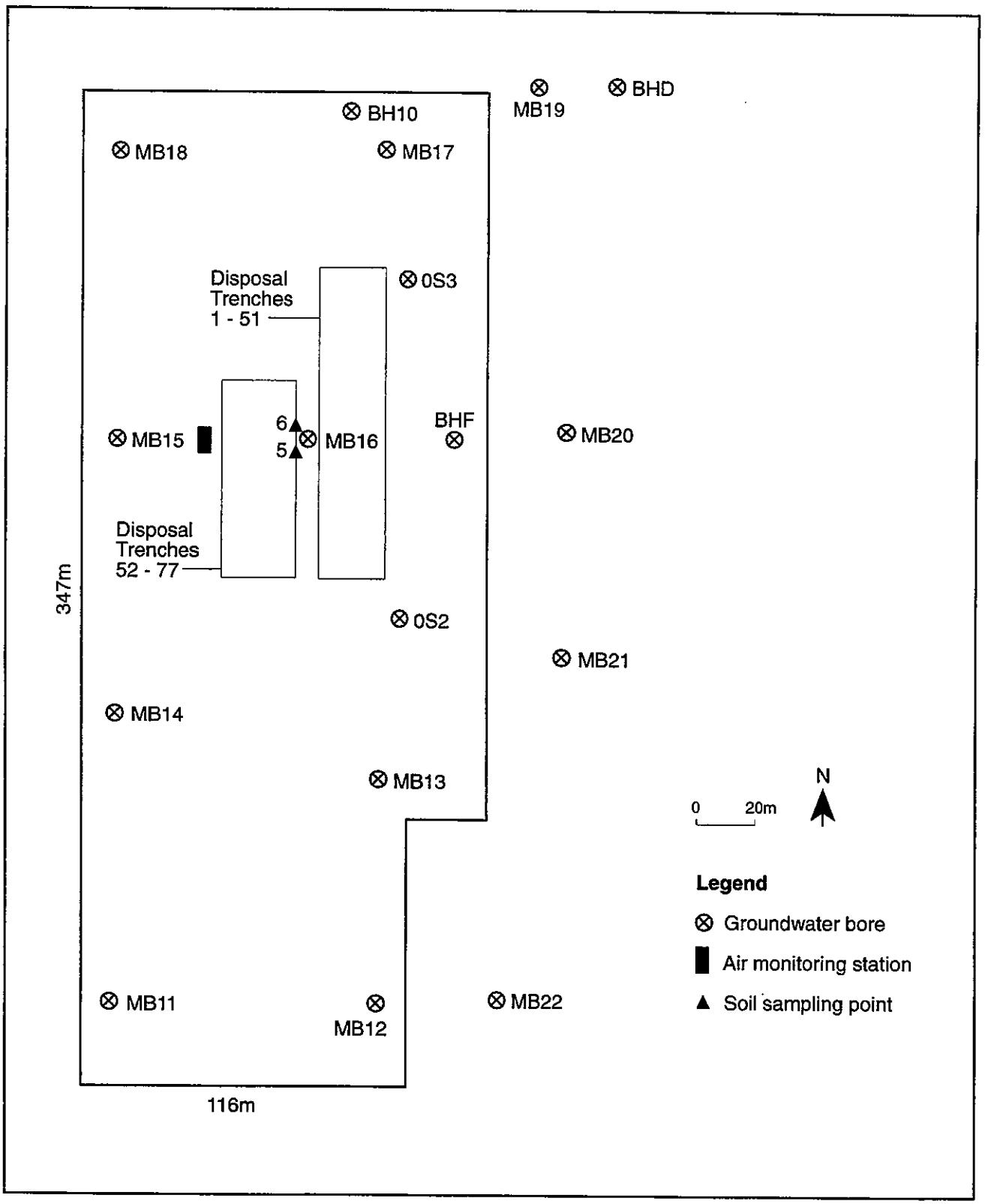


Figure 3: Little Forest Burial Ground - Location of trenches, groundwater bores, and soil sampling points

