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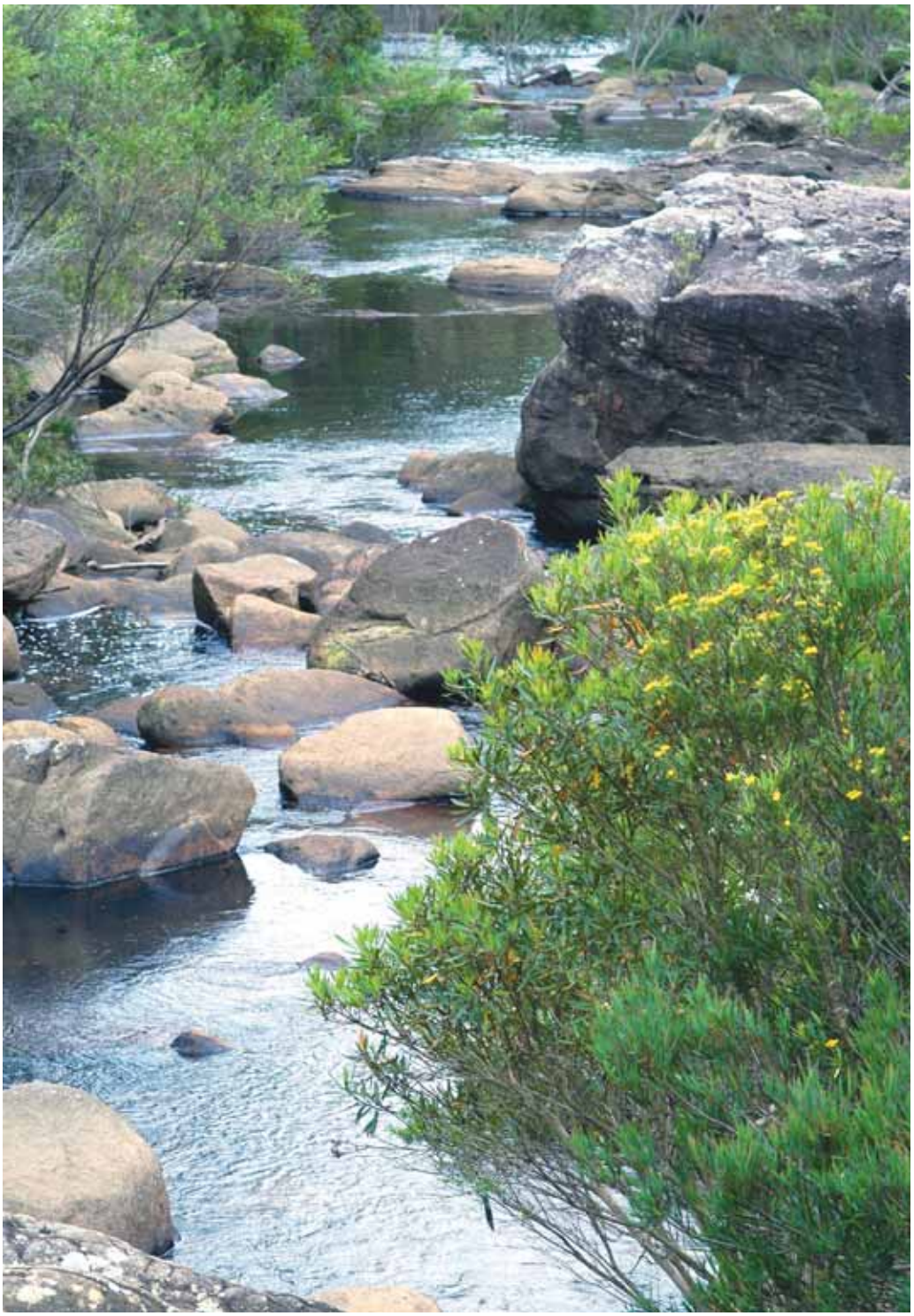
2005-2006



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Environmental and Effluent Monitoring at ANSTO Sites, 2005–2006

Emmy L Hoffmann, Tom Loosz, John M Ferris, Jennifer J Harrison

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 2005 to June 2006. Estimated 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. The maximum potential dose was 23% of the ANSTO ALARA objective of 0.02 mSv/year, 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 median tritium concentrations detected in groundwater and surface waters at the LHSTC were typically less than 2% of those set out in the Australian Drinking Water Guidelines. The airborne emissions from the NMC were below the ARPANSA-approved notification levels. 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	ANSTO's light-water research 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 and operates several national facilities, including Australia's current research reactor, HIFAR, produces radioisotopes and radiopharmaceuticals and conducts research in wide-ranging fields through national and international collaboration. Most of ANSTO's facilities are located at the Lucas Heights Science and Technology Centre (LHSTC), about 30 km south-west of the Sydney city centre. The LHSTC occupies 50 hectares and is surrounded by a 1.6 km diameter buffer zone (**Figure 1**, see section 5). The OPAL research reactor has been constructed on the LHSTC site and will replace HIFAR, which has served the Australian community in supplying radioisotopes and neutron beams for scientific research for almost 50 years.

ANSTO also operates the National Medical Cyclotron (NMC), located in Camperdown, Sydney, which produces certain short-lived radioisotopes for medical diagnosis. ANSTO's activities are regulated by a number of bodies, chief among them 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 the organisation, and strives for continual improvement in environmental performance. As part of its commitment to environmental protection, ANSTO has an Environmental Management System (EMS) that is certified to the AS/NZS ISO14001 standard. 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. ANSTO communicates with its stakeholders about safety, social and environmental issues via its Corporate & Social Responsibility reports. These reports are available electronically via the ANSTO digital reports database (ANSTO 2006a), or in hardcopy either from the Sutherland Shire Central Library or by request from ANSTO's Communications Manager.

This report summarises the results from the environmental and effluent monitoring carried out at the LHSTC and the NMC from July 2005 to June 2006, and assesses the potential effects of radioactive discharges, with particular emphasis on local residents.

2. ANSTO Facilities

2.1 HIFAR and OPAL

The HIFAR research reactor produces radioisotopes for medical and industrial use and generates neutrons for research applications. HIFAR has regulatory discharge authorisation from ARPANSA to release low levels of radionuclides to the atmosphere via stacks. The main radionuclides are tritium and argon-41 (a noble gas). 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.

At the time this report was prepared, the OPAL reactor had entered the final and extensive 'hot' commissioning phase, involving several stages of testing before achieving routine operation. There were no emissions arising from the pre-operational testing of OPAL's systems during 2005-06.

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.

2.3 NATIONAL MEDICAL CYCLOTRON

ANSTO also manufactures radiopharmaceuticals at the NMC (Camperdown, Sydney). The major radiopharmaceutical products made at the NMC in 2005-06 were thallium-201, gallium-67 and iodine-123 all of which have relatively short half-lives ranging from minutes to hours. Atmospheric emissions of iodine-123, thallium-201 and gallium-67 from the NMC are regulated by ARPANSA under the ANSTO Airborne Radioactivity Discharge Authorisation. The liquid effluent discharges from the NMC are subject to a commercial trade wastewater permit. 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 and lead-201. However, a system of delayed liquid effluent releases allows the radionuclides to decay significantly prior to being released to the sewer.

2.4 LIQUID EFFLUENT TREATMENT

Liquid effluent from the LHSTC is discharged via ANSTO's Main Discharge Pipeline (MDP, indicated on **Figure 2**, see section 5) to the Sydney Water sewer under the terms of a trade wastewater agreement with Sydney Water Corporation. The MDP is regularly inspected and maintained by ANSTO personnel. The effluent contains low levels of radionuclides, mainly tritium and caesium-137.

The annual volume of liquid effluent discharged is typically 70,000 to 100,000 m^3/year; comprising approximately 50% non-active trade waste, 45% sewage 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 back-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 potential off-site migration 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 Consent Agreement (No. 4423, ANSTO and Sydney Water)	Sydney Water Corporation	Detailed authorisation to discharge treated liquid effluent from LHSTC to the sewer.
Commercial Trade Wastewater Permit (No. 13966, ANSTO and Sydney Water)	Sydney Water Corporation	Permission to discharge pre-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 'nuclear actions' (e.g. 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. These are set so that even if all stack releases were at their respective annual notification levels, the effective dose to the public would not exceed the site ALARA objective of 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). Further explanation of notification levels is given in Hoffmann *et al.* (2001).

In July 2006, ARPANSA granted an operating licence for the OPAL reactor. ANSTO has also applied for a source licence for the Bragg Institute, which is responsible for the neutron beam facilities currently being constructed for OPAL. Once OPAL is operating, these instruments will be used to conduct research into materials for medicine, food, industry and biotechnology.

Treated, low-level liquid effluent from the LHSTC is routinely discharged to the sewer under the terms of a trade wastewater agreement 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. Originally determined by tracer studies (Hoffmann *et al.* 1995, 1996), the dilution factor is checked each year and has been shown to be very conservative since the Cronulla STP was upgraded to provide tertiary treatment.

Compliance with the requirements of the trade wastewater agreement is demonstrated by determining the concentration quotient for the flow proportional pipeline composite samples taken every four discharge days. This quotient is the sum of the concentration of gross (unspecified)

alpha, gross (unspecified) beta and tritium radioactivity divided by the permitted concentration for radium-226, strontium-90 and tritium respectively, and must not exceed one. Unspecified alpha- or beta- emitting radionuclides are assumed to be the most restrictive isotopes for each decay type, i.e. radium-226 (alpha decay) and strontium-90 (beta decay).

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 uranium, thorium, radon progeny and potassium-40 in the body). Natural background radiation varies from place to place on the earth (e.g. with rock type and altitude) and is affected by lifestyle (e.g. 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).

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 therefore 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 2005-06 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 6,900 samples were taken and some 14,200 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 minimise radioiodine concentrations, 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 tritium, gross alpha and beta radioactivity, pH, biological oxygen demand, grease, suspended solids, total dissolved solids, ammonia and zinc. The analysis method for gross alpha activity was changed in June 2006 to provide a lower detection limit. 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 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 May-June 2006. Eighteen 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 2005 to June 2006

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 (workdays; 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(workdays)	980	980
	Gas (water vapour)	H-3	4 Stacks (LHSTC)	Weekly	208	208
Liquid	Wastewater	H-3, GA, GB, Chem	6 Holding Tanks (LHSTC Waste Optns)	2 tanks daily(workdays)	490	1960
	Wastewater	H-3, GA, GB, Chem	Proportional samples from discharge pipeline	Every 3-4 Days	104	416
	Wastewater	Gamma	Composite of all discharges	Monthly composite	12	12
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	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		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	6940	14212

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 (e.g. 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 is the major component of the environmental sampling program. 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 3**) were sampled on a daily basis, prior to the bunds being emptied. These daily samples were sub-sampled and combined to give representative monthly composite 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 3**). 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 3**) 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 2005-06, 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 was 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 2005-06 for field parameter testing. Laboratory-based radiological and other water quality analyses were performed annually. Results of inorganic nutrient and hydrocarbon analyses are also reported. 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 3**) 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 charcoal cartridges with particle filters at four locations on the LHSTC boundary fence. The ANSTO-developed Maypack activated charcoal cartridge, used since 1980, was replaced with a commercial equivalent, the TC45, in April 2006. Measured iodine-131 activities continue to be corrected for decay from the first day of the sampling week, which means that results may be over-estimates, especially for iodine emissions that occur late in a given week.

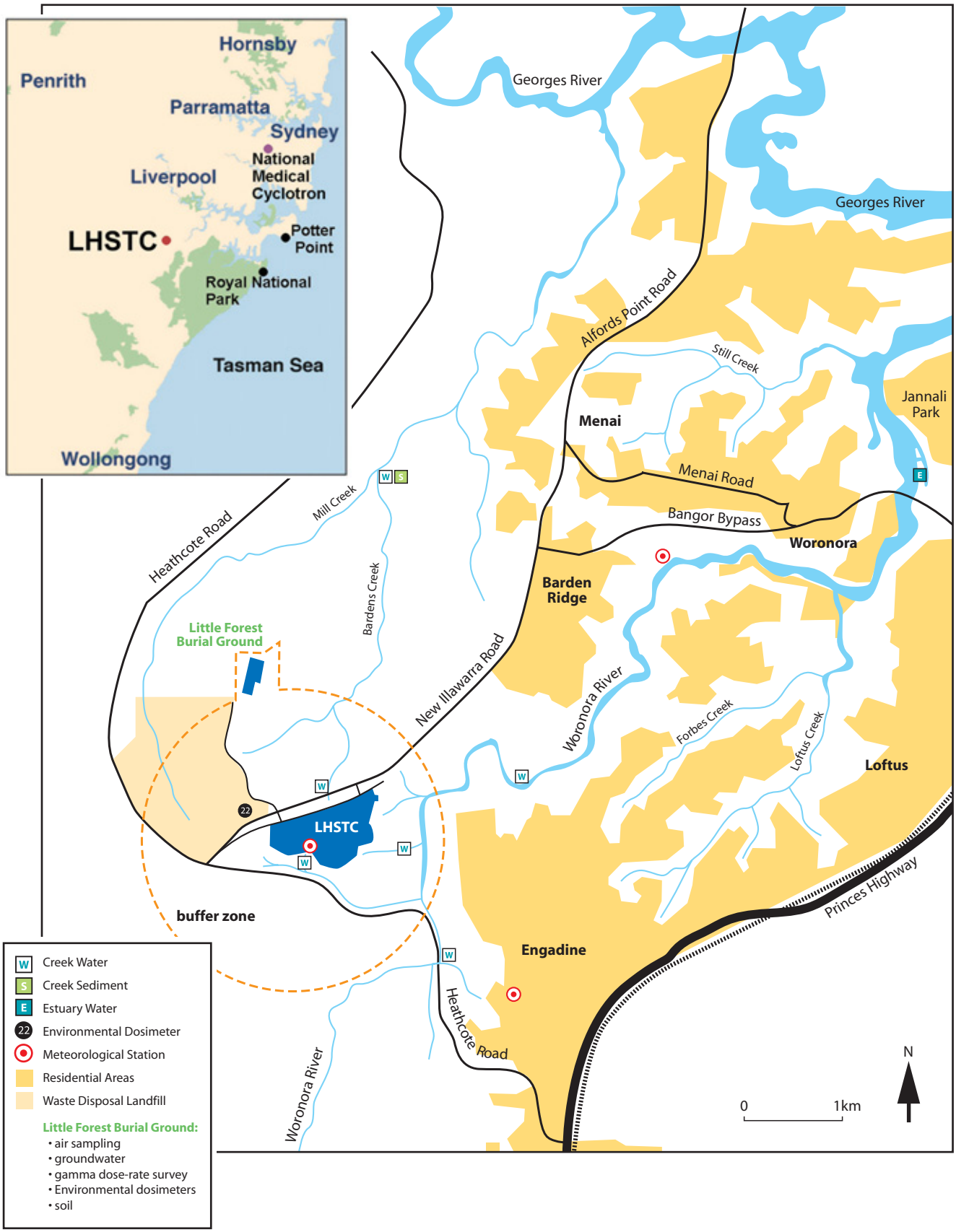

Figure 1. Location of ANSTO sites (the LHSTC and NMC) and off-site monitoring points.

