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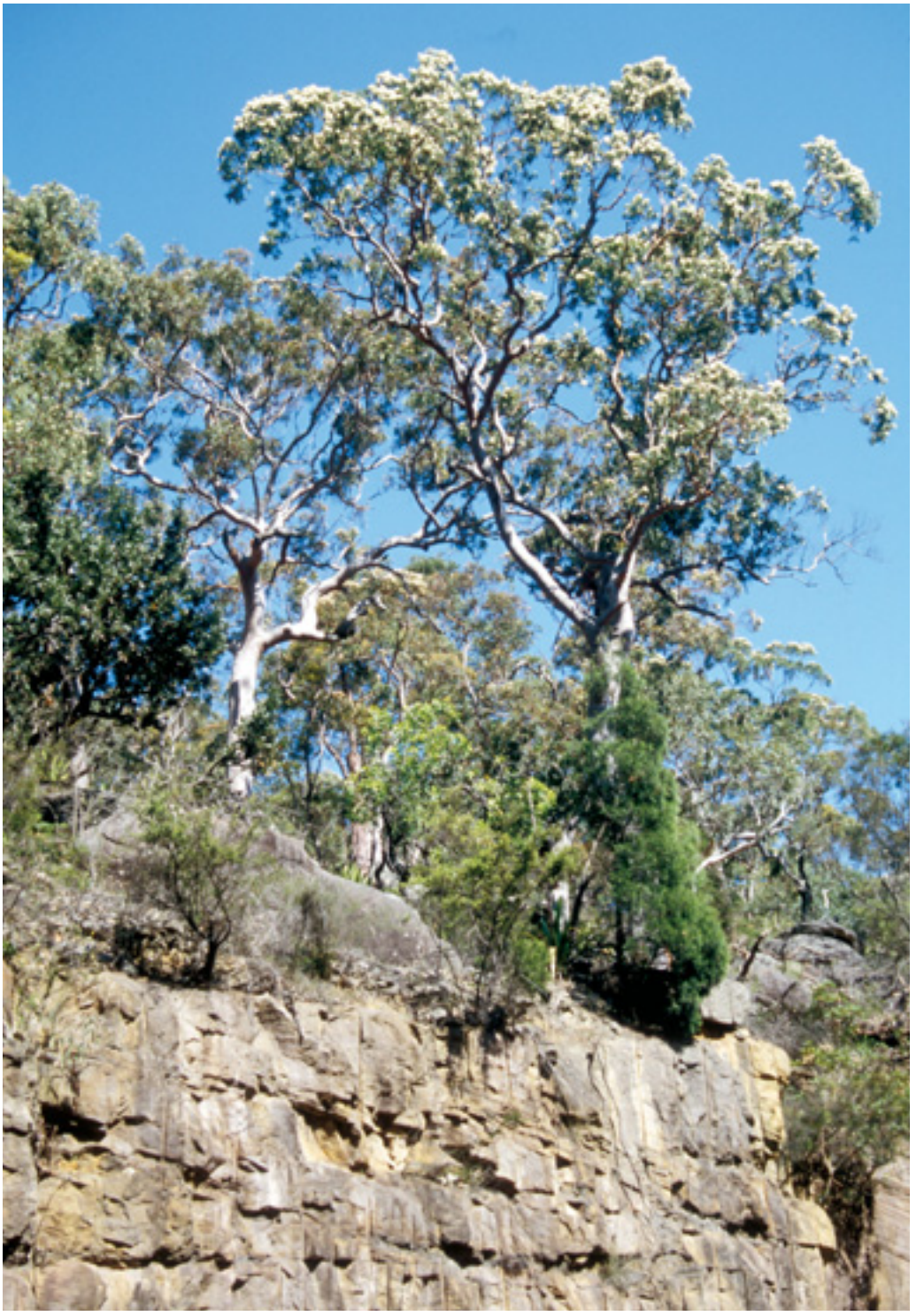
Environmental and Effluent Monitoring at ANSTO Sites

2004-2005



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Front Cover	Smooth-barked Apple (*Angophora costata*) flowering in December 2004, along the banks of the Woronora River at Lucas Heights, NSW, Australia
Photography	Dr John Ferris, ANSTO

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Environmental and Effluent Monitoring at ANSTO Sites, 2004–2005

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Abstract

This report presents the results of ANSTO's environmental and effluent monitoring at the Lucas Heights Science and Technology Centre (LHSTC) and the National Medical Cyclotron (NMC) sites, from July 2004 to June 2005. Effective doses to the critical group of members of the public potentially affected by routine airborne emissions from the LHSTC were less than 0.005 mSv/year. This estimated maximum potential dose is less than 24% of the ANSTO ALARA objective of 0.02 mSv/year, and much lower than the public dose limit of 1 mSv/year that is recommended by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). The effective doses to the critical group of members of the public potentially exposed to routine liquid effluent releases from the LHSTC have been realistically estimated as a quarter (or less) of the estimated doses to the critical group for airborne releases. The levels of tritium detected in groundwater and stormwater at the LHSTC were less than those set out in the Australian Drinking Water Guidelines. The airborne and liquid effluent emissions from the NMC were below both the ARPANSA-approved notification levels and Sydney Water limits for acceptance of trade wastewater to sewer. Results of environmental monitoring at both ANSTO sites confirm that the facilities continue to be operated well within regulatory limits. ANSTO's routine operations at the LHSTC and NMC make only a very small addition to the natural background radiation dose of ~1.5 mSv/year experienced by members of the Australian public.

INIS Descriptors

The following descriptors have been selected from the INIS Thesaurus to describe the subject matter of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS Manual for Indexing) and IAEA-INIS-13 (INIS Thesaurus) published in Vienna by the International Atomic Energy Agency. Airborne Particulates, Algae, Alpha Decay Radioisotopes, Alpha Particles, ANSTO, Argon-41, Arsenic-76, Australia, Beryllium-7, Bromine-82, Cerium-144, Caesium-134, Caesium-137, Chromium-51, Cobalt-57, Cobalt-60, Contamination, Cyclotrons, Dose-Constraint, Dose Limits, Drinking Water, Environmental Exposure Pathway, Environmental Impacts, Fishes, Fission Product Release, Fluorine-18, Gallium-67, Gaseous Wastes, Ground Water, Iodine-123, Iodine-131, Iodine-132, Iodine-133, Krypton-85m, Lead-201, Lead-210, Liquid Wastes, Mercury-197, Mercury-203, Molybdenum-99 Niobium-95, Noble Gases, Public Health, Radiation Doses, Radiation Monitoring, Radioactive Effluents, Radium-226, Radium-228, Ruthenium-103, Ruthenium-106, Sampling, Seawater, Sediments, Soils, Stack Disposal, Standards, Strontium-90, Surface Waters, Thallium-201, Thallium-202, Thermoluminescent Dosimetry, Tritium, Uranium-238, Water Quality, Wind, Xenon-133, Xenon-135, Xenon-135m, Zinc-65, Zirconium-95.

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SI Units

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

Multiples And Submultiples Of SI Units

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

List of Abbreviations

AAEC	The former Australian Atomic Energy Commission, now ANSTO
ADWG	Australian Drinking Water Guidelines
ALARA	As Low As Reasonably Achievable
ANSTO	Australian Nuclear Science and Technology Organisation
ANZECC	Australian and New Zealand Environment Conservation Council
ARI	Australian Radiopharmaceuticals and Industrials
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ASP	Aerosol Sampling Program
DEC	NSW Department of Environment and Conservation
EMP	Environmental Management Plan
EMS	Environmental Management System
EPA	Environment Protection Authority (incorporated into the DEC in Sept. 2003)
HEPA	High Efficiency Particulate Air filter
HIFAR	High Flux Australian Reactor
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INIS	International Nuclear Information System
ISO	International Organisation for Standardisation
LFBG	Little Forest Burial Ground
LH	Lucas Heights
LHSTC	Lucas Heights Science and Technology Centre
MDA	Minimum Detectable Activity
MDP	Main Discharge Pipeline
NHMRC	National Health and Medical Research Council
NMC	National Medical Cyclotron
NOHSC	National Occupational Health and Safety Commission
NRMMC	Natural Resource Management Ministerial Council
NSW	New South Wales
OPAL	Open Pool Australian Light-water reactor
PM	Particulate Matter
SI	Système International d'Unite
SPCC	The former State Pollution Control Commission (which became the NSW EPA, now the NSW DEC)
STP	Sewage Treatment Plant
TLD	Thermo-luminescent Dosimeter
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

1. Introduction

The Australian Nuclear Science and Technology Organisation (ANSTO) is an agency of the Commonwealth Government of Australia and operates several national facilities, including Australia's research reactor, HIFAR (the High Flux Australian Reactor), produces radioisotopes and radiopharmaceuticals and carries out research in nuclear science and technology. Most of the ANSTO facilities are located at the Lucas Heights Science and Technology Centre (LHSTC), some 40 km south-west of the Sydney city centre. The LHSTC occupies 70 hectares and is surrounded by a 1.6 km diameter buffer zone (**Figure 1**, see section 5). ANSTO also operates the National Medical Cyclotron (NMC), located in Camperdown, Sydney, which produces certain short-lived radioisotopes for medical investigations. ANSTO's activities are regulated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) under the *Australian Radiation Protection and Nuclear Safety Act* 1998.

ANSTO is committed to undertaking its activities in a manner that protects the environment and is consistent with national and international standards. ANSTO promotes environmental awareness throughout all levels of the organisation, and strives for continual improvement in environmental performance. As part of its commitment to environmental protection, ANSTO has implemented an Environmental Management System (EMS) that gained certification to the AS/NZS ISO14001 standard in 2004. The program for achieving the EMS objectives is documented in a series of Environmental Management Plans (EMPs), which cover airborne emissions, radioactive wastes, surface waters, groundwater, resource usage and management of the buffer zone and Little Forest Burial Ground (LFBG). ANSTO provides verifiable evidence of its environmental performance through an audited program of environmental monitoring, and publication of these results in this report and others in the annual Environmental and Effluent Monitoring series. The report series is available electronically via the ANSTO digital reports database (ANSTO 2005b), or in hardcopy either from the Sutherland Shire Central Library or by request from ANSTO's Communications Manager. In May 2005, ANSTO released its first Corporate and Social Responsibility report providing, amongst other things, an environmental 'scorecard' and statement of commitments.

This report summarises the results from the environmental and effluent monitoring carried out at the LHSTC and the NMC from July 2004 to June 2005, and assesses the potential effects of radioactive discharges, with particular emphasis on local residents.

2. ANSTO Facilities

2.1 HIFAR

The HIFAR research reactor produces radioisotopes for medical and industrial use and employs neutrons for research applications. HIFAR is authorised by ARPANSA to release low levels of radionuclides to the atmosphere via stacks. The main radionuclides are tritium and argon-41 (a noble gas). There are also small quantities of iodine-131, arsenic-76, bromine-82, mercury-197 and mercury-203. The tritium occurs as tritiated water vapour that can exchange with rainwater, resulting in the presence of tritium in local surface waters and groundwater at concentrations somewhat above the normal background for Australian waters. Low-level liquid waste is treated and discharged via the Sydney Water Corporation sewer under the terms of a trade wastewater agreement.

2.2 RADIOISOTOPE PRODUCTION

The production of radioisotopes for medical and industrial use by ANSTO Radiopharmaceuticals and Industrials (ARI) results in the release of small quantities of radionuclides to the environment from the LHSTC. ARPANSA regulates the atmospheric releases of radionuclides including iodine-131, xenon-133, xenon-135 and krypton-85 from stacks in the radioisotope and radiopharmaceutical production area at the LHSTC. Low-level liquid waste is treated and discharged via the Sydney Water sewer under the terms of a trade wastewater agreement.

2.3 NATIONAL MEDICAL CYCLOTRON

ANSTO also manufactures radiopharmaceuticals at the NMC (Camperdown, Sydney). The major radiopharmaceutical products made at the NMC in 2004-05 were thallium-201, gallium-67, iodine-

123 and fluorine-18, all of which have relatively short half-lives ranging from minutes to hours. The radionuclides that may be present in liquid effluent produced by the NMC include thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65, iodine-123, lead-201 and fluorine-18. However, a system of delayed liquid effluent releases allows the radionuclides to decay significantly prior to being released to the sewer; consequently, lead-201 (half-life 9.3 hours) and fluorine-18 (half-life 110 minutes) are not usually detectable in the effluent.

Atmospheric emissions of iodine-123, fluorine-18, thallium-201 and gallium-67 from the NMC are regulated by ARPANSA under the ANSTO Airborne Radioactivity Discharge Authorisation. The liquid waste discharges from the NMC to the sewer are covered by a trade wastewater agreement with Sydney Water that incorporates limits for specific radionuclides in the discharges.

2.4 LIQUID EFFLUENT TREATMENT

Liquid effluent from the LHSTC is analysed and discharged via ANSTO's Main Discharge Pipeline (MDP, indicated on **Figure 2**, see section 5) to the Sydney Water sewer. The MDP is regularly inspected and maintained by ANSTO personnel. The effluent contains low levels of radionuclides, mainly tritium and caesium-137, with others such as iodine-131, cobalt-60, chromium-51, radium-226 and cerium-144 occasionally detected.

The annual volume of effluent discharged is typically 80,000 to 100,000 m^3/year; comprising approximately 50% sewage, 45% non-active trade waste effluent and 5% low-level active wastewater from laboratories where radioactive materials are routinely handled. The low-level active effluent undergoes an alum-based chemical treatment process for the removal of radionuclides. The trade wastewater is tested and chemically treated if necessary. Sewage is partially treated by aeration on-site. The three liquid waste streams are combined in holding tanks and tested for radioactive content and specified non-radiological water-quality parameters prior to discharge to the sewer. Sewage from the Sutherland Shire, including ANSTO's effluent, is tertiary-treated at the Cronulla Sewage Treatment Plant (STP) before being released to the sea at the Potter Point ocean outfall (shown on **Figure 1**, inset, see section 5).

2.5 LITTLE FOREST BURIAL GROUND

Between 1960 and 1968, the Australian Atomic Energy Commission (AAEC, the precursor to ANSTO) used a small area locally known as Little Forest (**Figure 1**, see section 5) for the disposal, by burial, of solid waste with low levels of radioactivity and of beryllium oxide (non-radioactive) that was generated predominantly at the LHSTC. Routine maintenance of the LFBG includes regularly mowing the grass and filling any shallow depressions in the trench area with clay/shale of local origin. Regular surveillance and monitoring of the LFBG is designed to detect any off-site transport of radionuclides by windborne transport of soil particles or in surface waters or groundwater.

3. Regulatory and Legal Framework

ANSTO was formed in 1987 and is a Commonwealth Government Statutory Authority. It superseded the AAEC, which was created in 1953. In accordance with Section 7A of the *Australian Nuclear Science and Technology Organisation Act* 1987, ANSTO is exempt from the application of State laws where those laws relate to the use of land, environmental consequences of the activities of ANSTO, radioactive materials and dangerous goods, or certain types of licensing. Notwithstanding this, ANSTO has a policy of satisfying relevant NSW statutory requirements where no Commonwealth legislation exists. Key legislative and regulatory requirements at ANSTO facilities in relation to environmental protection are summarised in **Table A**.

Table A. Key legislative and regulatory requirements relevant to ANSTO facilities in relation to environmental protection.

Driver	Organisation	Summary
Australian Radiation Protection and Nuclear Safety Act 1998 and *Regulations* (1999)	ARPANSA	Licences and regulates the operation of Controlled Facilities and the production, use and disposal of radioactive materials at all ANSTO sites; specifies exemption levels.
Airborne Radioactive Discharge Authorisation (ARPANSA 2001)	ARPANSA	Reports against facility licence conditions. Incorporates a multi-layer system of radiological protection, designed to ensure that doses to the public are kept as low as reasonably achievable (ALARA) for the LHSTC and NMC.
Trade Wastewater Agreement (No. 4423, ANSTO and Sydney Water)	Sydney Water Corporation	Authorisation to discharge treated liquid effluent from LHSTC to the sewer.
Trade Wastewater Agreement (No. 13966, ANSTO and Sydney Water)	Sydney Water Corporation	Authorisation to discharge treated liquid effluent from the NMC to the sewer.
Protection of the Environment Operations Act 1997 *(NSW)*	NSW DEC (formerly NSW EPA)	The *Clean Waters Regulations* (1972) provide radiological limits for Class C stormwater/surface water drainage.
Crown Lands Act 1989 (NSW)	NSW Government	Environmental protection principles are observed in relation to the management and administration of ANSTO sites.
Environment Protection and Biodiversity Conservation Act 1999	Commonwealth Department of Environment and Heritage	Environmental assessment of projects having national importance (OPAL).
National Biodiversity Strategy (1996)	Commonwealth Department of Environment and Heritage	Integration of biodiversity conservation with natural resource management.
Native Vegetation Act 2003 (NSW)	NSW Government	Conservation and management of native vegetation.
Rural Fires Act 1997 (NSW)	NSW Government	Bushfire hazard management.

ANSTO reports to ARPANSA under an Airborne Radioactive Discharge Authorisation that incorporates a multi-layer system of radiological protection, designed to ensure that doses to the public are kept As Low As Reasonably Achievable (the ALARA principle). For practical implementation of the ALARA objective, the airborne discharge authorisation incorporates a system of conservative notification levels for stack discharges. Further explanation of notification levels is given in Hoffmann *et al.* (2001). The ALARA objective is 0.02 mSv/year, which is 2% of the 1 mSv/year limit for annual effective dose to members of the public that is recommended by ARPANSA (ARPANSA 2002a).

Routine discharges of treated, low-level liquid effluent from the LHSTC and NMC are made to the sewer under the terms of trade wastewater agreements negotiated with Sydney Water, and discharges are independently checked for compliance by Sydney Water and ARPANSA. Liquid effluent discharges from the LHSTC are required to comply with (a) drinking water quality levels for radioactivity at the Cronulla STP, and (b) concentration limits for non-radiological components of the effluent. For compliance measurements of activity concentrations at the LHSTC discharge point, an agreed dilution factor of 25 is assumed. This factor was previously determined by tracer studies (Hoffmann *et al.* 1995, 1996), and is checked every year.

Prior to each discharge, the LHSTC effluent is checked for compliance with the acceptance limits for gross (or 'unspecified') alpha and beta activity, and tritium. The unspecified alpha- or beta-emitting radionuclides are considered to be present as the most restrictive isotopes for each decay type, *ie* radium-226 (alpha decay) and strontium-90 (beta decay). Compliance with the requirements of the trade wastewater agreement is demonstrated by determining the concentration quotient for the flow proportional pipeline composite samples which are taken every four discharge days. This quotient is the sum of the concentration of gross alpha, gross beta and tritium radioactivity divided by the permitted concentration for radium-226, strontium-90 and tritium

respectively, and must not exceed one. Similarly, liquid effluent discharges from the NMC are also subject to limits set for specific radionuclides stipulated in the relevant trade wastewater agreement.

Stormwater from the LHSTC flows into small local streams that are classified as Class C surface waters under regulations associated with the *Protection of the Environment Operations Act* 1997 (NSW). The regulations set out relevant limits for gross alpha and beta radioactivity in these waters. The Australian Drinking Water Guidelines (ADWG; NHMRC and NRMMC 2004) are used to provide context for the presence of tritium and some other radionuclides in surface waters and groundwater, although there are no legal or other requirements for ANSTO to meet these levels and the guidelines themselves state that they are not applicable to environmental releases of radionuclides under regulatory control. Following their endorsement in 1996, the ADWG have been subject to an ongoing revision process that ensures the guidelines represent the latest scientific evidence in relation to good quality drinking water. In 1996 the ADWG gave a specific concentration guideline for tritium (7600 Bq/L) but in subsequent revisions a single guideline dose (1 mSv/year) for annual exposure to radioactivity in drinking water has been given. Dose estimation, based on the method given in the ADWG, indicates that a person drinking 2 L/day of water with a tritium concentration of 7600 Bq/L would receive an estimated dose of 0.1 mSv over a year. In referring to the ADWG guidelines for tritium, 7600 Bq/L is assumed to be an appropriate contextual level in this report.

Nutrient levels in groundwaters are compared with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000). Whilst the ANZECC guidelines focus on surface waters, they are recognised as a useful starting point for assessing groundwater quality. The most relevant ANZECC water quality guidelines are those for the protection of aquatic ecosystems, which provide default target values based on data from NSW lowland, east-flowing coastal rivers with 'slightly disturbed' ecosystems. Again, there is no requirement for ANSTO to meet these levels. For water quality parameters where no guidelines are set by ANZECC, results are compared with the ADWG.

4. Assessment of Potential Exposure

4.1 BACKGROUND RADIATION

Background radiation is naturally present in our environment. The average natural background effective dose-rate to the Australian public of ~1.5 mSv/year; (Webb *et al*. 1999) consists of ~0.9 mSv/year from external radiation sources (such as terrestrial and cosmic radiation) and ~0.6 mSv/year from internal radiation sources (such as potassium-40 and radon). Natural background radiation varies from place to place on the earth (*eg* with rock type and altitude) and is affected by lifestyle (*eg* choice of building materials, ventilation of homes, frequency of flying). The radiation dose from natural background averaged worldwide is estimated at ~3.5 mSv/year, but can be greater than 50 mSv/year (ARPANSA 2002b).

In October 2002, ARPANSA conducted a baseline gamma survey of the natural radiation in the suburbs within a 5km radius of the LHSTC (ARPANSA 2002b). The absorbed dose-rates ranged from 30 nGy (nanogray) per hour to 60 nGy per hour, compared with an Australian average value for background radiation dose-rate of about 50 to 60 nGy per hour. That is, the values measured range from close to the Australian average to about half of that value. The results for the Lucas Heights area reflect the predominance of sandstone, which has lower levels of uranium and thorium than most other rock types and produces less background gamma radiation.

4.2 EXPOSURE PATHWAYS AND CRITICAL GROUPS

Nuclear facilities contribute radioactivity that is additional to the background radiation we all experience and, consequently, such facilities are subject to very strict controls. In Australia, the recommended maximum additional public dose is 1 mSv/year (ARPANSA 2002a). ANSTO has a site dose constraint of 0.3 mSv/year (LHSTC) and a much lower ALARA objective of 0.02 mSv/year for dose to the public from airborne emissions from the LHSTC and NMC sites.

The concepts of *exposure pathways* (the possible avenues by which members of the public could be exposed to radioactivity originating from a given source) and *critical groups* (people at greatest potential risk of radiation exposure) are used internationally to derive discharge levels for release of radioactivity into the environment, and form the basis for ARPANSA regulations.

Potential exposure pathways by which radionuclides routinely discharged from ANSTO sites could lead to radiation exposure of members of the public, are:

- airborne emissions causing external radiation doses from dispersing radioactive gases;
- rain-out or deposition of airborne radionuclides entering the food chain, leading to exposure by drinking water or eating food;
- discharge of low levels of radioactivity through the Sydney Water sewage treatment system and into the sea, leading to exposure of workers at the sewage treatment plant, uptake by fish and accidental ingestion of seawater by swimmers; and
- contamination of groundwater or soil used for drinking or food production, leading to exposure by ingestion/inhalation.

Impact assessments for any activity associated with a nuclear facility are estimated as radiation doses to members of the public. A critical group is defined as a reasonably homogeneous group of members of the public typical of individuals who are likely to receive the highest radiation dose via a given exposure pathway from a given source (IAEA 1996).

In 2002, ANSTO identified theoretical critical groups for assessing the potential impact of its airborne and liquid effluent discharges from the LHSTC. Realistically assessed doses for the critical group of people potentially exposed to routine liquid effluent releases were up to 0.0002 mSv/year which is, at most, a quarter of the dose estimated for the critical group potentially affected by routine airborne releases (Hoffmann *et al.* 2003).

5. Sampling of Emissions and Environment

The ANSTO routine monitoring program for the 2004-05 financial year is summarised in **Table B**. The table describes the media sampled, the range of analyses performed, and the location and frequency of sampling. A total of approximately 6,800 samples were taken and some 13,400 analyses performed. Detailed descriptions of sampling and analytical methods are given in Hoffmann *et al. (*2001).

