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Environmental and Effluent Monitoring at ANSTO Sites 2006-2007 E-762

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ENVIRONMENTAL and EFFLUENT MONITORING at ANSTO SITES, 2006–2007

Compiled and edited by

Emmy Hoffmann, Tom Loosz, John M Ferris

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 2006 to June 2007. Estimated effective doses to the members of the public potentially affected by routine airborne emissions from the LHSTC were lower than in previous years due to the closure of the HIFAR research reactor. The maximum potential off-site dose of 0.002 mSv/year was 10% of the As Low As Reasonably Achievable (ALARA) objective of 0.02 mSv/year, and much lower than the public dose limit of 1 mSv/year that is recommended by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). The effective doses to the critical group potentially exposed to routine liquid effluent releases from the LHSTC have been realistically assessed at less than 25% of the estimated doses to the critical group for airborne releases.

Based on releases of liquid effluent from the LHSTC during 2006-07, a radiological risk assessment was conducted for marine biota in the receiving environment at Potter Point. The possible dose-rates to various species of marine biota were evaluated against international criteria recommended for the protection of biota from radiological hazards. In all cases it was concluded that the radiological risk to marine biota from ANSTO's effluent releases was negligible.

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 approximately 1.5 mSv/year experienced by members of the Australian public.

INIS DESCRIPTORS

The following descriptors have been selected from the International Nuclear Information System (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)
ERICA	The Environmental Risk from Ionising Contaminants: Assessment and Management project.
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 open pool light-water research reactor
PM	Particulate Matter
SI	Système International d'Unite (International System of Units)
SPCC	The former State Pollution Control Commission (which became the NSW EPA, now part of the NSW DEC)
STP	Sewage Treatment Plant
TLD	Thermoluminescent 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, OPAL, 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). During the period covered by this report, the OPAL research reactor replaced HIFAR, which 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 series *Environmental and Effluent Monitoring at ANSTO Sites*. These reports are available electronically via the ANSTO web page (ANSTO 2008a), 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 2006 to June 2007, and assesses the potential effects of radioactive discharges, with particular emphasis on local residents.

2. ANSTO FACILITIES

2.1 Research Reactors - HIFAR and OPAL

The HIFAR research reactor produced radioisotopes for medical and industrial use and generated neutrons for research applications up until its shutdown in January 2007. HIFAR has ongoing regulatory discharge authorisation from ARPANSA to release low levels of radionuclides to the atmosphere via stacks. During its operation, the main radionuclides released were tritium and argon-41 (a noble gas). Releases of argon-41 ceased upon shutdown. Releases of tritium continued at low levels as fuel and heavy water were removed from the reactor. 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.

During 2006-07 the OPAL reactor achieved full power and successfully completed several routine operating programs. It produced radioisotopes for medical and industrial use and generated neutrons for the commissioning of research instruments. OPAL also has regulatory discharge authorisation from ARPANSA to release low levels of radionuclides to the atmosphere via stacks, albeit at significantly lower levels than is the case for HIFAR. During its operation, the main radionuclides released from OPAL were tritium and argon-41. Releases were well within regulatory limits.

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 2006-07 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. A system of delayed liquid effluent releases allows these 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 cubic metres per 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 predecessor 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 and monitored 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 and 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 Water Resources	Annual reporting against the principles of ecologically sustainable development
National Biodiversity Strategy (1996)	Commonwealth Department of Environment and Water Resources	Integration of biodiversity conservation with natural resource management

Table A (continued)

Driver	Organisation	Summary
National Environment Protection Measures (Implementation) Act 1998	National Environment Protection Council (NEPC)	ANSTO reports annually to the Department of the Environment and Water Resources on implementation of the National Environment Protection Measures (NEPM's)
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. A number of neutron beam instruments operated by the Bragg Institute were also licensed for hot commissioning during the period covered by this report. 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 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 in 2001.

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 in some localities (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.

Impacts for any activity associated with a nuclear facility are typically 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).

ANSTO has identified the 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 2006-07 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 7,500 samples were taken and some 12,000 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 16 discharge stacks at the LHSTC (including OPAL - Building 80) and one at the NMC. For the major LHSTC stacks, airborne emissions were passed through High Efficiency Particulate Air (HEPA) filters to remove particles and through beds of activated charcoal[1] to trap and minimise any radioiodine concentrations prior to discharge through the stack.