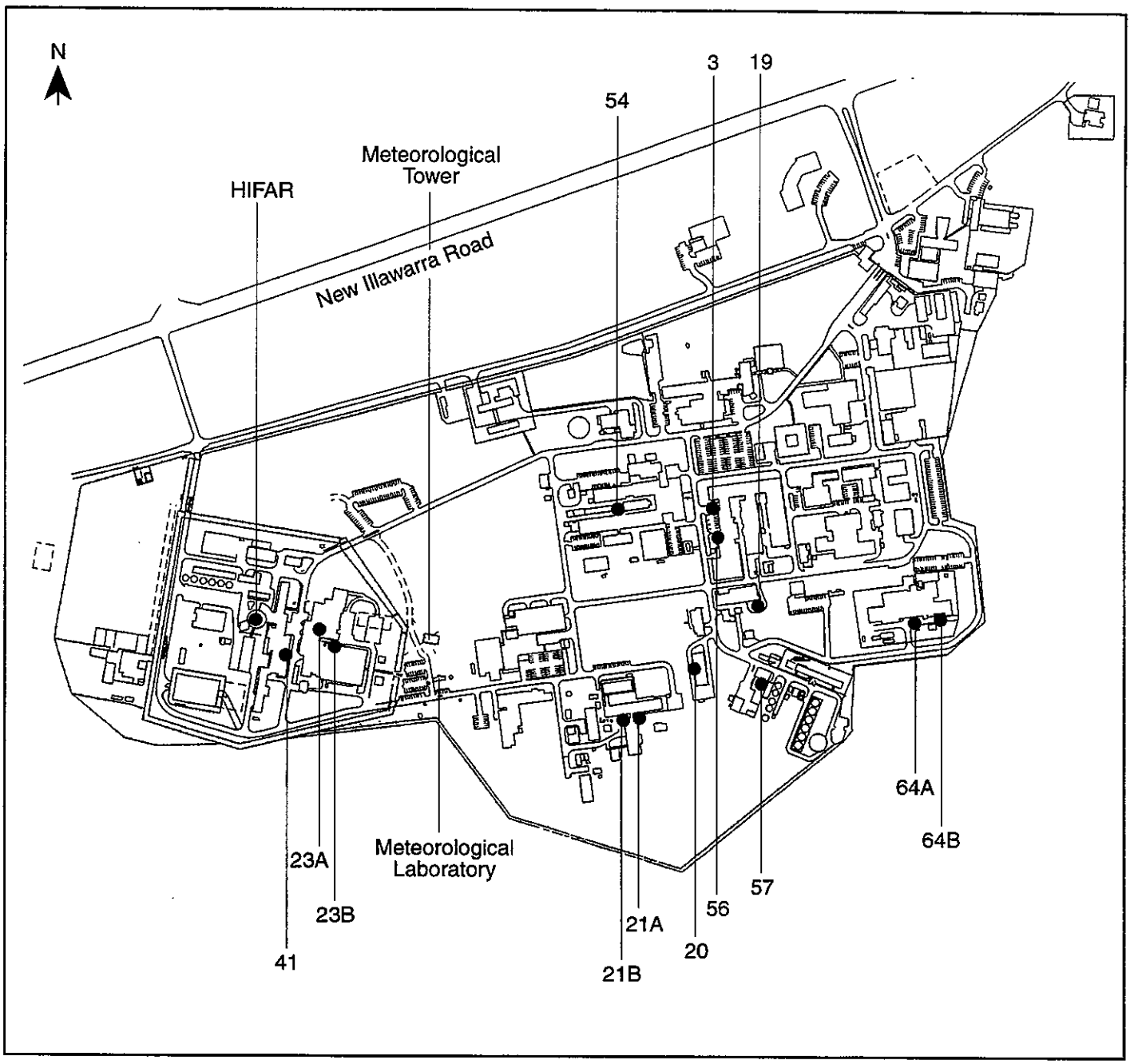


Figure 4: Location of airborne effluent release stacks and meteorological facilities at LHS&TC