5.1 AIR AND LIQUID EMISSIONS

Airborne radionuclide emissions were monitored at 15 stacks at the LHSTC and one at the NMC. Airborne emissions were passed through HEPA-filters to remove particles and charcoal filters to remove vapour, prior to discharge through stacks. The stacks were sampled continuously by drawing off a proportion of the airflow and accumulating weekly data for specific radionuclides from either real-time measurement or after physico-chemical trapping over a week. Tritiated water vapour was trapped from air bubbled through a series of water-filled bottles. Radioiodine was sampled using charcoal-filled 'Maypack' cartridges, also fitted with particle filters. Noble gases were measured in-situ using a gamma detector and recording daily accumulations of counts. Airflow through each stack was measured on a quarterly basis using a hot-wire anemometer. Combined, these measurements enable reporting of total radionuclide releases from each stack.

Proportional samples of all LHSTC liquid effluent discharges were collected and analysed for gross alpha and gross beta radioactivity, tritium, pH, biological oxygen demand, grease, suspended solids, total dissolved solids, ammonia and zinc. A volume-weighted composite sample was also produced from all pipeline samples each month and analysed for polonium-210 and gamma radioactivity. Liquid effluent from the NMC holding tanks was tested for pH and relevant gamma-emitters prior to discharge to the sewer.

As noted in section 3, the liquid effluent dilution between the ANSTO discharge tanks and the final effluent stream at the Cronulla STP, is re-assessed for at least two ANSTO effluent releases each year by direct measurement of tritium levels in the plant. Daily composite effluent samples were analysed for tritium to determine the dilution and overall tritium concentrations in the final tertiary treated effluent stream of the Cronulla STP in March-April and then again in June 2005. Samples were collected by Sydney Water using an automatic water sampler at a location known as the UV Inlet. The daily samples were a composite of 24 samples collected hourly commencing at midnight each day.

Table B. SUMMARY OF ENVIRONMENTAL MONITORING AT ANSTO SITES, July 2004 to June 2005

SAMPLE	TYPES	ANALYSES	LOCATIONS	SAMPLING FREQUENCY	ESTIMATED SAMPLES	ESTIMATED ANALYSES
				per year	per year	per year
SOURCE MONITORING						
Airborne	Gases & particles (Maypacks)	GA, GB, Gamma	15 Stacks (LHSTC); 1 Stack (NMC)	Daily (work; NMC) and Weekly(LHSTC)	2050	5170
	Air flow	Flow	15 Stacks (LHSTC)	Weekly(Maypacks) and Quarterly(Stack)	840	840
	Gases	Gamma	3 Stacks (LHSTC); 1 Stack (NMC)	Daily(work)	980	980
	Gas (water vapour)	H-3	4 Stacks (LHSTC)	Weekly	208	208
Liquid	Wastewater	H-3, GA, GB	1-2 Holding Tanks (LHSTC Waste Optns)	Daily(work)	368	1104
	Wastewater	H-3, GA, GB, Chem	1 Sample Tank (LHSTC Waste Optns)	Every 3-4 Days	104	416
	Wastewater	H-3, GA, GB, Gamma	1 Sample Tank (LHSTC Waste Optns)	Monthly(from pipeline composites)	12	48
ENVIRONMENTAL MONITORING						
Waters	Rainfall	volume	1 Site (LHSTC)	15 minute intervals	41	41
	Stormwater	H-3	3 Bunds (A, B, C)	Daily to give Monthly composite	1095	1131
	Stormwater	H-3, GA, GB, Gamma	1 Bund (C); 1 Site (MDP+60m)	Weekly and Monthly composite (from weekly samples)	104	280
	Creek or river or estuary	H-3	4 Sites (Barden's Ck, 3 x Woronora R)	Weekly(B Ck) and Monthly(W R)	88	88
	Creek or river or estuary	GA, GB, H-3	6 Sites (B Ck, MDP Ck, Strassman Ck, B&Mill Cks jnctn, B35)	Monthly(B, M & S Cks, B35) and Yearly(B&M Cks jnctn)	50	150
	Creek or river or estuary	Gamma	2 Sites (B&Mill Cks jnctn)	Yearly	2	2
	Seawater	H-3	1 Site (Potter Pt; ~20 samples)	6 Monthly (*ie* twice per year)	12	12
	Wastewater	H-3	3 Sewage Treatment Plant (Cronulla)	Yearly	263	263
	Groundwater	H-3, GA, GB, Gamma, WQ	19 Bores (LFBG)	6 Monthly	38	342
	Groundwater	H-3, GA, GB, Gamma, Chem	27 Bores (LHSTC & Buffer Zone)	Yearly	135	819
	Groundwater	WQ	27 Bores (LHSTC & Buffer Zone)	Quarterly	108	540
Air	Wind	speed & direction	1 Site (LHSTC at 10 and 49m)	15 minute intervals		
	Air	temperature, humidity	1 Site (LHSTC at 2, 10 and 49m)	15 minute intervals		
	Gases (Maypacks)	Gamma	4 Stations (LHSTC)	Weekly	208	832
	Particles	Pu, Be	1 Site (LFBG)	Quarterly Be and Pu	4	8
Soil/Sediment	Sediment	GA, GB, Gamma	3 Bunds (A, B, C); 2 Cks (Bardens, Mill Ck)	Yearly	5	15
Biota	Algae & fish & barnacles	Gamma	2 Sites (Potter Pt, RNP)	6 Monthly	12	12
Dosimetry		Gamma dose-rate survey	2 Sites (Effluent Pipeline, LFBG)	6 Monthly (E-pipe) and Yearly (LFBG)	3	3
		TLD	21 Sites (LHSTC, LFBG, Suburbs, Cronulla STP)	Quarterly	88	88
				APPROXIMATE TOTALS	6818	13392

Notes:
- Working days assumed to be 245, excluding weekends and public holidays.
- H-3 = tritium analysis (after distillation).
- GA = Gross Alpha counting; GB = Gross Beta counting.
- Gamma = Gamma spectrometry that varies in number of nuclides targetted (can include specific noble gases like Ar-41 or individual radionuclides like I-131).
- Chem = non-radiological analysis that varies in number of analytes (can include major ions, selected metals, organics, plant nutrients, pH, conductivity, suspended solids).
- Water Quality (WQ) = field WQ parameters (e.g. water level, pH, conductivity).
- Flow through Maypacks is measured using a floating ball gauge, and in stacks using a hot-wire anemometer.

5.2 ENVIRONMENT

Environmental sampling is carried out primarily to determine where and in what quantities radioactive emissions from the LHSTC are found in the local environment. ANSTO's environmental sampling strategy is based on our knowledge of potential radionuclide emission sources and the environmental pathways that may result in a potential dose to the public. Samples of various media, including surface waters and groundwater, air and sediment, plus some biota, are collected at locations in and around the LHSTC. These sample sites are shown in **Figures 1** to **4**. Off-site sampling locations include local creeks (*eg* Mill and Bardens Creeks), the Woronora River, the LFBG, Cronulla STP, Potter Point and The Royal National Park. Testing of environmental samples for radioactivity includes tritium analysis of water samples, gross alpha and gross beta analysis of water and sediment samples, and gamma spectrometric measurements of various media.

Water sampling formed the greater part of the environmental sampling program in the period from July 2004 to June 2005. The program included daily collection and weekly analysis of LHSTC rainwater for tritium activity. The stormwater bunds at the LHSTC (A, B and C in **Figure 2**) were sampled on a daily basis, prior to the bunds being emptied. These daily samples were combined to give representative monthly samples of stormwater. Weekly samples were taken at Bund C that drains ANSTO's waste operations area, and at a natural pool some 60 metres further downstream on the MDP creek (**Figure 2**). Weekly samples were also collected at the Bardens Creek weir, downstream of the stormwater Bund A. For some analyses, weekly samples were combined into monthly composites. Monthly water samples were taken from the State Pollution Control Commission (SPCC) sampling points (named for having been selected by the then SPCC in 1975; see **Figure 2**) at Bardens Creek weir, Strassman Creek and MDP Creek weir. These sites lie on the drainage lines leaving the LHSTC but are within ANSTO's 1.6 km buffer zone. The local area beyond the buffer zone was also sampled, with monthly collections of estuarine and fresh water from the Woronora River both upstream and downstream of ANSTO. Water and sediment samples were collected annually near the junction of Mill and Bardens Creeks, which drain the LFBG and the Lucas Heights urban landfill.

Groundwater monitoring at the LHSTC was first reported in Hoffmann *et al.* (2003). In 2004-05, the LHSTC groundwater monitoring network had 27 Type 1 piezometers (characterised as either shallow or deep), however not all of them were available for sampling due to construction activities on the OPAL site. This network has been designed to monitor specific facilities and to sample representative groundwater flows within and adjacent to the LHSTC (**Figure 3**). Groundwater from the nested (shallow and deep) piezometer pairs was purged and sampled approximately every three months in 2004-05 for field parameter testing. Laboratory-based radiological and other water quality analyses were performed annually. Results of inorganic nutrient and hydrocarbon analyses are also included for 2004-05, and a compilation of all the groundwater data from previous years will be published in the report: Consolidated Volume of Reports on Groundwater Investigations at the LHSTC (Parsons Brinkerhoff, in production). Groundwater at the LFBG was sampled every six months for field parameters and radiological measurements.

Levels of gamma radiation over the burial area at the LFBG are surveyed annually to monitor surface soil dose-rates. The Main Discharge Pipeline (**Figure 2**) is also surveyed annually for dose-rates along the accessible sections in order to detect any leaks.

Airborne particles were collected at the LFBG using a high-volume sampler approximately every two weeks for the species of interest: plutonium-239/240 and beryllium. Ambient air was sampled continuously and analysed weekly for iodine-131, using Maypacks with particle filters at four locations on the LHSTC boundary fence. In 2004-05, the Maypack samples were counted and reported individually rather than collectively.

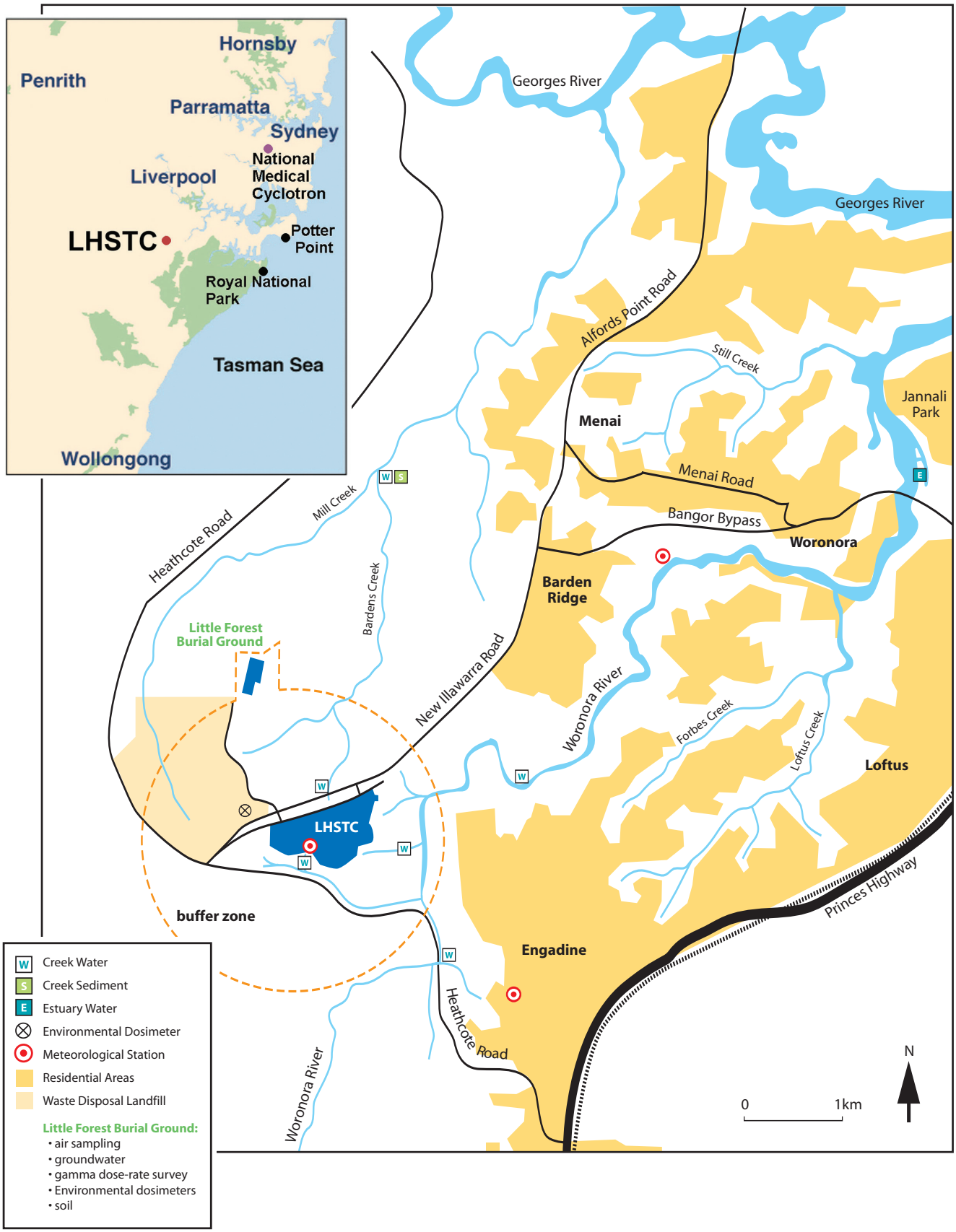

Figure 1. Location of ANSTO sites (the LHSTC and NMC) and off-site monitoring points.

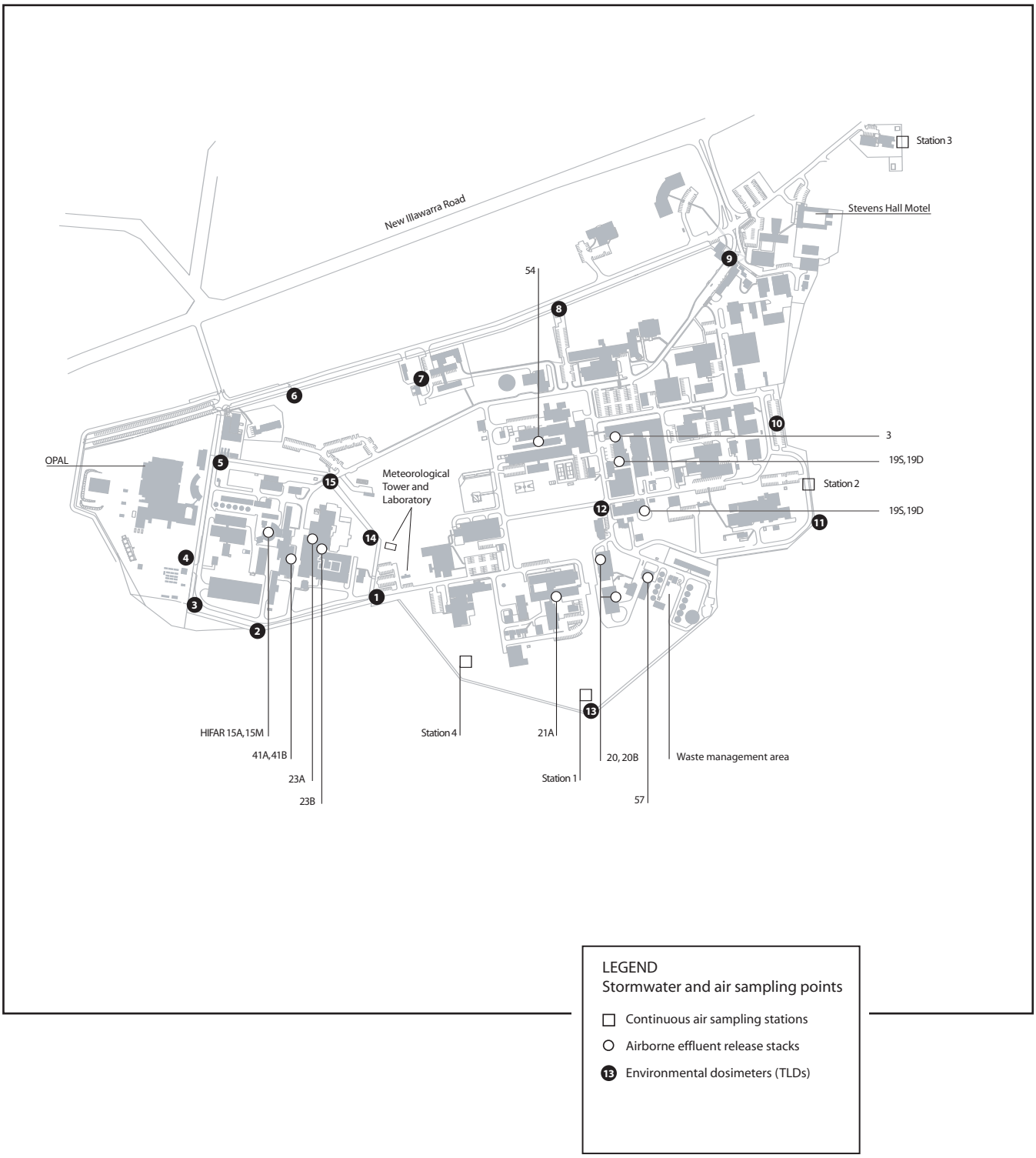

Figure 2. Location of airborne effluent release stacks and monitoring points for air and external radiation at the LHSTC.

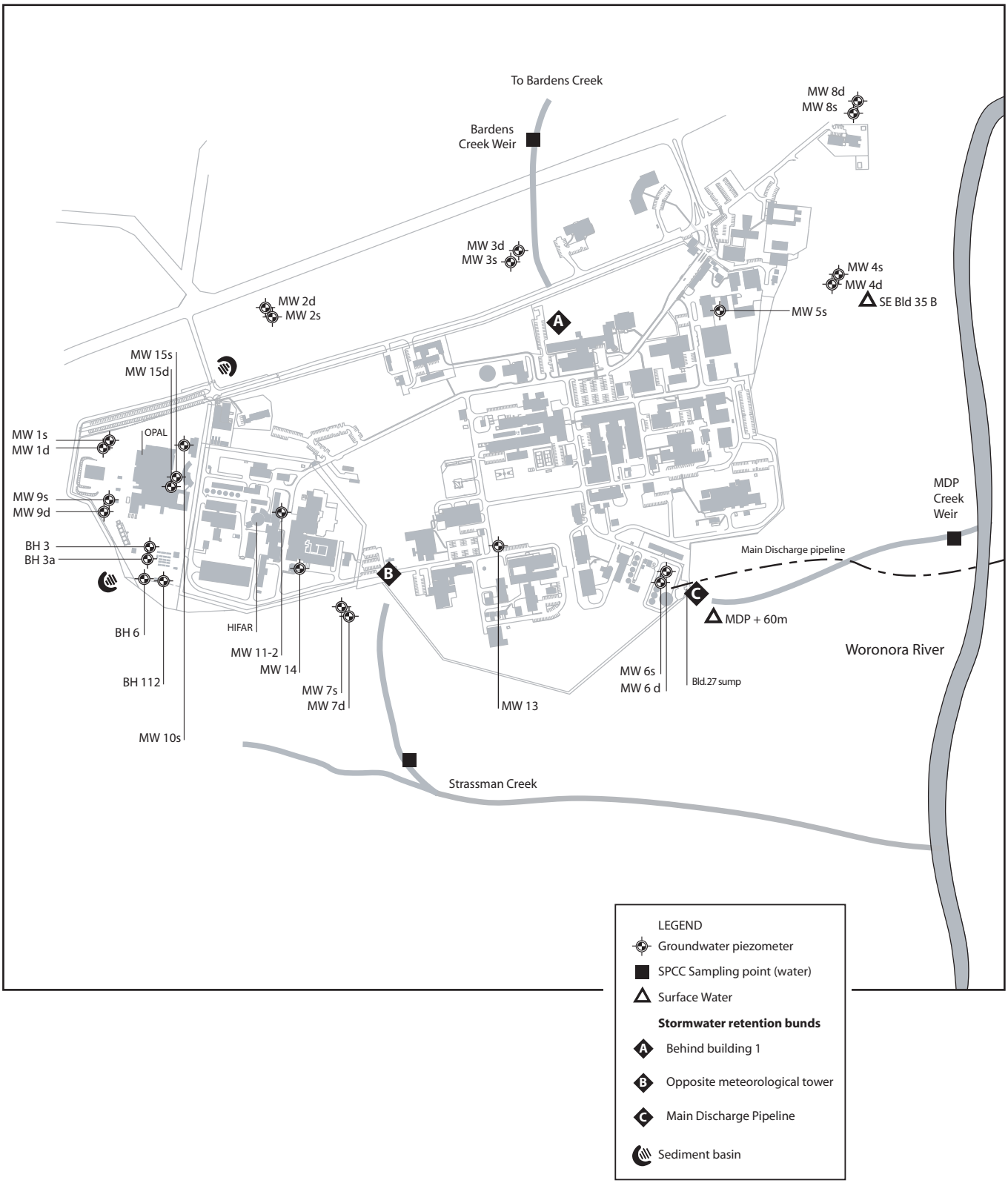

Figure 3. Location of groundwater and surface water monitoring points at the LHSTC.

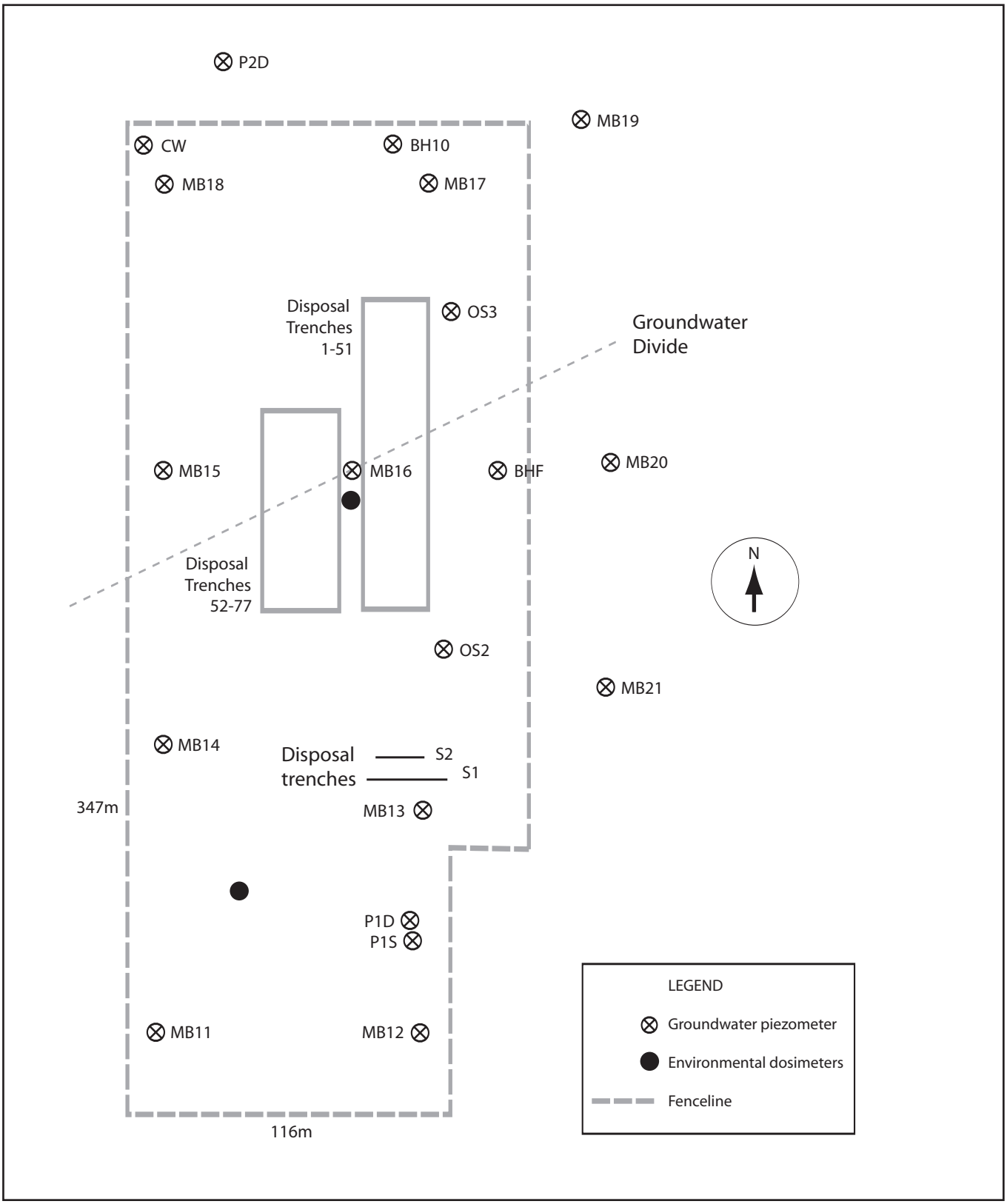

Figure 4. Little Forest Burial Ground – schematic showing the disposal trenches, groundwater flow paths and piezometers currently monitored.