All stacks were sampled continuously by drawing off a proportion of the exhaust airflow and passing it through sampling equipment appropriate for the target radionuclides. Tritiated water vapour was trapped from air bubbled through a series of water-filled bottles. Radioiodines were sampled using ‘Maypack’ cartridges filled with activated charcoal and

[1] Charcoal impregnated with 5% TEDA (triethylene di-amine). Such carbon filter media have a high affinity for the adsorption, chelation and retention of the various species of iodine.

fitted with particle filters. Noble gases were measured in-situ using flow-through sampling chambers and gamma detection systems. The flow-rate of air exhausted through the major stacks (Buildings 54, 23, 80 and at the NMC) was measured using continuous flow meters. For the remainder, airflow was measured manually 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, suspended solids, total dissolved solids, ammonia and zinc. A volume-weighted composite sample was also produced from all pipeline samples each month and analysed for polonium-210 and gamma radioactivity. Liquid effluent from the NMC holding tanks was tested for pH and relevant gamma-emitters prior to discharge to the sewer.

As noted in section 3, the liquid effluent dilution between the ANSTO discharge tanks and the final effluent stream at the Cronulla STP is re-assessed 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 April and June 2007. Sixteen 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 2006 to June 2007

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	16 Stacks (LHSTC); 1 Stack (NMC)	Daily (workdays; NMC) and Weekly (LHSTC)	2154	3231
	Air flow	Flow	16 Stacks (LHSTC)	Weekly (Maypacks) and Quarterly (Stack)	896	896
	Noble Gases	Gamma	4 Stacks (LHSTC); 1 Stack (NMC)	Daily (workdays)	980	980
	Gas (water vapour)	H-3	5 Stacks (LHSTC)	Weekly	260	260
Liquid	Wastewater	H-3, GA, GB, Chem	6 Holding Tanks (LHSTC Waste Optns)	2-4 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; H-3	1 Site (LHSTC)	15 minute intervals (daily total); weekly H-3	417	417
	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)	128	176
	Creek or river or estuary	H-3	4 Sites (Bardens Ck, 3 x Woronora R)	Weekly(B Ck) and Monthly(W R)	88	88
	Creek or river or estuary	GA, GB	4 Sites (SPCC creeks & Bld 35)	Monthly	48	96
	Creek or river or estuary	GA, GB, H-3, Gamma	2 Sites (B&Mill Cks jnctn)	Yearly	2	8
	Seawater	H-3	3 offshore Sites (Potter Pt; ~10-20 samples per site)	Biannually (i.e. twice per year)	30	30
	Wastewater	H-3	1 Sewage Treatment Plant (Cronulla)	Yearly (hourly sampling for ~10-20 daily composites)	240	20
	Groundwater	H-3, GA, GB, Gamma, WQ	19 Bores (LFBG)	Biannually	38	342
	Groundwater	H-3, GA, GB, Gamma, Chem	27 Bores (LHSTC & Buffer Zone)	Yearly	162	459
	Groundwater	WQ (5 parameters)	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 (TC-45)	Gamma (I-131)	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)	Biannually	12	12
Dosimetry	External gamma radiation	Dose-rate survey	1 Site (LFBG)	Yearly	0	1
	External gamma radiation	TLD	22 Sites (LHSTC, LFBG, Suburbs, Cronulla STP)	Quarterly	88	88
				APPROXIMATE TOTALS	**7569**	**12018**

Notes:

- Working days assumed to be 245, excluding weekends and public holidays.
- H-3 = Tritium analysis; GA = Gross Alpha counting; GB = Gross Beta counting.
- Gamma = Gamma spectrometry that varies in number of nuclides targeted (can include specific noble gases like Ar-41 or individual radionuclides like I-31).
- Chem = Chemical, 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 parameters (e.g. water level, pH, conductivity, redox potential, temperature).

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. North of the LFBG, 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 2006-07, the LHSTC groundwater monitoring network had 27 Type 1 piezometers (characterised as either shallow or deep), however not all 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 2006-07 for field parameter testing. Laboratory-based radiological and other water quality analyses were performed annually. Results of annual 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**) was visually inspected every month in order to detect any leaks. Dose-rate surveys are no longer performed on this pipeline.