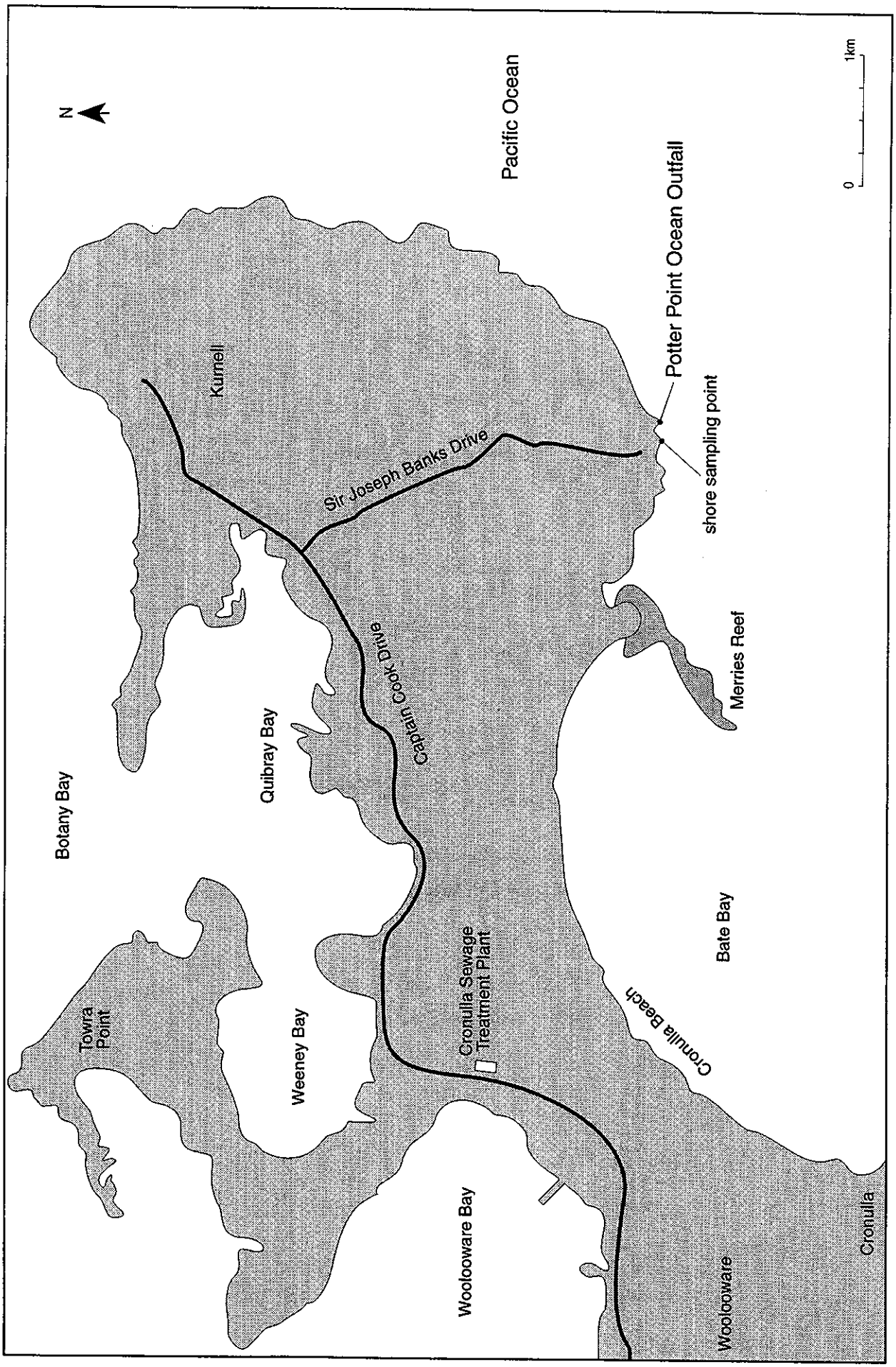


Figure 5: Location of Cronulla Sewage Treatment Plant and ocean outfall at Potter Point