5.3 QUALITY ASSURANCE

The ANSTO program of environmental and effluent monitoring operates within a quality system that complies with the Australian and New Zealand standard AS/NZS ISO 9001:2000 series for Quality Management Systems. This includes a commitment to continual improvement, put into practice through internal and external audits, client surveys and other management tools. ANSTO's environmental management system includes the external verification of analytical results from the environmental and effluent monitoring program, as agreed with ARPANSA.

5.4 METEOROLOGY

In common with similar organisations operating nuclear facilities, ANSTO undertakes a program of meteorological measurements. The prime reason for such a program is to allow estimates to be made of the downwind concentration of any airborne pollutants, particularly radionuclides, released from the LHSTC through routine operations or under accident conditions.

The on-site meteorological tower and associated laboratory are shown in **Figure 2**. Two off-site meteorological stations are also used to measure the influence of the local terrain on wind flow, dispersion patterns and temperatures. These stations (**Figure 1**) are located at the Boys' Town School (Engadine) and at the 'Shackels Estate' in the Woronora River valley.

The meteorology program includes measurements of wind speed, direction and variability, as well as precipitation, evaporation, temperature, pressure and humidity. These data are collected and analysed continuously, and are displayed on ANSTO's web site in addition to being reported to the Australian Bureau of Meteorology. Additionally, the data are used to aid in interpreting environmental results and groundwater hydrology for the LFBG and LHSTC sites. The long-term climatology data for the LHSTC from 1991 to 2003 was recently published (Clark 2003).

6. Environmental Monitoring (July 2004-June 2005)

Monitoring data in this report cover the financial year from July 2004 to June 2005 and are presented in **Tables 2** to **40**. Measurement uncertainties given in these tables are at the two-sigma level (*ie* twice the standard deviation), unless otherwise noted. For some environmental samples, analytical results were not significantly different from background levels and are reported as being below the Minimum Detectable Activity (MDA), calculated with 95% confidence.

The MDA can differ between sample types and radionuclides. Indicative median MDAs for various radionuclides and environmental media are given in **Table 1** (see Data Tables section below). In general, data are summarised as median ± interquartile range (the 75th minus the 25th percentile of the data, a similar concept to a standard deviation relative to the mean). For statistical calculations, data below the MDA (*ie* 'less than' data) were replaced with a value of half the MDA unless more than half the data were 'less thans', in which case no statistics are reported.

6.1 AIRBORNE EMISSIONS

Table 2 lists the airborne activity discharges for the 2004-05 financial year from the single stack at the NMC and 15 stacks at the LHSTC (**Figure 2**). The table shows the total amount of radioactivity discharged and the discharges expressed as a percentage of the relevant annual notification levels. The 'all other nuclides' column includes all radionuclides for which there is no specific notification level. Notification levels act as conservative trend indicators that trigger follow-up investigation and are more fully explained in Hoffmann *et al*. (2001).

Emissions of airborne iodine-123 from the NMC reached only 19.5% of the annual notification level, and all other nuclides reached less than 1% of annual notification levels, continuing a downward trend over the past four financial years.

All gross alpha and gross beta radioactivity, associated with airborne particles sampled from LHSTC stacks, was less than 5% of annual notification levels. The airborne discharge of argon-41 from stacks 15A and 15M (HIFAR) remained below notification levels in the 2004-05 financial year, reaching 70.9% and 82.2% of their respective annual notification levels. The airborne discharge of tritium from 15A, which accounts for most of the airborne tritium emission at the LHSTC, reached 20.5% of the annual notification level, reflecting the consistently low emissions of recent years. Discharges of iodine-131 from the ARI stacks 23A and 54 were within normal operational expectations, reaching 28.4% and 79.3% of their annual notification levels, respectively. Releases

of noble gases from stack 54 were at similar levels to the previous year, with emissions of xenon-133 reaching 122.4% of the annual notification level. However, the combined stack 54 emissions contributed only 13% of the very small off-site dose estimated for airborne discharges in 2004-05 (see section 8.1). The underlying cause of the emissions from stack 54 was investigated and found to be related to the irradiation of uranium targets for the production of molybdenum-99.

6.2 LIQUID EFFLUENT

6.2.1 Lucas Heights Science and Technology Centre

The LHSTC liquid effluent is routinely screened for tritium, gross alpha and gross beta activity as well as non-radiological water-quality parameters. Monthly, volume-weighted composite samples of all discharges are also analysed for polonium-210 (a volatile alpha-emitter) and gamma-emitters, including caesium-137, caesium-134, cerium-144, chromium-51, cobalt-60, iodine-131, lead-210, radium-226 and radium-228.

The total volume of treated liquid effluent discharged in the year 2004-05 was 72,953 m^3. **Table 3** shows the average activities of gross alpha, gross beta and tritium radioactivity in liquid effluent at discharge, calculated from all the samples collected each month. The alpha values are all less than the minimum detectable activity, the median of which was 47 Bq/m^3 hence the combined quotients in the last column are also shown as less-than values. The combined monthly activity quotients for alpha, beta and tritium activity ranged from < 0.04 to < 0.23, with a median value of < 0.09, *ie* less than 9% of the allowed quotient of one. **Figure 5** charts the monthly quotients for alpha, beta and tritium activities in liquid effluent discharges for the period July 2004 to June 2005.

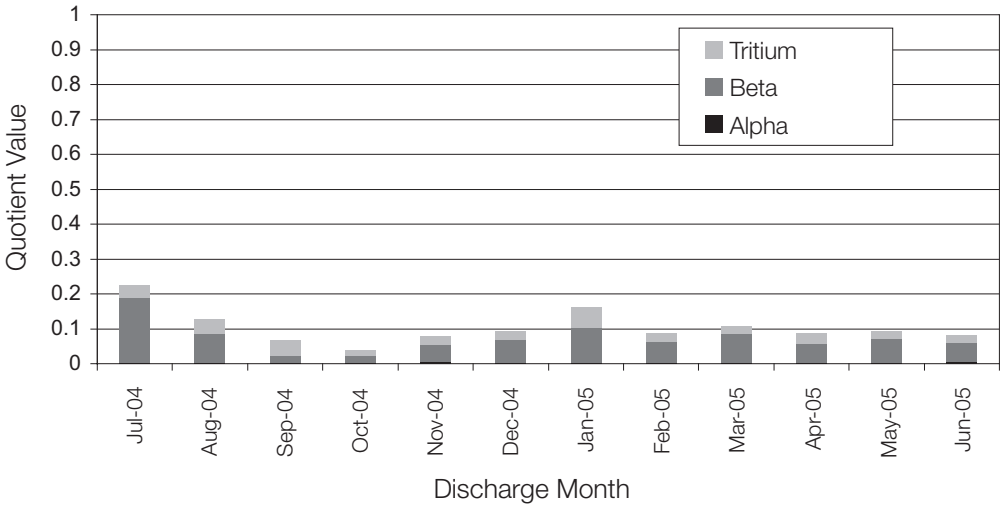

Figure 5. Monthly quotients for alpha, beta and tritium radioactivity in liquid effluent, LHSTC, July 2004 to June 2005.

The activities of gamma-emitting radionuclides in the monthly pipeline composite samples are given in **Table 4**. Of the radionuclides listed, only caesium-137 was detected consistently, ranging from 0.19 Bq/L to 10.10 Bq/L, with a median of 2.50 ± 1.99 Bq/L. Chromium-51, cobalt-60 and cerium-144 were detected in only two of the monthly composite samples, whilst low levels of iodine-131 were present in four samples. Alpha-spectrometry is performed on the monthly composites to check for the alpha-emitter polonium-210. Results were below the minimum detectable activity of 0.01Bq/L from July 2004 through to March 2005, whilst results for April to June 2005 were low, at 0.024, 0.038 and 0.044 Bq/L respectively.

The results for non-radioactive parameters of the liquid effluent (pH, ammonia, biological oxygen demand, grease, zinc, suspended solids and total dissolved solids) are shown in **Table 5**, along with the relevant standards for acceptance to the Sydney Water sewer. The range of values is reported, along with the mean and median: 95% of the samples analysed must be less than or equal to the relevant standards for acceptance. The medians are well below the acceptance standards and the data ranges show that 100% of samples were acceptable. The median pH falls within the acceptable range, although at least one sample had a pH less than 7, which is consistent with the slight acidity of water supplied to the site.

Levels of radioactivity and non-radioactive components of liquid effluent discharges to the sewer

from July 2004 to June 2005 met the standards for acceptance specified in the trade wastewater agreement with Sydney Water.

In June 2005, backflow through a sewer manhole resulted in up to 75 kL of liquid effluent entering the stormwater system and flowing into the buffer zone via MDP Creek. The water released had been cleared for discharge (*ie* complied with the ANSTO trade wastewater agreement with Sydney Water) and, in this case, also met radioactive and the majority of non-radioactive regulatory limits for Class C surface waters, specified under regulations associated with the *Protection of the Environment Operations Act* 1997 (NSW). Water collected from MDP Creek on the morning following the upstream liquid effluent release (**Table 19**) was well below the gross alpha/beta limits for Class C waters, and also less than the ADWG screening level of 0.5 Bq/L. Notwithstanding the fact that the release had no radiological impact, both physical and management controls have been implemented in response to this unplanned release to ensure that there is no recurrence.

6.2.2 National Medical Cyclotron

The average concentrations of radionuclides in treated liquid effluent to sewer from the NMC are shown in **Table 6**, along with the monthly (total) volume discharged. Around six effluent discharges were made each month, with an average volume of 0.8 cubic metres and an annual total of 54.4 cubic metres. The discharges contained variable amounts of radioactivity depending upon radiopharmaceutical production schedules, however the maximum average activity discharged per month of thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65 and iodine-123 were only 13%, 15%, 1%, 2%, 1% and 2% of their respective limits. Liquid effluent discharges from the NMC were well within the requirements of the trade wastewater agreement in 2004-05.

6.2.3 Effluent Dilution – LHSTC to the Cronulla STP

Tertiary treatment, introduced in July 2001, has significantly increased the residence time and recirculation of effluent within the Cronulla STP, resulting in an increase in the final effluent stream dilution and a reduction in the peak tritium concentration and variability in the tertiary-treated effluent. A seven-day study of effluent dilution at Cronulla STP in 2003-04 (Hoffmann *et al.* 2004) found that the transit time of effluent from ANSTO to Cronulla STP was fairly constant at 5-6 hours. Under average flow conditions the detention time in the plant is approximately 22 hours, with 89% of this time in the secondary and tertiary stages of the plant.

Table 7 shows the results of the two studies conducted in 2004-05 to check that the dilution of ANSTO's liquid effluent meets the agreed criteria set in the current trade wastewater agreement with Sydney Water. The maximum tritium activity observed at the UV Inlet during the study was 60.4 Bq/L. The minimum in-line dilution ratio at the UV Inlet for the study was 53:1 with average dilutions in the order of 200-300:1. These studies demonstrated compliance with the agreed dilution factor of 25.

The 2005 effluent studies have shown that, over more than one month of routine releases, the levels of tritium observed within the Cronulla STP were significantly less than those stipulated in the Sydney Water trade wastewater agreement. This confirms that ANSTO is in full compliance with its obligations under the agreement. During the study, the mean tritium value in the final effluent stream was 16.4 ± 0.6 Bq/L. This value is dependent on the recent history of ANSTO releases and the dynamics of the water flow through the plant, and is very low compared with the ADWG guideline of 7600 Bq/L.

6.3 AIR

6.3.1 Ambient Iodine-131 in Air

Ambient air was sampled continuously and analysed weekly for iodine-131, using Maypacks and particle filters at four locations on the LHSTC boundary fence. In 2004-05, the analysis method was changed to allow each Maypack to be counted and reported separately (**Table 8**), rather than collectively. As a result, the analysis sensitivity was improved, with the minimum detectable activity decreasing by 40% to 0.0011 Bq/m^3. Iodine-131 activities continue to be corrected for decay from the first day of the sampling week, which means that data are over-estimates, especially for iodine emissions that occur late in a given week.

Low concentrations of iodine-131 were detected in 28% of all weekly air samples, with Station 2 recording iodine-131 most frequently, almost 50% of the time. The remaining 72% of weekly results were below the minimum detectable level of 0.0011 Bq/m^3. As expected, the detection pattern is seasonal, reflecting the position of the monitoring points relative to the main iodine-emitting stacks (23A and 54) as well as the prevailing winds and weather conditions.

6.3.2 Little Forest Burial Ground – Airborne particulates

Quarterly samples of airborne particles were collected at the LFBG on windy days (to maximise particulate collection) using a mobile high-volume air sampler. The total volume of air sampled during the year was 7196 m^3.

Equal portions of the exposed filters were analysed for stable beryllium via inductively coupled plasma mass spectrometry and plutonium-239/240 activity by alpha spectrometry, and these results are given in **Table 9** together with the equivalent volume sampled. The MDA or mass measured on the filter portion is divided by the equivalent sampling volume to obtain the concentration in air. Beryllium and plutonium-239/240 were below the minimum detectable levels of 0.04 µg and 0.001 Bq, respectively. The exposure standard for atmospheric contaminants such as beryllium in air is 2 $\mu g/m^3$ (Worksafe Australia: NOHSC 1995) applicable to workers exposed 8 hours per day, 50 weeks per year.

6.3.3 External Gamma Radiation

Thermoluminescent dosimeters (TLDs) were used to measure external gamma radiation (including the contribution from natural background radioactivity) at various locations around the LHSTC (**Figure 2**), at three private residences in nearby suburbs, and at the Cronulla STP. In 2004-05 three new locations were added to the monitoring network: two at the LFBG and one at the Lucas Heights landfill depot (**Figure 1**). The data are given in **Table 10**.

The TLDs at sites 2 and 3 on the southern sector of the LHSTC perimeter fence (see **Figure 2**) are affected by nearby stored radioactive material. This part of the site boundary is not readily accessed by the general public. The effective dose-rates from external gamma radiation for other locations at LHSTC and off-site at the LFBG and landfill depot were in the range 0.83 to 1.41 mSv/year for 2004-05.

Measurements at the three local residences, which can be taken as indicative of local background for the LHSTC, showed external gamma dose-rates ranging from 1.05 to 1.31 mSv/year for 2004-05, consistent with the background levels reported for Australian capital cities by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000). Midway through 2004-05, dosimeter number 18 was relocated (within the same house) and placed adjacent to a brick wall. The approximately 40% increase in the accumulated dose, compared with the previous year, resulted from the additional natural radioactivity known to be present in brick or concrete (Kathren 1984). The ranges for TLDs at local residences significantly overlap the ranges reported for the LHSTC and LFBG, showing that ambient external radiation levels at the LHSTC and LFBG are generally within the range of local background radiation.

As in previous years, measurements of the external gamma dose-rates at the Cronulla STP were lower than at the LHSTC and the three local residences. This is attributed to the lower terrestrial radioactivity contribution as a consequence of the location of the TLD badge on a sewage holding tank approximately 2 m above ground level and the shielding effects of the sewage.

TLDs were also deployed outdoors at the NMC, and results for 2004-05 are given in **Table 11**. The median external dose-rates were 1.82 ± 0.09 mSv/year. Whilst these values are slightly higher than those at the LHSTC, these TLDs are mounted on walls and are therefore exposed to the greater natural radioactivity of the bricks. The LHSTC badges on the other hand, are predominantly situated in the open, away from buildings. The dose-rates at the NMC, which include background radiation, are close to the average Australian natural background level.

6.3.4 Aerosol Particles

ANSTO has been measuring and characterising fine aerosol particles at Lucas Heights for the international Aerosol Sampling Program (ASP) for well over 10 years. The ASP is a study to determine the elemental composition of fine suspended particulates.

Fine aerosol particles with aerodynamic diameters less than 2.5 µm (referred to as PM 2.5) mainly originate from combustion sources such as motor vehicle exhausts, fossil fuel burning and high temperature industrial processes. ANSTO is not a significant source of such particulate emissions. Natural sources include bushfires, airborne soil particles and sea spray. **Figure 6** shows the average monthly mass of PM 2.5 particles collected at the LHSTC in the 2004 calendar year.

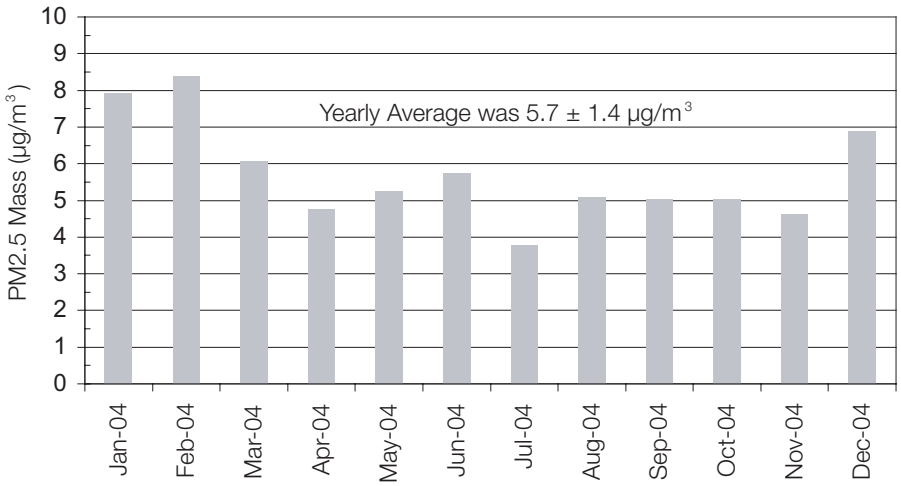

Figure 6. Average monthly mass of fine aerosol particles (less than 2.5 µm in diameter) collected over 24-hour periods at the LHSTC, January to December 2004.

Although an Australian standard has not been set, the measured levels of fine particles in the calendar year 2004 were generally well within the requirements of the USEPA air quality standard, which specifies an annual average of 15 µg/m^3 (USEPA 2002). A more detailed analysis of the particulate composition demonstrated that most of the aerosol particles measured at the LHSTC did not originate from ANSTO activities but are transported in from surrounding areas across the Sydney Basin and beyond. The summary data can be found on the ANSTO web-site (ANSTO 2005).

6.4 SURFACE WATERS

Surface waters include stormwater runoff as well as discharges of near-surface groundwater, with the proportion depending on the weather in the preceding days. Concrete bunds (of about 6 m^3 capacity) on the three main stormwater outlets at the LHSTC (A, B and C in **Figure 3**) temporarily retain surface waters before their release off-site. These bunds are inspected, and emptied if necessary, each week-day morning to facilitate on-site containment and treatment of any small accidental releases of contaminated liquid. The bunds are also used as environmental monitoring points. Sedimentation traps, designed to capture water runoff and sediment from the OPAL construction site, are situated in the North and South West (**Figure 3**). Waters flowing out of the sediment traps are sampled quarterly to determine baseline values prior to the commissioning of OPAL, ANSTO's replacement reactor.

6.4.1 Tritium in Surface Waters

Tritiated water vapour released to air from HIFAR operations readily exchanges with rainwater and other surface waters and is present in stormwater and groundwater at the LHSTC. Tritium was detected in monthly composite water samples (daily samples combined) from Bunds A, B and C (**Table 12**) at levels ranging from 20 to 430 Bq/L, with a median activity of 110 ± 120 Bq/L.

Quarterly samples taken from North and South Western OPAL sediment traps indicate low levels of tritium, ranging from less than the MDA to 40 Bq/L with a median activity of 20 ± 20 Bq/L (**Table 13**).

Weekly samples from Bund C, situated at the top of MDP Creek, were analysed for tritium and the results are shown in **Table 14**. Tritium activity ranged from 10 to 240 Bq/L, with a median activity of 80 ± 70 Bq/L. Weekly samples were also collected from a natural pool on the same drainage line but some sixty metres downstream of Bund C – this was the stormwater sampling point prior to the construction of the bunds in 1994. The tritium levels in weekly samples from this site, MDP+60m, (**Table 15**) ranged from 20 to 170 Bq/L, with a median of 70 ± 40 Bq/L. Similarly, weekly water samples were collected from the Bardens Creek weir, downstream of Bund A on the north side of New Illawarra Rd (**Figure 3**). The results are given in **Table 16**. The tritium activity in weekly samples from Bardens Creek weir ranged from 20 to 1190 Bq/L, with a median activity of 80 ± 60 Bq/L.

The range of tritium activities recorded in these water samples from July 2004 to June 2005 was typical of recent years at the LHSTC. The maximum tritium activity in any of the samples from stormwater bunds and nearby sampling points was less than 16% of the ADWG level of 7600 Bq/L (NHMRC and NRMMC 2004), given here for context only as this water is not collected and supplied

as potable water. The median tritium activities for surface waters at LHSTC are much lower, in the range from 20 to 110 Bq/L, *ie* they are typically less than 2% of the ADWG levels.

6.4.2 Gross Alpha and Beta Radioactivity in Surface Waters

Stormwater from the LHSTC flows into several small streams (*eg* Bardens, Strassman, MDP Creeks, shown on **Figures 1** and **3**), that are classified as Class C waters under the regulations associated with the *Protection of the Environment Operations Act* 1997 (NSW). As such, there are regulatory limits for gross (total) alpha and gross beta radioactivity of these waters (1.1 and 11.1 Bq/L, respectively), which apply at the SPCC compliance monitoring points.

Gross alpha and gross beta data for monthly composite samples (combined weekly samples) at Bund C from July 2004 to June 2005 are given in **Table 17**. The alpha activities ranged from less than the minimum detectable activity to 0.05 Bq/L, with a median of 0.01 ± 0.01 Bq/L. For gross beta, the range of activities was from 0.09 to 0.68 Bq/L and the median was 0.22 ± 0.26 Bq/L. Gross alpha and beta data for monthly composite samples (combined weekly samples) downstream of the bund at MDP+60m are given in **Table 18**. The gross alpha activities ranged from 0.01 to 0.04 Bq/L, with a median of 0.02 ± 0.01 Bq/L. For gross beta, the range of activities was from 0.12 to 0.40 Bq/L and the median 0.20 ± 0.10 Bq/L. All of the measured alpha and beta levels comply with the regulatory limits for Class C surface waters.

The results of gross alpha and gross beta analyses of monthly samples from Bardens Creek weir, Strassman Creek, South East of Building 35B and MDP Creek weir are given in **Table 19**. Combining the four sets of data, gross alpha levels ranged from less than the minimum detectable activity to 0.04 Bq/L, with a median value of 0.01 ± 0.02 Bq/L. Gross beta radioactivity ranged from less than the minimum detectable activity to 0.38 Bq/L, with a median of 0.03 ± 0.06 Bq/L. Water samples collected near the junction of Mill and Bardens Creeks, which drain the LFBG, showed only natural background levels of gross alpha, gross beta, gamma and tritium activity (**Table 20**).