Airborne particles were collected at the LFBG using a high-volume sampler approximately every two weeks and analysed for the species of interest plutonium-239/240 and beryllium.

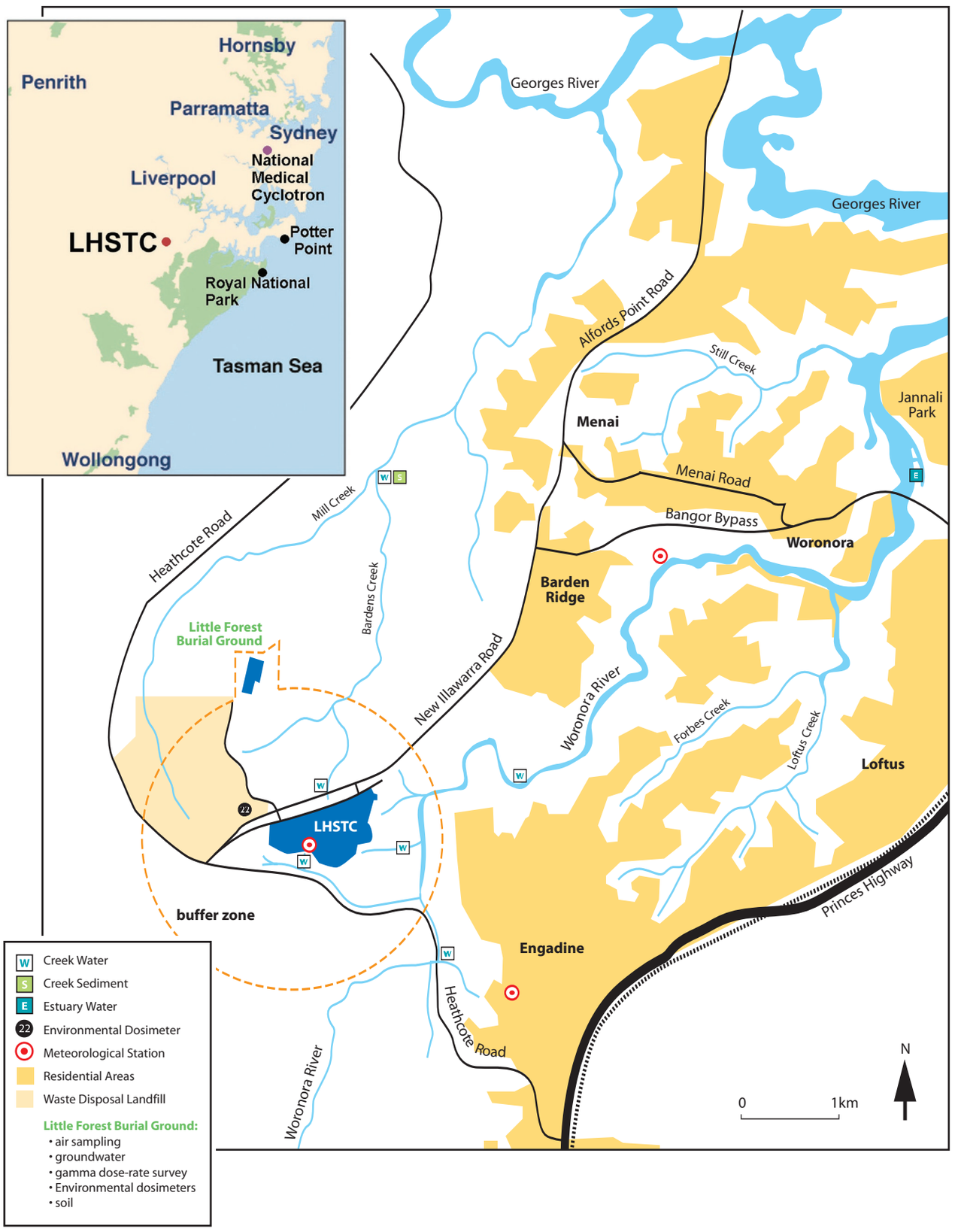

Figure 1. Location of ANSTO sites (the LHSTC and NMC) and off-site monitoring points.