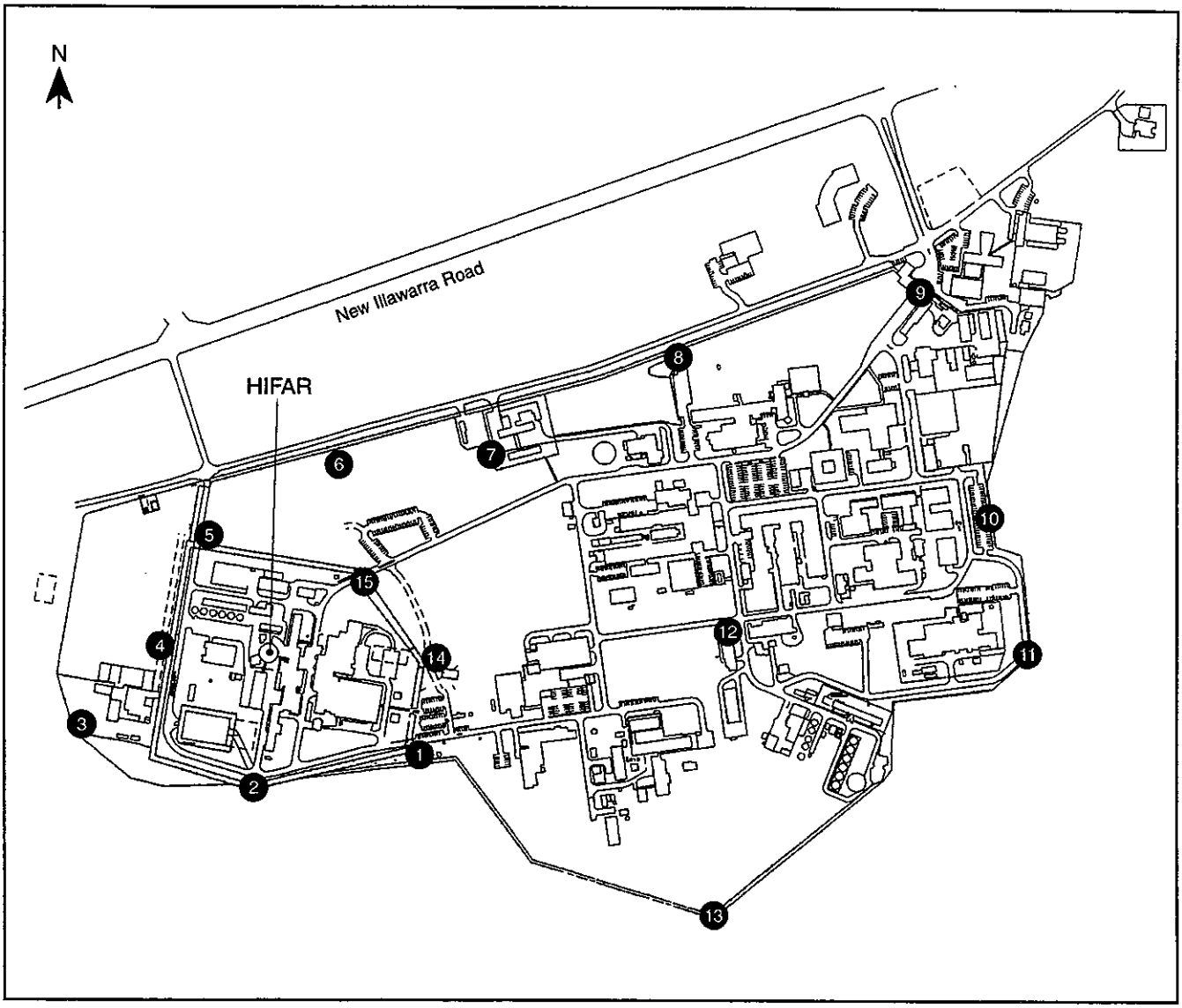


Figure 6: Location of external radiation dosimeters at Lucas Heights Science & Technology Centre