Quarterly gross alpha and gross beta measurements taken in water collected from the OPAL sediment traps are given in **Table 13**. Gross alpha activities ranged from 0.04 to 0.23 Bq/L, with a median value of 0.13 ± 0.08 Bq/L. Gross beta radioactivity ranged from 0.14 to 0.45 Bq/L, with a median value of 0.27 ± 0.18 Bq/L.

All results for surface waters from July 2004 to June 2005 were below the limits for gross alpha and gross beta activity in the relevant NSW regulations. In fact, 100% of alpha and 98.5% of beta results were below the ADWG screening level of 0.5 Bq/L.

6.4.3 Gamma-emitting Radionuclides in Surface Waters

Gamma Spectrometry was performed on surface water samples from five sites, four of which are within the buffer zone - MDP Bund C; MDP+60m and the OPAL sediment traps. Yearly water samples collected upstream of the junction of Mill and Bardens creeks were also measured for gamma-emitting radioactivity. Gamma spectrometry of monthly composite samples taken from Bund C (**Table 17**) for July 2004 to 2005 show typical low levels of caesium-137 activity, ranging from less than minimum detectable activity to 0.073 Bq/L, with a median of 0.015 ± 0.017 Bq/L. Other gamma-emitters detected were potassium-40 and beryllium-7, both of natural origin. Beryllium-7 is a cosmic spallation product that undergoes dry and/or wet deposition processes. Consequently, it is often found in pooled surface waters. Similarly, isotopes from the LHSTC airborne discharges may occasionally be found, as was the case for the iodine-131 which was detected in the September 2004 composite sample.

In monthly composite samples from the natural pool located approximately sixty metres downstream of Bund C (MDP+60m, **Table 18**) caesium-137 was detected with a median activity of 0.016 ± 0.007 Bq/L. Similarly low levels of caesium-137 have been reported in previous years. Low levels of naturally occurring potassium-40 and beryllium-7 were also occasionally detected.

Gamma spectrometry results for quarterly water samples from the OPAL sediment traps are shown in **Table 13**. A single sample had measurable low levels of caesium-137 activity, which is consistent with levels found in unfiltered waters in the environment. Beryllium-7 levels were slightly higher than those detected in other LHSTC surface water samples. However, this is attributable to the large pools of water that remained in the traps for extended periods, enhancing the deposition and accumulation of beryllium-7. Low levels of potassium-40 were also occasionally detected.

Water samples collected near the junction of Mill and Bardens creeks in November 2005 contained only natural potassium-40 gamma activity (**Table 20**).

6.5 ESTUARINE AND SEA WATERS

Monthly samples of brackish/estuarine waters were collected from the Woronora River and analysed for tritium activity (**Table 21**). Two additional sampling sites in the freshwater reaches of the Woronora River were added to the monitoring programme in 2004-05 and are shown on **Figure 1**. Both are located closer to the LHSTC: the first is a control site below the Heathcote Road bridge but upstream of the LHSTC and includes flows from Heathcote Creek. The second is at the causeway downstream of the LHSTC. These sampling locations were chosen to monitor tritium levels in the Woronora River both upstream and downstream of ANSTO's stormwater runoff, and to maximise the possibility of detecting any such tritium activity. However, continuing a 20-year trend, no tritium was detected at station E5.9 in the Woronora Estuary. Nor was any tritium found in the newly-established Woronora River sampling points: all results were less than the minimum detectable activity.

Sea water samples were collected in the vicinity of the Potter Point ocean outfall on two occasions, March 15 and June 8, 2005 (**Table 7)**. On each occasion samples were collected hourly from three locations at 5, 90 and 270 metres distant from the Potter Point outfall, at a depth of 1 metre below the surface. A total of 45 samples were collected and analysed for tritium. Of these, 23 samples were below the minimum detectable activity. Both sampling occasions were timed to coincide with the Cronulla STP effluent study. Tritium levels in the seawater were near background levels and the final effluent stream tritium levels were also very low, making it difficult to estimate the extent of any further dilution occurring between the Cronulla STP and the near shore area at Potter Point. Nevertheless, a minimum offshore dilution ratio of 2:1 can be calculated for 8 June 2005 using data from the sampling point nearest the outfall.

6.6 GROUNDWATER LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE

The LHSTC lies on the Woronora Plateau and the dominant outcropping rock formation at Lucas Heights is Hawkesbury Sandstone, with minor components of shale (*eg* at Little Forest). Groundwater flow at the LHSTC is primarily dependent on the topographic features of the plateau. The subsurface structure comprises a near-surface soil and regolith layer that is typically less than two metres deep, underlain by weathered sandstone extending to approximately ten metres, with unweathered sandstone beneath that. Following heavy rain, water seeps from the surface soil into the heads of the gullies that surround the LHSTC, via a shallow groundwater path. Flows from the plateau to the gullies typically peak several days after the rainfall event. Discharge also occurs through a deeper groundwater path, over a much longer time scale and further down the gullies.

6.6.1 Field Parameters and Major Ions in LHSTC Groundwater

The quarterly data for field parameters in groundwater are presented in **Tables 22**-**25**. Note that due to construction work on the OPAL site, several of the piezometers were damaged and some could not be sampled - please refer to the table footnotes for details. Samples from BH3 were compromised by the ingress of surface water through the damaged casing therefore data for this piezometer are not reported.

Groundwater quality at the LHSTC is typical of a sandstone aquifer, tending to be acidic and with generally low salinity (indicated by electrical conductivity, EC). In 2004-05, quarterly pH measurements ranged from 3.8 to 7.7 with a median of 5.1 ± 1.0, and EC ranged between 22 and 867 µS/cm with a median of 166 ± 227 µS/cm (**Tables 22**-**25**). The Eh, which indicates oxidation-reduction potential, had a positive median of 211 ± 106 mV, as would be expected of near-surface oxygenated waters. Some piezometers were found to have low Eh, which is often associated with greater dissolved organic carbon arising from soil bacterial activity. The temperatures of the groundwaters were measured in a flow-through cell at the surface, with a median of 19.3 ± 1.7°C. There was no significant difference in temperature between the shallow piezometers and their deeper counterparts.

Table 26 gives the annual results for major ions in the LHSTC groundwaters. Note that cation concentrations are for dissolved ions, whereas anion concentrations include dissolved and undissolved ions. The LHSTC groundwaters are predominantly sodium-chloride-sulfate type waters, consistent with a primary influence from marine aerosol input. However, the results for shallow piezometer MW4s are a notable exception, with relatively high Ca, Mg, SO_4, HCO_3 and pH levels, but with low Eh. Salinity results for MW4s (**Tables 22**-**25**, EC) were also the highest recorded of all the LHSTC piezometers. This well is located in a natural drainage line below a chlorinated swimming pool. The groundwater chemistry of MW4s is likely to be derived from leakage of treated water from the swimming pool and increased plant or bacterial respiration in the saturated soils around MW4s.

6.6.2 Nutrients and Hydrocarbons in LHSTC Groundwater

The groundwater samples collected in August, 2004 were sent to external commercial laboratories for inorganic nutrients analyses (**Table 28**). In addition, the sample from MW5s, located near the underground petroleum fuel tank, was also tested for hydrocarbons (**Table 29**). Results for MW5s were below the limits of detection for total petroleum hydrocarbons and monocyclic aromatic hydrocarbons (benzene, toluene, ethyl benzene and xylene), suggesting that there is no sign of leakage from the fuel tank in nearby groundwater.

Nutrients such as nitrogen and phosphorus stimulate the growth of plants (including algae) and typical sources of enhanced nutrient levels in waterways are fertiliser run-off, sewage and eroded soil. Soils derived from the local sandstone are generally considered to be poor in nutrients, particularly phosphorus. In groundwaters, high levels of nitrates or ammonia can be indicative of specific contamination with sewage, fertilizers or leachate from municipal waste.

Total phosphorus concentrations in unfiltered LHSTC groundwater ranged from 0.004 to 0.190 mg/L, with a median of 0.013 ± 0.019 mg/L in 2004-05. Most samples are less than the relevant ANZECC default target for the protection of aquatic ecosystems of 0.025 mg/L. Soluble reactive phosphorus concentrations (0.45 µm filtered) indicate the amount of this nutrient most readily available for biological uptake, and levels were close to, or below, the 0.002 mg/L limit of detection, ten times less than the ANZECC default target of 0.020 mg/L. This comparison indicates that the bulk of the total phosphorus is particle-associated rather than dissolved in the LHSTC groundwater samples, although there is not a strong correlation with turbidity in these data. Particle-associated phosphorus tends not to move with groundwater flow and will therefore not contribute to nutrient concentrations in the base-flow of local streams.

The median concentration of total nitrogen in LHSTC groundwater was 0.10 ± 0.18 mg/L, and was therefore at the detection limit and well below the ANZECC default target of 0.35 mg/L. Total nitrogen concentrations ranged from less than the detection limit to 0.62 mg/L, with four piezometers exceeding the default target value. There is a clear tendency for the 'shallow' piezometers to have greater total concentrations of nitrogen. NOx-N (nitrate and nitrite) results for LHSTC groundwaters ranged from <0.01 to 0.24 mg/L, with a median concentration (0.030 ± 0.08 mg/L) below the ANZECC 0.04 mg/L default target.

Ammonia levels in LHSTC groundwaters were also low, ranging from less than the detection limit to 0.19 mg/L, and with no ammonia detected in more than half the LHSTC groundwater samples. The maximum ammonia concentration lies below the ADWG aesthetic guideline of 0.5 mg/L (no default target is specified in the relevant ANZECC guidelines).

The generally low levels of major plant nutrients in LHSTC groundwater are consistent with the local rock and soil types and also with grounds management that limits the use of fertiliser on lawn areas and preferentially plants native vegetation in garden beds.

6.6.3 Radioactivity in LHSTC Groundwater

Groundwater samples collected at the LHSTC in August 2004 were filtered and analysed for alpha, beta, tritium and gamma radioactivity, and the data are given in **Table 27**. Gross alpha activity ranged from less than the minimum detectable activity to 0.18 Bq/L, with a median of 0.04 ± 0.05 Bq/L. Gross beta activities were similar, ranging from 0.02 to 0.16 Bq/L, with a median of 0.05 ± 0.05 Bq/L. The gross alpha and gross beta activities in the groundwater were all below the levels prescribed for Class C surface waters in New South Wales, but note that this is only an indicative comparison because these are groundwaters rather than surface waters. Gamma-emitting radionuclides, specifically americium-241, caesium-137 and cobalt-60, were not detected in 2004-05.

Tritium activity in the LHSTC groundwater (**Table 27**, **Figure 7**) was analysed by ANSTO's low-background tritium facility for enhanced sensitivity. Tritium data ranged from less than the minimum detectable activity of 2.3 Bq/L to 79.7 Bq/L, a somewhat lower maximum than was reported for either 2002-03 or 2003-04. Nonetheless, the median of 12.4 ± 22.6 Bq/L is indistinguishable from previous years. The maximum activity measured in LHSTC groundwater in 2004-05 was only about 1% of the ADWG (NHMRC and NRMMC 2004). Shallower piezometers generally displayed higher tritium levels than the deeper ones.

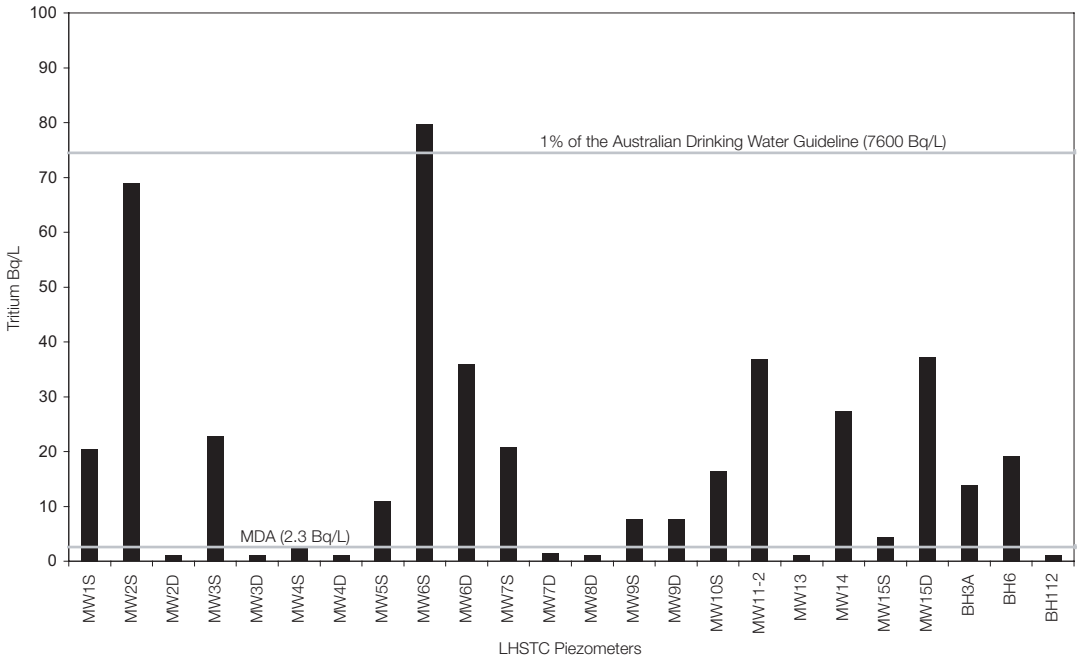

Figure 7. Tritium levels in LHSTC groundwater, August 2004.

6.6.4 Groundwater from LHSTC Waste Management Area

Combined groundwater/stormwater seepage from the general vicinity of Building 27 was monitored monthly for gamma-emitting isotopes and tritium from January 1996 to June 2004. During this period tritium activities ranged from 210 to 700 Bq/L, with a median of 390 ± 110, and no anthropogenic gamma-emitters were detected. Routine collection of these samples was discontinued from July 2004 because groundwater from the waste management and fuel storage areas is more appropriately monitored at the shallow and deep piezometers, MW6s and MW6d.

6.7 GROUNDWATER - LITTLE FOREST BURIAL GROUND

Little Forest is located in a groundwater recharge area, so that rain water moves down-gradient from the site along pathways of least resistance. For the LFBG, these pathways include surface water runoff, groundwater flow via the shallow vadose zone to a distinct shale layer and saturated flow into the underlying Hawkesbury Sandstone. As indicated by tritium measurements, the groundwater flows predominantly North, North-West and South away from a groundwater divide running through the central position of the burial trenches. **Figure 4** shows the location of the burial trenches and piezometer network at LFBG.

Data from six-monthly sampling of groundwater field parameters are reported in **Tables 30** and **31**. In 2004-05, the groundwater pH ranged from 4.1 to 8.6 with a median of 5.7 ± 0.8 while electrical conductivity ranged between 208 and 8000 µS/cm with a median of 1636 ± 2246 µS/cm. The LFBG tends towards slightly less acid groundwater than the LHSTC, with variable but generally higher salinity. This chemistry is probably a natural consequence of the LFBG's location on shale. Oxidation/reduction measurements were generally positive, with a median of 150 ± 113 mV, but some piezometers displayed low or negative values, which are indicative of low oxygen concentrations.

Routine six-monthly groundwater level monitoring and sampling from the LFBG piezometer network is also undertaken to measure tritium, gross alpha and gross beta radioactivity and gamma-emitting radionuclides. Results of this monitoring are shown in **Tables 32** to **33**. The majority of tritium concentrations in groundwater from the LFBG for 2004-05 are below levels considered safe for drinking water in Australia, though it should be noted that these waters do not contribute to any known potable water supply. The maximum tritium concentration of 7840 Bq/L, 3 percent above the drinking water guideline level, was recorded in piezometer MB16, which lies between the main burial trenches and where elevated tritium activity is therefore expected. Gross alpha and gross beta activities in LFBG groundwater were below the levels prescribed for Class C surface waters in New South Wales. Gamma spectrometry of the unfiltered LFBG groundwater samples showed low levels of natural potassium-40. Cobalt-60 was found in a sample from MB16, at levels similar to those reported in recent years. Trace levels of cobalt-60 were detected in MB12. Trace levels of caesium-137 were detected in piezometers MB13 and P2D. Americium-241 was not detected in LFBG groundwater in 2004-05.

6.8 RAINWATER

In 2004-05, the collection and analysis of rainwater for tritium activity was incorporated into the environmental monitoring program. Daily (24-hour) rainwater samples were collected at ANSTO's meteorological station, shown on **Figure 2**, and combined to form a weekly composite sample. Results are given in **Table 34**. During the year, 41 weekly rainwater composites were produced and analysed for tritium. The tritium analysis included a distillation step to remove possible interfering species, such as radioiodines, whenever sufficient sample volume was available. Distillations were performed on 75% of samples and 90% of all tritium results were below the minimum detectable activity, see **Figure 8**, below. The maximum tritium value was 120 Bq/L (in an undistilled sample), which represents less than 2% of the ADWG guideline for tritium of 7600 Bq/L.

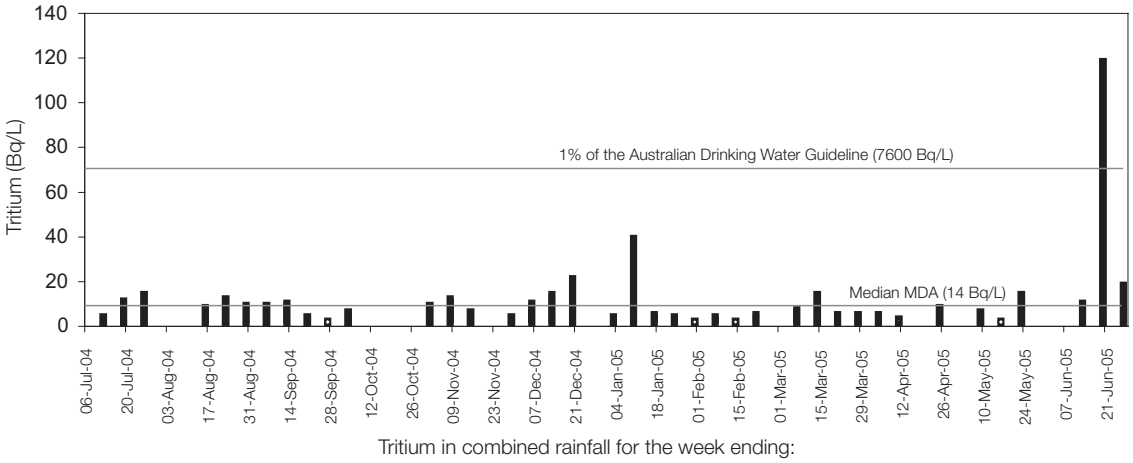

Figure 8. Tritium activity in LHSTC rainwater (weekly composites of daily samples), July 2004 to June 2005.

6.9 SOIL AND SEDIMENT

6.9.1 Bund Sediments

Sediment samples from ANSTO's three stormwater bunds were not collected during 2004-05 because the degree of sedimentation was low, and sufficient capacity was therefore available in the event of an unplanned release into the stormwater system.

6.9.2 Sediment from Local Streams

Sediment was collected near the confluence of Mill and Bardens Creeks, which ultimately drain the Lucas Heights landfill and LFBG areas (see **Figure 1**). Levels of gross alpha, gross beta and gamma radioactivity were measured (**Table 20**) and showed only low levels of natural activity attributable to progeny of the uranium-238 and thorium-232 decay series and potassium-40.

6.9.3 Gamma Dose-Rate Survey – Little Forest Burial Ground

Dose-rates over all of the LFBG trenches (**Figure 4**) were measured during March and April 2005 using a hand-held meter at near-ground level (**Table 35**). Recorded dose-rates ranged from 0.08 to 0.19 μSv/hour and are consistent with background readings taken at the LFBG gate, approximately 200 metres away from the trench area.

In December 2004, an intrusion occurred at the LFBG. Although there was minimal disturbance of the soil cover, a small section of the disposal trench area was affected. This area was monitored using hand-held dose-rate meters and a portable contamination monitor. The alpha and beta activities and gamma dose-rates measured were at background levels. Six soil samples were collected and analysed by gamma spectrometry, showing typically low levels of natural background radioactivity. All of the results indicate that there was no mobilisation of radioactivity as a consequence of this incident and the potential radiological exposure to members of the public from the LFBG continues to be assessed as negligible.

6.9.4 Gamma Dose-Rate Survey – Main Discharge Pipeline

In addition to routine monthly visual inspections of the effluent discharge pipeline, dose-rate surveys are performed at least once per year. The results of the MDP pipeline dose-rate surveys for July 2004 to June 2005 are summarised in **Table 36**. The measured dose-rates along the pipeline ranged from 0.05 to 0.12 μSv/hour, and were within the range measured for natural background radiation. No soil samples were collected during 2004-05.

6.10 BIOTA (POTTER POINT)

Treated sewage effluent from the Sutherland Shire, including low-level effluent from the LHSTC, passes through the Cronulla STP and is discharged at Potter Point (**Figure 1**, inset). Collections of fish, algae (seaweed) and barnacles continued at the Potter Point ocean outfall and a reference site at The Royal National Park from July 2004 to June 2005, with authorisation from NSW Fisheries. These organisms represent different levels in the food chain and are known to concentrate a variety of elements, including radionuclides, from their environment. Harvesting of fish was performed according to animal collection protocols approved by ANSTO's Animal Care and Ethics Committee. The fish, commonly known as Luderick (*Girella sp.*), were filleted and skinned, while green algae (mainly *Ulva sp.* or *Enteromorpha sp.*) and surf barnacles (*Tesseropera rosea*) were left whole and unwashed. All samples were dried, ground and analysed for gamma-emitting radioisotopes (**Tables 37**-**39**).

The radioactivity measured in marine fish, algae and barnacles sampled at Potter Point in 2004-05 was of natural origin, apart from the low levels of iodine-131 found in the algae and barnacles sampled on 28 April 2005. Iodine-131 is not normally detected in barnacles. However, in this case the sample was taken closer to the outfall than in previous sampling years. The result was 3.5 ± 0.7 Bq/kg. This iodine-131 activity may have been due to the presence of algae attached to the barnacle sample, rather than the barnacles themselves. A second barnacle sample collected on 9 May 2005 was below the minimum detectable activity for iodine-131, suggesting that the initial result may have been due to the change of sampling location. Iodine-131 is a medical radioisotope used in the treatment of thyroid cancer. ANSTO's liquid effluent is therefore not the only source of iodine-131 in the Sutherland Shire sewerage system. Only naturally occurring radionuclides were detected in samples collected from the reference site.

6.11 METEOROLOGICAL MONITORING

6.11.1 Rainfall and Evaporation

Rainfall and potential evaporation data for the LHSTC are summarised in **Table 40**, from 1995 to 2005. The meteorological statistics recorded here include monthly total rainfall (R Total; mm), number of days on which rain fell (R Days), monthly potential evaporation (E Total; mm) and the maximum daily evaporation (E max; mm). The total rainfall during 2004-05 was 841.3 mm from 105 rain days, towards the lower end of the interquartile range around the median. Total rainfall for the previous decade (1994-95 to 2003-04), calculated as median ± interquartile range on a financial year basis was 896 ± 75 mm. The wettest month during 2004-05 was October 2004 with 219.1 mm and the maximum 24-hour rainfall was 62.4 mm recorded at 9 am on 21 October 2004. The total evaporation for 2004-05 was 1201.8 mm, with a maximum 24-hour value of 14.2 mm recorded in December 2004.

6.11.2 Wind Speed and Direction

The winds (recorded at 10m) that predominated at Lucas Heights during summer and winter of 2004-05 are shown in **Table C**. Winds during autumn and spring represent a transition between those of summer and winter seasons, with sea breezes observed later in the afternoon.

Table C: Seasonal prevailing winds at the LHSTC, recorded at 10m during 2004-05.