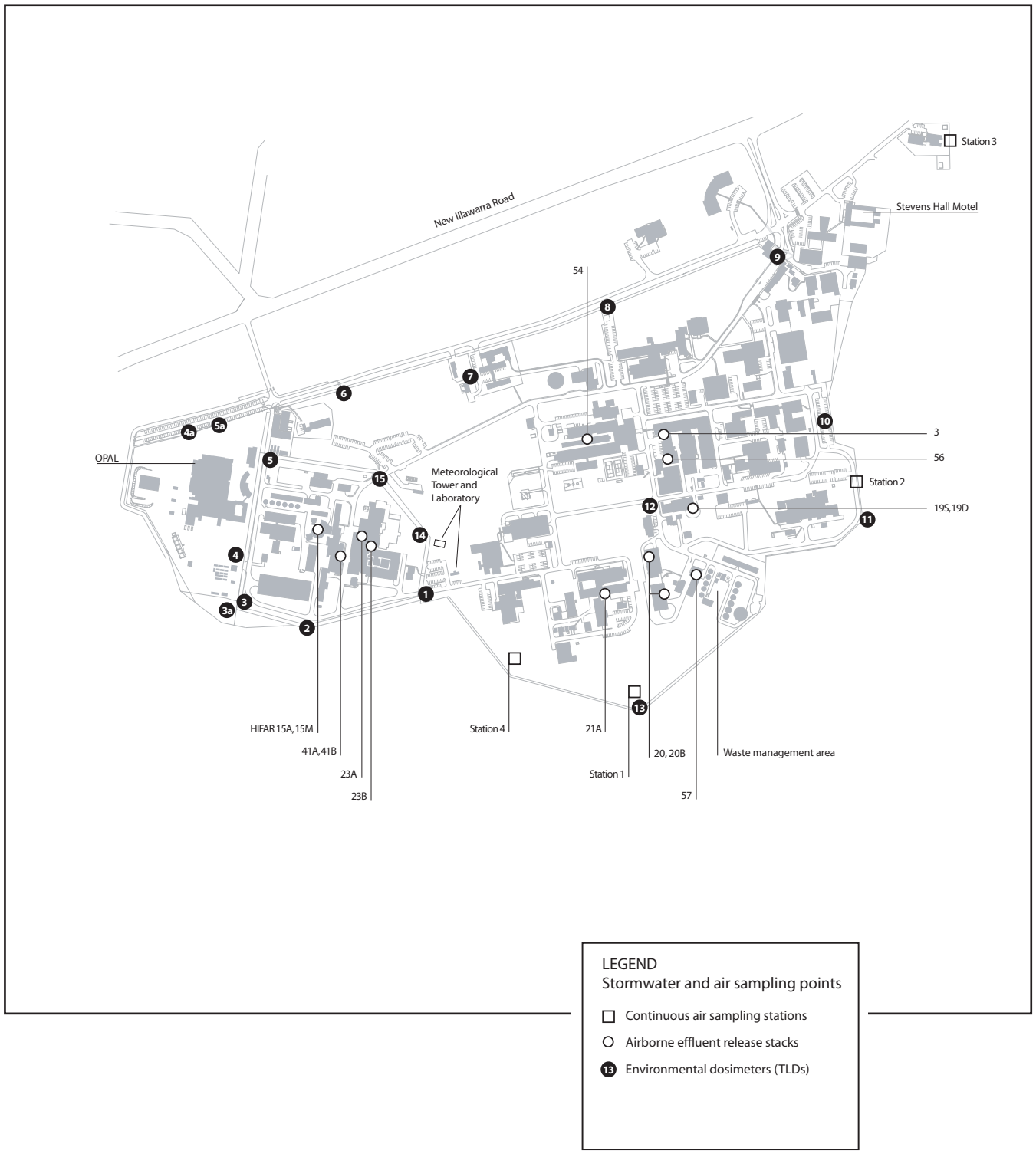

Figure 2. Location of airborne effluent release stacks and monitoring points for air and external radiation at the LHSTC.

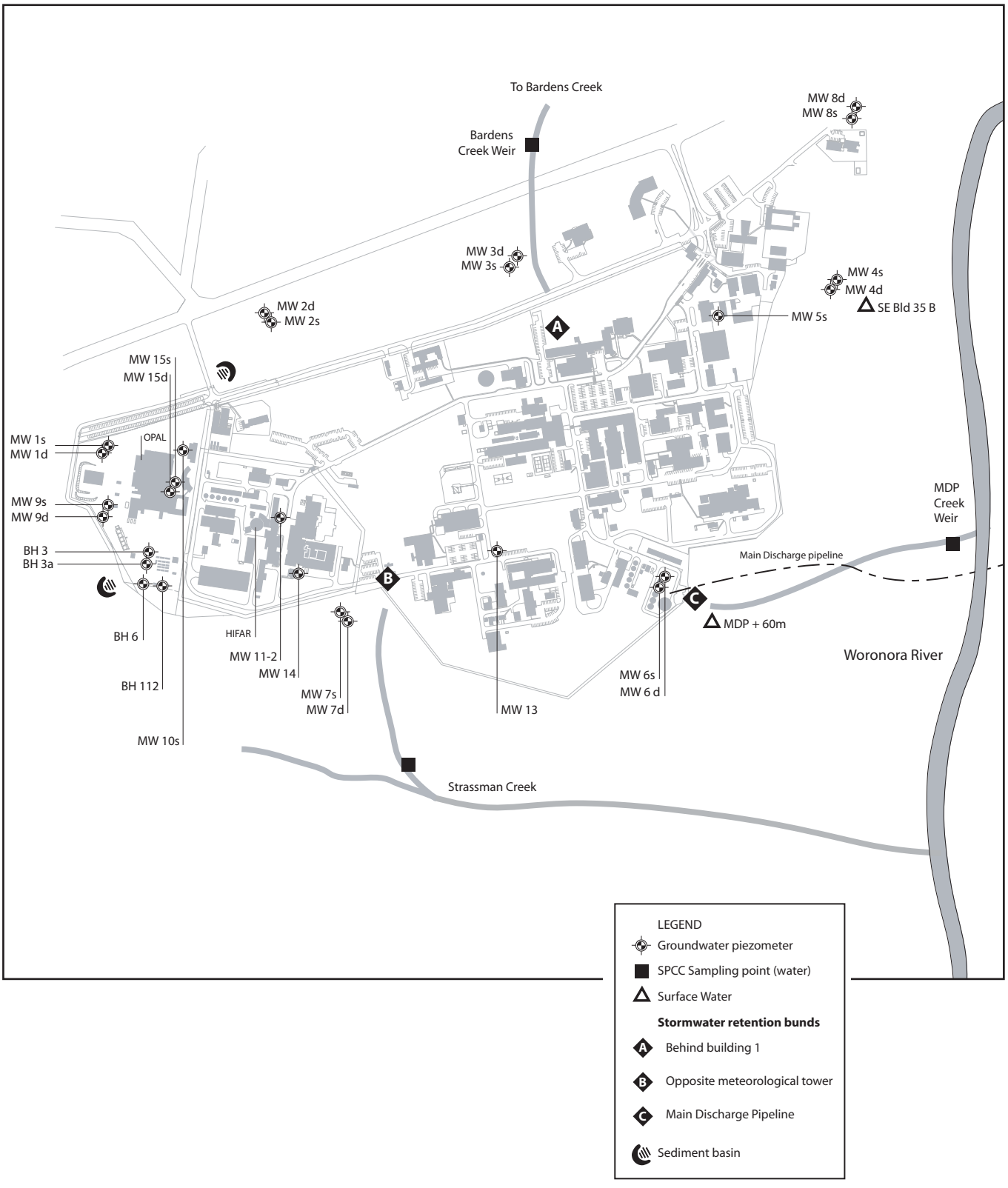

Figure 3. Location of groundwater and surface water monitoring points at the LHSTC.

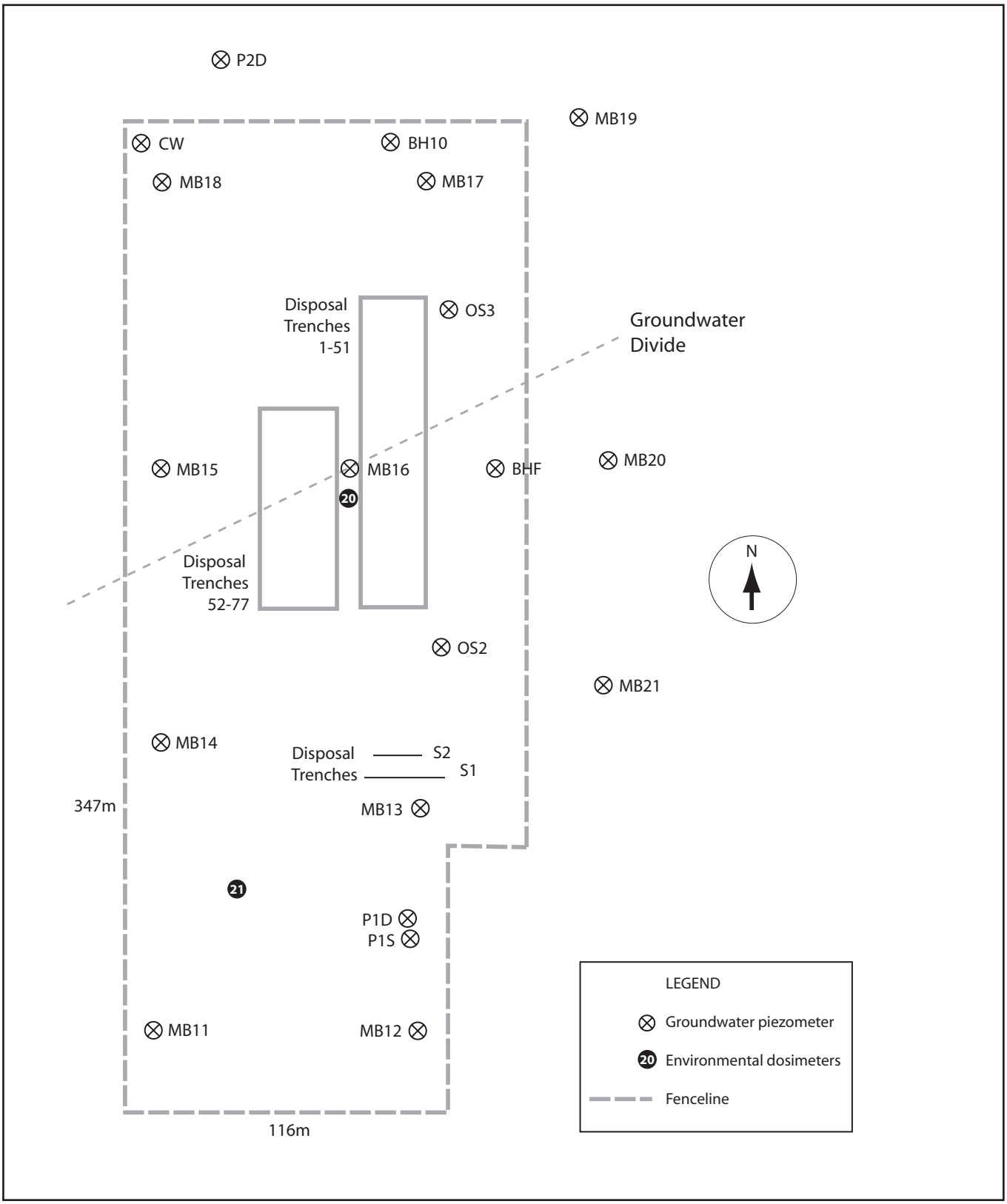

Figure 4. Little Forest Burial Ground – schematic showing the waste disposal trenches and piezometers currently monitored.

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 temperature, evaporation, humidity, pressure and precipitation. These data are collected and analysed continuously, and are displayed on ANSTO's web site (http://www.ansto.gov.au/metinfo.htm) in addition to being reported to the Australian Bureau of Meteorology. The meteorological data collected are used within ANSTO's emergency response system and also 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 is published in Clark, 2003.

6. Environmental and Effluent Monitoring (July 2005-June 2006)

Monitoring data in this report cover the financial year from July 2005 to June 2006 and are presented in **Tables 2** to **42**. Measurement uncertainties given in these tables are at the two-sigma level (i.e. 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 (i.e. '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 2005-06 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 16.7% of the annual notification level Production of fluorine-18 ceased early in the financial year, and all other nuclides combined were below 18% of annual notification levels.

All gross alpha and gross beta radioactivity associated with airborne particles sampled from LHSTC stacks was less than 3% of annual notification levels. The airborne discharge of argon-41 from stacks 15A and 15M (HIFAR) remained below notification levels in 2005-06, reaching 76.3% and 47.0% 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 28.5% 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 10% and 91.1% of their annual notification levels, respectively. Releases of noble gases from stack 54 were at similar levels to recent years. Emissions of xenon-133 reached 111% of the annual notification level, which is not a regulatory limit but effectively a trend indicator and trigger for further investigation. The combined stack 54 emissions contributed less than a quarter of the very small off-site dose associated with LHSTC airborne discharges (see section 8.1).

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 2005-06 was 73,715 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. Most of the individual alpha results were less than the minimum detectable activity, the median of which was 43 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 < 0.44, with a median value of < 0.12, i.e. less than 12% 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 2005 to June 2006.

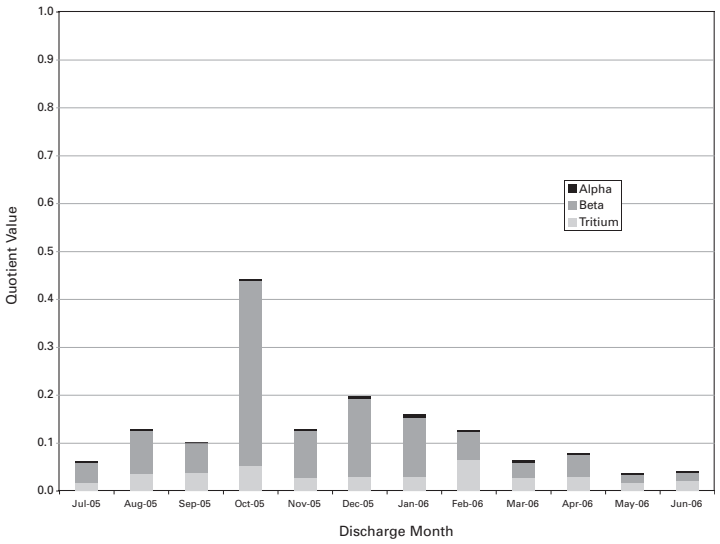

Figure 5. Monthly quotients for alpha, beta and tritium radioactivity in liquid effluent, LHSTC, July 2005 to June 2006.

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 0.65 Bq/L to 12.74 Bq/L. Low levels of iodine-131 were present in five samples from December 2005 to April 2006.

Alpha-spectrometry is performed on the monthly composites to check for the alpha-emitter polonium-210, which was found at a very low level ranging from 0.01 Bq/L to 0.02 Bq/L from July 2005 through to June 2006.

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. 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 some samples had a pH less than 7 - this is consistent with the slight

acidity of water supplied to the site. Grease was measured from July 2005 to February 2006 whilst total dissolved solids were measured from February 2006, as stipulated in the revised trade waste agreement with Sydney Water.

The relative increase in beta activity in October 2005 was associated with Cs-137 (**Table 4**), but the discharge quotient was less than half the limit of one. Levels of radioactivity and non-radioactive components of liquid effluent discharges to the sewer from July 2005 to June 2006 complied with the standards for acceptance specified in the trade wastewater agreement with Sydney Water.

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 four effluent discharges were made each month, with an average volume of about one cubic metre and an annual total of 48.7 cubic metres. Liquid effluent discharges contained variable amounts of radioactivity depending upon the radiopharmaceutical production schedule, however the maximum average activity discharged per month of thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65 and iodine-123 were only 52%, 31%, 2%, 1%, 2% and 7% of their respective limits.

6.2.3 Effluent Dilution – LHSTC to the Cronulla STP

Tertiary treatment was introduced at the Cronulla STP in July 2001, and significantly increased the residence time and recirculation of effluent within the plant, resulting in an increase in the final effluent stream dilution. A study in 2003-04 (Hoffmann *et al.* 2004) found that the transit time of effluent from ANSTO to Cronulla STP was fairly constant at five to six hours, and that under average flow conditions the retention time in the plant was approximately 22 hours.

Table 7 shows the results of a one month study conducted in 2005-06 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 in 18 daily composite samples at the UV Inlet during the study was 32 ± 1 Bq/L. The minimum in-line dilution ratio at the UV Inlet for the study was 37:1 with an average dilution over the study period of 264:1. These studies demonstrated compliance with the agreed dilution factor of 25.

The 2006 effluent studies have also 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 14 ± 1 Bq/L. This value is very low compared with the ADWG guideline of 7600 Bq/L, and is dependent on the recent history of ANSTO releases and the dynamics of the water flow through the plant.

6.3 AIR

6.3.1 Ambient Iodine-131 in Air

Ambient air was sampled continuously and analysed weekly for iodine-131 at four locations on the LHSTC boundary fence. On average, low concentrations of iodine-131 were detected in 25% of all weekly air samples see **Table 8**, with Station 2 recording iodine-131 most frequently, around 50% of the time. The remaining 75% of weekly results were below the minimum detectable level at the time of counting. The median MDA value for iodine-131 was 0.0011 Bq/m^3. Ambient levels of iodine-131 at the eastern site perimeter peaked at 0.2 – 0.3 Bq/m^3 for the week ended 28 March 06. This result reflected the prevailing wind direction combined with elevated airborne releases of iodine during that week, and is far less than the occupational derived air concentration for I-131 of 740 Bq/m^3 (i.e. the concentration that represents the Allowable Level of Intake, if breathed by Reference Man for a working year of 2000 hours).

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 6567 m^3.