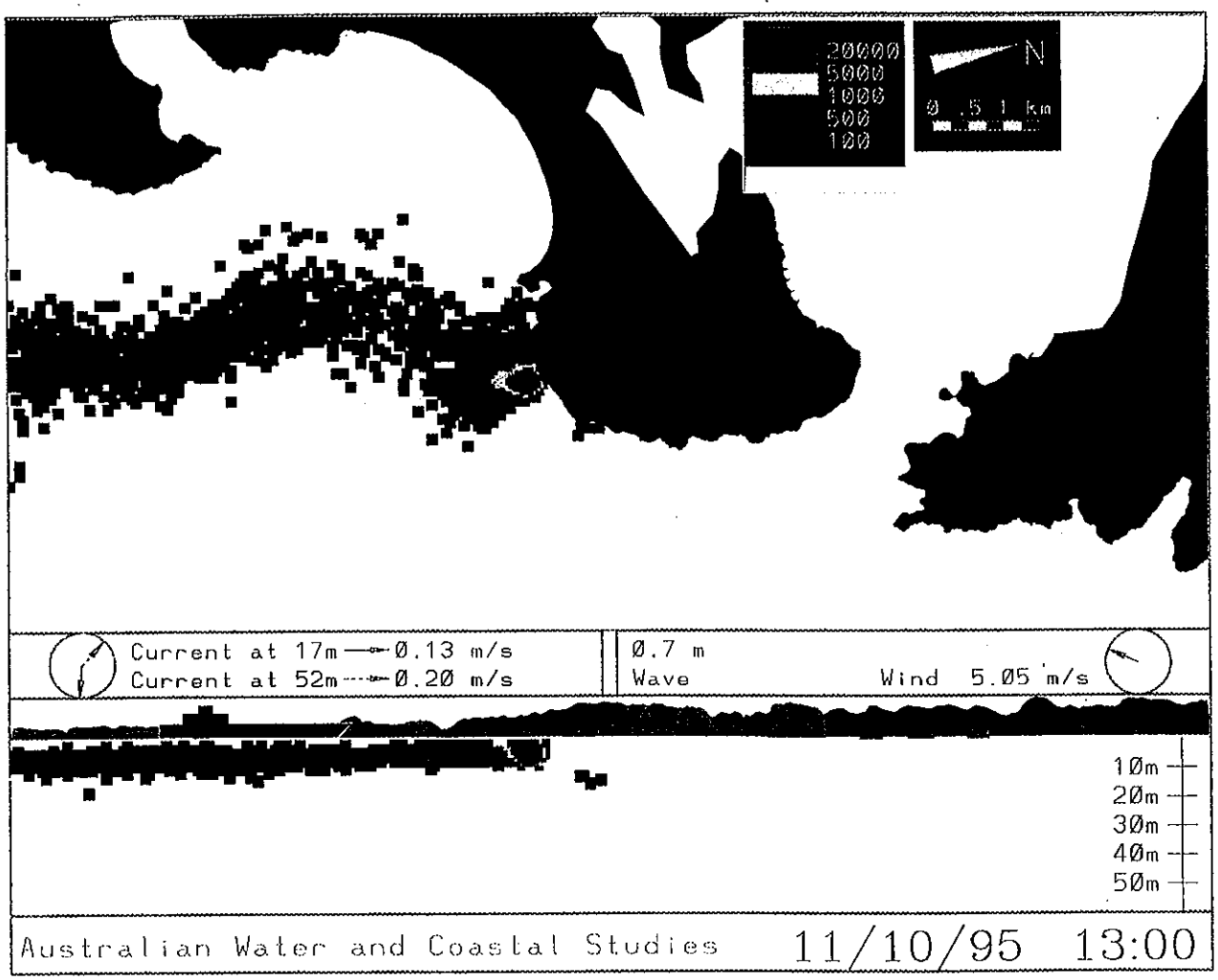


Figure 7: Numerical Modelling of the Potter Point Ocean Outfall Sewage Plume at 13:00 hours on 11 October 1995, by Australian Water and Coastal Studies Pty Ltd.

GLOSSARY OF TERMS

absorbed dose: The energy imparted to matter by ionising radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is joules per kilogram, called the gray (Gy). See radiation dose.

activity (of a substance): The number of disintegrations per unit of time taking place in a radioactive material. The unit of activity is the becquerel (Bq), one disintegration per second.

alpha particle: A positively charged particle emitted from the nucleus of an atom during radioactive decay. Consists of two protons and two neutrons (a helium-4 nucleus). Although alpha particles are normally highly energetic, they travel only a few centimetres in air and are stopped by a sheet of paper or outer layer of dead skin.

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

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

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

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

beta particle (ray): A particle emitted from an atom during radioactive decay. Beta particles are either electrons with a negative charge or positrons with a positive electric charge. High energy beta particles can travel metres in air and several millimetres into the human body; low energy beta are unable to penetrate the skin. Most beta particles can be stopped by a small thickness of light material, eg. aluminium or plastic sheeting.

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

daughter product: A nuclide formed 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.

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

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

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

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

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