Season	Time of day	Wind Direction (*ie* blowing from)	Wind Speed
Summer	Day (sea breeze)	NE-ENE sectors	2 - 4 m/s
	Night/Early morning	S-SE sectors	1 - 2 m/s
Winter	Day (sea breeze)	NNW-WSW and S-SSE sectors	2 - 4 m/s
	Night/Early morning	WSW-S sectors	1 - 2 m/s

For the period 2004-05 at Lucas Heights, the wind at 10m was blowing from the W-SE sector for approximately 60% of the time, with winds from the S and SSE occurring most often. The wind speed for the year was in the range 2-4 m/s and 1-2 m/s for 45% and 34% of the time respectively.

7. A Decade of Monitoring

Monitoring data are usually collected with the aim of satisfying requirements for compliance and reporting over periods of a year or less. The same data provide a measure of ongoing trends and year to year variation. Examples of longer term data from ANSTO's environmental monitoring are set out below.

7.1 AIRBORNE DOSE

The modelling of airborne dose to the public integrates data for airborne emissions with meteorological measurements, within the concept of exposure pathways to critical groups. Thus, a single performance index is generated for the principal source of potential radiation exposure to members of the public from routine ANSTO operations at the LHSTC. **Figure 9** shows a decade of data for the maximum annual airborne effective dose at the 1.6 km boundary of ANSTO's buffer zone.

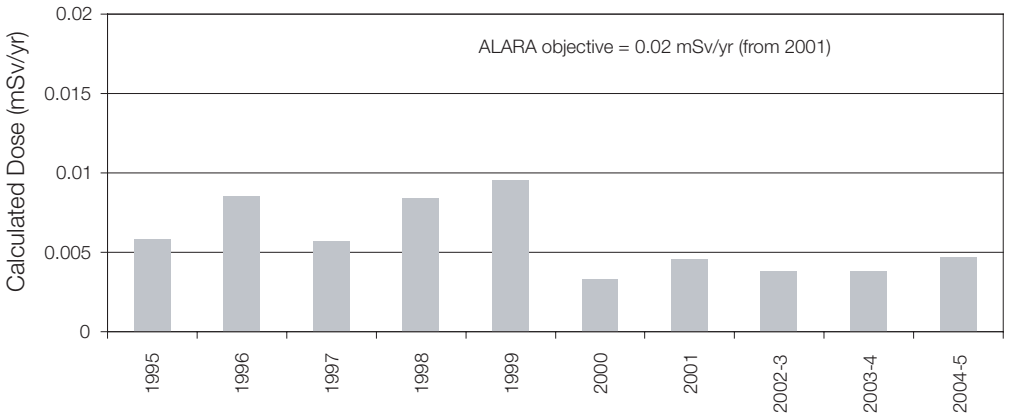

Figure 9. Maximum annual effective dose from LHSTC airborne discharges at the 1.6 km boundary of ANSTO's buffer zone, 1995 to 2004-05.

The data show that the calculated airborne doses at 1.6 km have all been less than half the ALARA objective of 0.02 mSv/year. The lowest effective doses to the public from routine ANSTO operations have occurred in the last five years.

7.2 RADIOACTIVITY IN LIQUID EFFLUENT

Figure 10 shows the average monthly radioactivity concentration quotient in ANSTO's liquid effluent discharges to the sewer from the LHSTC.

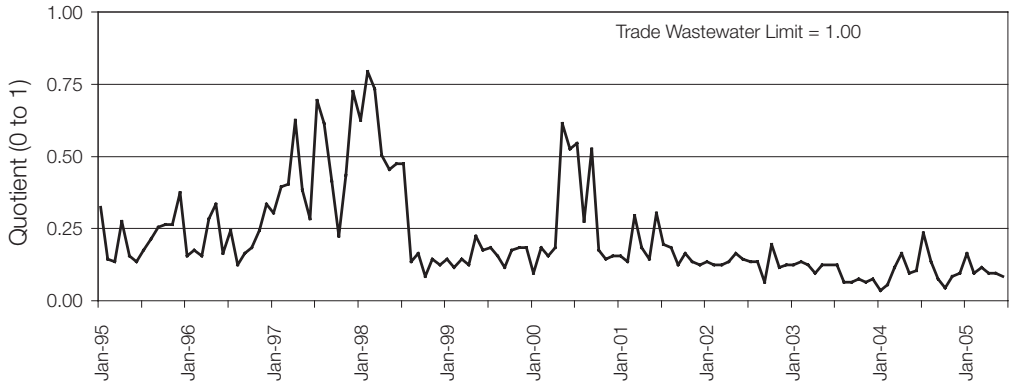

Figure 10. Average monthly radioactivity concentration quotient in liquid effluent discharges from the LHSTC, 1995 to 2004-05.

The average monthly quotient for concentrations of radioactivity in liquid effluent released to the sewer summarises ANSTO's radiological performance relative to its trade wastewater agreement with Sydney Water. Any quotient less than 1 indicates compliance with the terms of the agreement. Calculation of the quotient is explained in section 3, and a detailed explanation of these calculations is given in Hoffmann *et al.* 1999.

The monthly radioactivity quotient has remained below the limit specified by successive trade wastewater agreements for the past decade. Since 2002, the monthly quotient has been consistently less than a quarter of this limit.

7.3 ALPHA AND BETA RADIOACTIVITY IN STORMWATER

The gross alpha and beta radioactivity of stormwater is routinely measured for the three most significant drainage lines at the LHSTC, at points agreed with the SPCC in 1985. **Figure 11** shows the annual maximum of monthly gross alpha data for the SPCC sampling points from 1995 to 2004-05, in relation to limits for Class C surface waters (*Protection of the Environment Operations Act* 1997 NSW).

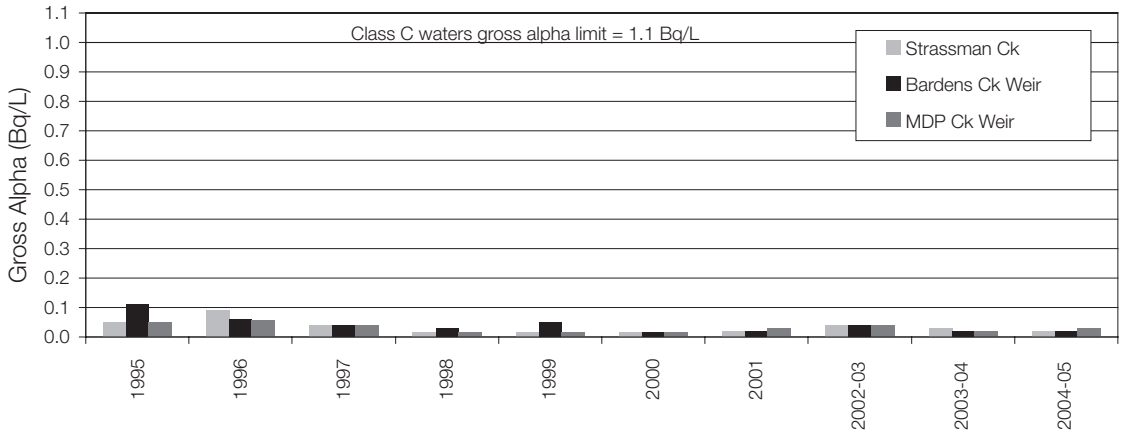

Figure 11. Annual maximum of monthly alpha radioactivity in stormwater at SPCC sampling points.

The maximums of monthly screening tests for gross alpha and beta radioactivity in stormwater draining from the LHSTC (**Figures 11** and **12**) have easily complied with the requirements for Class C waters in relevant state legislation (*Protection of the Environment Operations Act* 1997 NSW) over the past decade. The maximum alpha and beta radioactivity measured in stormwater has tended to decrease in that time.

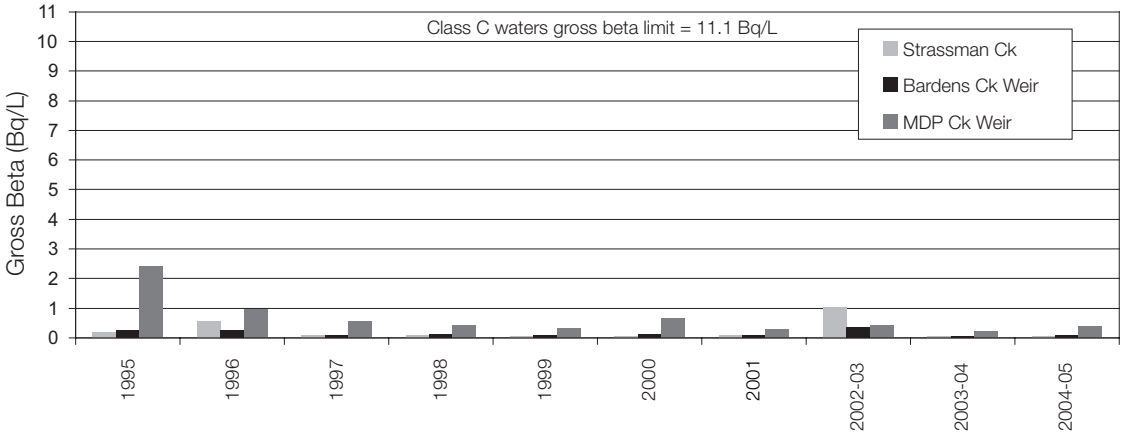

Figure 12. Annual maximum of monthly beta radioactivity in stormwater at SPCC sampling points.

8. Potential Doses to the Public and the Environment

The principal sources of potential radiation exposure to members of the public from routine ANSTO operations at the LHSTC and NMC are from airborne emissions and low-level liquid effluent discharges. Meteorological and airborne emissions monitoring data provide the necessary input to the atmospheric dispersion and dose-estimation model, PC-Cream, which is used to compute the effective dose to hypothetical individuals due to the routine airborne release of radionuclides. The conservative assumptions routinely used in the PC-Cream dose-modelling are explained in Hoffmann and Loosz (2002).

Currently, there is no internationally agreed approach to assessing doses to non-human species and no established guidelines against which to determine the risks of such doses. Following the ICRP (1991), it is assumed here that demonstrating protection of humans from the potential effects of ionising radiation also demonstrates adequate protection of the environment. ANSTO is participating in a European initiative, Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA), which is working to provide an integrated approach to assessment and management of environmental risks from ionising radiation, using practical tools. ANSTO is a member of the ERICA 'End User Group', which aims to provide external stakeholder input and guidance to the initiative and the ERICA website (ERICA 2005) regularly reports progress.

8.1 AIRBORNE DISCHARGES

The annual effective doses to hypothetical individuals potentially exposed to radiation in routine airborne discharges from the LHSTC in 2004-05 were modelled, based on the LHSTC stack discharge data and concurrent meteorological information (**Table 41**). For the purposes of this report, the critical group of members of the public potentially affected by routine airborne releases comprises hypothetical individuals living around the 1.6 km buffer zone boundary and for whom the estimated effective doses are presented in **Table 41**. People working at the LHSTC are not considered here. The estimated effective doses to this critical group from routine airborne emissions ranged from 0.0009 to 0.0047 mSv/year, with a median of 0.0017 ± 0.0014 mSv/year.

Figure 13 shows the directional dose from LHSTC airborne emissions for 2004-05, estimated for the critical group of hypothetical individuals on a 1.6 km radius from HIFAR, relative to the ALARA objective. The maximum estimated effective dose for the critical group was 0.0047 mSv/year to the North, which is less than 24% of the ALARA objective of 0.02 mSv/year.

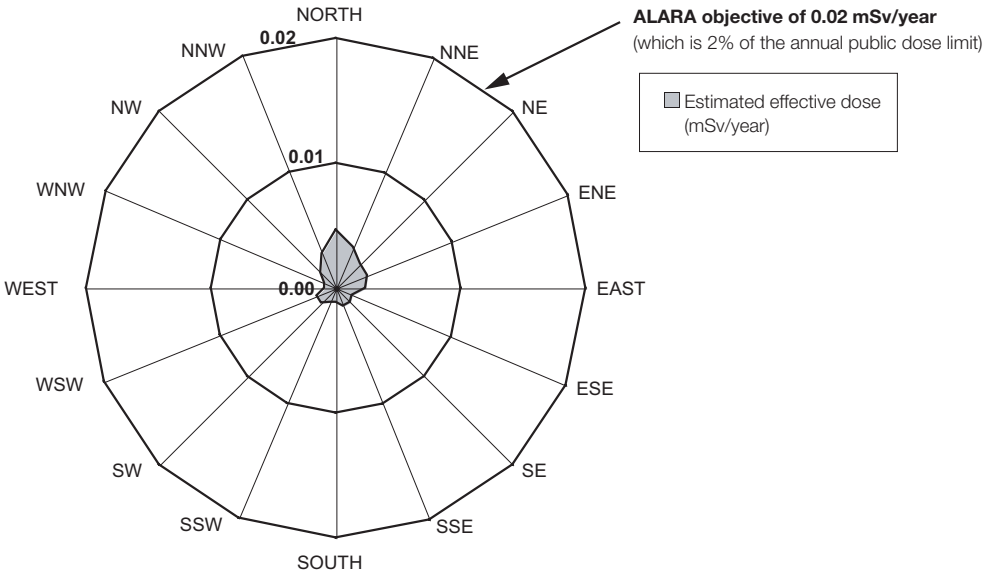

Figure 13. Estimated effective dose to the public (mSv/year) at a 1.6 km radius from HIFAR, from routine LHSTC airborne discharges, July 2004 to June 2005.

Finding that the maximum dose is estimated for the northerly direction is consistent with relatively frequent winds blowing from the South and SSE, as noted in section 6.10.2. The theoretical dose from LHSTC airborne emissions is much lower than the public dose limit of 1 mSv/year and the natural background in Australia of ~1.5 mSv/year (not including medical investigations; Webb *et al*. 1999). A comparison of these doses is shown on **Figure 14**.

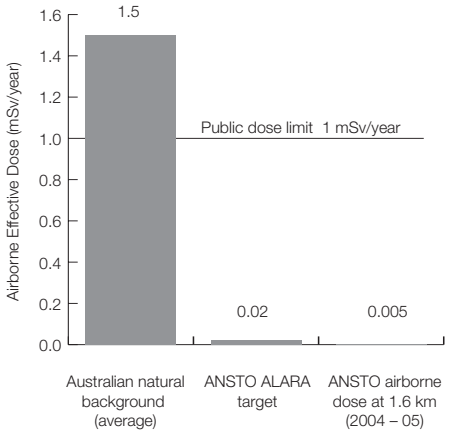

Figure 14. Comparison of doses from ANSTO's airborne discharges with Australian natural background and ANSTO's ALARA target.

Thermoluminescent dosimeters placed around LHSTC and at some local residences also indicated that the external gamma radiation levels at residential locations in the vicinity of the LHSTC were not noticeably affected by ANSTO's operations. Airborne discharges from the NMC were well below the relevant four-weekly, quarterly and annual notification levels, thereby ensuring that the potential dose to humans is below the ALARA objective of 0.02 mSv/year.

8.2 LIQUID EFFLUENT DISCHARGES

The effective dose-rates to the critical group of members of the public potentially exposed to radiation from routine liquid effluent discharges from the LHSTC have been calculated to be no more than a quarter of the minimum dose estimated for members of the public potentially exposed to airborne emissions from the LHSTC (Hoffmann *et al.* 2003).

Liquid effluent discharged to the Sydney sewerage system from the NMC ultimately enters the sea off-shore via the deep ocean outfalls. The small amounts of short-lived radioactivity in the effluent from the NMC and the high dilution in the sewage system means that any potential doses are very small. Since the release is to the ocean, off-shore, there is unlikely to be any significant environmental pathway to humans, such as through the consumption of seafood.

9. Conclusion

For the period from July 2004 to June 2005, the estimated potential doses to members of the public from airborne discharges at the LHSTC remain only a very small fraction of the radiation dose received by everyone each year from naturally-occurring sources of radiation. The monitoring results from Potter Point confirm that the potential radiation dose to members of the public as a result of ANSTO's liquid effluent discharges to the sewer is also very low. The levels of tritium in groundwater and stormwater at the LHSTC are less than Australian drinking water guidelines. The airborne and liquid effluent emissions from the NMC, from July 2004 to June 2005, were below the ARPANSA-approved notification levels and concentration limits set by Sydney Water, respectively. It is concluded that ANSTO's operations at the LHSTC and the NMC make only a very small addition to the natural background radiation dose.

10. Acknowledgements

The environmental and effluent monitoring program at ANSTO is very much a team effort. The following people are sincerely thanked for their contribution: Richard Barton, Robert Blackley, Ashley Browne, Brett Clarke, David Cohen, Leisa Dyer, Hong Duong, Tegan Evans, Ashley Gillen, Yassin Hammami, Tanya Henley, Cath Hughes, Joseph Ioppolo, Duncan Kemp, Kate Lucas, Jim Pascoe, Adam Philip, Tim Payne, Michael Polewski, Werner Reynolds, Peter Robinson, John Saratsopoulos, Matthew Shelley and Ron Szymczak. Thanks are also extended to those who made contributions to the text and/or provided constructive comments on text drafts.

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Data Tables

Table 1. MEDIAN DETECTION LIMITS FOR ANALYSES OF ENVIRONMENTAL MEDIA, July 2004 to June 2005

Environmental Media	Gamma-emitters						Gross Alpha	Gross Beta	Tritium	Pu-239/240 (Bq total)	Stable Beryllium (µg total)
	Am-241	I-131	Cs-137	Co-60	K-40	Be-7					
WATERS											
(Bq/L)	0.013	-	0.016	0.023	0.495	0.095	0.03	0.05	14	-	-
SOIL / SEDIMENT											
(Bq/g)	0.001	-	0.001	0.001	0.068	0.011	-	-	-	-	-
FISH											
(Bq/kg fresh weight)	0.37	1.9	0.46	0.69	11	3.9	-	-	-	-	-
ALGAE (seaweed)											
(Bq/kg fresh weight)	0.32	0.6	0.31	0.55	7	3.8	-	-	-	-	-
BARNACLES											
(Bq/kg fresh weight)	0.53	2.0	0.55	0.97	17	6.7	-	-	-	-	-
MAYPACKS											
(Bq/m^3)	-	0.0011	-	-	-	-	-	-	-	-	-
AIRBORNE PARTICLES											
(High-volume air filters)	-	-	-	-	-	-	-	-	-	0.001	0.04

Notes:

- Since environmental media exhibit natural variation, the minimum detectable activity (MDA) is calculated for each sample or batch analysed, and the median values for different analytes and sample matrices are given above.
- In the following data tables, "< MDA" indicates that the result was below the minimum detectable activity, calculated with 95% confidence.

Table 2 . ANNUAL AIRBORNE ACTIVITY DISCHARGE REPORT, LHSTC AND NMC, June 2004 to June 2005

	Particulates		Gases and Vapours																	
STACK	Gross Alpha (MBq)	Gross Beta (MBq)	I-131 (MBq)	Tritium (GBq)	Ar-41 (TBq)	Hg-197 (MBq)	Hg-203 (MBq)	As-76 (MBq)	Br-82 (MBq)	I-132 (MBq)	I-133 (MBq)	Xe-133 (TBq)	Xe-135 (TBq)	Xe-135m (TBq)	Kr-85m (TBq)	Kr-87 (GBq)	Kr-88 (TBq)	F-18 (GBq)	I-123 (GBq)	All Other Nuclides (MBq)
3	ND	ND																		2.09
	-	-																		0.4%
15A	ND	1.60	8.86	2047.00	127.70	51.70	6.31	103.90	7.58											
	-	2.7%	22.2%	20.5%	70.9%	18.5%	15.8%	41.6%	30.3%											
15M	ND	ND	1.44	335.70	16.43															
	-	-	14.4%	74.6%	82.2%															
19S	ND	ND	6.35																	ND
	-	-	12.7%																	-
19D	ND	ND	0.21																	ND
	-	-	0.4%																	-
20	ND	0.05		96.46																19.66
	-	0.1%		43.8%																3.9%
20B	ND	ND																		6.2
																				1.20%
21A	ND	ND																		0.31
	-	-																		0.1%
23A	ND	15.48	9371																	ND
	-	4.6%	28.4%																	-
23B	ND	ND	4.27																	ND
	-	-	3.9																	-
41A	ND	ND																		102.60
	-	-																		20.5%
41B	ND	ND																		27.50
	-	-																		5.5%
54	ND	ND	22200							111400	4190	342.60	30.28	54.28	17.86	ND	ND			ND
	-	-	79.3%							46.4%	27.9%	122.4%	7.6%	13.6%	27.5%	-	-			-
56	ND	ND																		2.74
	-	-																		0.5%
57	ND	ND		52.87																1.87
	-	-		24.0%																0.4%
NMC																		1.49	19.53	2.85
																		0.60%	19.53%	0.6%

Notes:
- Percentages reported are the discharge as a percentage of the annual Notification Level. ND = Not Detected.
- The “All Other Nuclides” column includes all nuclides for which no specific notification level exists, ie it may include some of the other listed nuclides.
- The sampling period for NMC was 2 July 2004 to 01 July 2005. The LHSTC sampling period was 24 June 2004 to 21 June 2005.

Table 3. RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, LHSTC, July 2004 to June 2005

Month	Total Volume Discharged (m^3)	Radioactivity Average Concentration in Discharges (Bq/m^3)			Concentration Quotient
		Alpha	Beta	Tritium	
Jul 2004	4525	< MDA	2.31×10^4	7.31×10^6	< 0.23
Aug 2004	3682	< MDA	1.03×10^4	7.91×10^6	< 0.13
Sep 2004	4589	< MDA	2.34×10^3	8.43×10^6	< 0.07
Oct 2004	8811	< MDA	2.24×10^3	3.16×10^6	< 0.04
Nov 2004	7221	< MDA	6.39×10^3	5.04×10^6	< 0.08
Dec 2004	6599	< MDA	8.11×10^3	4.72×10^6	< 0.09
Jan 2005	4499	< MDA	1.23×10^4	1.16×10^7	< 0.16
Feb 2005	4822	< MDA	7.33×10^3	4.61×10^6	< 0.09
Mar 2005	7057	< MDA	1.02×10^4	4.49×10^6	< 0.11
Apr 2005	6617	< MDA	6.59×10^3	6.13×10^6	< 0.09
May 2005	6845	< MDA	8.49×10^3	4.07×10^6	< 0.09
Jun 2005	7686	< MDA	7.23×10^3	3.99×10^6	< 0.08
Activity Concentration Limit		1.25×10^4 (as Ra-226)	1.25×10^5 (as Sr-90)	1.95×10^8	1.00

Notes:

- The requirements for acceptance of LHSTC liquid effluent to sewer are set out in an agreement with the Sydney Water Corporation: *Consent to Discharge Industrial Trade Wastewater* (consent number 4423).
- Concentration Quotient = the sum of the monthly alpha, beta and tritium activities, divided by the relevant Activity Concentration. The monthly concentration quotient must be no greater than one to comply with the terms of the agreement.
- Alpha-emitting nuclides are assumed to be all radium-226 and beta-emitters are assumed to be all strontium-90 (*ie* possible worst case) when calculating the concentration quotient.