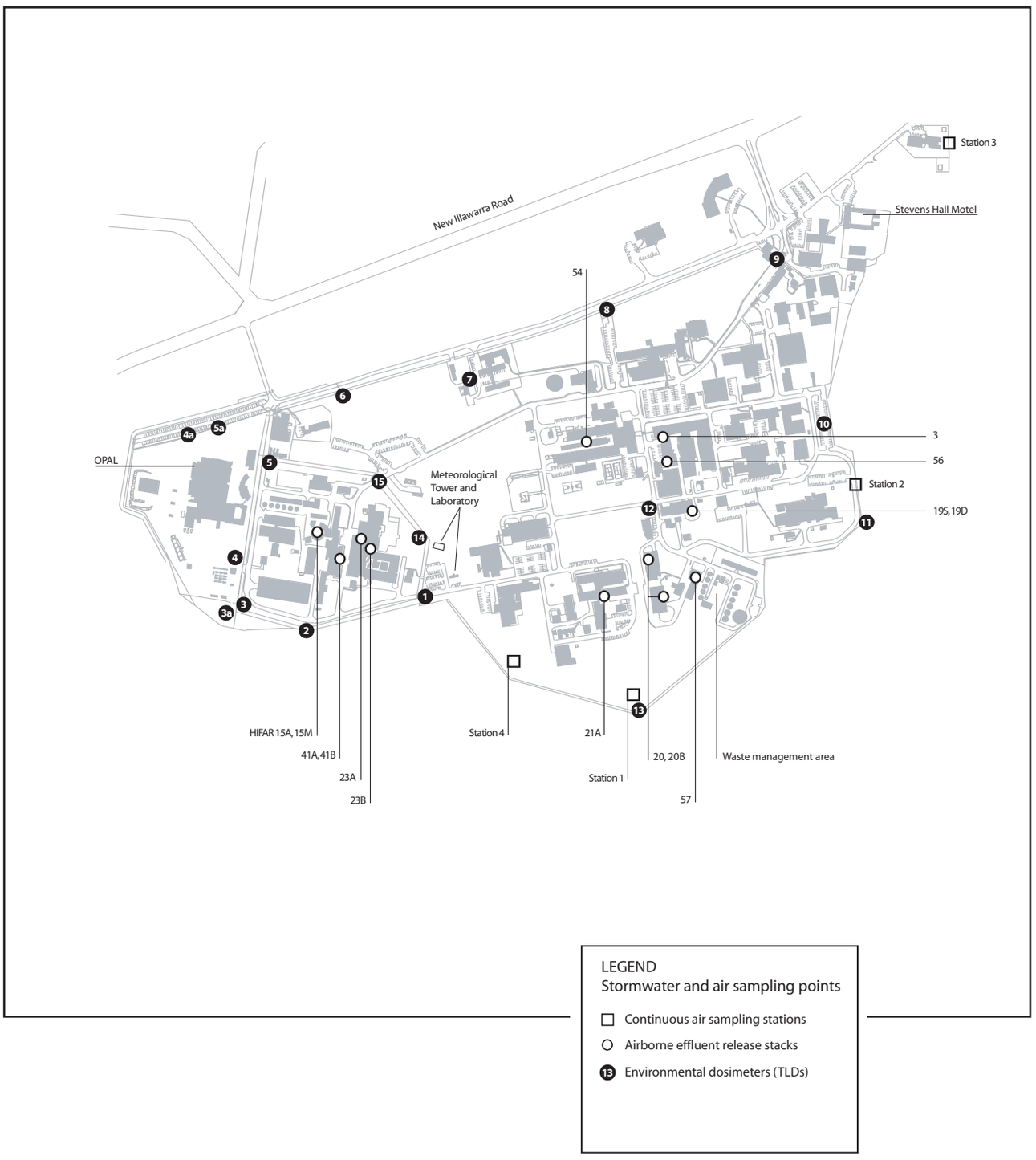

Figure 2. Location of airborne effluent release stacks and monitoring points for air and external radiation at the LHSTC.