Equal portions of the exposed filters were analysed for stable beryllium via inductively coupled plasma mass spectrometry and for plutonium-239/240 activity via alpha spectrometry. These results are given in **Table 9** together with the equivalent volume sampled. The amounts of beryllium and plutonium-239/240 on the filter portion are 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, on all quarterly samples. The exposure standard for atmospheric contaminants such as beryllium in air is 2 µg/m^3 (Worksafe Australia: NOHSC 1995), applicable to workers exposed 8 hours per day, 50 weeks per year. The limit of detection for Pu-239/240 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.

6.3.3 External Gamma Radiation

Thermoluminescent dosimeters (TLDs) were used to measure external gamma radiation at various locations around the LHSTC (**Figure 2**), in the buffer zone and at three private residences in nearby suburbs (**Figure 1**), and at the Cronulla STP. Changes to fencing around HIFAR and OPAL resulted in the permanent relocation of three dosimeters in March/April 2006, affecting data for the last quarter of the year. Dosimeter 3 was transferred to a new fence, effectively remaining in a similar position; however dosimeters 4 and 5 were moved to the outer perimeter fence - north of OPAL and the neutron guide hall, see locations 3a, 4a and 5a, **Figure 2**.

The external gamma data include the contribution from natural background radioactivity and are given in **Table 10**. The TLDs at sites 2 and 3 on the southern sector of the LHSTC perimeter fence 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 0.88 to 1.38 mSv/year for 2005-06.

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 1.08 to 1.74 mSv/year for 2005-06, consistent with the background levels reported for Australian capital cities by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000). 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 2005-06 are given in **Table 11**. The median external dose-rates were 1.84 ± 0.07 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 2005 calendar year.

A National Environmental Protection Measure (NEPM) for fine particles in Australia has been set at an annual average of 8 µg/m^3. The LHSTC annual averages of 5.7 µg/m^3 and 5.2 µg/m^3 for 2004 and 2005 respectively were well below this NEPM goal. 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 2006b).

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 on **Figure 3**) temporarily

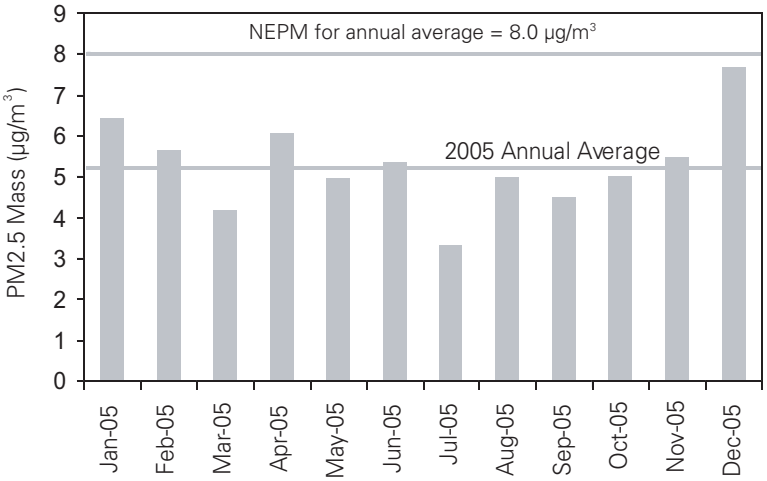

Figure 6. Average monthly mass of fine aerosol particles (less than 2.5 µm in diameter) collected over 24-hour periods at the LHSTC, January to December 2005.

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 basins, designed to capture surface water runoff and sediment from the OPAL construction site, are situated to the North and South West (**Figure 3**). Waters flowing out of the sediment basins are sampled quarterly providing sufficient water is available, to determine baseline values prior to the commissioning of OPAL.

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 (of daily samples) from Bunds A, B and C (**Table 12**) at levels ranging from 50 to 8540 Bq/L, with a median activity of 110 ± 130 Bq/L. The maximum tritium concentrations were in Bund A between January and March 2006. Investigations were not fully conclusive but indicated that the increased tritium activity concentrations in the stormwater were consistent with specific weather conditions promoting condensation and/or rain-out of routine tritium emissions in the area close to HIFAR. Tritium concentrations in Bund A monthly composites peaked around the Australian Drinking Water Guideline level but were fairly rapidly diluted downstream, as is evident in samples taken from the Barden's Creek Weir (**Figure 3**) during this three month period (**Table 16**).

Quarterly samples taken from North and South Western OPAL sediment basins indicate low levels of tritium, ranging from less than the MDA to 50 Bq/L, with a median activity of 10 ± 10 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 320 Bq/L, with a median activity of 80 ± 80 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 ± 20 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 3300 Bq/L, with a median activity of 110 ± 240 Bq/L.

The range of tritium activities recorded in these water samples from July 2005 to June 2006 was typical of recent years at the LHSTC with the exception of Bardens Weir, which receives surface water from the daily drainage of Bund A. The maximum tritium activity in any of the samples from stormwater bunds and nearby sampling points was 12% higher than 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 10 to 110 Bq/L, i.e 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 (e.g. 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 2005 to June 2006 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 0.02 ± 0.01 Bq/L. For gross beta, the range of activities was from 0.24 to 0.43 Bq/L and the median was 0.27 ± 0.04 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 0.08 Bq/L, with a median of 0.03 ± 0.02 Bq/L. For gross beta, the range of activities was from 0.10 to 0.25 Bq/L and the median 0.14 ± 0.06 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 0.26 Bq/L, with a median value of 0.01 ± 0.02 Bq/L. Gross beta radioactivity ranged from 0.01 to 0.33 Bq/L, with a median of 0.06 ± 0.08 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 basins are given in **Table 13**. Gross alpha activities ranged from 0.06 to 0.52 Bq/L, with a median value of 0.12 ± 0.06 Bq/L. Gross beta radioactivity ranged from 0.11 to 0.49 Bq/L, with a median value of 0.26 ± 0.24 Bq/L. These results are consistent with data reported previously.

All results for surface waters from July 2005 to June 2006 were below the limits for gross alpha and gross beta activity in the relevant NSW regulations. In fact, greater than 98% of alpha and 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 basins. 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 from Bund C (**Table 17**) for 2005-06 show typical low levels of caesium-137 activity, ranging from 0.006 to 0.022 Bq/L, with a median of 0.008 ± 0.005 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 iodine-131 which was detected at 0.005 ± 0.002 Bq/L in the May 2006 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 0.007 ± 0.003 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 basins are shown in **Table 13**. Only naturally occurring nuclides were detected in the two OPAL sediment basins. Beryllium-7 levels are generally higher than those detected in other LHSTC surface water samples. However, this is attributable to the large pools of water that remain in the basins for extended periods after rain, enhancing the deposition and accumulation of beryllium-7. Low levels of potassium-40 were also occasionally detected in the South West sediment basin

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

6.5 RIVER AND SEA WATERS

Samples of brackish water were collected from the Woronora River estuary and fresh waters from two sites in the river's upper reaches (see **Figure 1**). These two freshwater sampling points were established in July 2004 to better monitor tritium levels in the Woronora River upstream and downstream of ANSTO's potential influence. The first is a control site that lies upstream of the LHSTC and includes flows from Heathcote Creek. The second is at the causeway downstream of the LHSTC. The monthly samples from all three sites on the Woronora River were analysed for tritium and the results are given in **Table 21**. Continuing a 20-year trend, no tritium was detected in the Woronora Estuary (station E5.9). In 2005-06, 98% of tritium results for the freshwater sampling points were less than the minimum detectable activity.

Sea water was collected in the vicinity of the Potter Point ocean outfall on two occasions, June 14 and 29, 2006 (**Table 7**). On each occasion, samples were collected hourly from three locations at 10, 90 and 270 metres distant from the Potter Point outfall, at a depth of 1 metre below the surface. A total of 48 samples were collected. Seven samples were chosen at random from each date and analysed for tritium. All of these 14 samples were below the minimum detectable activity. Both sampling occasions were timed to coincide with the Cronulla STP effluent study (section 6.2.3); however no CSTP sample was provided by Sydney Water for 14 June 2006. 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 any further dilution occurring between the Cronulla STP and the near shore area at Potter Point.

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 (e.g. 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**.

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 2005-06, quarterly pH measurements ranged from 3.6 to 6.7 with a median of 4.9 ± 1.0, and EC ranged between 144 and 1136 µS/cm with a median of 351 ± 77 µS/cm (**Tables 22-25**). The Eh, which indicates oxidation-reduction potential, had a positive median of 204 ± 96 mV, as would be expected of near-surface oxygenated waters. The lower Eh observed in piezometers such as MW1S and MW4S can indicate less well oxygenated water. The median groundwater temperature was 18.7 ± 1.5°C. Overall, there were no statistically significant differences in pH, EC or Eh between the shallow and deeper piezometers.

Table 26 gives the annual results for major ions in the LHSTC groundwater. The LHSTC groundwaters are predominantly sodium-chloride-sulfate type waters, consistent with a primary influence from marine aerosol input. Shallow piezometer MW4s continued to be the most saline and had the highest pH, consistent with its somewhat higher Ca, Mg, SO4, and HCO3 concentrations. This piezometer is located in a natural drainage line below a chlorinated swimming pool, and its groundwater chemistry may be influenced by some leakage of treated water from the pool.

6.6.2 Nutrients and Hydrocarbons in LHSTC Groundwater

The groundwater samples collected in November 2005 were sent to external commercial laboratories for inorganic nutrients analyses (**Table 27**). A sample from MW5s, located near the underground petroleum fuel tank, was also tested for hydrocarbons (**Table 28**). Results for MW5s were below the limits of detection for monocyclic aromatic hydrocarbons (benzene, toluene, ethyl benzene and xylene) and for total petroleum hydrocarbons (including the volatile fraction), indicating that there is no sign of leakage from the fuel tank into nearby groundwater.

Nutrients such as nitrogen and phosphorus stimulate the growth of plants (including algae). 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 groundwater, 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 0.003 to 0.046 mg/L, with a median of 0.007 ± 0.003 mg/L in 2005-06. 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. 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.

Total nitrogen concentrations in LHSTC groundwater were calculated by adding the total Kjeldahl and oxidized nitrogen results. The values ranged from less than the combined detection limit (0.11 mg/L) to 1.58 mg/L, with five piezometers exceeding the ANZECC default target of 0.35 mg/L. However, more than 50% of total nitrogen results were less than the detection limit and well below the default target value. Oxidized nitrogen (nitrate and nitrite) results for LHSTC groundwater ranged from < 0.01 to 1.48 mg/L, with a median concentration (0.05 ± 0.15 mg/L) just above the ANZECC 0.04 mg/L default target. There is a clear tendency for the shallow piezometers to show greater concentrations of nitrogen than deeper ones.

Ammonia levels in LHSTC groundwaters were low, ranging from less than the detection limit to 0.35 mg/L, and with no ammonia detected in more than half the LHSTC groundwater samples (i.e. a median value of < 0.01 mg/L). 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 our grounds management policy to limit the use of fertiliser on lawn areas and preferentially plant native vegetation in garden beds.

6.6.3 Radioactivity in LHSTC Groundwater

Groundwater samples collected at the LHSTC in November 2005 were filtered and analysed for alpha, beta, tritium and gamma radioactivity, and the data are given in **Table 29**. Gross alpha activity ranged from less than the minimum detectable activity to 0.22 Bq/L, with a median of 0.07 ± 0.07 Bq/L. Gross beta activities were similar, ranging from 0.02 to 0.20 Bq/L, with a median of 0.10 ± 0.10 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 (note that this is only an indicative comparison because these are groundwaters rather than surface waters). Anthropogenic gamma-emitters, specifically americium-241, caesium-137 and cobalt-60, were not detected in 2005-06 or in previously reported data.

Tritium activity in the LHSTC groundwater (**Table 29, 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 3 Bq/L to 97 Bq/L, with a median of 13.5 ± 22.8 Bq/L that is statistically indistinguishable from data reported since 2002-03. The maximum activity measured in LHSTC groundwater in 2005-06 was about 1% of the ADWG (NHMRC and NRMMC 2004). Shallower piezometers showed higher tritium levels than corresponding deeper ones for all but two piezometer pairs.

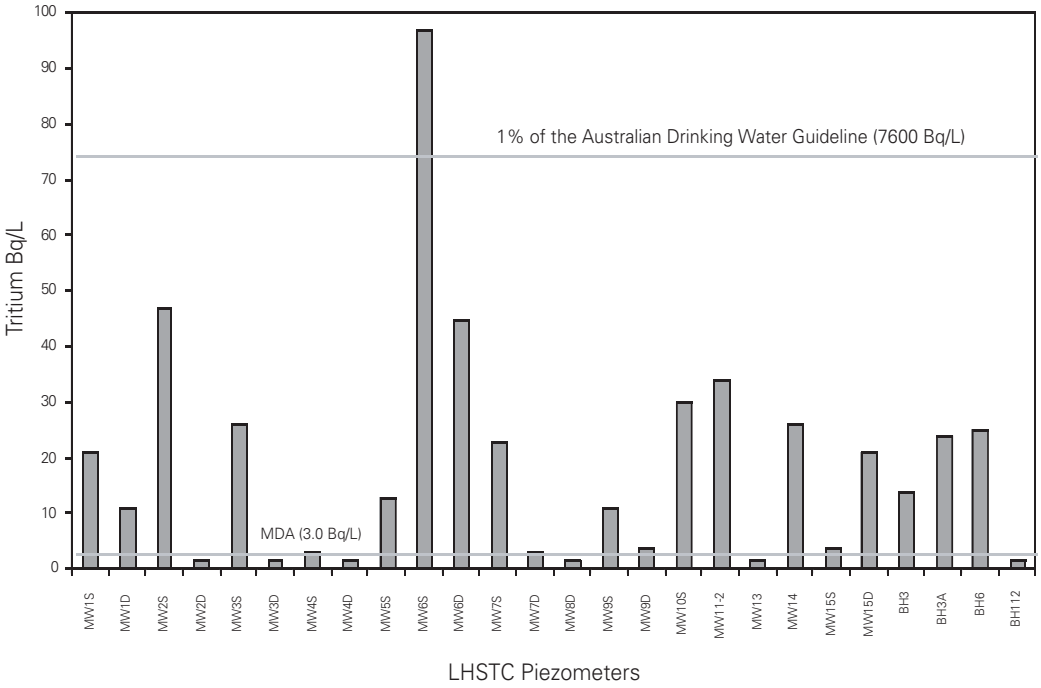

Figure 7. Tritium levels in LHSTC groundwater, November 2005

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 2005-06, the groundwater pH ranged from 3.95 to 6.82 with a median of 5.54 ± 0.10, while electrical conductivity ranged between 318 and 10100 µS/cm with a median of 2534 ± 400 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 119 ± 14 mV, with piezometer MB20 displaying a negative value, which is 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**. Tritium concentrations in groundwater from the LFBG for 2005-06 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 7170 Bq/L, 5 percent below the drinking water guideline level, was recorded in piezometer BH10, which lies north of the main burial trenches and intercepts the path of groundwater flow. 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 present in both samples taken at peizometer MB16, at levels similar to those reported in recent years. Americium-241 and caesium-137 were not detected in LFBG groundwater in 2005-06.

6.8 RAINWATER

In 2005-06, 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, 39 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 56% of samples, and 62% of all tritium results were below the minimum detectable activity, see **Figure 8**, below. The maximum tritium value was 491 Bq/L in an undistilled sample, which represents less than seven percent of the ADWG guideline for tritium of 7600 Bq/L.

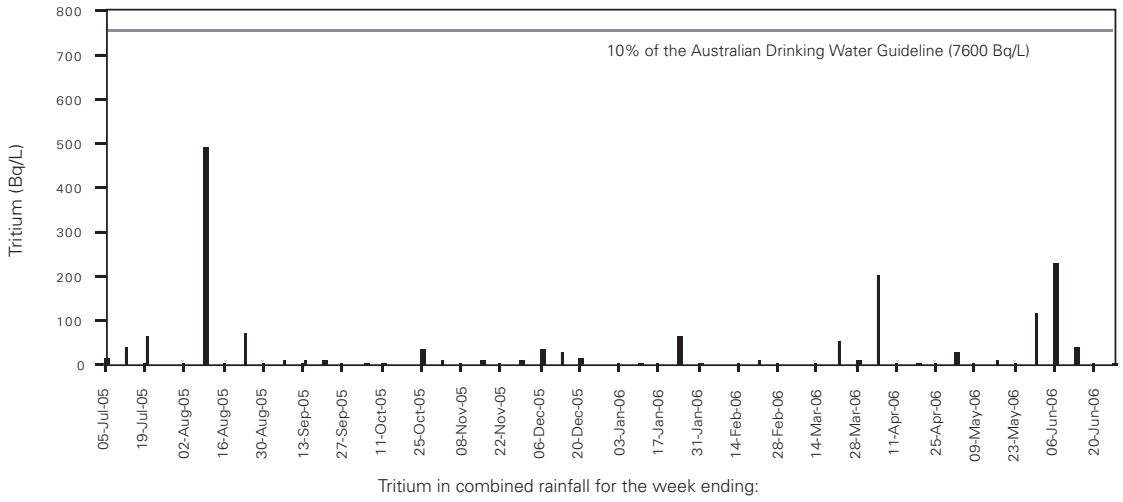

Figure 8. Tritium activity in LHSTC rainwater (weekly composites of daily samples), July 2005 to June 2006.