Table 4. GAMMA-EMITTERS IN LIQUID EFFLUENT, MONTHLY PIPELINE COMPOSITE SAMPLES, LHSTC, July 2004 to June 2005

	Gamma-emitters (Bq/L)								
MONTH	**Cr-51**	**Co-60**	**Cs-134**	**Cs-137**	**Ce-144**	**I-131**	**Pb-210**	**Ra-226**	**Ra-228**
Jul 2004	< MDA	0.57 ± 0.06	< MDA	10.10 ± 0.10	< MDA	< MDA	< MDA	< MDA	< MDA
Aug 2004	2.91 ± 0.26	< MDA	< MDA	3.04 ± 0.09	< MDA	< MDA	< MDA	< MDA	< MDA
Sep 2004	< MDA	< MDA	< MDA	1.50 ± 0.06	< MDA	< MDA	< MDA	< MDA	< MDA
Oct 2004	< MDA	< MDA	< MDA	0.68 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
Nov 2004	< MDA	< MDA	< MDA	0.19 ± 0.02	< MDA	< MDA	< MDA	< MDA	< MDA
Dec 2004	< MDA	< MDA	< MDA	2.76 ± 0.06	< MDA	0.18 ± 0.01	< MDA	< MDA	< MDA
Jan 2005	< MDA	< MDA	< MDA	4.30 ± 0.09	< MDA	< MDA	< MDA	< MDA	< MDA
Feb 2005	< MDA	< MDA	< MDA	3.28 ± 0.06	< MDA	< MDA	< MDA	< MDA	< MDA
Mar 2005	1.59 ± 0.02	< MDA	< MDA	4.23 ± 0.08	< MDA	0.27 ± 0.01	< MDA	< MDA	< MDA
Apr 2005	< MDA	< MDA	< MDA	1.54 ± 0.05	3.46 ± 0.06	0.16 ± 0.01	< MDA	< MDA	< MDA
May 2005	< MDA	< MDA	< MDA	1.62 ± 0.05	0.62 ± 0.06	< MDA	< MDA	< MDA	< MDA
Jun 2005	< MDA	0.26 ± 0.04	< MDA	2.24 ± 0.07	< MDA	0.23 ± 0.04	< MDA	< MDA	< MDA

Notes:
- Gamma spectrometry was performed on the “monthly pipeline composite”, which is made up of volume-proportional samples from all treated liquid effluent discharges during a given month.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Median MDA values for the relevant radionuclides are as follows: 0.62 for Cr-51, 0.10 for Co-60, 0.10 for Cs-134, 0.21 for Cs-137, 0.35 for Ce-144, 0.09 for I-131, 1.41 for Pb-210, 1.59 for Ra-226, and 0.38 for Ra-228.

Table 5. NON-RADIOACTIVE COMPONENTS OF LIQUID EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, LHSTC, July 2004 to June 2005

Parameter	**2004-05 Concentration** (mg/L)			**Standard for Acceptance** (mg/L)
	Mean	**Median**	**Range**	
pH	7.2	7.1	6.5 - 7.9	**7 – 10**
Ammonia	12.1	11.4	0.4 - 26.1	**50**
BOD	22.1	17.0	2.0 - 78.0	**230**
Grease	5.7	5.0	3.0 - 25.0	**110**
Zinc	0.1	0.1	0.1 - 0.4	**5**
Suspended Solids	21	9	1 - 270	**600**
Total Dissolved Solids	389	380	210 - 776	**10,000**

Notes:

- The discharge of effluent to sewer is governed by a trade waste agreement with Sydney Water. The effluent is sampled every 4th discharge day and 95% of the samples analysed must be less than or equal to the Standard for Acceptance.
- BOD: The domestic concentration applies for biological oxygen demand.

Table 6. RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO THE SEWER, NMC, July 2004 to June 2005

Month	Volume Discharged (m^3)	Average pH	Average Concentration in Liquid Effluent (MBq/m^3)					
			Tl-201	**Tl-202**	**Ga-67**	**Co-57**	**Zn-65**	**I-123**
Jul 2004	4.8	7.3	0.50	0.64	0.04	0.20	0.27	ND
Aug 2004	4.8	7.9	2.60	4.35	ND	3.98	0.80	ND
Sep 2004	4.0	7.4	2.71	6.88	0.24	2.21	0.67	ND
Oct 2004	4.8	7.7	1.27	2.32	0.24	0.27	0.19	0.11
Nov 2004	4.8	7.5	16.52	4.68	0.06	1.20	0.37	ND
Dec 2004	4.8	7.0	3.33	5.86	0.64	3.41	1.11	0.09
Jan 2005	4.0	7.4	0.06	0.44	0.03	0.78	0.18	ND
Feb 2005	2.4	7.7	0.14	0.15	ND	0.28	0.26	ND
Mar 2005	4.8	7.3	0.28	0.14	0.03	0.57	0.25	0.02
Apr 2005	4.8	7.0	0.43	0.25	ND	0.41	0.09	ND
May 2005	5.6	7.3	26.60	14.86	5.26	7.26	0.60	0.04
Jun 2005	4.8	7.3	11.54	9.17	3.44	3.79	0.68	0.12
Monthly Discharge Limit		**7 – 10**	**200**	**100**	**600**	**400**	**100**	**6.00**

Notes:
- The discharge of NMC liquid effluent to sewer is governed by a trade wastewater agreement with Sydney Water.
- ND indicates that the radionuclide was not detected.

Table 7. EFFLUENT DILUTION STUDIES, CRONULLA SEWAGE TREATMENT PLANT AND POTTER POINT, July 2004 to June 2005

CRONULLA SEWAGE TREATMENT PLANT - Effluent

Date	Effluent released from LHSTC			Maximum CSTP tritium activity (Bq/L)	Average CSTP tritium activity (Bq/L)	Estimated minimum dilution ratio: LHSTC to CSTP
	Number of tanks released	Total volume	Average tritium activity			
12-3-05 to 13-4-05	18	4235	5112	60.4 ± 0.6	17.9 ± 0.6	53:1
5-6-05 to 9-6-05	2	608	1642	16.0 ± 0.6	8.7 ± 0.6	88:1

POTTER POINT OCEAN OUTFALL - Seawater

Date	Sampling start time (h:mm)	Sampling end time (h:mm)	Number of seawater samples collected	Maximum tritium activity (Bq/L)	Average tritium activity (Bq/L)	CSTP tritium activity (Bq/L)
15-3-05	8:30	15:00	24	4.8 ± 0.9	3.2 ± 0.9	4.3 ± 0.2
8-6-05	9:00	15:00	21	4.5 ± 0.3	3.0 ± 0.8	8.4 ± 0.8

Notes:
- Effluent at the CSTP was sampled at a location known as the UV Inlet.
- The minimum dilution ratio is estimated by taking the ratio of each measured UV Inlet tritium activity to the LHSTC tritium activity of the effluent release most likely to be the source of the tritium (commonly the previous day's release).

Table 8. AMBIENT IODINE-131 IN AIR, LHSTC PERIMETER, July 2004 to June 2005

Sampling week ended	I-131 in Air (Bq/m^3) Station 1	Station 2	Station 3	Station 4	Sampling week ended	I-131 in Air (Bq/m^3) Station 1	Station 2	Station 3	Station 4
6-7-04	0.0012 ± 0.0006	0.0021 ± 0.0009	< MDA	< MDA	4-1-05	0.0010 ± 0.0006	< MDA	< MDA	0.0012 ± 0.0006
13-7-04	< MDA	0.0031 ± 0.0009	0.0015 ± 0.0006	0.0049 ± 0.0013	11-1-05	< MDA	< MDA	< MDA	< MDA
20-7-04	< MDA	< MDA	0.0030 ± 0.0009	< MDA	18-1-05	< MDA	< MDA	< MDA	0.0009 ± 0.0005
27-7-04	0.0019 ± 0.0007	0.0018 ± 0.0006	< MDA	0.0058 ± 0.0015	25-1-05	< MDA	< MDA	< MDA	< MDA
3-8-04	< MDA	0.0011 ± 0.0006	< MDA	< MDA	1-2-05	< MDA	< MDA	< MDA	< MDA
10-8-04	< MDA	< MDA	< MDA	0.0030 ± 0.0009	8-2-05	< MDA	< MDA	< MDA	0.0014 ± 0.0007
17-8-04	< MDA	0.0018 ± 0.0006	< MDA	< MDA	15-2-05	< MDA	< MDA	< MDA	< MDA
24-8-04	< MDA	< MDA	-	< MDA	22-2-05	< MDA	< MDA	< MDA	< MDA
31-8-04	0.0026 ± 0.0007	0.0010 ± 0.0005	< MDA	0.0073 ± 0.0017	1-3-05	< MDA	< MDA	< MDA	< MDA
7-9-04	< MDA	0.0017 ± 0.0008	< MDA	< MDA	8-3-05	< MDA	0.0023 ± 0.0007	< MDA	< MDA
14-9-04	0.0019 ± 0.0006	0.0028 ± 0.0015	< MDA	0.0033 ± 0.0010	15-3-05	0.0137 ± 0.0030	0.0212 ± 0.0046	0.0029 ± 0.0008	0.0020 ± 0.0007
21-9-04	< MDA	0.0014 ± 0.0005	< MDA	< MDA	22-3-05	0.0030 ± 0.0008	0.0019 ± 0.0006	< MDA	0.0006 ± 0.0005
28-9-04	< MDA	< MDA	< MDA	0.0053 ± 0.0014	29-3-05	< MDA	0.0049 ± 0.0012	< MDA	< MDA
5-10-04	< MDA	< MDA	< MDA	< MDA	5-4-05	0.0007 ± 0.0004	< MDA	< MDA	0.0010 ± 0.0006
12-10-04	< MDA	< MDA	< MDA	0.0014 ± 0.0006	12-4-05	< MDA	< MDA	< MDA	< MDA
19-10-04	< MDA	0.0011 ± 0.0006	< MDA	< MDA	19-4-05	0.0007 ± 0.0004	0.0019 ± 0.0006	< MDA	< MDA
26-10-04	< MDA	< MDA	< MDA	< MDA	26-4-05	< MDA	0.0006 ± 0.0004	< MDA	< MDA
2-11-04	< MDA	< MDA	< MDA	< MDA	4-5-05	< MDA	0.0019 ± 0.0006	< MDA	< MDA
9-11-04	< MDA	< MDA	< MDA	< MDA	10-5-05	0.0044 ± 0.0011	0.0922 ± 0.0196	0.0086 ± 0.0019	< MDA
16-11-04	< MDA	0.0013 ± 0.0005	< MDA	< MDA	17-5-05	< MDA	0.0335 ± 0.0072	0.0072 ± 0.0016	< MDA
23-11-04	< MDA	< MDA	< MDA	< MDA	24-5-05	< MDA	0.0200 ± 0.0043	0.0033 ± 0.0009	< MDA
30-11-04	< MDA	< MDA	< MDA	< MDA	31-5-05	< MDA	0.0096 ± 0.0021	0.0021 ± 0.0006	< MDA
7-12-04	< MDA	< MDA	< MDA	< MDA	7-6-05	0.0008 ± 0.0004	0.0058 ± 0.0013	0.0010 ± 0.0005	< MDA
14-12-04	< MDA	< MDA	< MDA	< MDA	14-6-05	0.0018 ± 0.0006	0.0041 ± 0.0010	< MDA	< MDA
21-12-04	< MDA	< MDA	< MDA	< MDA	21-6-05	< MDA	0.0023 ± 0.0007	< MDA	< MDA
30-12-04	< MDA	< MDA	< MDA	< MDA	28-6-05	< MDA	< MDA	< MDA	< MDA

Notes:
- Four continuous air samplers are located along the eastern boundary of the LHSTC site, see Figure 2.
- Results are conservative since any I-131 activity is corrected for decay from the first day of the sampling week.
- < MDA indicates that the result was below the minimum detectable activity. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.
- - indicates missing data, the sample spectrum was lost during analysis.

Table 9. RADIOACTIVITY IN AIRBORNE PARTICLES, LFBG, July 2004 to June 2005

Sampling Period	Equivalent Volume (m^3)	(% of Filter)	Beryllium (µg total)	(µg/m^3)	Pu-239/240 (Bq total)	(Bq/m^3)
Jul – Sep 04	492	25	< MDA	$< 8.1 \times 10^{-5}$	< MDA	$< 2.0 \times 10^{-6}$
Oct – Dec 04	337	25	< MDA	$< 1.2 \times 10^{-4}$	< MDA	$< 3.0 \times 10^{-6}$
Jan – Mar 05	532	25	< MDA	$< 9.4 \times 10^{-5}$	< MDA	$< 1.9 \times 10^{-6}$
Apr – Jun 05	438	25	< MDA	$< 4.6 \times 10^{-5}$	< MDA	$< 2.2 \times 10^{-6}$

Notes:

- Airborne particulates were collected using a mobile high-volume air sampler and samples were accumulated on a single filter over a period of 3 months. The sampling duration and frequency was approximately 4 hours, every 2 weeks.
- The Worksafe Australia Exposure Standard for atmospheric contaminants such as beryllium in air is 2 µg/m^3 (applicable to workers exposed 8 hours per day, 50 weeks per year).
- The limit of detection for Pu-239/240 in Bq/m^3 would equate to a committed effective dose to adults of < 0.0002 mSv/year, or < 0.02% of the allowable public dose limit of 1 mSv/year.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1. The concentrations were calculated using the actual MDA divided by the volume of air sampled.

Table 10. ANNUAL EFFECTIVE DOSE FROM EXTERNAL GAMMA RADIATION, LHSTC AND LOCAL AREA, July 2004 to June 2005

	ANSTO Environmental Thermoluminescent Dosimeters	
	Dosimeter Location: LHSTC site	**Annual Effective Dose** (mSv/year) **2004-05**
1	HIFAR fence - south east	1.12 ± 0.04
2	HIFAR fence - south	3.00 ± 0.11
3	Perimeter fence - west	2.77 ± 0.11
4	HIFAR fence - west	1.41 ± 0.05
5	HIFAR fence - north west	1.26 ± 0.05
6	Perimeter fence - north A	0.98 ± 0.04
7	Internal fence - north	1.00 ± 0.04
8	Perimeter fence - north B	0.95 ± 0.04
9	Perimeter fence - north east	0.93 ± 0.04
10	Perimeter fence - east	1.00 ± 0.04
11	Perimeter fence - south east	0.92 ± 0.03
12	Corner of Curie and Roentgen St	1.15 ± 0.04
13	Perimeter fence - south	0.83 ± 0.03
14	HIFAR fence - east	1.15 ± 0.04
15	HIFAR fence - north east	1.28 ± 0.05
	Dosimeter Location: off-site	
16	Private house - Barden Ridge	1.06 ± 0.04
17	Private house - Yarrawarra	1.05 ± 0.04
18	Private house - Woronora	1.31 ± 0.05
19	Cronulla Sewage Treatment Plant	0.70 ± 0.03
20	LFBG trenches near MB16	0.94 ± 0.04
21	LFBG background	1.08 ± 0.04
22	Lucas Heights Landfill Depot	0.98 ± 0.04

Notes:
- Refer to Figure 2 for the current locations of dosimeters 1 to 15 at the LHSTC.
- Monitoring at locations 20, 21 and 22 commenced in 2004-05. Dosimeter number 18 was relocated within the same house in January 2005.
- The uncertainties have been estimated (at the 95% confidence level) from the standard deviation of the results for several dosimeters placed at the same location.
- The data (absorbed dose to air in mGy) were converted to effective dose for adults (mSv) using a conservative conversion factor of 1.

Table 11. ANNUAL EFFECTIVE DOSE FROM EXTERNAL GAMMA RADIATION, NMC AND LOCAL AREA, July 2004 to June 2005

ANSTO Environmental Thermoluminescent Dosimeters		
	Dosimeter Location	**Annual Effective Dose** (mSv/year) **2004-05**
1	Front entrance	1.98 ± 0.08
2	East wall	1.66 ± 0.06
3	Stair on north wall	1.82 ± 0.07
4	West wall	1.81 ± 0.07

Notes:
- The uncertainties have been estimated (at the 95% confidence level) from the standard deviation of the results for several dosimeters placed at the same location.
- The data (absorbed dose to air in mGy) were converted to effective dose for adults (mSv) using a conservative conversion factor of 1.

Table 12. TRITIUM IN STORMWATER BUNDS, MONTHLY COMPOSITES, LHSTC July 2004 to June 2005

	TRITIUM (Bq/L)		
Month	**BUND A**	**BUND B**	**BUND C**
Jul 2004	130 ± 10	100 ± 10	80 ± 10
Aug 2004	210 ± 10	70 ± 10	130 ± 10
Sep 2004	200 ± 10	90 ± 10	120 ± 10
Oct 2004	190 ± 10	20 ± 10	60 ± 10
Nov 2004	260 ± 10	30 ± 10	90 ± 10
Dec 2004	260 ± 10	60 ± 10	60 ± 10
Jan 2005	210 ± 10	130 ± 10	100 ± 10
Feb 2005	400 ± 20	70 ± 10	200 ± 10
Mar 2005	430 ± 20	30 ± 10	110 ± 10
Apr 2005	400 ± 20	180 ± 10	90 ± 10
May 2005	70 ± 10	100 ± 10	110 ± 10
Jun 2005	220 ± 10	80 ± 10	100 ± 10

Notes:
- Refer to Figure 3 for the locations of the bunds. One litre was collected daily from each bund. Aliquots of each daily sample were combined to form a monthly composite from each bund for tritium analysis.

Table 13. RADIOACTIVITY IN SURFACE WATER, OPAL SEDIMENT TRAPS, LHSTC, July 2004 to June 2005

Bund Location	Date	Gross Alpha	Gross Beta	RADIOACTIVITY (Bq/L) Gamma-emitters					Tritium
				Am-241	Be-7	Cs-137	Co-60	K-40	
North	19-7-04	0.16 ± 0.02	0.33 ± 0.02	< MDA	< MDA	< MDA	< MDA	< MDA	20 ± 10
	1-10-04	0.09 ± 0.02	0.16 ± 0.01	< MDA	1.020 ± 0.158	< MDA	< MDA	< MDA	20 ± 10
	2-2-05	0.23 ± 0.03	0.32 ± 0.02	< MDA	1.223 ± 0.183	< MDA	< MDA	0.651 ± 0.199	< MDA
	4-4-05	0.04 ± 0.01	0.14 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA	30 ± 10
South West	19-7-04	0.16 ± 0.03	0.45 ± 0.02	< MDA	< MDA	< MDA	< MDA	< MDA	20 ± 10
	1-10-04	0.11 ± 0.02	0.21 ± 0.01	< MDA	1.965 ± 0.249	0.017 ± 0.006	< MDA	0.649 ± 0.106	40 ± 10
	2-2-05	0.17 ± 0.03	0.35 ± 0.02	< MDA	1.069 ± 0.167	< MDA	< MDA	< MDA	< MDA
	4-4-05	0.06 ± 0.01	0.14 ± 0.01	< MDA	0.523 ± 0.102	< MDA	< MDA	< MDA	< MDA

Notes:
- The NSW Regulations (*Prot. Env. Operations Act* 1997) limits for radioactivity in Class C waters are: gross alpha 1.1 Bq/L; gross beta 11.1 Bq/L.
- The gross beta results include the contribution from K-40 (a natural beta-gamma emitter). Be-7 is also of natural origin.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 14. TRITIUM IN STORMWATER, BUND C, LHSTC, July 2004 to June 2005

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
6-7-04	80 ± 10	9-11-04	70 ± 10	15-3-05	90 ± 10
13-7-04	140 ± 10	16-11-04	100 ± 10	22-3-05	70 ± 10
20-7-04	100 ± 10	23-11-04	110 ± 10	29-3-05	170 ± 10
27-7-04	70 ± 10	30-11-04	130 ± 10	5-4-05	40 ± 10
3-8-04	70 ± 10	7-12-04	10 ± 10	12-4-05	20 ± 10
10-8-04	80 ± 10	14-12-04	90 ± 10	19-4-05	100 ± 10
17-8-04	20 ± 10	21-12-04	40 ± 10	26-4-05	90 ± 10
24-8-04	240 ± 10	30-12-04	20 ± 10	4-5-05	100 ± 10
31-8-04	130 ± 10	4-1-05	50 ± 10	10-5-05	80 ± 10
9-9-04	230 ± 10	11-1-05	30 ± 10	17-5-05	20 ± 10
14-9-04	140 ± 10	18-1-05	20 ± 10	24-5-05	160 ± 10
21-9-04	100 ± 10	25-1-05	90 ± 10	31-5-05	150 ± 10
28-9-04	70 ± 10	1-2-05	30 ± 10	7-6-05	30 ± 10
5-10-04	140 ± 10	8-2-05	100 ± 10	14-6-05	10 ± 10
12-10-04	110 ± 10	15-2-05	50 ± 10	21-6-05	10 ± 10
19-10-04	40 ± 10	22-2-05	180 ± 10	28-6-05	60 ± 10
26-10-04	40 ± 10	1-3-05	60 ± 10		
2-11-04	60 ± 10	8-3-05	120 ± 10		

Notes:
- Refer to Figure 3 for the location of this sampling point. The weekly grab samples were also combined into monthly composite samples and analysed for gross alpha, gross beta and gamma activity.

Table 15. TRITIUM IN SURFACE WATER, MDP+60m, LHSTC, July 2004 to June 2005

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
6-7-04	70 ± 10	9-11-04	70 ± 10	15-3-05	80 ± 10
13-7-04	80 ± 10	16-11-04	100 ± 10	22-3-05	80 ± 10
20-7-04	80 ± 10	23-11-04	110 ± 10	29-3-05	130 ± 10
27-7-04	70 ± 10	30-11-04	110 ± 10	5-4-05	50 ± 10
3-8-04	60 ± 10	7-12-04	40 ± 10	12-4-05	30 ± 10
10-8-04	80 ± 10	14-12-04	70 ± 10	19-4-05	90 ± 10
17-8-04	20 ± 10	21-12-04	50 ± 10	26-4-05	90 ± 10
24-8-04	140 ± 10	30-12-04	30 ± 10	4-5-05	70 ± 10
31-8-04	100 ± 10	4-1-05	30 ± 10	10-5-05	60 ± 10
9-9-04	80 ± 10	11-1-05	50 ± 10	17-5-05	20 ± 10
14-9-04	110 ± 10	18-1-05	30 ± 10	24-5-05	100 ± 10
21-9-04	70 ± 10	25-1-05	80 ± 10	31-5-05	80 ± 10
28-9-04	60 ± 10	1-2-05	40 ± 10	7-6-05	60 ± 10
5-10-04	110 ± 10	8-2-05	130 ± 10	14-6-05	30 ± 10
12-10-04	170 ± 10	15-2-05	60 ± 10	21-6-05	50 ± 10
19-10-04	20 ± 10	22-2-05	150 ± 10	28-6-05	80 ± 10
26-10-04	40 ± 10	1-3-05	80 ± 10		
2-11-04	50 ± 10	8-3-05	110 ± 10		

Notes:
- Refer to Figure 3 for the location of this sampling point, 60m downstream of MDP Bund C.

Table 16. TRITIUM IN SURFACE WATER, BARDENS CREEK WEIR, LHSTC, July 2004 to June 2005

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
6-7-04	50 ± 10	9-11-04	50 ± 10	15-3-05	70 ± 10
13-7-04	110 ± 10	16-11-04	40 ± 10	22-3-05	210 ± 10
20-7-04	70 ± 10	23-11-04	60 ± 10	29-3-05	110 ± 10
27-7-04	60 ± 10	30-11-04	50 ± 10	5-4-05	180 ± 10
3-8-04	60 ± 10	7-12-04	80 ± 10	12-4-05	90 ± 10
10-8-04	60 ± 10	14-12-04	70 ± 10	19-4-05	100 ± 10
17-8-04	440 ± 20	21-12-04	90 ± 10	26-4-05	260 ± 10
24-8-04	120 ± 10	30-12-04	60 ± 10	4-5-05	90 ± 10
31-8-04	120 ± 10	4-1-05	150 ± 10	10-5-05	70 ± 10
9-9-04	120 ± 10	11-1-05	320 ± 20	17-5-05	60 ± 10
14-9-04	80 ± 10	18-1-05	90 ± 10	24-5-05	90 ± 10
21-9-04	60 ± 10	25-1-05	150 ± 10	31-5-05	50 ± 10
28-9-04	40 ± 10	1-2-05	130 ± 10	7-6-05	50 ± 10
5-10-04	80 ± 10	8-2-05	110 ± 10	14-6-05	60 ± 10
12-10-04	50 ± 10	15-2-05	100 ± 10	21-6-05	40 ± 10
19-10-04	30 ± 10	22-2-05	150 ± 10	28-6-05	1190 ± 30
26-10-04	20 ± 10	1-3-05	90 ± 10		
2-11-04	70 ± 10	8-3-05	90 ± 10		

Notes:
- Refer to Figure 3 for the location of this sampling point.