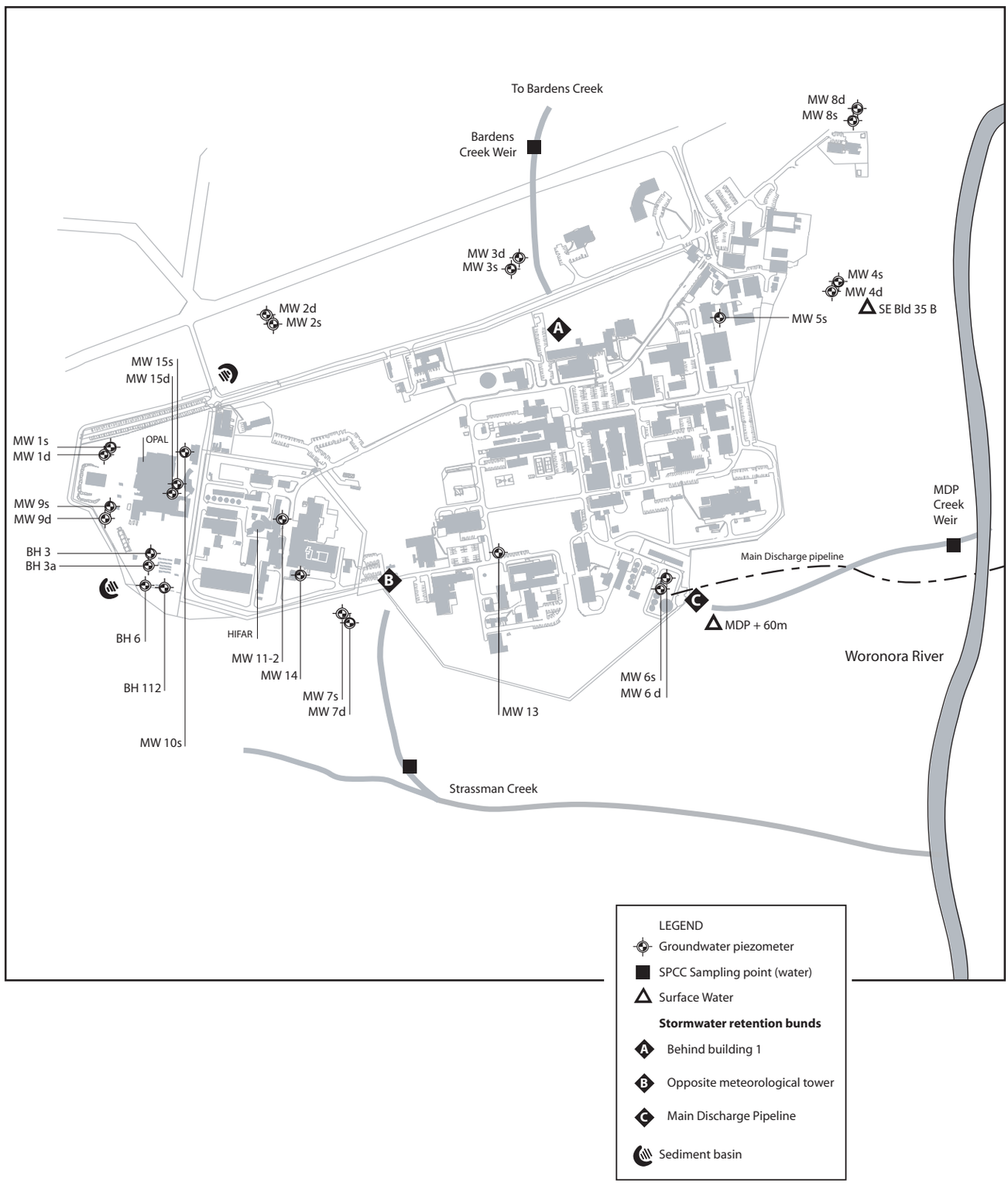

Figure 3. Location of groundwater and surface water monitoring points at the LHSTC.