6.9 SOIL AND SEDIMENT

6.9.1 Bund Sediments

Sediments that accumulate in the stormwater bunds are removed at least once each year. The sediments are sampled and analysed (prior to their removal) for gross alpha, gross beta and gamma radioactivity (**Table 35**). The naturally-occurring gamma-emitters potassium-40, beryllium-7 and the uranium-238 and thorium-232 decay series were found in addition to traces of americium-241, caesium-137, cerium-144 and cobalt-60, which have occasionally been detected at low levels in previous years. All of the measured activity concentrations were far below exemption levels for classification of radioactive materials (ARPANSA 2004).

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 (shown on **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 June 2006 using a hand-held meter at near-ground level (**Table 36**). Recorded dose-rates ranged from 0.07 to 0.21 μSv/hour and are consistent with background readings taken at the LFBG gate, approximately 200 metres away from the trench area.

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 each year. The results of the MDP pipeline dose-rate surveys for 2005-06 are summarised in **Table 37**. The measured dose-rates along the pipeline and the ground beneath it ranged from 0.03 to 0.13 μSv/hour, and were within the range measured for natural background radiation. Soil samples were collected near joint 8 in May 2006 following a minor leak at that point. These samples were qualitatively screened for gamma-emitters, and only trace levels were found.

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 2005 to June 2006, 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 (mainly *Tesseropera rosea*) were left whole and unwashed. All samples were dried, ground and analysed for gamma-emitting radioisotopes (**Tables 38-40**). The collection of marine fish from the reference site was unsuccessful in 2005-06 despite several attempts.

The radioactivity measured in marine fish, algae and barnacles sampled at Potter Point in 2005-06 was of natural origin, apart from the low levels of iodine-131 found in the algae. 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 41**, from 1996 to 2006. 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 2005-06 was 664.0 mm from 93 rain days. Total rainfall for the previous decade, calculated as median ± interquartile range on a financial year basis was 880.7 ± 76.1 mm, indicating that rainfall in 2005-06 was below the 25th percentile derived from the previous ten years' data. The wettest month during 2005-06 was November 2005, with 139.2 mm. The total evaporation for 2005-06 was 1255.0 mm, with a maximum 24-hour value of 12.0 mm recorded in December 2005.

6.11.2 Wind Speed and Direction

The winds (recorded at 10m) that predominated at Lucas Heights during summer and winter of 2005-06 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 2005-06.

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

For the period 2005-06 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 48% and 33% 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.

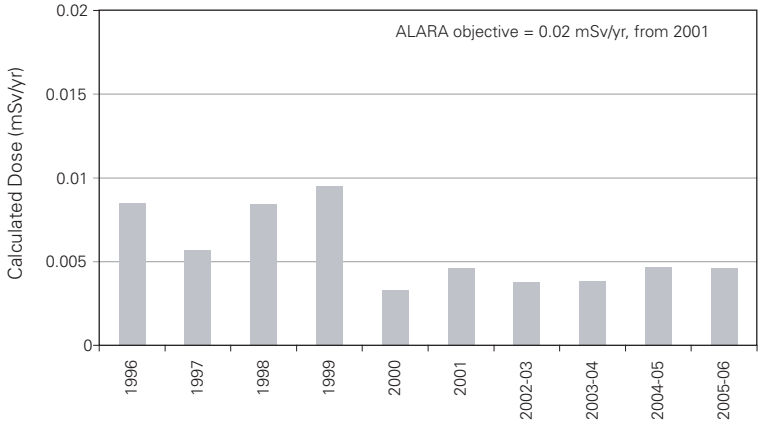

Figure 9. Maximum annual effective dose from LHSTC airborne discharges at the 1.6 km boundary of ANSTO's buffer zone, 1996 to 2005-06.

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 and have remained less than a quarter of this figure for the past six years.

7.2 RADIOACTIVITY IN LIQUID EFFLUENT

The maximum annual quotient for concentrations of radioactivity in liquid effluent released to the sewer (**Figure 10**) 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.

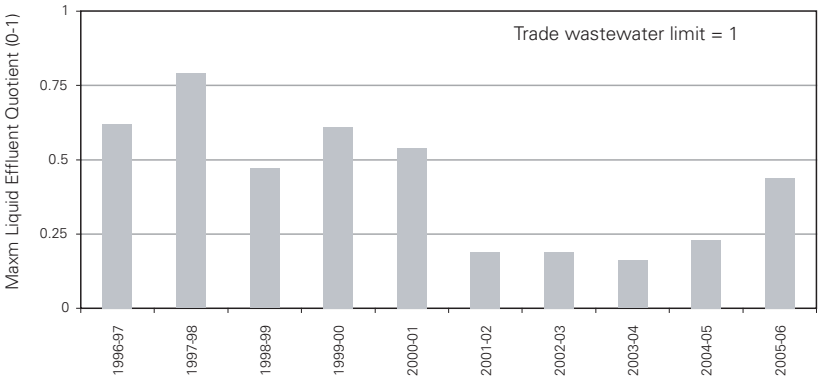

Figure 10. Maximum annual radioactivity concentration quotient in liquid effluent discharges from the LHSTC, July 1996 to June 2006.

The maximum annual radioactivity quotient has remained below the limit specified by successive trade wastewater agreements for the past decade. Since 2001-02, the monthly quotient has been consistently less than half of this limit. The slightly increased maximum quotient recorded for 2005-06 is within the operational variability shown by the data.

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 in relation to limits for Class C surface waters (*Protection of the Environment Operations Act* 1997 NSW).

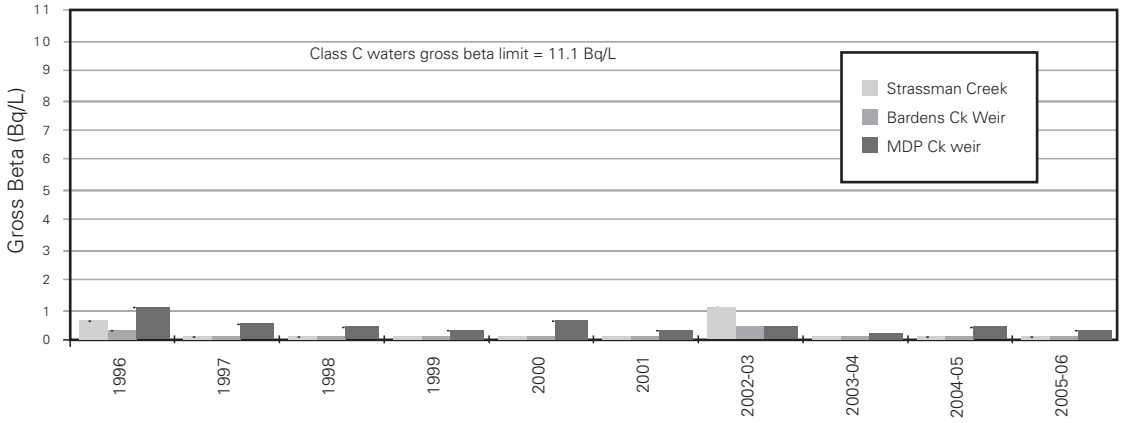

Figure 11. Annual maximum of monthly alpha radioactivity in stormwater at SPCC sampling points, 1996 to 2005-06.

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.

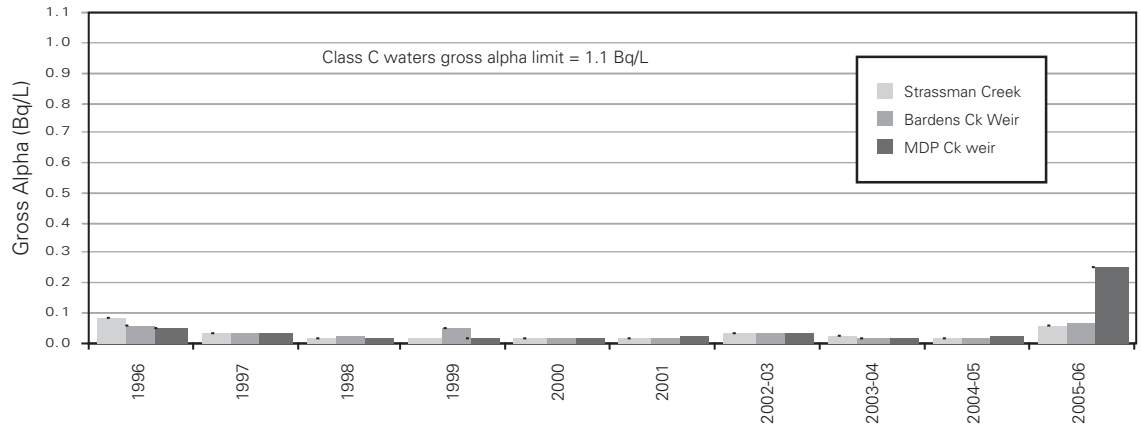

Figure 12. Annual maximum of monthly beta radioactivity in stormwater at SPCC sampling points, 1996 to 2005-06.

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. The ERICA website (ERICA 2006) 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 2005-06 were modelled, based on the LHSTC stack discharge data and concurrent meteorological information. 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 42**. The estimated effective doses to this critical group from routine airborne emissions ranged from 0.0011 to 0.0046 mSv/year, with a median of 0.0018 ± 0.0016 mSv/year.

Figure 13 shows the directional dose from LHSTC airborne emissions for 2005-06, estimated for the critical group of hypothetical individuals on a 1.6 km radius from HIFAR. The maximum estimated effective dose for the critical group was 0.0046 mSv/year to the North, which is 23% of the ALARA objective of 0.02 mSv/year.

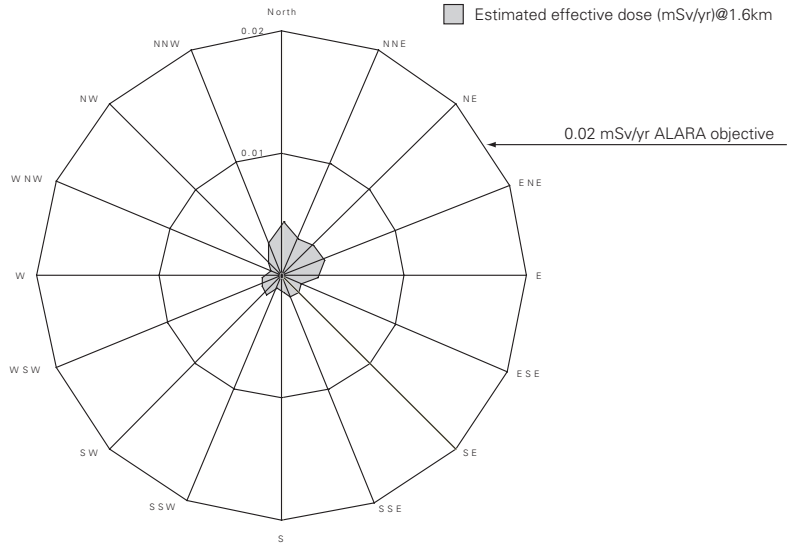

Figure 13. Estimated effective dose to the public (mSv/year) at a 1.6 km radius from HIFAR, from routine LHSTC airborne discharges, July 2005 to June 2006.

The maximum annual dose is estimated for the northerly direction, in keeping with relatively frequent winds blowing from the South and SSE, as noted in section 6.11.2. The potential annual dose received by ANSTO's nearest neighbours at 1.6 km is placed in the context of natural background and averaged medical exposure in **Figure 14.**

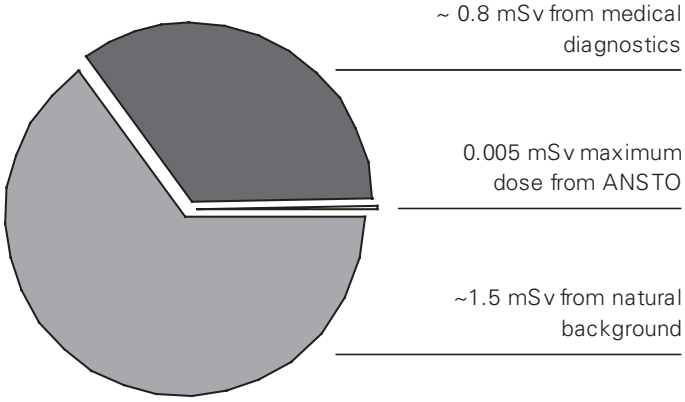

Figure 14. Comparison of the maximum potential dose from ANSTO's airborne discharges (mSv/year) with the average dose Australians receive from natural background and medical procedures (ARPANSA 2006).

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, 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 mean 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 2005 to June 2006, the estimated potential doses to members of the public from airborne discharges at the LHSTC added only a very small fraction to 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. Tritium levels in groundwater at the LHSTC were less than the Australian drinking water guidelines, specifically the 7600 Bq/L level that would confer 10% of the NH&MRC public dose limit if used as a sole source of drinking water for a year. Stormwater tritium levels at the LHSTC were also less than Australian drinking water guidelines, except for an on-site peak in stormwater tritium concentration consistent with deposition under prevailing atmospheric conditions and rapidly diluted downstream. The airborne and liquid effluent emissions from the NMC, from July 2005 to June 2006, were below the ARPANSA-approved notification levels and radioactivity concentration limits, 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.

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Data Tables

Table 1. MEDIAN DETECTION LIMITS FOR ANALYSES OF ENVIRONMENTAL MEDIA

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)	0.012	0.008	0.014	0.021	0.434	0.087	0.03	0.04	12	-	-
SOIL / SEDIMENT (Bq/g)	0.001	-	0.001	0.001	0.085	0.011	-	-	-	-	-
FISH (Bq/kg fresh weight)	0.37	0.67	0.44	0.64	9	2.7	-	-	-	-	-
ALGAE (seaweed) (Bq/kg fresh weight)	0.26	0.35	0.30	0.51	7	2.4	-	-	-	-	-
BARNACLES (Bq/kg fresh weight)	0.57	1.1	0.58	0.79	16	6.5	-	-	-	-	-
MAYPACKS / TC-45 (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, July 2005 to June 2006

	Particulates		Gases and Vapours																	
STACK	Gross Alpha (KBq)	Gross Beta (KBq)	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																		3.986
	-	-																		0.8%
15A	ND	1071	15.29	2852	137.3	73.7	4.279	108	7.919											ND
	-	1.8%	38.2%	28.5%	76.3%	26.3%	10.7%	43.2%	31.7%											-
15M	ND	ND	2.43	403.2	9.39															ND
	-	-	24.3%	89.6%	47.0%															-
19S	ND	ND	33.07																	ND
	-	-	66.1%																	-
19D	ND	ND	1.29																	ND
	-	-	2.6%																	-
20	70.4	82.3		148.08																17.667
	0.7%	0.1%		67.3%																3.5%
20B	ND	ND																		3.853
																				0.8%
21A	ND	ND																		0.4497
	-	-																		0.1%
23A	ND	9070	3285																	ND
	-	2.7%	10.0%																	-
23B	ND	ND	9.52																	ND
	-	-	8.7%																	-
41A	ND	ND																		17.201
	-	-																		3.4%
41B	ND	ND																		21.354
	-	-																		4.3%
54	ND	ND	25500							147400	5499	310.2	111.28	69.39	14.18	ND	0.0792			ND
	-	-	91.1%							61.4%	36.7%	110.8%	27.8%	17.3%	21.8%	-	1.3%			-
56	ND	ND																		6.047
	-	-																		1.2%
57	ND	ND		33.146																2.429
	-	-		15.1%																0.5%
NMC	ND	ND																0.2	16.73	87.03
	-	-																0.10%	16.7%	17.4%

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, and may include some of the other listed nuclides.