Table 17. RADIOACTIVITY IN STORMWATER, BUND C MONTHLY COMPOSITES, LHSTC, July 2004 to June 2005

Month	Gross Alpha (Bq/L)	Gross Beta (Bq/L)	Gamma-emitters (Bq/L) Am-241	Be-7	Cs-137	Co-60	I-131	K-40
Jul 2004	0.05 ± 0.01	0.68 ± 0.01	< MDA	0.108 ± 0.028	0.073 ± 0.009	< MDA	< MDA	0.145 ± 0.048
Aug 2004	0.02 ± 0.01	0.49 ± 0.01	< MDA	0.331 ± 0.047	0.065 ± 0.008	< MDA	< MDA	0.113 ± 0.036
Sep 2004	< MDA	0.46 ± 0.01	< MDA	0.552 ± 0.071	0.054 ± 0.007	< MDA	0.115 ± 0.032	< MDA
Oct 2004	< MDA	0.42 ± 0.01	< MDA	0.165 ± 0.033	0.019 ± 0.004	< MDA	< MDA	< MDA
Nov 2004	< MDA	0.23 ± 0.01	< MDA	0.315 ± 0.044	0.018 ± 0.003	< MDA	< MDA	0.080 ± 0.034
Dec 2004	0.02 ± 0.01	0.20 ± 0.01	< MDA	0.145 ± 0.031	0.016 ± 0.003	< MDA	< MDA	< MDA
Jan 2005	0.02 ± 0.01	0.09 ± 0.01	< MDA	0.307 ± 0.050	0.011 ± 0.003	< MDA	< MDA	0.126 ± 0.047
Feb 2005	0.01 ± 0.01	0.19 ± 0.01	< MDA	0.095 ± 0.025	0.013 ± 0.003	< MDA	< MDA	< MDA
Mar 2005	< MDA	0.24 ± 0.01	< MDA	0.112 ± 0.003	0.014 ± 0.003	< MDA	< MDA	0.106 ± 0.039
Apr 2005	0.02 ± 0.01	0.13 ± 0.01	< MDA	0.242 ± 0.046	0.008 ± 0.003	< MDA	< MDA	< MDA
May 2005	0.02 ± 0.01	0.21 ± 0.01	< MDA	0.101 ± 0.029	0.011 ± 0.002	< MDA	< MDA	< MDA
Jun 2005	< MDA	0.10 ± 0.01	< MDA	0.167 ± 0.033	< MDA	< MDA	< MDA	0.199 ± 0.039

Notes:
- Refer to Figure 3 for the MDP Bund C sampling location. The weekly samples were analysed for tritium then combined to make the monthly composites, reported above.
- The NSW Regulations (*Prot. Env. Operations Act* 1997) limits for radioactivity in Class C waters are: gross alpha 1.1 Bq/L; gross beta 11.1 Bq/L.
- The gross beta results include the contribution from K-40 (a natural beta-gamma emitter). Be-7 is also of natural origin.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 18. RADIOACTIVITY IN SURFACE WATER, MDP+60m MONTHLY COMPOSITES, LHSTC, July 2004 to June 2005

			Gamma-emitters (Bq/L)				
Month	**Gross Alpha** (Bq/L)	**Gross Beta** (Bq/L)	**Am-241**	**Be-7**	**Cs-137**	**Co-60**	**K-40**
Jul 2004	0.04 ± 0.01	0.24 ± 0.01	< MDA	< MDA	0.013 ± 0.004	< MDA	< MDA
Aug 2004	0.02 ± 0.01	0.40 ± 0.01	< MDA	0.099 ± 0.027	0.019 ± 0.003	< MDA	< MDA
Sep 2004	0.02 ± 0.01	0.21 ± 0.01	< MDA	< MDA	0.019 ± 0.004	< MDA	< MDA
Oct 2004	0.03 ± 0.01	0.30 ± 0.01	< MDA	0.145 ± 0.031	0.018 ± 0.003	< MDA	< MDA
Nov 2004	0.02 ± 0.01	0.26 ± 0.01	< MDA	0.130 ± 0.025	0.019 ± 0.003	< MDA	0.076 ± 0.033
Dec 2004	0.02 ± 0.01	0.19 ± 0.01	< MDA	0.139 ± 0.023	0.022 ± 0.003	< MDA	< MDA
Jan 2005	0.01 ± 0.01	0.13 ± 0.01	< MDA	0.248 ± 0.043	0.018 ± 0.003	< MDA	0.097 ± 0.047
Feb 2005	0.02 ± 0.01	0.19 ± 0.01	< MDA	< MDA	0.015 ± 0.003	< MDA	< MDA
Mar 2005	0.02 ± 0.01	0.22 ± 0.01	< MDA	< MDA	0.013 ± 0.003	< MDA	< MDA
Apr 2005	0.02 ± 0.01	0.14 ± 0.01	< MDA	0.086 ± 0.033	0.010 ± 0.003	< MDA	< MDA
May 2005	0.02 ± 0.01	0.12 ± 0.01	< MDA	< MDA	0.010 ± 0.002	< MDA	0.078 ± 0.034
Jun 2005	0.01 ± 0.01	0.15 ± 0.01	< MDA	0.238 ± 0.114	0.008 ± 0.003	< MDA	< MDA

Notes:
- Refer to Figure 3 for the location of this sampling point, 60m downstream of the MDP Bund. The weekly samples were analysed for tritium, then combined to make the monthly composites, reported above.
- The NSW Regulations (*Prot. Env. Operations Act* 1997) limits for radioactivity in Class C waters are: gross alpha 1.1 Bq/L; gross beta 11.1 Bq/L.
- The gross beta results include the contribution from K-40 (a natural beta-gamma emitter). Be-7 is also of natural origin.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 19. RADIOACTIVITY IN SURFACE WATER, SPCC SAMPLING POINTS, LHSTC, July 2004 to June 2005

	Strassman Creek		Bardens Creek Weir		MDP Creek		South East of Bld 35B	
Month	**Gross Alpha** (Bq/L)	**Gross Beta** (Bq/L)	**Gross Alpha** (Bq/L)	**Gross Beta** (Bq/L)	**Gross Alpha** (Bq/L)	**Gross Beta** (Bq/L)	**Gross Alpha** (Bq/L)	**Gross Beta** (Bq/L)
Jul 2004	0.02 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.06 ± 0.01	0.02 ± 0.01	0.13 ± 0.01	0.02 ± 0.01	0.06 ± 0.01
Aug 2004	0.01 ± 0.01	0.02 ± 0.01	< MDA	0.03 ± 0.01	< MDA	0.11 ± 0.01	< MDA	0.04 ± 0.01
Sep 2004	0.01 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	< MDA	0.10 ± 0.01	0.03 ± 0.01	0.04 ± 0.01
Oct 2004	0.02 ± 0.01	0.02 ± 0.01	< MDA	0.08 ± 0.01	< MDA	0.13 ± 0.01	< MDA	< MDA
Nov 2004	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.06 ± 0.01	< MDA	0.15 ± 0.01	< MDA	< MDA
Dec 2004	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.13 ± 0.01	0.04 ± 0.02	0.05 ± 0.01
Jan 2005	0.01 ± 0.01	0.04 ± 0.01	< MDA	0.02 ± 0.01	< MDA	0.17 ± 0.01	0.03 ± 0.02	0.03 ± 0.01
Feb 2005	< MDA	0.04 ± 0.01	< MDA	0.01 ± 0.01	0.01 ± 0.01	0.14 ± 0.01	< MDA	< MDA
Mar 2005	0.01 ± 0.01	0.03 ± 0.01	< MDA	0.01 ± 0.01	0.01 ± 0.01	0.15 ± 0.01	< MDA	< MDA
Apr 2005	0.01 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.10 ± 0.01	< MDA	0.01 ± 0.01
May 2005	0.01 ± 0.01	0.03 ± 0.01	< MDA	0.02 ± 0.01	0.01 ± 0.01	0.10 ± 0.01	< MDA	0.03 ± 0.01
Jun 2005	< MDA	0.03 ± 0.01	< MDA	0.02 ± 0.01	0.02 ± 0.01	0.38 ± 0.01	< MDA	0.03 ± 0.01

Notes:
- See Figure 3 for the location of the SPCC sampling points.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.
- All gross beta results include the beta activity due to natural K-40.
- The NSW Regulations (*Prot. Env. Operations Act 1997*) limits for radioactivity in Class C waters are: gross alpha 1.1 Bq/L; gross beta 11.1 Bq/L.

Table 20. RADIOACTIVITY IN CREEKS NORTH OF THE LFBG, July 2004 to June 2005

WATER (Bq/L)

Location	Date Sampled	Gross Alpha	Gross Beta	Gamma-emitters				Tritium
				Am-241	Cs-137	Co-60	K-40	
Mill Creek	24-11-04	0.02 ± 0.01	0.29 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
Bardens Creek	24-11-04	0.01 ± 0.01	0.09 ± 0.01	< MDA	< MDA	< MDA	< MDA	20 ± 10

SEDIMENT (Bq/g DW)

Location	Date Sampled	Gross Alpha	Gross Beta	Gamma-emitters				
				Am-241	Cs-137	Co-60	K-40	Be-7
Mill Creek	24-11-04	0.26 ± 0.10	0.10 ± 0.02	< MDA	< MDA	< MDA	0.033 ± 0.008	< MDA
Bardens Creek	24-11-04	0.47 ± 0.11	0.13 ± 0.02	< MDA	< MDA	< MDA	0.048 ± 0.009	< MDA

Notes:
- See Figure 1 for the location of these sampling points.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 21. TRITIUM IN WATERS, WORONORA RIVER, July 2004 to June 2005

Month	**Tritium** (Bq/L)		
	Estuary Station E5.9	**Causeway**	**Heathcote Rd Bridge**
Jul 2004	< MDA	< MDA	< MDA
Aug 2004	< MDA	< MDA	< MDA
Sep 2004	< MDA	< MDA	< MDA
Oct 2004	< MDA	< MDA	< MDA
Nov 2004	< MDA	< MDA	< MDA
Dec 2004	< MDA	< MDA	< MDA
Jan 2005	< MDA	< MDA	< MDA
Feb 2005	< MDA	< MDA	< MDA
Mar 2005	< MDA	< MDA	< MDA
Apr 2005	< MDA	< MDA	< MDA
May 2005	< MDA	< MDA	< MDA
Jun 2005	< MDA	< MDA	< MDA

Notes:
- Figure 1 shows the sampling locations. Station E5.9 and the Causeway are downstream of ANSTO whilst the Heathcote Rd Bridge location is upstream.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence.

Table 22. FIELD PARAMETERS IN GROUNDWATER, LHSTC, August 2004

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	8.93	20.1	34	5.2	160
MW1D	-	-	-	-	-	-
MW2S	7	3.42	17.1	29	5.2	260
MW2D	14	3.41	17.7	45	6.0	150
MW3S	7	2.10	16.8	37	4.4	350
MW3D	20	12.25	18.1	53	6.0	110
MW4S	7	1.50	15.4	143	7.7	20
MW4D	24	4.53	17.6	39	6.1	140
MW5S	9	3.50	20.7	32	5.1	240
MW6S	9	4.12	17.1	27	6.6	120
MW6D	24	6.90	18.4	47	6.4	100
MW7S	6	4.51	19.8	30	6.6	140
MW7D	20	14.05	18.1	73	4.4	380
MW8S	-	-	-	-	-	-
MW8D	27	23.25	18.3	22	5.7	200
MW9S	18	13.16	19.5	39	4.9	280
MW9D	21	13.16	19.0	47	4.9	320
MW10S	10	3.90	18.9	40	5.7	240
MW11-2	20	13.86	19.9	48	5.4	190
MW13	24	15.41	19.8	47	4.3	350
MW14	23	13.95	18.4	51	5.8	160
MW15S	10	3.41	17.8	48	4.9	270
MW15D	15	7.24	18.2	39	5.5	200
BH3	-	-	-	-	-	-
BH3A	13	10.70	18.0	43	4.8	250
BH6	14	10.22	20.1	49	7.0	80
BH112	25	20.83	19.5	58	6.2	160

Notes:
- MW1D was not sampled as piezometer was damaged.
- MW8S was not sampled as piezometer was dry.
- Data for BH3 were compromised due to casing damage hence are not reported.
- Field parameters were measured five times (the average reading is given) using a flowcell and a calibrated water quality analyser probe.
- SWL - Standing water level.
- mBTOC - metres below the top of the piezometer casing.
- EC - electrical conductivity, measured in micro Siemens per centimetre.
- Eh - oxidation/reduction potential measured in millivolts.

Table 23. FIELD PARAMETERS IN GROUNDWATER, LHSTC, December 2004

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	8.40	19.8	195	4.2	240
MW1D	-	-	-	-	-	-
MW2S	7	2.91	18.4	102	4.6	240
MW2D	25	3.73	18.2	164	5.6	210
MW3S	6	1.96	18.8	139	4.2	270
MW3D	23	8.83	18.5	166	5.4	200
MW4S	5	1.59	19.1	529	6.5	80
MW4D	23	4.19	18.2	142	5.6	230
MW5S	7	4.22	21.0	63	5.1	270
MW6S	6	3.82	19.3	80	5.8	260
MW6D	13	9.21	18.9	161	5.4	200
MW7S	5	4.18	21.5	107	4.9	270
MW7D	20	13.57	20.0	276	3.8	290
MW8S	-	-	-	-	-	-
MW8D	28	23.28	20.6	76	5.6	310
MW9S	14	11.04	19.9	138	4.2	330
MW9D	14	12.83	20.8	151	4.6	330
MW10S	6	3.27	19.7	93	5.7	190
MW11-2	20	14.85	22.3	158	4.7	230
MW13	25	15.61	21.2	166	4.0	290
MW14	20	14.00	20.4	202	5.0	240
MW15S	8	2.89	18.5	161	4.5	250
MW15D	14	5.04	18.6	134	5.1	260
BH3	-	-	-	-	-	-
BH3A	14	10.45	20.5	150	4.6	270
BH6	14	10.07	19.5	136	6.3	260
BH112	25	21.29	25.6	184	5.4	160

Notes:
- MW1D was not sampled as piezometer was damaged.
- MW8S was not sampled as piezometer was dry.
- Data for BH3 are compromised due to casing damage hence are not reported.
- Field parameters were measured five times (the average reading is given) using a flowcell and a calibrated water quality analyser probe.
- SWL - Standing water level.
- mBTOC - metres below the top of the piezometer casing.
- EC - electrical conductivity, measured in micro Siemens per centimetre.
- Eh - oxidation/reduction potential measured in millivolts.

Table 24. FIELD PARAMETERS IN GROUNDWATER, LHSTC, February 2005

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	8.46	21.4	352	4.5	280
MW1D	-	-	-	-	-	-
MW2S	5	3.31	19.7	193	4.7	200
MW2D	11	7.18	18.1	293	5.2	160
MW3S	5	2.22	20.2	282	4.0	390
MW3D	20	15.48	18.5	324	5.4	200
MW4S	5	1.72	20.7	867	6.4	70
MW4D	10	4.27	18.6	261	5.4	100
MW5S	6	4.56	22.7	164	4.7	240
MW6S	7	3.92	21.2	155	5.7	210
MW6D	23	20.16	19.0	293	5.4	200
MW7S	5	3.36	21.9	212	4.9	210
MW7D	20	14.20	18.7	535	3.9	420
MW8S	-	-	-	-	-	-
MW8D	26	23.37	21.3	111	5.3	290
MW9S	17	10.24	19.0	282	4.3	280
MW9D	20	12.74	18.6	320	4.4	220
MW10S	10	3.38	20.8	268	5.1	230
MW11-2	15	12.56	20.5	341	4.5	280
MW13	20	15.58	20.2	309	4.1	220
MW14	20	13.61	19.5	390	5.1	160
MW15S	7	2.89	20.6	314	4.4	250
MW15D	12	7.33	19.3	246	5.2	230
BH3	-	-	-	-	-	-
BH3A	bailed	10.44	18.8	311	4.7	250
BH6	-	-	-	-	-	-
BH112	24	21.14	19.9	378	4.8	180

Notes:
- MW1D and BH6 were not sampled as piezometers were damaged.
- MW8S was not sampled as piezometer was dry.
- Data for BH3 were compromised due to casing damage hence are not reported.
- BH3A was sampled using a hand bailer.
- Field parameters were measured five times (the average reading is given) using a flowcell and a calibrated water quality analyser probe.
- SWL - Standing water level.
- mBTOC - metres below the top of the piezometer casing.
- EC - electrical conductivity, measured in micro Siemens per centimetre.
- Eh - oxidation/reduction potential measured in millivolts.

Table 25. FIELD PARAMETERS IN GROUNDWATER, LHSTC, May 2005

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	8.69	18.8	300	4.4	210
MW1D	-	-	-	-	-	-
MW2S	7	3.29	18.7	191	5.0	110
MW2D	25	6.09	18.1	313	5.4	90
MW3S	5	2.17	20.1	291	4.0	210
MW3D	19	12.97	19.1	352	5.5	120
MW4S	6	1.62	19.0	855	6.5	40
MW4D	8	4.28	19.3	265	5.4	150
MW5S	8	4.29	22.4	204	4.7	140
MW6S	8	3.98	20.3	207	5.8	140
MW6D	13	5.80	19.9	343	5.4	120
MW7S	6	4.67	18.9	178	4.7	60
MW7D	18	13.60	19.5	545	3.8	340
MW8S	-	-	-	-	-	-
MW8D	26	23.45	18.8	126	5.5	130
MW9S	15	11.06	17.8	279	4.1	290
MW9D	16	12.96	17.9	324	4.5	260
MW10S	-	-	-	-	-	-
MW11-2	14	9.31	20.0	326	4.4	160
MW13	20	15.58	20.4	361	4.0	190
MW14	20	13.33	19.0	383	4.6	210
MW15S	7	2.93	19.4	311	4.3	270
MW15D	15	9.69	18.4	237	5.5	190
BH3	-	-	-	-	-	-
BH3A	13	10.31	18.3	298	4.4	200
BH6	-	-	-	-	-	-
BH112	24	20.05	18.5	365	4.9	200

Notes:
- MW1D, MW10s, BH3 and BH6 were not sampled as these piezometers were damamged.
- MW8S was not sampled as piezometer was dry.
- Field parameters were measured five times (the average reading is given) using a flowcell and a calibrated water quality analyser probe.
- SWL - Standing water level.
- mBTOC - metres below the top of the piezometer casing.
- EC - electrical conductivity, measured in micro Siemens per centimetre.
- Eh - oxidation/reduction potential measured in millivolts.

Table 26. MAJOR IONS IN GROUNDWATER, LHSTC, August 2004

Piezometer	Na^+ (mg/L)	K^+ (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)
MW1S	30.7	3.22	4.14	0.42	55	13	7
MW1D	-	-	-	-	-	-	-
MW2S	27.3	0.30	4.86	0.71	48	8	32
MW2D	35.5	0.98	6.26	1.56	72	8	36
MW3S	34.4	1.04	3.46	0.62	57	17	<1
MW3D	42.3	1.53	9.54	4.43	73	8	294
MW4S	47.1	1.32	23.60	91.10	57	160	2940
MW4D	30.2	0.62	5.37	0.77	57	7	30
MW5S	29.2	0.80	4.17	2.15	43	12	61
MW6S	12.7	0.68	2.55	18.90	16	24	337
MW6D	52.5	0.85	2.37	3.26	71	3	160
MW7S	33.7	1.79	4.81	2.21	37	40	1
MW7D	65.4	1.11	9.00	1.50	120	17	<1
MW8S	-	-	-	-	-	-	-
MW8D	19.7	0.69	2.19	2.72	35	5	30
MW9S	31.4	0.40	3.64	0.70	59	7	<1
MW9D	43.3	1.01	5.47	2.58	73	15	<1
MW10S	29.2	0.92	2.05	10.40	51	10	185
MW11-2	48.6	1.04	5.08	1.50	70	12	42
MW13	37.2	0.68	4.49	0.58	69	8	<1
MW14	53.6	1.44	7.40	2.44	73	23	66
MW15S	46.5	0.82	4.00	2.17	61	20	<1
MW15D	37.7	1.39	4.06	2.59	43	23	70
BH3	-	-	-	-	-	-	-
BH3A	41.7	0.44	4.03	1.39	58	11	8
BH6	25.2	4.44	2.27	27.80	20	25	770
BH112	44.4	1.29	7.71	2.27	86	5	<1

Notes:
- Cation concentrations (Na, K, Mg, Ca) are for dissolved ions.
- Anion concentrations (Cl, SO_4, HCO_3) include dissolved and undissolved ions.
- MW1D was not sampled as piezometer was damaged.
- MW8S was not sampled as piezometer was dry.
- Data for BH3 were compromised due to casing damage hence are not reported.

Table 27. RADIOACTIVITY IN GROUNDWATER, LHSTC, August 2004

RADIOACTIVITY (Bq/L)								
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MW1S	27-08-04	0.02 ± 0.01	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	20.4 ± 0.6
MW1D	-	-	-	-	-	-	-	-
MW2S	29-08-04	< MDA	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	68.9 ± 0.8
MW2D	29-08-04	0.03 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW3S	27-08-04	0.07 ± 0.01	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	22.9 ± 0.6
MW3D	27-08-04	0.03 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW4S	3-09-04	0.05 ± 0.02	0.06 ± 0.02	< MDA	< MDA	< MDA	< MDA	2.5 ± 0.5
MW4D	3-09-04	0.03 ± 0.01	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW5S	29-08-04	0.04 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	11.0 ± 0.5
MW6S	3-09-04	0.01 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	79.7 ± 0.8
MW6D	3-09-04	0.02 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	35.9 ± 0.7
MW7S	8-09-04	0.05 ± 0.01	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	20.8 ± 0.6
MW7D	3-09-04	0.18 ± 0.02	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	1.5 ± 0.6
MW8S	-	-	-	-	-	-	-	-
MW8D	6-09-04	0.01 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW9S	27-08-04	0.07 ± 0.01	0.04 ± 0.01	< MDA	< MDA	< MDA	< MDA	7.7 ± 0.5
MW9D	27-08-04	0.10 ± 0.01	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	7.7± 0.5
MW10S	29-08-04	< MDA	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	16.4 ± 0.6
MW11-2	7-09-04	0.03 ± 0.01	0.04 ± 0.01	< MDA	< MDA	< MDA	< MDA	36.9 ± 0.7
MW13	29-08-04	0.14 ± 0.01	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW14	7-09-04	0.04 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	27.4 ± 0.6
MW15S	7-09-04	0.11 ± 0.01	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	4.3 ± 0.5
MW15D	7-09-04	0.07 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	37.3 ± 0.7
BH3	-	-	-	-	-	-	-	-
BH3A	7-09-04	0.08 ± 0.01	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	13.8 ± 0.6
BH6	27-08-04	0.02 ± 0.01	0.09 ± 0.01	< MDA	< MDA	< MDA	< MDA	19.2 ± 0.6
BH12	27-08-04	0.05 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA

Notes:
- Gross beta activity includes any contribution from natural K-40. Tritium analyses were performed in ANSTO's low-level facility for greater sensitivity (MDA was 2.3 Bq/L).
- MW1D was not sampled as piezometer was damaged.
- MW8S was not sampled as piezometer was dry.
- Data for BH3 were compromised due to casing damage hence are not reported.
- < MDA: indicates that the result was below the minimal detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 28. NUTRIENTS IN GROUNDWATER, LHSTC, August 2004

Piezometer	Ammonia NH_3-N (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Oxidized Nitrogen: NO_x-N (mg/L)	Total Nitrogen (mg/L)	Soluble Reactive Phosphorous (mg/L)	Total Phosphorus (mg/L)
MW1S	0.05	0.61	0.01	0.62	0.003	0.066
MW1D	-	-	-	-	-	-
MW2S	< MDL	0.11	0.02	0.13	< MDL	0.009
MW2D	< MDL	< MDL	0.01	< MDL	< MDL	0.013
MW3S	< MDL	0.10	0.07	0.17	0.002	0.008
MW3D	0.02	< MDL	< MDL	< MDL	< MDL	0.014
MW4S	0.10	0.36	0.02	0.38	0.002	0.007
MW4D	< MDL	< MDL	< MDL	< MDL	< MDL	0.027
MW5S	0.02	0.12	0.10	0.22	< MDL	0.010
MW6S	< MDL	0.22	0.15	0.37	0.002	0.015
MW6D	0.02	0.15	0.01	0.16	0.002	0.190
MW7S	-	-	-	-	-	-
MW7D	0.01	< MDL	0.01	< MDL	0.002	0.045
MW8S	-	-	-	-	-	-
MW8D	< MDL	< MDL	0.04	< MDL	< MDL	0.025
MW9S	< MDL	< MDL	0.03	< MDL	0.002	0.071
MW9D	< MDL	< MDL	0.01	< MDL	< MDL	0.006
MW10S	0.08	0.15	0.14	0.29	< MDL	0.014
MW11-2	0.01	< MDL	0.14	0.14	0.002	0.006
MW13	0.01	< MDL	0.03	< MDL	< MDL	0.009
MW14	0.01	< MDL	0.01	< MDL	0.002	0.013
MW15S	< MDL	< MDL	0.24	0.24	0.003	0.005
MW15D	< MDL	< MDL	0.03	< MDL	< MDL	0.004
BH3	-	-	-	-	-	-
BH3A	< MDL	< MDL	0.10	0.10	0.002	0.006
BH6	0.19	0.31	0.06	0.37	0.002	0.028
BH112	< MDL	< MDL	0.01	< MDL	< MDL	0.011

Notes:
- Samples were unfiltered except soluble reactive phosphorus (0.45 µm filtered).
- Total nitrogen = Nox-N plus total Kjeldahl nitrogen.
- MW1D was not sampled as the piezometer was damaged, and there was insufficent volume in piezometer MW7S to collect a sample.
- MW8S was not sampled as piezometer was dry.
- Data for BH3 were compromised due to casing damage hence are not reported.
- < MDL indicates that the result was below the Method Detection Limit. MDL values in mg/L for the relevant analyses were as follows: 0.01 for ammonia, 0.10 for total kjeldahl and total nitrogen analyses, 0.01 for oxidized nitrogen and 0.002 for phosphorus.