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

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 12.5 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 (milli)	$= 10^{-3} = 0.001$
M (mega)	$= 10^{6} = 1\ 000\ 000$	μ (micro)	$= 10^{-6} = 0.000001$
G (giga)	$= 10^{9} = 1\ 000\ 000\ 000$	n (nano)	$= 10^{-9} = 0.000000001$
T (tera)	$= 10^{12} = 1\ 000\ 000\ 000\ 000$	p (pico)	$= 10^{-12} = 0.000000000001$

APPENDIX D

ENVIRONMENTAL SAMPLE COLLECTION, PREPARATION AND ANALYTICAL PROCEDURES

SAMPLE COLLECTION AND PREPARATION

Potter Point Biological Samples

As part of the environmental monitoring program at Potter Point ocean outfall, samples of fish ('Blackfish' or 'Luderick', *Girella sp.*), macrophytic algae ('green hair weed', *Enteromorpha intestinalis*), barnacles and particulates >37 μm were collected.

The Blackfish were caught off the rocks using a fishing line baited with weed, while the green algae and barnacles were scraped off the rocks. Particulate samples were obtained from a boat situated in the sewage plume, by pumping approximately 200 to 600 litres of water through a 37 μm nylon mesh plankton net. The particulates >37 μm (including plankton) were then rinsed onto GF-C laboratory filter papers, and dried. Fish were filleted and scaled, while the algae and barnacles were left whole.

All samples were oven-dried at approximately 70^{0}C, barnacles were dried whole. 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 homogenised and packed into plastic petri dishes for gamma-counting.

Soils

Soils are sampled with a scoop to take the first 4 cm from the surface. About 1 kg is collected. Samples are then dried, and passed through a quarter-inch mesh sieve to remove large stones and vegetative matter. After weighing, the samples are ashed, and counted for gross beta activity. For gamma spectrometry, a 65 mm petri dish is packed with approximately 40 to 50 grams of sample. The remaining ash is sieved to yield a particle size range of 125 to 250 microns, which is used for alpha counting.