Table 3. RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, LHSTC, July 2005 to June 2006

Month	Total Volume Discharged (m^3)	Radioactivity Average Concentration in Discharges (Bq/m^3)			Concentration Quotient
		Alpha	Beta	Tritium	
Jul 2005	4708	< 40.0	5.19×10^3	3.42×10^6	< 0.06
Aug 2005	6582	< 40.0	1.12×10^4	6.88×10^6	< 0.13
Sep 2005	5848	< 51.9	7.55×10^3	7.54×10^6	< 0.10
Oct 2005	4101	< 40.0	4.83×10^4	1.04×10^7	< 0.44
Nov 2005	7464	< 40.0	1.24×10^4	5.17×10^6	< 0.13
Dec 2005	8104	< 56.1	2.04×10^4	5.87×10^6	< 0.20
Jan 2006	5020	< 82.7	1.52×10^4	5.99×10^6	< 0.16
Feb 2006	6204	< 45.8	7.39×10^3	1.27×10^7	< 0.13
Mar 2006	6184	< 50.0	3.87×10^3	5.57×10^6	< 0.06
Apr 2006	5943	< 41.8	5.65×10^3	5.82×10^6	< 0.08
May 2006	6418	< 44.9	1.94×10^3	3.58×10^6	< 0.04
Jun 2006	7139	24.2	1.83×10^3	4.51×10^6	0.04
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.
- A more sensitive alpha analysis method was introduced in June 2006, hence the lower reported value for that month.

Table 4. GAMMA-EMITTERS IN LIQUID EFFLUENT, MONTHLY PIPELINE COMPOSITE SAMPLES, LHSTC, July 2005 to June 2006

	Gamma-emitters (Bq/L)								
MONTH	**Cr-51**	**Co-60**	**Cs-134**	**Cs-137**	**Ce-144**	**I-131**	**Pb-210**	**Ra-226**	**Ra-228**
Jul 2005	< MDA	< MDA	< MDA	1.14 ± 0.07	< MDA	< MDA	< MDA	< MDA	< MDA
Aug 2005	< MDA	0.39 ± 0.06	< MDA	3.28 ± 0.10	< MDA	< MDA	< MDA	< MDA	< MDA
Sep 2005	< MDA	< MDA	< MDA	3.98 ± 0.08	< MDA	< MDA	< MDA	< MDA	< MDA
Oct 2005	< MDA	< MDA	< MDA	12.74 ± 0.13	< MDA	< MDA	< MDA	< MDA	< MDA
Nov 2005	< MDA	< MDA	< MDA	5.59 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
Dec 2005	1.35 ± 0.25	0.21 ± 0.03	< MDA	7.75 ± 0.08	< MDA	0.52 ± 0.03	< MDA	< MDA	< MDA
Jan 2006	< MDA	< MDA	< MDA	5.17 ± 0.10	< MDA	0.58 ± 0.04	< MDA	< MDA	< MDA
Feb 2006	< MDA	< MDA	< MDA	1.95 ± 0.78	< MDA	0.14 ± 0.03	< MDA	< MDA	< MDA
Mar 2006	< MDA	0.25 ± 0.02	< MDA	0.99 ± 0.03	< MDA	0.21 ± 0.02	< MDA	< MDA	< MDA
Apr 2006	< MDA	0.17 ± 0.02	< MDA	2.43 ± 0.07	< MDA	0.59 ± 0.02	< MDA	< MDA	< MDA
May 2006	< MDA	< MDA	< MDA	0.65 ± 0.07	< MDA	< MDA	< MDA	< MDA	< MDA
Jun 2006	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< 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: 0.57 for Cr-51, 0.12 for Co-60, 0.09 for I-123, 0.09 for Cs-134, 0.39 for Ce-144, 1.53 for Pb-210, 1.58 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 2005 to June 2006

Parameter	**2005-06 Concentration** (mg/L) Mean	Median	Range	**Standard for Acceptance** (mg/L)
pH	7.1	7.0	6.5 - 9.8	**7 – 10**
Ammonia	9.2	8.6	1.9 - 17.2	**100**
Biological Oxygen Demand	30	24	2 - 104	**230**
Grease	5	5	5 - 9	**110**
Zinc	0.3	0.3	0.1 - 1.6	**5**
Suspended Solids	46	36	7 - 213	**600**
Total Dissolved Solids	462	469	234 - 607	**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 must be less than or equal to the Standard for Acceptance.
- Measurement of grease levels was no longer required by Sydney Water from March 2006.
- Measurements of total dissolved solids commenced in February 2006 in accordance with the latest agreement with Sydney Water.

Table 6. RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO THE SEWER, NMC, July 2005 to June 2006

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 2005	3.9	7.4	104.56	7.27	11.29	2.46	0.26	0.39
Aug 2005	4.8	7.7	0.97	2.87	0.20	1.16	0.06	0.01
Sep 2005	4.5	7.2	9.87	6.97	2.16	0.71	0.17	0.01
Oct 2005	3.4	8.3	ND	0.52	0.05	0.10	0.44	ND
Nov 2005	3.9	7.3	0.22	1.96	ND	0.07	0.14	ND
Dec 2005	3.0	7.5	55.92	30.82	3.79	4.36	2.39	0.12
Jan 2006	4.9	7.1	0.36	4.53	ND	1.14	0.51	0.01
Feb 2006	3.9	7.3	0.12	1.57	0.01	1.92	0.49	ND
Mar 2006	4.6	7.4	1.50	1.10	0.05	5.29	0.92	0.02
Apr 2006	3.9	7.0	3.05	0.86	ND	3.28	0.73	0.23
May 2006	3.9	7.8	1.19	0.30	ND	0.30	0.19	0.05
Jun 2006	4.0	8.3	3.70	4.04	ND	2.63	0.66	0.05
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 commercial trade wastewater permit issued by Sydney Water.
- ND indicates that the radionuclide was not detected.

Table 7. EFFLUENT DILUTION STUDIES, CRONULLA SEWAGE TREATMENT PLANT AND POTTER POINT, July 2005 to June 2006

LHSTC AND CRONULLA SEWAGE TREATMENT PLANT - Summary

Date	Effluent released from LHSTC: Number of tanks released	Effluent released from LHSTC: Total volume (kL)	Effluent released from LHSTC: Average tritium activity (Bq/L)	Maximum CSTP tritium activity (Bq/L)	Average CSTP tritium activity (Bq/L)	Average UV inlet dilution ratio: LHSTC to CSTP
26-5-06 to 29-6-06	29	8137	3863	32 ± 1	15 ± 1	264:1

CRONULLA SEWAGE TREATMENT PLANT - Effluent

Date	CSTP tritium (Bq/L)	Date	CSTP tritium (Bq/L)	Date	CSTP tritium (Bq/L)
26-5-06	12 ± 1	8-6-06	7 ± 1	19-6-06	21 ± 1
27-5-06	10 ± 1	9-6-06	< MDA	20-6-06	14 ± 1
28-5-06	8 ± 1	12-6-06	22 ± 1	21-6-06	32 ± 1
29-5-06	6 ± 1	13-6-06	6 ± 1	26-6-06	14 ± 1
6-6-06	20 ± 1	15-6-06	31 ± 1	27-6-06	14 ± 1
7-6-06	6 ± 1	16-6-06	21 ± 1	29-6-06	14 ± 1

POTTER POINT OCEAN OUTFALL - Seawater

Date	Sampling start time (h:mm)	Sampling end time (h:mm)	Number of seawater samples analysed	Maximum tritium activity (Bq/L)	Average tritium activity (Bq/L)	CSTP tritium activity (Bq/L)
14-6-06	9:00	15:00	7	< MDA	< MDA	No sample
29-6-05	9:00	15:00	7	< MDA	< MDA	14 ± 1

Notes:
- Effluent at the CSTP was sampled at a location known as the UV Inlet. All average values are weighted for flow volume.
- 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 effluent release from one or two days prior).
- The minimum detectable activity (MDA) for tritium for these studies is 5 Bq/L.

Table 8. AMBIENT IODINE-131 IN AIR, LHSTC PERIMETER, July 2005 to June 2006

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
5-7-05	< MDA	< MDA	< MDA	< MDA	3-1-06	< MDA	< MDA	< MDA	< MDA
12-7-05	< MDA	0.0009 ± 0.0004	< MDA	< MDA	10-1-06	< MDA	< MDA	< MDA	< MDA
19-7-05	< MDA	0.0013 ± 0.0005	< MDA	< MDA	17-1-06	< MDA	< MDA	< MDA	< MDA
26-7-05	< MDA	0.0023 ± 0.0006	< MDA	< MDA	24-1-06	< MDA	< MDA	< MDA	< MDA
2-8-05	< MDA	0.0083 ± 0.0019	0.0017 ± 0.0006	< MDA	31-1-06	< MDA	< MDA	< MDA	< MDA
9-8-05	0.0012 ± 0.0005	0.0200 ± 0.0044	0.0009 ± 0.0004	< MDA	7-2-06	< MDA	0.0014 ± 0.0006	< MDA	< MDA
16-8-05	0.0010 ± 0.0005	< MDA	< MDA	< MDA	14-2-06	< MDA	< MDA	< MDA	< MDA
23-8-05	< MDA	0.0032 ± 0.0008	0.0014 ± 0.0004	< MDA	21-2-06	< MDA	0.0014 ± 0.0007	< MDA	< MDA
30-8-05	< MDA	0.0012 ± 0.0005	< MDA	< MDA	28-2-06	< MDA	< MDA	< MDA	< MDA
6-9-05	< MDA	< MDA	< MDA	< MDA	7-3-06	0.0145 ± 0.0032	0.0177 ± 0.0038	0.0031 ± 0.0012	0.0021 ± 0.0009
13-9-05	< MDA	< MDA	< MDA	< MDA	14-3-06	0.0245 ± 0.0054	0.0545 ± 0.0115	0.0040 ± 0.0010	0.0058 ± 0.0016
20-9-05	-	< MDA	< MDA	< MDA	21-3-06	0.0063 ± 0.0015	0.0287 ± 0.0062	0.0023 ± 0.0008	0.0045 ± 0.0013
27-10-05	< MDA	< MDA	< MDA	< MDA	28-3-06	0.0080 ± 0.0019	0.2045 ± 0.0435	0.0364 ± 0.0079	0.0116 ± 0.0027
5-10-05	0.0012 ± 0.0005	< MDA	< MDA	< MDA	4-4-06	0.0143 ± 0.0031	0.0494 ± 0.0106	0.0280 ± 0.0060	0.0067 ± 0.0017
11-10-05	0.0015 ± 0.0006	0.0047 ± 0.0011	< MDA	< MDA	11-4-06	0.0065 ± 0.0016	0.0417 ± 0.0089	0.0074 ± 0.0018	< MDA
18-10-05	0.0057 ± 0.0013	0.0304 ± 0.0065	0.0055 ± 0.0013	0.0043 ± 0.0011	18-4-06	0.0058 ± 0.0015	0.0518 ± 0.0111	0.0035 ± 0.0010	0.0029 ± 0.0010
25-10-05	0.0172 ± 0.0037	0.0762 ± 0.0162	0.0068 ± 0.0016	0.0101 ± 0.0022	26-4-06	< MDA	0.0202 ± 0.0044	0.0023 ± 0.0008	< MDA
1-11-05	0.0041 ± 0.0011	0.0242 ± 0.0052	0.0040 ± 0.0010	0.0015 ± 0.0005	2-5-06	< MDA	0.0211 ± 0.0046	0.0031 ± 0.0011	< MDA
8-11-05	0.0034 ± 0.0009	0.0057 ± 0.0013	< MDA	0.0026 ± 0.0008	9-5-06	< MDA	0.0117 ± 0.0026	< MDA	< MDA
15-11-05	0.0038 ± 0.0009	0.0082 ± 0.0018	< MDA	0.0026 ± 0.0008	16-5-06	< MDA	< MDA	< MDA	< MDA
22-11-05	0.0012 ± 0.0005	0.0035 ± 0.0009	< MDA	< MDA	23-5-06	< MDA	0.0080 ± 0.0020	< MDA	< MDA
29-11-05	0.0019 ± 0.0006	0.0050 ± 0.0012	< MDA	< MDA	30-5-06	< MDA	< MDA	< MDA	< MDA
6-12-05	< MDA	0.0030 ± 0.0008	< MDA	< MDA	6-6-06	< MDA	< MDA	< MDA	< MDA
13-12-05	< MDA	0.0028 ± 0.0007	< MDA	< MDA	13-6-06	< MDA	< MDA	< MDA	< MDA
20-12-05	0.0010 ± 0.0004	< MDA	< MDA	< MDA	20-6-06	< MDA	< MDA	< MDA	< MDA
30-12-05	< MDA	< MDA	< MDA	< MDA	27-6-06	< 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.
- Dash (-) indicates missing data due to a pump malfunction.
- From 11-4-06, commercial cartridges replaced the Maypacks, which were produced by ANSTO.
- < 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.

Table 9. RADIOACTIVITY IN AIRBORNE PARTICLES, LFBG, July 2005 to June 2006

Sampling Period	Equivalent Volume (m^3)	(% of Filter)	Beryllium (µg total)	(µg/m^3)	Pu-239/240 (Bq total)	(Bq/m^3)
Jul – Sep 05	512	25	< MDA	$< 7.8 \times 10^{-5}$	< MDA	$< 2.0 \times 10^{-6}$
Oct – Dec 05	300	25	< MDA	$< 1.3 \times 10^{-4}$	< MDA	$< 3.3 \times 10^{-6}$
Jan – Mar 06	381	25	< MDA	$< 1.1 \times 10^{-4}$	< MDA	$< 2.6 \times 10^{-6}$
Apr – Jun 06	449	25	< MDA	$< 2.0 \times 10^{-4}$	< 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.
- < 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 2005 to June 2006

	ANSTO Environmental Thermoluminescent Dosimeters	
	Dosimeter Location: LHSTC site	**Annual Effective Dose** (mSv/year) **2005-06**
1	HIFAR fence - south east	1.15 ± 0.04
2	HIFAR fence - south	3.05 ± 0.12
3	Perimeter fence - west	2.92 ± 0.11
4	HIFAR fence - west	1.38 ± 0.05
5	HIFAR fence - north west	1.23 ± 0.05
6	Perimeter fence - north A	1.04 ± 0.04
7	Internal fence - north	1.07 ± 0.04
8	Perimeter fence - north B	0.96 ± 0.04
9	Perimeter fence - north east	1.00 ± 0.04
10	Perimeter fence - east	1.06 ± 0.04
11	Perimeter fence - south east	0.99 ± 0.04
12	Corner of Curie and Roentgen St	1.16 ± 0.04
13	Perimeter fence - south	0.88 ± 0.03
14	HIFAR fence - east	1.25 ± 0.05
15	HIFAR fence - north east	1.33 ± 0.05
	Dosimeter Location: off-site	
16	Private house - Barden Ridge	1.37 ± 0.05
17	Private house - Yarrawarra	1.08 ± 0.04
18	Private house - Woronora	1.74 ± 0.07
19	Cronulla Sewage Treatment Plant	0.78 ± 0.03
20	LFBG - on trenches	1.30 ± 0.05
21	LFBG - background	1.17 ± 0.04
22	Lucas Heights Waste Management Centre - Depot	1.06 ± 0.04

Notes:

- Changes to fencing around HIFAR and OPAL required three dosimeters to be permanently relocated, effective from the last quarter of 2005-06: dosimeter 3 to a new fence in a similar position; dosimeters 4 and 5 to the new perimeter fence north of OPAL and the neutron guide hall. Refer to Figure 2.
- 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 2005 to June 2006

ANSTO Environmental Thermoluminescent Dosimeters		
	Dosimeter Location	**Annual Effective Dose** (mSv/year) **2005-06**
1	Front entrance	2.07 ± 0.08
2	East wall	1.62 ± 0.06
3	Stair on north wall	1.88 ± 0.07
4	West wall	1.78 ± 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 2005 to June 2006

	TRITIUM (Bq/L)		
Month	**BUND A**	**BUND B**	**BUND C**
Jul 2005	280 ± 10	80 ± 10	80 ± 10
Aug 2005	60 ± 10	240 ± 10	80 ± 10
Sep 2005	80 ± 10	110 ± 10	70 ± 10
Oct 2005	160 ± 10	90 ± 10	160 ± 10
Nov 2005	110 ± 10	50 ± 10	150 ± 10
Dec 2005	210 ± 10	100 ± 10	110 ± 10
Jan 2006	7220 ± 50	250 ± 10	70 ± 10
Feb 2006	2940 ± 30	130 ± 10	70 ± 10
Mar 2006	8540 ± 60	100 ± 10	100 ± 10
Apr 2006	360 ± 20	190 ± 10	220 ± 20
May 2006	80 ± 10	100 ± 10	70 ± 10
Jun 2006	510 ± 20	110 ± 10	80 ± 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 SEDIMENTATION BASINS, LHSTC, July 2005 to June 2006