Table 29. HYDROCARBONS IN GROUNDWATER, LHSTC, August 2004

	HYDROCARBONS								
	Monocyclic Aromatic Hydrocarbons (µg/L)					**Volatile TPH**	**Total Petroleum Hydrocarbons** (µg/L)		
Piezometer	Benzene	Toluene	Ethyl benzene	m- & p-Xylene	o-Xylene	C_6-C_9	C_{10}-C_{14}	C_{15}-C_{28}	C_{29}-C_{36}
MW5S	< EQL	< EQL	< EQL	< EQL	< EQL	< EQL	< EQL	< EQL	< EQL

Notes:
- TPH is Total Petroleum Hydrocarbons.
- < EQL indicates that the result was below the Estimated Quantitation Limit. The EQL for the monocyclic aromatic hydrocarbon analyses was 1µg/L, except for m- and p-Xylene with an EQL of 2 µg/L. The EQL for total petroleum hydrocarbons analyses was 50 µg/L except for C_{15}-C_{28} which had an EQL of 200 µg/L.

Table 30. FIELD PARAMETERS IN GROUNDWATER, LFBG, October 2004

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MB11	7	4.60	17.9	571	5.9	170
MB12	5	3.75	16.9	442	5.6	230
MB13	4	1.13	16.1	208	5.6	240
MB14	6	4.12	17.3	2745	6.2	60
MB15	6	4.89	17.6	597	5.9	130
MB16	6	3.30	17.7	367	6.2	140
MB17	4	2.81	16.7	501	5.4	270
MB18	6	4.41	17.7	1641	6.4	130
MB19	6	4.28	18.1	3801	7.6	70
MB20	5	3.85	15.5	1221	8.6	-80
MB21	4	2.73	15.7	644	7.4	80
BH10	-	-	-	-	-	-
BHF	8	3.49	17.5	2161	5.2	210
OS2	-	-	-	-	-	-
OS3	4	2.15	17.3	320	5.4	160
P1S	6	3.83	17.7	3784	4.4	330
P1D	12	4.72	18.4	7821	6.5	120
P2D	20	13.43	18.8	6575	8.6	40
CW	9	4.71	18.6	2395	5.8	190

Notes:
- SWL - Standing water level.
- mBTOC - metres below the top of the piezometer casing.
- Field parameters were measured five times (the average reading is given) using a flowcell and a calibrated water quality analyser probe.
- EC - electrical conductivity, measured in micro Siemens per centimetre.
- Eh - oxidation/reduction potential measured in millivolts.
- BH10 and OS2 were not sampled as piezometers were dry.

Table 31. FIELD PARAMETERS IN GROUNDWATER, LFBG, April 2005

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MB11	6	4.36	20.7	941	5.6	280
MB12	5	3.61	20.9	936	5.2	190
MB13	5	2.32	20.3	347	5.1	170
MB14	5	3.75	19.7	2768	5.7	150
MB15	7	4.50	20.7	520	5.7	170
MB16	6	2.66	19.8	336	5.4	100
MB17	4	2.13	20.9	452	5.5	230
MB18	6	4.28	20.0	1729	6.1	160
MB19	6	3.57	18.0	4345	6.1	50
MB20	5	2.75	17.5	967	6.4	-80
MB21	4	2.44	19.0	1636	6.3	20
BH10	4	2.24	19.9	1853	5.5	120
BHF	7	2.86	18.5	1961	5.1	140
OS2	-	-	-	-	-	-
OS3	3	1.85	20.9	309	5.1	180
P1S	6	3.76	20.6	4439	4.1	230
P1D	12	4.38	19.1	8000	5.5	60
P2D	25	13.43	18.7	4892	6.0	50
CW	10	4.60	19.3	2168	5.8	150

Notes:
- SWL - Standing water level.
- mBTOC - metres below the top of the piezometer casing.
- Field parameters were measured five times (the average reading is given) using a flowcell and a calibrated water quality analyser probe.
- EC - electrical conductivity, measured in micro Siemens per centimetre.
- Eh - oxidation/reduction potential measured in millivolts.
- OS2 was not sampled as piezometer was dry.

Table 32. RADIOACTIVITY IN GROUNDWATER, LFBG, October 2004

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MB11	8-10-04	0.02 ± 0.01	0.04 ± 0.01	< MDA	< MDA	< MDA	< MDA	MDA
MB12	8-10-04	0.02 ± 0.01	0.05 ± 0.01	< MDA	< MDA	0.017 ± 0.007	< MDA	MDA
MB13	8-10-04	0.07 ± 0.01	0.08 ± 0.01	< MDA	0.017 ± 0.006	< MDA	< MDA	780 ± 20
MB14	8-10-04	< MDA	0.14 ± 0.03	< MDA	< MDA	< MDA	< MDA	80 ± 10
MB15	8-10-04	0.07 ± 0.02	0.15 ± 0.01	< MDA	< MDA	< MDA	< MDA	40 ± 10
MB16	8-10-04	0.16 ± 0.06	0.34 ± 0.03	< MDA	< MDA	< MDA	< MDA	7840 ± 50
MB17	8-10-04	0.08 ± 0.02	0.03 ± 0.01	< MDA	< MDA	< MDA	0.381 ± 0.093	880 ± 20
MB18	8-10-04	0.08 ± 0.03	0.06 ± 0.02	< MDA	< MDA	< MDA	0.302 ± 0.121	1000 ± 20
MB19	8-10-04	< MDA	0.23 ± 0.04	< MDA	< MDA	< MDA	0.698 ± 0.143	130 ± 10
MB20	8-10-04	0.08 ± 0.03	0.22 ± 0.02	< MDA	< MDA	< MDA	0.327 ± 0.129	MDA
MB21	8-10-04	< MDA	0.10 ± 0.01	< MDA	< MDA	< MDA	0.311 ± 0.131	MDA
BH10	-	-	-	-	-	-	-	-
BHF	8-10-04	0.08 ± 0.04	0.23 ± 0.02	< MDA	< MDA	< MDA	0.596 ± 0.118	1610 ± 20
OS2	-	-	-	-	-	-	-	-
OS3	8-10-04	0.15 ± 0.01	0.20 ± 0.01	< MDA	< MDA	< MDA	< MDA	880 ± 20
CW	8-10-04	< MDA	0.25 ± 0.03	< MDA	< MDA	< MDA	< MDA	930 ± 20
P1S	8-10-04	0.45 ± 0.11	0.31 ± 0.05	< MDA	< MDA	< MDA	< MDA	10 ± 10
P1D	8-10-04	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	140 ± 10
P2D	8-10-04	< MDA	0.48 ± 0.07	< MDA	0.012 ± 0.005	< MDA	0.276 ± 0.135	120 ± 10

Notes:
- See Figure 4 for the location of the sampling piezometers.
- BH10 and OS2 were not sampled as piezometers were dry.
- Gross beta results include the contribution from natural K-40.
- < MDA indicates that the result was below the minimal detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 33. RADIOACTIVITY IN GROUNDWATER, LFBG, April 2005

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MB11	14-04-05	< MDA	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB12	15-04-05	0.52 ± 0.02	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB13	15-04-05	0.06 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	1210 ± 30
MB14	14-04-05	< MDA	0.08 ± 0.03	< MDA	< MDA	< MDA	< MDA	100 ± 10
MB15	14-04-05	< MDA	0.04 ± 0.01	< MDA	< MDA	< MDA	0.260 ± 0.125	110 ± 10
MB16	15-04-05	0.33 ± 0.02	0.42 ± 0.01	< MDA	< MDA	0.100 ± 0.021	< MDA	5110 ± 60
MB17	14-04-05	0.05 ± 0.01	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	780 ± 20
MB18	14-04-05	< MDA	0.10 ± 0.02	< MDA	< MDA	< MDA	< MDA	900 ± 30
MB19	18-04-05	< MDA	0.19 ± 0.05	< MDA	< MDA	< MDA	0.350 ± 0.135	210 ± 10
MB20	18-04-05	< MDA	0.20 ± 0.02	< MDA	< MDA	< MDA	0.499 ± 0.142	< MDA
MB21	18-04-05	< MDA	0.11 ± 0.02	< MDA	< MDA	< MDA	0.381 ± 0.123	80 ± 10
BH10	14-04-05	0.09 ± 0.04	0.11 ± 0.02	< MDA	< MDA	< MDA	< MDA	7360 ± 70
BHF	15-04-05	0.07 ± 0.03	0.19 ± 0.02	< MDA	< MDA	< MDA	< MDA	1560 ± 30
OS2	-	-	-	-	-	-	-	-
OS3	14-04-05	0.17 ± 0.02	0.20 ± 0.01	< MDA	< MDA	< MDA	< MDA	990 ± 30
CW	14-04-05	< MDA	0.15 ± 0.03	< MDA	< MDA	< MDA	< MDA	1010 ± 30
P1S	15-04-05	0.52 ± 0.13	0.32 ± 0.06	< MDA	< MDA	< MDA	0.517 ± 0.116	< MDA
P1D	15-04-05	< MDA	0.04 ± 0.01	< MDA	< MDA	< MDA	0.451 ± 0.107	160 ± 10
P2D	18-04-05	0.26 ± 0.10	0.51 ± 0.06	< MDA	< MDA	< MDA	0.444 ± 0.144	90 ± 10

Notes:
- See Figure 4 for the location of the sampling piezometers.
- OS2 was not sampled as piezometer was dry.
- Gross beta results include the contribution from natural K-40.
- < MDA: indicates that the result was below the minimal detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 34. TRITIUM IN RAINWATER, LHSTC, July 2004 to June 2005

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
13-7-04	< MDA	9-11-04	< MDA	8-3-05	< MDA
20-7-04	< MDA	16-11-04	< MDA	15-3-05	< MDA
27-7-04	< MDA	23-11-04	-	22-3-05	< MDA
3-8-04	-	30-11-04	< MDA	29-3-05	< MDA
10-8-04	-	7-12-04	< MDA	5-4-05	< MDA
17-8-04	< MDA	14-12-04	< MDA	12-4-05	< MDA
24-8-04	< MDA	21-12-04	20 ± 10	19-4-05	-
31-8-04	< MDA	28-12-04	-	26-4-05	< MDA
7-9-04	< MDA	4-1-05	< MDA	3-5-05	-
14-9-04	< MDA	11-1-05	40 ± 10	10-5-05	< MDA
21-9-04	< MDA	18-1-05	< MDA	17-5-05	< MDA
28-9-04	< MDA	25-1-05	< MDA	24-5-05	< MDA
5-10-04	< MDA	1-2-05	< MDA	31-5-05	-
12-10-04	-	8-2-05	< MDA	7-6-05	-
19-10-04	< MDA	15-2-05	< MDA	14-6-05	< MDA
26-10-04	< MDA	22-2-05	< MDA	21-6-05	120 ± 10
2-11-04	< MDA	1-3-05	-	28-6-05	20 ± 10

Notes:
- Refer to Figure 2 for the location of this sampling point.
- Dashes (-) indicate insufficient sample.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 35. GAMMA DOSE-RATE SURVEY, LFBG TRENCHES, March - April 2005

Date of Survey	Location	Dose-rate (µSv/hour)
29-3-05 to 6-4-05	Background reading (outside LFBG gate)	0.09 - 0.16
	Trenches 1-51	0.08 - 0.19
	Trenches 52-77	0.08 - 0.18
	Trenches S1 and S2	0.09 - 0.17

Notes:
- See Figure 4 for the location of the burial trenches and sampling points.

Table 36. GAMMA DOSE-RATE SURVEYS, MAIN DISCHARGE PIPELINE, LHSTC, July 2004 to June 2005

Date of Survey	Location	Dose-rate (µSv/hour)		Background Dose-rate (µSv/hour)
		Ground Below Joint	Pipe Joint	
23-9-04	Joints # 1-22	0.07 - 0.12	0.05 - 0.12	0.07 - 0.15

Notes:
- The survey excluded joints numbered 18 & 19 which are inaccessible.

Table 37. RADIOACTIVITY IN FISH, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2004 to June 2005

Location	Date Sampled	Gamma-emitters in Luderick (Bq/kg FW)					
		Am-241	**Be-7**	**I-131**	**Cs-137**	**Co-60**	**K-40**
Potter Point Ocean Outfall	13-12-04	< MDA	< MDA	< MDA	< MDA	< MDA	144 ± 15
	09-05-05	< MDA	< MDA	< MDA	< MDA	< MDA	152 ± 15
The Royal National Park Reference Site	14-12-04	< MDA	< MDA	< MDA	< MDA	< MDA	150 ± 15
	03-05-05	< MDA	< MDA	< MDA	< MDA	< MDA	139 ± 15

Notes for Tables 37, 38 and 39:
- See Figure 1 for sampling locations at the Potter Point ocean outfall and the reference site. Duplicate samples were collected where possible.
- The whole, unwashed samples of algae (*Ulva sp.*) and barnacles (*Tesseropera rosea*) were dried and ground prior to gamma spectrometry analysis.
- The fish, Luderick (*Girella sp.*) were cut into flesh fillets, dried and ground prior to gamma spectrometry analysis.
- Fresh Weight (FW): Radioactivity is in units of becquerels per kilogram of fresh (wet) sample.
- Be-7 and K-40 are of natural origin.
- < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 38. RADIOACTIVITY IN ALGAE, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2004 to June 2005

Location	Date Sampled	Gamma-emitters in Algae (Bq/kg FW)					
		Am-241	**Be-7**	**I-131**	**Cs-137**	**Co-60**	**K-40**
Potter Point Ocean Outfall	13-12-04	< MDA	< MDA	25.1 ± 2.5	< MDA	< MDA	239 ± 23
	28-04-05	< MDA	< MDA	54.6 ± 5.2	< MDA	< MDA	222 ± 21
The Royal National Park Reference Site	14-12-04	< MDA	< MDA	< MDA	< MDA	< MDA	175 ± 17
	03-05-05	< MDA	< MDA	< MDA	< MDA	< MDA	228 ± 22

Table 39. RADIOACTIVITY IN BARNACLES, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2004 to June 2005

Location	Date Sampled	Gamma-emitters in Barnacles (Bq/kg FW)					
		Am-241	**Be-7**	**I-131**	**Cs-137**	**Co-60**	**K-40**
Potter	13-12-04	< MDA	< MDA	< MDA	< MDA	< MDA	22 ± 5
Point	28-04-05	< MDA	< MDA	3.5 ± 0.7	< MDA	< MDA	28 ± 6
Ocean Outfall	09-05-05	< MDA	< MDA	< MDA	< MDA	< MDA	37 ± 6
The Royal	14-12-04	< MDA	< MDA	< MDA	< MDA	< MDA	25 ± 5
National Park	03-05-05	< MDA	< MDA	< MDA	< MDA	< MDA	23 ± 5
Reference Site							

Table 40. RAINFALL AND POTENTIAL EVAPORATION AT THE LHSTC, January 1995 to June 2005

		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Jan	R Total	122.1	136.0	113.2	75.0	111.9	29.6	191.0	55.2	22.5	38.9	41.4
	R Days	12	13	11	11	14	12	9	10	6	8	13
	E Total	135.8	125.2	151.8	163.9	165.4	138.0	151.3	176.6	173.2	163.9	149.5
	E Max	7.9	7.6	7.8	10.1	10.0	8.0	10.1	13.4	11.0	9.2	8.5
Feb	R Total	47.6	64.1	127.7	56.0	196.5	11.0	110.6	295.1	89.1	92.5	81.7
	R Days	12	15	10	8	14	9	11	18	12	9	6
	E Total	122.9	137.5	118.5	154.7	113.1	149.6	108.4	103.4	118.2	138.6	133.1
	E Max	7.6	7.8	11.3	10.0	6.6	9.3	6.4	8.7	8.0	7.8	8.3
Mar	R Total	205.4	33.7	61.2	15.5	40.2	217.6	122.0	143.3	89.0	52.8	93.7
	R Days	16	9	10	8	10	14	20	15	8	5	10
	E Total	123.7	101.7	124.0	127.8	94.3	94.6	110.1	90.2	118.1	109.3	112.2
	E Max	8.4	6.1	6.2	7.7	5.1	5.1	7.9	5.5	8.5	7.5	6.7
Apr	R Total	14.2	33.2	0.5	161.3	94.3	31.9	70.2	15.4	147.2	107.4	20.2
	R Days	2	6	1	10	17	12	7	6	16	7	6
	E Total	91.0	99.2	91.9	94.9	72.0	65.3	78.0	68.8	69.0	73.4	80.3
	E Max	5.5	6.4	7.0	8.1	4.0	4.0	5.0	3.5	4.9	5.6	8.1
May	R Total	199.9	143.5	96.5	203.7	48.7	34.5	105.3	50.6	358.8	9.2	27.1
	R Days	16	14	16	13	10	9	10	11	17	1	5
	E Total	67.7	60.1	64.7	61.8	44.7	54.9	58.1	61.6	71.7	69.8	57.0
	E Max	6.0	3.9	4.7	4.9	3.4	3.4	4.5	3.7	6.8	3.8	4.0
Jun	R Total	40.4	51.8	51.0	80.2	66.6	34.2	9.3	18.1	58.0	5.4	78.3
	R Days	8	9	10	11	14	9	6	5	7	3	10
	E Total	44.1	58.9	54.7	45.5	45.9	45.7	44.4	49.1	49.3	58.4	48.0
	E Max	3.3	3.8	6.4	4.1	2.8	4.5	2.4	3.1	3.5	3.7	5.2
Jul	R Total	1.0	78.4	48.2	86.8	163.3	31.4	109.2	26.4	35.5	37.4	
	R Days	4	6	6	12	12	9	14	2	8	8	
	E Total	52.7	60.0	52.7	50.1	47.4	52.1	44.3	57.0	49.7	52.8	
	E Max	3.5	3.2	2.6	3.8	4.1	3.8	2.3	3.3	3.8	4.2	
Aug	R Total	0.0	129.9	18.7	316.3	31.2	19.2	49.4	14.3	30.0	68.3	
	R Days	0	6	5	15	8	11	6	7	7	5	
	E Total	86.1	76.0	82.4	51.0	65.6	59.6	75.4	73.0	75.4	74.9	
	E Max	5.2	5.0	6.9	3.3	3.2	4.3	5.5	5.9	5.8	4.4	
Sep	R Total	249.3	74.8	105.6	37.7	20.7	37.2	18.2	7.0	4.4	35.9	
	R Days	13	7	15	9	5	6	10	4	2	8	
	E Total	85.8	120.0	78.7	82.5	82.5	120.6	82.9	118.4	113.8	87.4	
	E Max	7.0	7.5	6.0	5.5	4.4	7.5	5.0	8.5	6.8	5.8	
Oct	R Total	34.4	31.2	60.2	26.7	211.0	55.1	39.8	1.4	62.4	219.1	
	R Days	10	10	8	8	13	9	8	4	13	10	
	E Total	121.9	118.1	136.9	121.1	104.1	117.2	128.9	149.8	102.5	119.0	
	E Max	6.6	6.8	7.6	6.8	6.3	6.8	7.6	8.5	6.6	8.4	
Nov	R Total	135.4	70.8	21.7	110.3	32.7	150.3	57.1	14.5	50.0	71.2	
	R Days	15	12	9	15	9	17	11	6	10	14	
	E Total	126.4	146.5	150.2	113.6	112.1	100.5	129.6	157.1	133.2	130.9	
	E Max	7.2	7.3	7.5	7.2	5.4	6.0	9.4	10.3	7.0	10.8	
Dec	R Total	93.9	68.8	27.3	37.8	112.8	46.4	15.9	59.8	45.9	67.0	
	R Days	13	6	7	9	13	11	8	9	8	10	
	E Total	155.0	160.6	162.9	148.9	140.4	170.5	150.5	177.2	142.9	156.7	
	E Max	8.5	8.2	11.2	9.6	6.8	10.1	10.8	12.7	9.0	14.2	
Annual	**R Total**	**1143.6**	**916.2**	**731.8**	**695.8**	**1129.9**	**698.4**	**898.0**	**701.1**	**992.8**	**805.1**	
	R Days	**121**	**113**	**108**	**129**	**139**	**128**	**120**	**97**	**114**	**88**	
	E Total	**1220.4**	**1260.5**	**1269.4**	**1215.8**	**1087.5**	**1168.6**	**1161.9**	**1282.2**	**1217.0**	**1235.1**	

Notes: Rainfall (R) and potential Evaporation (E) are measured in millimetres.

Table 41. ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, July 2004 to June 2005

Receptor Location	**2004-05 Estimated Effective Dose** (mSv/year)
Nearest Resident	0.00220
LHSTC Library	0.00289
LHSTC Building 9	0.00422
LHSTC Main gate	0.00196
Stevens Hall Motel	0.00531
LH Waste Management Centre	0.00138
BMX track	0.00074
Woronora Valley	0.00049
At 1.6 kilometre radius from HIFAR	
NORTH	0.00467
NNE	0.00353
NE	0.00278
ENE	0.00273
EAST	0.00236
ESE	0.00140
SE	0.00159
SSE	0.00154
SOUTH	0.00112
SSW	0.00121
SW	0.00169
WSW	0.00165
WEST	0.00091
WNW	0.00102
NW	0.00173
NNW	0.00298
At 4.8 kilometre radius from HIFAR	
NORTH	0.00117
NNE	0.00068
NE	0.00062
ENE	0.00061
EAST	0.00051
ESE	0.00029
SE	0.00033
SSE	0.00034
SOUTH	0.00024
SSW	0.00027
SW	0.00038
WSW	0.00036
WEST	0.00021
WNW	0.00022
NW	0.00040
NNW	0.00070

Notes:

- The annual effective dose at each compass point is estimated using stack discharges and concurrent meteorological data as input to the computer model, PC-Cream.
- The annual dose limit for members of the public is 1 mSv/year (ARPANSA, 2002a)

Appendix A – Corrections to the previous report

Corrections for the previous report *Environmental and Effluent Monitoring at ANSTO Sites 2003-2004* (ANSTO E-755) are listed below:

- Page 58, Table 26, Note 1 should read: “Concentrations quoted are for total ions (suspended and dissolved)”.