Sediments

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

Vegetation, biota

The vegetation samples are only available in sufficient quantities at sites where the stormwater drains are large enough to retain enough water to support plant growth. The plant species sampled is Crofton Weed (*Eupatorium adenophorum*). Two to three kilograms are collected, and the whole, unwashed vegetation is dried, weighed and ashed.

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

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

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

Air Samples: Ambient iodine-131
Four (4) continuous air sampling stations are situated along the eastern fence boundary of the site (where suburban residences are closest) in order to monitor concentrations of iodine-131 in air. The locations of these samplers are shown on **Figure 2**. At each station the air is sampled by means of a vacuum pump drawing air through a pair of Maypacks (activated charcoal filter cartridges), so that duplicate samples are available. Air is sampled at a rate of approximately 35 m^3 per day. Filters are replaced and analysed weekly, with air flow rates through the filters being checked at the same time.

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

The system is triggered by wind speeds of 3 m s^{-1} or more. Below this speed, surface dusts are not raised from this type of well-grassed landform. Air is drawn at approximately 8 litres per minute through 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.

Environmental Radiation - ARL dosimeters
External radiation levels at the perimeter of LHS&TC and in some surrounding suburban areas are measured using environmental 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.

Measurements were made over four consecutive exposure periods of three months duration, and the TLD badges were sent to 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 calculated from the standard deviation of the daily rates.

ANALYTICAL PROCEDURES

Tritium in waters

Water samples to be analysed for tritium are prepared by distillation according to the International Standards Organisation (ISO) standard 9698 1989(E). One mL of distilled sample is combined with 10 mL of Instagel scintillant, refrigerated and stored in the dark for several hours prior to counting on a Canberra/Packard model 300c liquid scintillation counter. Total counting time is 100 minutes per sample, comprising five 20-minute counts. The average limit of detection for 1995 was 50 Bq/L.

Low levels of tritium in waters - by electrolysis

As the tritium isotope is a weak beta emitter, it is difficult to detect at environmental levels. This method achieves a low limit of detection through pre-concentration of the sample by electrolysis. Samples are distilled to remove any salts, then 600 mL of the distillate is subjected to electrolysis, thus concentrating the tritium in the sample.
10 mL of the concentrated sample is added to Instagel scintillant, and counted for thirty 20 minute intervals in a liquid scintillation spectrometer. The limit of detection is 0.024 Bq/L

Alpha and beta activity in soils

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

Potassium-40 beta activity

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

Gross alpha and beta activity - planchette samples

Water samples from the SPCC sampling points are analysed according to Australian Standard AS 3550.5 - 1990 for drinking waters. The samples are evaporated in small aliquots onto aluminium planchettes, and counted in a Canberra 2400 thin-window gas-flow proportional alpha/beta counter.

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

All other water samples (LFBG bore waters, and monthly composites frm Stormwater Outlet No.1) are evaporated in large volumes, the residue homogenised

and tabletted, and counted for both alpha and beta activity in the Canberra 2400 alpha/beta counter.

A tablet of KCl and an alloy disc of aluminium and natural uranium are used to standardise the counter for beta and alpha activity, respectively.

Gamma spectrometry - water, 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 used to deduct the background radioactivity (due to the detector components), from the sample activity. Peaks at certain energies in the stripped spectrum are used to identify the isotope and the amount present in the sample. A spectrum report is printed for each sample, showing the sample description, the peaks identified, gross and net areas of the peaks and associated errors.

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

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

Air samples - Ambient Iodine-131
One set of Maypacks are set aside each week 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;
- that all the measured activity was released at one point (there are actually four locations being measured).

Iodine-131 results are corrected for decay (due to the 8 day half-life) back to the first day of the sampling period.

Little Forest Burial Ground Air Filters

The air samples at LFBG are used to monitor possible aerial dust dispersion of contaminants from the site.

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).

APPENDIX E

AIRBORNE EFFLUENT SAMPLE COLLECTION AND ANALYSIS

Airborne Effluent
The authorised airborne effluent discharges from LHS&TC 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.