				RADIOACTIVITY (Bq/L)					
				Gamma-emitters					
Location	**Date**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Be-7**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
OPAL- North	26-9-05	0.06 ± 0.01	0.15 ± 0.01	< MDA	1.097 ± 0.150	< MDA	< MDA	< MDA	< MDA
	3-11-05	0.10 ± 0.01	0.15 ± 0.01	< MDA	0.418 ± 0.085	< MDA	< MDA	< MDA	< MDA
	27-2-06	0.52 ± 0.05	0.49 ± 0.02	< MDA	0.363 ± 0.082	< MDA	< MDA	< MDA	10 ± 10
	6-6-06	0.06 ± 0.01	0.11 ± 0.01	< MDA	0.541 ± 0.128	< MDA	< MDA	< MDA	< MDA
OPAL - South West	26-9-05	0.19 ± 0.03	0.34 ± 0.02	< MDA	0.513 ± 0.105	< MDA	< MDA	0.496 ± 0.128	< MDA
	3-11-05	0.07 ± 0.02	0.19 ± 0.01	< MDA	< MDA	< MDA	< MDA	0.419 ± 0.131	50 ± 10
	27-2-06	0.35 ± 0.04	0.39 ± 0.02	< MDA	0.453 ± 0.167	< MDA	< MDA	0.456 ± 0.201	< MDA
	6-6-06	0.18 ± 0.02	0.40 ± 0.02	< MDA	0.156 ± 0.070	< MDA	< MDA	< MDA	< MDA

Notes:
- See Figure 3 for the locations of the sedimentation basins.
- The NSW Regulations (Prot. Env. Operations Act 1997) limits for radioactivity in Class C surface 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 2005 to June 2006

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
5-7-05	80 ± 10	8-11-05	50 ± 10	14-3-06	130 ± 10
12-7-05	80 ± 10	15-11-05	200 ± 10	21-3-06	60 ± 10
19-7-05	20 ± 10	22-11-05	190 ± 10	28-3-06	170 ± 10
26-7-05	170 ± 10	29-11-05	70 ± 10	4-4-06	120 ± 10
2-8-05	130 ± 10	6-12-05	130 ± 10	11-4-06	150 ± 10
9-8-05	130 ± 10	13-12-05	90 ± 10	18-4-06	50 ± 10
16-8-05	120 ± 10	20-12-05	140 ± 10	24-4-06	90 ± 10
23-8-05	30 ± 10	30-12-05	110 ± 10	2-5-06	90 ± 10
30-8-05	20 ± 10	3-1-06	50 ± 10	9-5-06	170 ± 10
6-9-05	50 ± 10	10-1-06	40 ± 10	16-5-06	20 ± 10
13-9-05	100 ± 10	17-1-06	30 ± 10	23-5-06	70 ± 10
20-9-05	70 ± 10	24-1-06	170 ± 10	30-5-06	30 ± 10
27-9-05	30 ± 10	31-1-06	40 ± 10	6-6-06	30 ± 10
5-10-05	90 ± 10	7-2-06	120 ± 10	13-6-06	80 ± 10
11-10-05	70 ± 10	14-2-06	60 ± 10	20-6-06	50 ± 10
18-10-05	80 ± 10	21-2-06	50 ± 10	27-6-06	140 ± 10
25-10-05	310 ± 10	28-2-06	60 ± 10		
1-11-05	10 ± 10	7-3-06	160 ± 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 2005 to June 2006

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
5-7-05	80 ± 10	8-11-05	40 ± 10	14-3-06	80 ± 10
12-7-05	70 ± 10	15-11-05	140 ± 10	21-3-06	80 ± 10
19-7-05	50 ± 10	22-11-05	130 ± 10	28-3-06	80 ± 10
26-7-05	130 ± 10	29-11-05	40 ± 10	4-4-06	90 ± 10
2-8-05	80 ± 10	6-12-05	130 ± 10	11-4-06	90 ± 10
9-8-05	80 ± 10	13-12-05	100 ± 10	18-4-06	80 ± 10
16-8-05	70 ± 10	20-12-05	80 ± 10	24-4-06	70 ± 10
23-8-05	60 ± 10	30-12-05	90 ± 10	2-5-06	90 ± 10
30-8-05	60 ± 10	3-1-06	70 ± 10	9-5-06	70 ± 10
6-9-05	70 ± 10	10-1-06	60 ± 10	16-5-06	60 ± 10
13-9-05	70 ± 10	17-1-06	30 ± 10	23-5-06	100 ± 10
20-9-05	40 ± 10	24-1-06	130 ± 10	30-5-06	70 ± 10
27-9-05	50 ± 10	31-1-06	60 ± 10	6-6-06	20 ± 10
5-10-05	70 ± 10	7-2-06	70 ± 10	13-6-06	70 ± 10
11-10-05	80 ± 10	14-2-06	70 ± 10	20-6-06	70 ± 10
18-10-05	60 ± 10	21-2-06	70 ± 10	27-6-06	170 ± 10
25-10-05	150 ± 10	28-2-06	70 ± 10		
1-11-05	120 ± 10	7-3-06	80 ± 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 2005 to June 2006

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
5-7-05	170 ± 10	8-11-05	40 ± 10	14-3-06	420 ± 10
12-7-05	110 ± 10	15-11-05	40 ± 10	21-3-06	1460 ± 30
19-7-05	160 ± 10	22-11-05	50 ± 10	28-3-06	370 ± 10
26-7-05	110 ± 10	29-11-05	20 ± 10	4-4-06	610 ± 20
2-8-05	40 ± 10	6-12-05	40 ± 10	11-4-06	490 ± 20
9-8-05	80 ± 10	13-12-05	60 ± 10	18-4-06	240 ± 10
16-8-05	40 ± 10	20-12-05	100 ± 10	24-4-06	230 ± 10
23-8-05	50 ± 10	30-12-05	40 ± 10	2-5-06	180 ± 10
30-8-05	40 ± 10	3-1-06	60 ± 10	9-5-06	100 ± 10
6-9-05	60 ± 10	10-1-06	210 ± 10	16-5-06	220 ± 10
13-9-05	40 ± 10	17-1-06	1190 ± 20	23-5-06	190 ± 10
20-9-05	50 ± 10	24-1-06	2910 ± 30	30-5-06	260 ± 20
27-9-05	140 ± 10	31-1-06	3290 ± 40	6-6-06	80 ± 10
5-10-05	80 ± 10	7-2-06	2150 ± 30	13-6-06	190 ± 10
11-10-05	70 ± 10	14-2-06	900 ± 20	20-6-06	90 ± 10
18-10-05	40 ± 10	21-2-06	670 ± 20	27-6-06	130 ± 10
25-10-05	60 ± 10	28-2-06	710 ± 20		
1-11-05	20 ± 10	7-3-06	880 ± 20		

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

Table 17. RADIOACTIVITY IN STORMWATER, BUND C MONTHLY COMPOSITES, LHSTC, July 2005 to June 2006

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 2005	0.03 ± 0.01	0.27 ± 0.01	< MDA	< MDA	0.008 ± 0.003	< MDA	< MDA	< MDA
Aug 2005	0.03 ± 0.01	0.25 ± 0.01	< MDA	0.138 ± 0.025	0.007 ± 0.002	< MDA	< MDA	0.080 ± 0.039
Sep 2005	0.03 ± 0.01	0.26 ± 0.01	< MDA	0.213 ± 0.040	0.006 ± 0.003	< MDA	< MDA	< MDA
Oct 2005	< MDA	0.43 ± 0.01	< MDA	0.123 ± 0.027	0.015 ± 0.003	< MDA	< MDA	< MDA
Nov 2005	0.05 ± 0.01	0.38 ± 0.01	< MDA	0.276 ± 0.042	0.010 ± 0.002	< MDA	< MDA	0.081 ± 0.039
Dec 2005	0.02 ± 0.01	0.28 ± 0.01	< MDA	0.128 ± 0.034	0.008 ± 0.003	< MDA	< MDA	0.200 ± 0.043
Jan 2006	0.03 ± 0.01	0.24 ± 0.01	< MDA	0.582 ± 0.070	0.008 ± 0.002	< MDA	< MDA	0.143 ± 0.035
Feb 2006	0.02 ± 0.01	0.29 ± 0.01	< MDA	0.240 ± 0.038	0.021 ± 0.003	< MDA	< MDA	< MDA
Mar 2006	0.02 ± 0.01	0.25 ± 0.01	< MDA	0.130 ± 0.027	0.008 ± 0.002	< MDA	< MDA	< MDA
Apr 2006	< MDA	0.29 ± 0.01	< MDA	0.082 ± 0.028	0.012 ± 0.003	< MDA	< MDA	< MDA
May 2006	0.03 ± 0.02	0.31 ± 0.01	< MDA	0.113 ± 0.020	0.022 ± 0.003	< MDA	0.005 ± 0.002	0.147 ± 0.039
Jun 2006	0.02 ± 0.01	0.27 ± 0.01	< MDA	< MDA	0.006 ± 0.002	< MDA	< MDA	< MDA

Notes:
- Refer to Figure 3 for the MDP Bund C sampling location. The weekly grab 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 surface 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 2005 to June 2006

			Gamma-emitters (Bq/L)				
Month	**Gross Alpha** (Bq/L)	**Gross Beta** (Bq/L)	**Am-241**	**Be-7**	**Cs-137**	**Co-60**	**K-40**
Jul 2005	0.02 ± 0.01	0.18 ± 0.01	< MDA	< MDA	0.009 ± 0.003	< MDA	< MDA
Aug 2005	0.03 ± 0.01	0.12 ± 0.01	< MDA	< MDA	0.009 ± 0.002	< MDA	< MDA
Sep 2005	0.01 ± 0.01	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
Oct 2005	0.03 ± 0.01	0.12 ± 0.01	< MDA	0.052 ± 0.023	0.007 ± 0.003	< MDA	< MDA
Nov 2005	0.04 ± 0.01	0.25 ± 0.01	< MDA	0.259 ± 0.036	0.005 ± 0.003	< MDA	< MDA
Dec 2005	0.01 ± 0.01	0.19 ± 0.01	< MDA	< MDA	0.008 ± 0.003	< MDA	< MDA
Jan 2006	0.02 ± 0.01	0.21 ± 0.01	< MDA	0.061 ± 0.016	0.011 ± 0.002	< MDA	0.147 ± 0.032
Feb 2006	0.04 ± 0.01	0.14 ± 0.01	< MDA	0.049 ± 0.016	0.012 ± 0.003	< MDA	< MDA
Mar 2006	0.02 ± 0.01	0.12 ± 0.01	< MDA	< MDA	0.009 ± 0.004	< MDA	0.157 ± 0.047
Apr 2006	0.03 ± 0.01	0.14 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
May 2006	0.08 ± 0.01	0.18 ± 0.01	< MDA	< MDA	0.007 ± 0.003	< MDA	< MDA
Jun 2006	0.04 ± 0.01	0.13 ± 0.01	< MDA	< MDA	0.007 ± 0.002	< MDA	< MDA

Notes:
- Refer to Figure 3 for the location of this sampling point, 60m downstream of the MDP Bund. The weekly grab 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 surface 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 2005 to June 2006

	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 2005	< MDA	0.03 ± 0.01	< MDA	0.02 ± 0.01	< MDA	0.16 ± 0.01	< MDA	0.05 ± 0.01
Aug 2005	0.01 ± 0.01	0.04 ± 0.01	< MDA	0.01 ± 0.01	0.01 ± 0.01	0.15 ± 0.01	< MDA	0.06 ± 0.02
Sep 2005	0.01 ± 0.01	0.03 ± 0.01	< MDA	0.02 ± 0.01	< MDA	0.12 ± 0.01	< MDA	0.13 ± 0.02
Oct 2005	0.02 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.10 ± 0.01	0.07 ± 0.01	0.18 ± 0.01
Nov 2005	0.03 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.06 ± 0.01	0.02 ± 0.01	0.12 ± 0.01	< MDA	0.05 ± 0.01
Dec 2005	0.01 ± 0.01	0.06 ± 0.01	< MDA	0.02 ± 0.01	< MDA	0.19 ± 0.01	< MDA	0.04 ± 0.01
Jan 2006	0.01 ± 0.01	0.04 ± 0.01	< MDA	0.03 ± 0.01	0.02 ± 0.01	0.22 ± 0.01	< MDA	0.02 ± 0.01
Feb 2006	0.05 ± 0.01	0.07 ± 0.01	0.05 ± 0.01	0.10 ± 0.01	0.04 ± 0.01	0.13 ± 0.01	< MDA	0.05 ± 0.01
Mar 2006	0.06 ± 0.01	0.08 ± 0.01	0.07 ± 0.01	0.12 ± 0.01	0.26 ± 0.03	0.33 ± 0.02	< MDA	0.04 ± 0.01
Apr 2006	0.01 ± 0.01	0.08 ± 0.01	< MDA	0.04 ± 0.01	0.01 ± 0.01	0.14 ± 0.01	< MDA	0.07 ± 0.01
May 2006	0.03 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.05 ± 0.01	0.02 ± 0.01	0.24 ± 0.01	< MDA	0.07 ± 0.01
Jun 2006	0.05 ± 0.01	0.08 ± 0.01	0.03 ± 0.01	0.06 ± 0.01	0.04 ± 0.01	0.16 ± 0.01	0.02 ± 0.01	0.06 ± 0.01

Notes:
- See Figure 3 for the location of the SPCC sampling points. Single grab samples were collected once per month.
- 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 surface waters are: gross alpha 1.1 Bq/L; gross beta 11.1 Bq/L.
- < 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 20. RADIOACTIVITY IN CREEKS NORTH OF THE LFBG, July 2005 to June 2006

WATER (Bq/L)

Location	Date Sampled	Gross Alpha	Gross Beta	Gamma-emitters				Tritium
				Am-241	Cs-137	Co-60	K-40	
Mill Creek	14-9-05	< MDA	0.16 ± 0.01	< MDA	< MDA	< MDA	0.340 ± 0.140	< MDA
Bardens Creek	14-9-05	< MDA	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	20 ± 10

SEDIMENT (Bq/g DW)

Location	Date Sampled	Gross Alpha	Gross Beta	Gamma-emitters				Be-7
				Am-241	Cs-137	Co-60	K-40	
Mill Creek	14-9-05	0.59 ± 0.11	0.14 ± 0.02	< MDA	< MDA	< MDA	0.041 ± 0.008	< MDA
Bardens Creek	14-9-05	0.73 ± 0.11	0.28 ± 0.02	< MDA	0.001 ± 0.001	< MDA	0.103 ± 0.014	< 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 2005 to June 2006

Month	**Tritium** (Bq/L)		
	Estuary Station E5.9	**Causeway**	**Heathcote Rd Bridge**
Jul 2005	< MDA	< MDA	< MDA
Aug 2005	< MDA	< MDA	< MDA
Sep 2005	< MDA	< MDA	< MDA
Oct 2005	< MDA	< MDA	< MDA
Nov 2005	< MDA	< MDA	< MDA
Dec 2005	< MDA	< MDA	< MDA
Jan 2006	< MDA	< MDA	< MDA
Feb 2006	< MDA	< MDA	< MDA
Mar 2006	< MDA	< MDA	< MDA
Apr 2006	< MDA	< MDA	< MDA
May 2006	< MDA	< MDA	< MDA
Jun 2006	< MDA	30 ± 10	< 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 2005

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	10	9.18	18.8	322	4.8	81
MW1D	13	9.34	18.4	368	4.3	362
MW2S	6	3.44	17.1	227	4.6	213
MW2D	10	5.42	17.6	361	5.3	154
MW3S	6	2.07	17.5	307	4.2	250
MW3D	20	12.98	18.2	372	5.2	179
MW4S	6	1.83	16.5	935	6.4	76
MW4D	10	4.50	17.4	307	5.4	126
MW5S	7	4.60	18.8	228	5.1	165
MW6S	8	4.22	17.6	246	5.9	133
MW6D	10	6.12	18.1	363	5.3	141
MW7S	6	5.22	19.5	229	4.9	93
MW7D	18	13.72	18.3	624	3.8	383
MW8S	-	-	-	-	-	-
MW8D	25	23.56	17.8	164	5.3	165
MW9S	16	11.79	18.1	340	4.1	252
MW9D	20	13.24	18.2	387	4.3	194
MW10S	7	3.90	17.2	310	5.4	262
MW11-2	15	11.35	18.7	398	4.3	284
MW13	20	15.80	19.1	386	4.0	232
MW14	20	13.74	18.7	502	5.3	154
MW15S	10	3.49	18.4	379	4.2	360
MW15D	10	3.58	18.3	186	5.8	328
BH3	20	15.70	18.7	336	6.1	62
BH3A	13	10.52	18.6	356	4.4	255
BH6	13	10.12	18.6	332	5.5	172
BH112	24	20.66	19.0	434	5.0	206

Notes:
- MW8S was not sampled as the 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 23. FIELD PARAMETERS IN GROUNDWATER, LHSTC, November 2005

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	9.38	18.6	354	4.5	179
MW1D	15	9.53	18.4	428	4.0	329
MW2S	9	3.44	17.0	223	4.7	178
MW2D	10	3.52	16.9	344	5.1	172
MW3S	6	2.12	18.0	326	4.2	229
MW3D	11	4.61	17.5	406	5.5	122
MW4S	6	1.52	17.5	1136	6.4	-42
MW4D	10	3.63	17.0	305	5.3	91
MW5S	9	3.30	20.2	245	4.8	158
MW6S	9	4.03	18.0	223	5.9	153
MW6D	12	5.81	17.9	344	5.3	161
MW7S	6	4.71	20.1	272	4.4	327
MW7D	20	13.90	18.9	616	3.6	449
MW8S	-	-	-	-	-	-
MW8D	30	23.68	18.4	160	5.0	172
MW9S	17	10.96	19.3	322	5.1	209
MW9D	20	13.38	19.5	343	4.3	262
MW10S	10	3.80	19.4	324	5.1	215
MW11-2	15	9.70	21.0	378	4.2	241
MW13	24	15.90	20.3	371	4.0	242
MW14	22	13.82	20.1	465	4.5	236
MW15S	11	3.44	18.5	369	4.2	273
MW15D	12	3.50	18.5	302	5.4	294
BH3	23	15.77	19.5	340	5.2	189
BH3A	14	10.62	19.3	362	4.4	234
BH6	15	10.12	18.9	337	5.6	196
BH112	25	18.13	20.2	461	4.0	292

Notes:
- MW8S was not sampled as the 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 24. FIELD PARAMETERS IN GROUNDWATER, LHSTC, February 2006

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	9.35	19.6	351	4.3	35
MW1D	15	9.51	18.8	419	3.8	239
MW2S	6	3.52	19.5	222	4.5	203
MW2D	14	3.59	17.8	338	4.3	246
MW3S	5	1.49	21.3	144	4.7	206
MW3D	12	4.40	19.1	435	5.5	82
MW4S	4	1.10	22.0	863	6.7	93
MW4D	14	4.64	18.1	318	5.3	90
MW5S	8	4.55	22.6	208	4.7	237
MW6S	7	3.95	21.9	253	6.0	254
MW6D	15	5.93	19.7	334	5.2	171
MW7S	6	5.47	19.7	477	4.3	97
MW7D	20	14.28	18.5	611	3.7	430
MW8S	-	-	-	-	-	-
MW8D	27	23.79	18.7	170	4.9	210
MW9S	19	11.88	19.3	329	4.2	278
MW9D	22	14.01	18.5	403	4.4	235
MW10S	7	3.64	21.4	324	5.0	187
MW11-2	18	14.08	21.0	353	4.6	263
MW13	21	15.98	20.7	375	3.8	303
MW14	20	13.89	20.2	427	4.9	186
MW15S	8	3.25	20.3	377	4.0	260
MW15D	15	9.98	20.3	377	5.3	141
BH3	21	16.55	19.9	362	5.4	104
BH3A	12	10.60	20.0	356	4.3	196
BH6	-	-	-	-	-	-
BH112	23	21.22	21.1	353	5.2	125

Notes:
- MW8S was not sampled as the piezometer was dry.
- BH6 was not sampled because the piezometer was damaged.
- 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 2006

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	9.36	19.3	357	4.5	59
MW1D	17	9.54	18.7	423	4.0	301
MW2S	7	3.56	18.1	212	4.7	271
MW2D	15	5.75	17.4	315	4.9	235
MW3S	6	2.62	18.5	310	4.3	204
MW3D	20	9.98	17.7	436	5.6	81
MW4S	6	2.87	17.7	772	6.1	77
MW4D	15	4.80	17.8	320	5.4	165
MW5S	8	5.39	21.8	276	4.4	225
MW6S	7	4.34	19.4	212	5.6	202
MW6D	16	6.10	18.4	339	5.4	161
MW7S	-	-	-	-	-	-
MW7D	20	14.14	18.1	615	3.9	421
MW8S	-	-	-	-	-	-
MW8D	27	23.82	17.1	177	5.3	182
MW9S	16	12.05	17.1	314	4.4	272
MW9D	20	13.82	18.0	334	4.8	248
MW10S	8	3.86	19.7	320	5.0	194
MW11-2	20	14.95	19.4	380	4.4	318
MW13	20	15.92	18.4	298	4.9	228
MW14	20	13.77	18.7	438	5.1	189
MW15S	10	3.33	19.6	378	4.2	306
MW15D	11	3.53	19.4	509	5.7	159
BH3	21	16.32	17.5	381	5.5	120
BH3A	13	10.58	18.5	364	4.4	219
BH6	-	-	-	-	-	-
BH112	25	21.06	17.8	409	4.9	205

Notes:
- BH6 was not sampled as this piezometer was damaged.
- MW7S and MW8S were not sampled as the piezometers were 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, November 2005

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	35.7	2.01	6.21	2.22	70	31	<1
MW1D	48.0	0.31	5.79	0.41	101	18	<1
MW2S	26.2	0.26	3.88	0.67	48	11	<1
MW2D	38.2	1.06	6.49	1.89	76	11	<1
MW3S	36.0	0.35	3.83	0.79	67	33	<1
MW3D	41.7	1.48	9.23	4.71	84	8	28
MW4S	41.1	1.90	21.50	96.10	55	66	382
MW4D	32.1	0.61	5.50	0.90	66	10	10
MW5S	26.4	0.76	3.54	2.47	42	18	3
MW6S	13.3	0.95	2.56	19.30	16	23	40
MW6D	43.1	0.62	2.94	4.95	76	6	10
MW7S	29.4	1.53	3.58	4.07	38	40	3
MW7D	63.5	1.02	8.66	1.43	145	29	<1
MW8S	-	-	-	-	-	-	-
MW8D	16.9	0.54	1.37	4.57	31	7	10
MW9S	34.5	0.81	4.85	4.92	31	7	6
MW9D	37.4	0.66	5.54	1.62	76	18	<1
MW10S	32.1	1.20	3.14	5.84	34	32	5
MW11-2	46.4	0.92	5.28	0.91	94	13	<1
MW13	36.0	0.51	4.13	0.85	58	16	<1
MW14	54.8	1.10	7.45	1.76	97	29	<1
MW15S	44.1	0.73	4.53	1.40	91	21	<1
MW15D	36.9	3.29	2.38	6.33	54	34	7
BH3	36.1	4.36	4.73	6.50	67	17	11
BH3A	45.6	0.38	3.78	1.75	72	29	<1
BH6	34.0	3.26	2.32	15.90	28	63	28
BH112	44.0	1.22	7.86	3.47	110	7	<1

Notes:
- Cation concentrations (Na, K, Mg, Ca) are for dissolved ions.
- Anion concentrations (Cl, SO_4, HCO_3) include dissolved and undissolved ions.
- MW8S was not sampled as piezometer was dry.

Table 27. NUTRIENTS IN GROUNDWATER, LHSTC, November 2005

Piezometer	Ammonia NH_3-N (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Oxidized Nitrogen: NO_x-N (mg/L)	Total Nitrogen (calculated) (mg/L)	Soluble Reactive Phosphorous (mg/L)	Total Phosphorus (mg/L)
MW1S	0.02	0.49	0.50	0.99	0.002	0.038
MW1D	< MDL	0.11	0.25	0.36	< MDL	0.005
MW2S	< MDL	< MDL	0.03	< 0.13	< MDL	0.008
MW2D	< MDL	< MDL	< MDL	< 0.11	< MDL	0.005
MW3S	< MDL	0.12	0.03	0.15	< MDL	0.014
MW3D	0.01	< MDL	0.01	< 0.11	< MDL	0.005
MW4S	0.35	0.71	0.03	0.74	0.002	0.007
MW4D	< MDL	< MDL	< MDL	< 0.11	< MDL	0.008
MW5S	< MDL	< MDL	0.14	< 0.24	< MDL	0.007
MW6S	< MDL	0.29	0.13	0.42	0.002	0.024
MW6D	< MDL	< MDL	0.02	< 0.12	< MDL	0.009
MW7S	-	-	-	-	-	-
MW7D	< MDL	0.28	0.01	0.29	0.002	0.008
MW8S	-	-	-	-	-	-
MW8D	< MDL	0.10	0.05	0.15	< MDL	0.046
MW9S	< MDL	0.10	0.07	0.17	< MDL	0.006
MW9D	< MDL	< MDL	0.03	< 0.13	< MDL	0.005
MW10S	< MDL	< MDL	1.48	< 1.58	< MDL	0.009
MW11-2	< MDL	< MDL	0.22	< 0.32	< MDL	0.006
MW13	< MDL	< MDL	0.06	< 0.16	< MDL	0.006
MW14	0.01	< MDL	< MDL	< 0.11	< MDL	0.014
MW15S	0.01	< MDL	0.09	< 0.19	< MDL	0.005
MW15D	< MDL	< MDL	0.18	< 0.28	< MDL	0.006
BH3	0.01	< MDL	0.02	< 0.12	< MDL	0.009
BH3A	< MDL	< MDL	0.17	< 0.27	0.002	0.007
BH6	< MDL	0.12	0.17	0.29	0.002	0.014
BH112	< MDL	< MDL	0.01	< 0.11	< MDL	0.003

Notes:
- MW7S and MW8S were not sampled as these piezometers were dry.
- Samples were unfiltered except soluble reactive phosphorus (0.45 µm filtered).
- < MDL indicates that the result was below the external laboratory's Method Detection Limit. MDL values in mg/L for the relevant analyses were as follows: 0.01 for ammonia, 0.10 for total kjeldahl, 0.01 for oxidized nitrogen and 0.002 for phosphorus.
- Total nitrogen is a maximum value calculated by summing the oxidised nitrogen and total Kjeldahl nitrogen results.

Table 28. HYDROCARBONS IN GROUNDWATER, LHSTC, 24 November 2005

	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 29. RADIOACTIVITY IN GROUNDWATER, LHSTC, November 2005

RADIOACTIVITY (Bq/L)								
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MW1S	25-11-05	0.11 ± 0.01	0.18 ± 0.01	< MDA	< MDA	< MDA	< MDA	21 ± 1
MW1D	25-11-05	0.13 ± 0.01	0.20 ± 0.01	< MDA	< MDA	< MDA	< MDA	11 ± 1
MW2S	24-11-05	0.02 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	47 ± 1
MW2D	24-11-05	0.04 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW3S	24-11-05	0.14 ± 0.01	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	26 ± 1
MW3D	24-11-05	0.04 ± 0.01	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW4S	24-11-05	0.09 ± 0.02	0.15 ± 0.02	< MDA	< MDA	< MDA	< MDA	3 ± 1
MW4D	24-11-05	0.05 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW5S	24-11-05	0.04 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	13 ± 1
MW6S	24-11-05	0.02 ± 0.01	0.13 ± 0.01	< MDA	< MDA	< MDA	< MDA	97 ± 1
MW6D	24-11-05	0.01 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	45 ± 1
MW7S	1-12-05	0.05 ± 0.01	0.12 ± 0.01	< MDA	< MDA	< MDA	< MDA	23 ± 1
MW7D	1-12-05	0.22 ± 0.02	0.15 ± 0.01	< MDA	< MDA	< MDA	0.380 ± 0.096	3 ± 1
MW8S	-	-	-	-	-	-	-	-
MW8D	24-11-05	0.02 ± 0.01	0.02 ± 0.01	< MDA	< MDA	< MDA	0.273 ± 0.086	< MDA
MW9S	1-12-05	0.07 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	11 ± 1
MW9D	1-12-05	0.13 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	0.358 ± 0.095	4 ± 1
MW10S	1-12-05	0.07 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	30 ± 1
MW11-2	1-12-05	0.06 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	34 ± 1
MW13	25-11-05	0.19 ± 0.01	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW14	1-12-05	0.07 ± 0.01	0.09 ± 0.01	< MDA	< MDA	< MDA	< MDA	26 ± 1
MW15S	29-11-05	0.19 ± 0.01	0.17 ± 0.01	< MDA	< MDA	< MDA	< MDA	4 ± 1
MW15D	29-11-05	0.10 ± 0.01	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	21 ± 1
BH3	29-11-05	0.08 ± 0.01	0.17 ± 0.01	< MDA	< MDA	< MDA	< MDA	14 ± 1
BH3A	29-11-05	0.08 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	0.330 ± 0.094	24 ± 1
BH6	29-11-05	< MDA	0.04 ± 0.01	< MDA	< MDA	< MDA	< MDA	25 ± 1
BH112	29-11-05	0.07 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	0.278 ± 0.098	< 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 3 Bq/L).
- MW8S was not sampled as the piezometer was dry.
- < 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 30. FIELD PARAMETERS IN GROUNDWATER, LFBG, October 2005

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MB11	7	4.79	18.5	1939	5.6	20
MB12	5	3.92	17.5	857	5.5	280
MB13	5	2.27	17.1	356	5.3	160
MB14	6	4.08	18.4	3296	5.9	10
MB15	6	4.85	18.5	1479	5.8	100
MB16	5	2.94	17.6	336	5.5	120
MB17	5	2.62	18.2	500	5.5	150
MB18	6	4.81	18.9	2136	6.3	60
MB19	6	4.41	17.8	4748	6.2	70
MB20	5	3.66	18.2	928	6.5	-110
MB21	4	2.90	16.6	1382	6.5	60
BH10	4	2.55	16.4	2012	5.7	90
BHF	6	3.15	17.5	2081	5.2	140
OS2	-	-	-	-	-	-
OS3	7	2.17	17.9	333	5.2	130
P1S	5	3.97	18.1	8000	4.0	370
P1D	15	4.56	19.2	8000	5.5	70
P2D	20	13.99	19.9	4945	6.1	50
CW	9	4.90	20.2	2232	5.8	110

Notes:
- 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.
- OS2 was not sampled as the piezometer was dry.

Table 31. FIELD PARAMETERS IN GROUNDWATER, LFBG, March 2006

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MB11	7	4.80	20.1	2603	5.4	150
MB12	5	4.02	21.8	807	5.4	210
MB13	5	2.55	20.9	421	5.1	170
MB14	5	4.01	19.4	3455	5.8	40
MB15	6	4.73	19.6	1429	5.5	130
MB16	6	2.80	20.3	318	5.4	80
MB17	5	2.55	20.7	524	6.6	140
MB18	6	4.53	19.7	2265	6.1	50
MB19	6	4.30	17.9	4802	6.7	140
MB20	5	3.60	18.4	1028	6.7	140
MB21	4	2.95	20.5	1019	6.8	140
BH10	4	2.30	20.4	2018	5.5	80
BHF	7	3.05	18.6	3670	5.2	120
OS2	-	-	-	-	-	-
OS3	4	2.06	21.1	329	5.5	120
P1S	6	4.40	20.6	4825	4.0	320
P1D	10	4.69	20.6	10100	5.2	100
P2D	26	13.43	19.6	3454	6.7	160
CW	10	4.90	19.2	2610	5.6	150

Notes:
- 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.
- OS2 was not sampled as the piezometer was dry.

Table 32. RADIOACTIVITY IN GROUNDWATER, LFBG, October 2005

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	Date Sampled	Gross Alpha	Gross Beta	Am-241	Cs-137	Co-60	K-40	Tritium
MB11	25-10-05	< MDA	0.07 ± 0.02	< MDA	< MDA	< MDA	< MDA	MDA
MB12	7-11-05	< MDA	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	MDA
MB13	25-10-05	0.11 ± 0.02	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	1510 ± 20
MB14	25-10-05	< MDA	0.11 ± 0.03	< MDA	< MDA	< MDA	0.283 ± 0.014	160 ± 10
MB15	25-10-05	< MDA	0.04 ± 0.02	< MDA	< MDA	< MDA	< MDA	210 ± 10
MB16	25-10-05	0.26 ± 0.02	0.45 ± 0.01	< MDA	< MDA	0.072 ± 0.012	< MDA	6120 ± 50
MB17	25-10-05	0.10 ± 0.02	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	760 ± 20
MB18	25-10-05	< MDA	0.09 ± 0.02	< MDA	< MDA	< MDA	0.332 ± 0.161	880 ± 20
MB19	26-10-05	0.03 ± 0.02	0.14 ± 0.02	< MDA	< MDA	< MDA	0.564 ± 0.148	240 ± 10
MB20	26-10-05	0.02 ± 0.01	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	MDA
MB21	26-10-05	< MDA	0.27 ± 0.03	< MDA	< MDA	< MDA	< MDA	110 ± 10
BH10	25-10-05	0.08 ± 0.03	0.20 ± 0.03	< MDA	< MDA	< MDA	< MDA	7150 ± 50
BHF	25-10-05	0.07 ± 0.03	0.42 ± 0.04	< MDA	< MDA	< MDA	0.335 ± 0.141	2240 ± 30
OS2	-	-	-	-	-	-	-	-
OS3	25-10-05	0.13 ± 0.02	0.14 ± 0.01	< MDA	< MDA	< MDA	< MDA	1210 ± 20
CW	25-10-05	< MDA	0.13 ± 0.02	< MDA	< MDA	< MDA	0.337 ± 0.135	800 ± 20
P1S	25-10-05	0.92 ± 0.19	0.49 ± 0.08	< MDA	< MDA	< MDA	0.411 ± 0.138	20 ± 10
P1D	26-10-05	0.70 ± 0.25	< MDA	< MDA	< MDA	< MDA	0.455 ± 0.122	170 ± 10
P2D	26-10-05	< MDA	0.50 ± 0.07	< MDA	< MDA	< MDA	0.437 ± 0.134	60 ± 10

Notes:
- See Figure 4 for the location of the sampling piezometers.
- OS2 was not sampled as piezometers were dry.
- Samples were settled and decanted prior to analysis but not filtered.
- 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, March 2006

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MB11	30-03-06	< MDA	0.05 ± 0.02	< MDA	< MDA	< MDA	0.309 ± 0.132	< MDA
MB12	30-03-06	< MDA	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB13	30-03-06	0.05 ± 0.02	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	1040 ± 20
MB14	30-03-06	< MDA	0.11 ± 0.04	< MDA	< MDA	< MDA	0.421 ± 0.119	180 ± 10
MB15	30-03-06	< MDA	< MDA	< MDA	< MDA	< MDA	0.272 ± 0.130	220 ± 10
MB16	30-03-06	0.31 ± 0.02	0.49 ± 0.01	< MDA	< MDA	0.038 ± 0.020	< MDA	4830 ± 40
MB17	31-03-06	0.04 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	0.348 ± 0.124	660 ± 20
MB18	30-03-06	< MDA	0.07 ± 0.02	< MDA	< MDA	< MDA	< MDA	800 ± 20
MB19	31-03-06	< MDA	0.25 ± 0.05	< MDA	< MDA	< MDA	0.702 ± 0.148	240 ± 10
MB20	31-03-06	0.05 ± 0.02	0.41 ± 0.02	< MDA	< MDA	< MDA	0.450 ± 0.139	< MDA
MB21	31-03-06	< MDA	0.13 ± 0.01	< MDA	< MDA	< MDA	0.320 ± 0.144	50 ± 10
BH10	30-03-06	< MDA	0.10 ± 0.02	< MDA	< MDA	< MDA	< MDA	7170 ± 50
BHF	30-03-06	0.20 ± 0.07	0.29 ± 0.03	< MDA	< MDA	< MDA	< MDA	4340 ± 40
OS2	-	-	-	-	-	-	-	-
OS3	30-03-06	0.09 ± 0.02	0.17 ± 0.01	< MDA	< MDA	< MDA	< MDA	820 ± 20
CW	31-03-06	< MDA	0.27 ± 0.04	< MDA	< MDA	< MDA	0.361 ± 0.125	810 ± 20
P1S	30-03-06	0.75 ± 0.17	0.30 ± 0.07	< MDA	< MDA	< MDA	< MDA	20 ± 10
P1D	30-03-06	< MDA	0.21 ± 0.09	< MDA	< MDA	< MDA	< MDA	150 ± 10
P2D	3-04-06	0.16 ± 0.09	0.44 ± 0.05	< MDA	< MDA	< MDA	0.473 ± 0.145	70 ± 10

Notes:
- See Figure 4 for the location of the sampling piezometers.
- OS2 was not sampled as piezometer was dry.
- Samples were settled and decanted prior to analysis but not filtered.
- 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 2005 to June 2006

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
5-7-05	< MDA	1-11-05	< MDA	28-2-06	< MDA
12-7-05	40 ± 10	8-11-05	< MDA	7-3-06	< MDA
19-7-05	60 ± 10	15-11-05	< MDA	14-3-06	-
26-7-05	-	22-11-05	< MDA	21-3-06	50 ± 10
2-8-05	-	29-11-05	< MDA	28-3-06	< MDA
9-8-05	490 ± 10	6-12-05	30 ± 10	4-4-06	200 ± 10
16-8-05	-	13-12-05	30 ± 10	11-4-06	-
23-8-05	70 ± 10	20-12-05	20 ± 10	18-4-06	< MDA
30-8-05	-	27-12-05	-	25-4-06	-
6-9-05	< MDA	3-1-06	-	2-5-06	20 ± 10
13-9-05	< MDA	10-1-06	< MDA	9-5-06	-
20-9-05	< MDA	17-1-06	< MDA	16-5-06	< MDA
27-9-05	< MDA	24-1-06	60 ± 10	23-5-06	-
5-10-05	< MDA	31-1-06	< MDA	30-5-06	110 ± 10
11-10-05	< MDA	7-2-06	-	6-6-06	230 ± 20
18-10-05	< MDA	14-2-06	< MDA	13-6-06	40 ± 10
25-10-05	30 ± 10	21-2-06	< MDA	20-6-06	-
				27-6-06	< MDA

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. RADIOACTIVITY IN SEDIMENT, STORMWATER BUNDS, LHSTC, July 2005 to June 2006

		RADIOACTIVITY (Bq/L)							
				Gamma-emitters (Bq/g DW)					
Bund Location	**Date**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Be-7**	**Cs-137**	**Co-60**	**K-40**	**Ce-144**
Bund A	5-9-05	0.42 ± 0.10	0.47 ± 0.02	< MDA	0.191 ± 0.022	0.004 ± 0.001	0.003 ± 0.001	0.201 ± 0.024	
	3-4-06	0.37 ± 0.10	0.45 ± 0.02	< MDA	0.046 ± 0.006	0.001 ± 0.001	< MDA	0.267 ± 0.031	
Bund B	5-9-05	0.39 ± 0.10	0.38 ± 0.02	< MDA	0.108 ± 0.013	0.001 ± 0.001	0.011 ± 0.001	0.207 ± 0.025	
	3-4-06	0.17 ± 0.09	0.27 ± 0.02	< MDA	0.043 ± 0.006	< MDA	0.003 ± 0.001	0.169 ± 0.020	
Bund C	11-8-05	0.43 ± 0.10	0.37 ± 0.02	0.002 ± 0.001	0.045 ± 0.006	0.034 ± 0.004	0.002 ± 0.006	0.115 ± 0.015	0.019 ± 0.003
	3-4-06	0.20 ± 0.10	0.20 ± 0.02	< MDA	0.024 ± 0.006	0.011 ± 0.001	< MDA	0.080 ± 0.013	

Notes:
- See Figure 2 for the locations of the stormwater bunds.
- The gross beta results include the contribution from K-40 (a natural beta-gamma emitter). Be-7 is also of natural origin. Units are becquerels per gram dry weight (Bq/g DW).
- < 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 36. GAMMA DOSE-RATE SURVEY, LFBG TRENCHES, June 2006

Date of Survey	**Location**	**Dose-rate** (μSv/hour)
1-6-06 to 9-6-06	Background reading (LFBG gate)	0.07 – 0.15
	Trenches 1-51	0.07 – 0.21
	Trenches 52-77	0.07 – 0.18
	Trenches S1 and S2	0.07 – 0.17

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

Table 37. GAMMA DOSE-RATE SURVEYS, MAIN DISCHARGE PIPELINE, LHSTC, July 2005 to June 2006

Date of Survey	Location	Dose-rate (μSv/hour)		Background Dose-rate (μSv/hour)
		Ground Below Joint	Pipe Joint	
7-9-05	Joints # 1-22	0.07 – 0.13	0.06 – 0.11	0.07 – 0.14
26-5-06	Joints # 1-22	0.03 – 0.09	0.03 – 0.09	0.03 – 0.09

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

Table 38. RADIOACTIVITY IN FISH, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2005 to June 2006

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	06-3-06	< MDA	< MDA	< MDA	< MDA	< MDA	121 ± 12
The Royal National Park Reference Site	-	-	-	-	-	-	-

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.
- Collection of fish at the Royal National Park was unsuccessful, despite several attempts.
- Radioactivity is in units of becquerels per kilogram of fresh (wet) sample weight.
- < 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 39. RADIOACTIVITY IN ALGAE, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2005 to June 2006

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	06-03-06	< MDA	< MDA	2.7 ± 0.3	< MDA	< MDA	264 ± 25
	26-06-06	< MDA	< MDA	1.4 ± 0.2	< MDA	< MDA	122 ± 12
The Royal National Park Reference Site	08-03-06	< MDA	< MDA	< MDA	< MDA	< MDA	171 ± 17

Table 40. RADIOACTIVITY IN BARNACLES, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2005 to June 2006

Location	Date Sampled	Gamma-emitters in Barnacles (Bq/kg FW)					
		Am-241	**Be-7**	**I-131**	**Cs-137**	**Co-60**	**K-40**
Potter Point Ocean Outfall	06-03-06	< MDA	< MDA	< MDA	< MDA	< MDA	33 ± 5
	26-06-06	< MDA	< MDA	< MDA	< MDA	< MDA	26 ± 5
The Royal National Park Reference Site	08-03-06	< MDA	< MDA	< MDA	< MDA	< MDA	28 ± 6

Table 41. RAINFALL AND POTENTIAL EVAPORATION AT THE LHSTC, July 1996 to June 2006

		1996-97	1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
Jul	R Total	78.4	48.2	86.8	163.3	31.4	109.2	26.4	35.5	37.4	53.2
	R Days	6	6	12	12	9	14	2	8	8	6
	E Total	60.0	52.7	50.1	47.4	52.1	44.3	57.0	49.7	52.8	55.6
	E Max	3.2	2.6	3.8	4.1	3.8	2.3	3.3	3.8	4.2	3.9
Aug	R Total	129.9	18.7	316.3	31.2	19.2	49.4	14.3	30.0	68.3	4.0
	R Days	6	5	15	8	11	6	7	7	5	4
	E Total	76.0	82.4	51.0	65.6	59.6	75.4	73.0	75.4	74.9	77.2
	E Max	5.0	6.9	3.3	3.2	4.3	5.5	5.9	5.8	4.4	4.4
Sep	R Total	74.8	105.6	37.7	20.7	37.2	18.2	7.0	4.4	35.9	41.0
	R Days	7	15	9	5	6	10	4	2	8	9
	E Total	120.0	78.7	82.5	82.5	120.6	82.9	118.4	113.8	87.4	95.8
	E Max	7.5	6.0	5.5	4.4	7.5	5.0	8.5	6.8	5.8	6.0
Oct	R Total	31.2	60.2	26.7	211.0	55.1	39.8	1.4	62.4	219.1	76.2
	R Days	10	8	8	13	9	8	4	13	10	11
	E Total	118.1	136.9	121.1	104.1	117.2	128.9	149.8	102.5	119.0	120.9
	E Max	6.8	7.6	6.8	6.3	6.8	7.6	8.5	6.6	8.4	7.8
Nov	R Total	70.8	21.7	110.3	32.7	150.3	57.1	14.5	50.0	71.2	139.2
	R Days	12	9	15	9	17	11	6	10	14	14.0
	E Total	146.5	150.2	113.6	112.1	100.5	129.6	157.1	133.2	130.9	126.0
	E Max	7.3	7.5	7.2	5.4	6.0	9.4	10.3	7.0	10.8	7.1
Dec	R Total	68.8	27.3	37.8	112.8	46.4	15.9	59.8	45.9	67.0	24.3
	R Days	6	7	9	13	11	8	9	8	10	4
	E Total	160.6	162.9	148.9	140.4	170.5	150.5	177.2	142.9	156.7	189.7
	E Max	8.2	11.2	9.6	6.8	10.1	10.8	12.7	9.0	14.2	12.0
Jan	R Total	113.2	75.0	111.9	29.6	191.0	55.2	22.5	38.9	41.4	82.9
	R Days	11	11	14	12	9	10	6	8	13	13
	E Total	151.8	163.9	165.4	138.0	151.3	176.6	173.2	163.9	149.5	127.8
	E Max	7.8	10.1	10.0	8.0	10.1	13.4	11.0	9.2	8.5	7.2
Feb	R Total	127.7	56.0	196.5	11.0	110.6	295.1	89.1	92.5	81.7	96.2
	R Days	10	8	14	9	11	18	12	9	6	5
	E Total	118.5	154.7	113.1	149.6	108.4	103.4	118.2	138.6	133.1	141.2
	E Max	11.3	10.0	6.6	9.3	6.4	8.7	8.0	7.8	8.3	10.1
Mar	R Total	61.2	15.5	40.2	217.6	122.0	143.3	89.0	52.8	93.7	34.7
	R Days	10	8	10	14	20	15	8	5	10	8
	E Total	124.0	127.8	94.3	94.6	110.1	90.2	118.1	109.3	112.2	104.8
	E Max	6.2	7.7	5.1	5.1	7.9	5.5	8.5	7.5	6.7	7.7
Apr	R Total	0.5	161.3	94.3	31.9	70.2	15.4	147.2	107.4	20.2	2.4
	R Days	1	10	17	12	7	6	16	7	6	2
	E Total	91.9	94.9	72.0	65.3	78.0	68.8	69.0	73.4	80.3	106.1
	E Max	7.0	8.1	4.0	4.0	5.0	3.5	4.9	5.6	8.1	7.7
May	R Total	96.5	203.7	48.7	34.5	105.3	50.6	358.8	9.2	27.1	17.6
	R Days	16	13	10	9	10	11	17	1	5	6
	E Total	64.7	61.8	44.7	54.9	58.1	61.6	71.7	69.8	57.0	68.9
	E Max	4.7	4.9	3.4	3.4	4.5	3.7	6.8	3.8	4.0	5.1
Jun	R Total	51.0	80.2	66.6	34.2	9.3	18.1	58.0	5.4	78.3	92.3
	R Days	10	11	14	9	6	5	7	3	10	11
	E Total	54.7	45.5	45.9	45.7	44.4	49.1	49.3	58.4	48.0	41.0
	E Max	6.4	4.1	2.8	4.5	2.4	3.1	3.5	3.7	5.2	3.0
Annual	**R Total**	**904.0**	**873.4**	**1173.8**	**930.5**	**948.0**	**867.3**	**888.0**	**534.4**	**841.3**	**664.0**
	R Days	**105**	**111**	**147**	**125**	**126**	**122**	**98**	**81**	**105**	**93**
	E Total	**1286.8**	**1312.4**	**1102.6**	**1100.2**	**1170.8**	**1161.3**	**1332.0**	**1230.9**	**1201.8**	**1255.0**

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

Table 42. ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, July 2005 to June 2006

Receptor Location	**2005-06 Estimated Effective Dose** (mSv/year)
Nearest Resident	0.0026
LHSTC Library	0.0037
LHSTC Building 9	0.0052
LHSTC Main gate	0.0025
Stevens Hall Motel	0.0068
LH Waste Management Centre	0.0013
BMX track	0.0008
Woronora Valley	0.0006
At 1.6 kilometre radius from HIFAR	
NORTH	0.0046
NNE	0.0034
NE	0.0036
ENE	0.0036
EAST	0.0028
ESE	0.0015
SE	0.0018
SSE	0.0018
SOUTH	0.0013
SSW	0.0011
SW	0.0020
WSW	0.0019
WEST	0.0016
WNW	0.0011
NW	0.0016
NNW	0.0031
At 4.8 kilometre radius from HIFAR	
NORTH	0.0012
NNE	0.0005
NE	0.0008
ENE	0.0008
EAST	0.0006
ESE	0.0003
SE	0.0004
SSE	0.0004
SOUTH	0.0003
SSW	0.0003
SW	0.0005
WSW	0.0004
WEST	0.0004
WNW	0.0003
NW	0.0004
NNW	0.0008

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

APPENDIX A – Corrections to Previous Reports

A correction for some previous reports in the *Environmental and Effluent Monitoring at ANSTO Sites* series is listed below:

- Liquid effluent from the NMC is discharged to sewer under the terms of a Commercial Trade Wastewater Permit, rather than a Trade Wastewater Consent Agreement. The corrections implemented in this report also affect previous reports in this series.