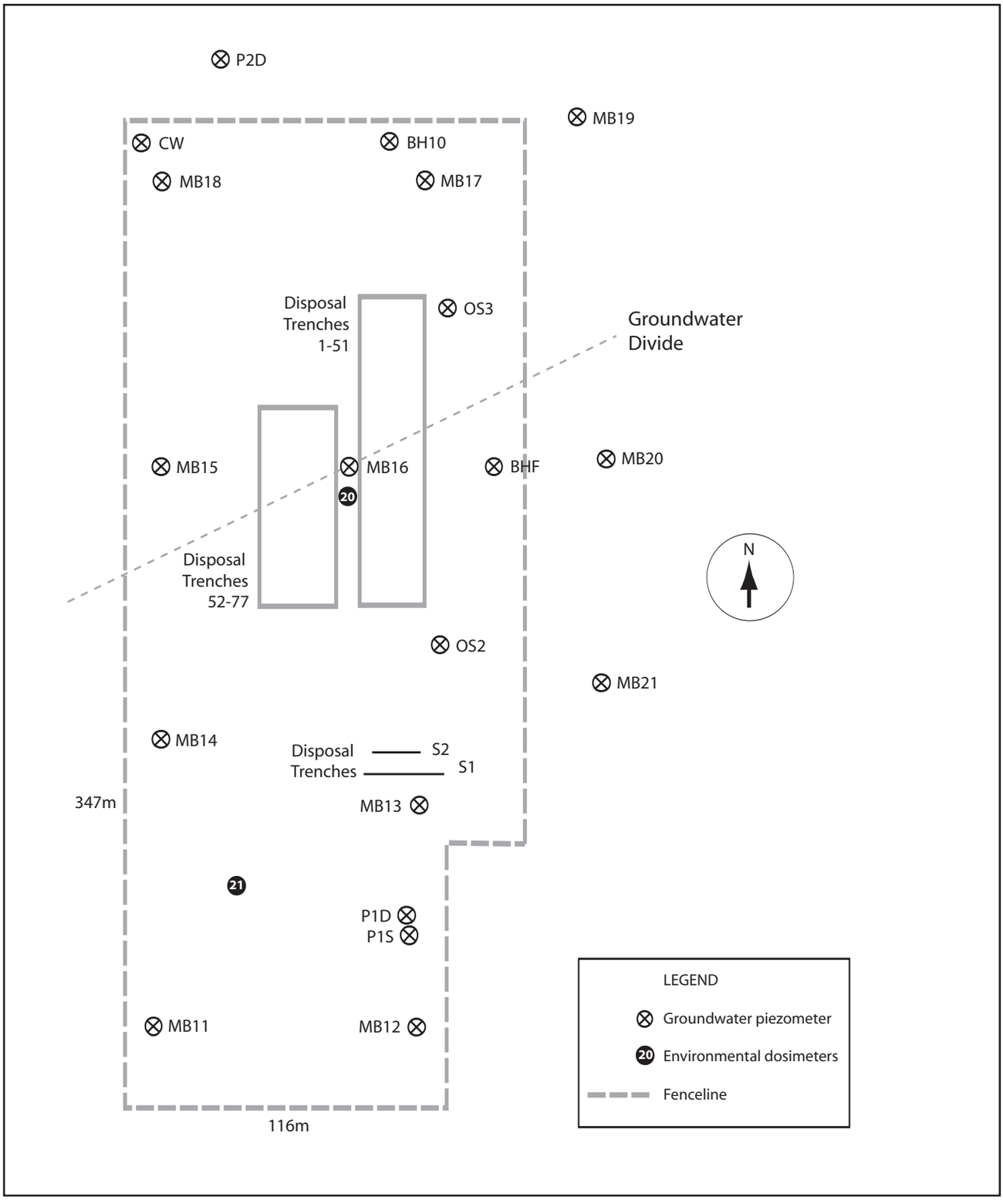

Figure 4. Little Forest Burial Ground – schematic showing the waste disposal trenches and piezometers currently monitored.

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 were corrected for decay since the first day of the sampling week, which means that results are over-estimated, especially for iodine emissions that occurred late in a given week.

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. In addition to ANSTO's routine quality assurance procedures, including the use of blanks, duplicates and traceable standards to calibrate equipment, ANSTO's ISO14001-compliant 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 obtain site-specific data 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 (ANSTO 2008b) 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 was published in Clark, 2003.

6. ENVIRONMENTAL AND EFFLUENT MONITORING (JULY 2006 - JUNE 2007)

Monitoring data in this report cover the financial year from July 2006 to June 2007 and are presented in **Tables 2** to **41**. 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.

Indicative median MDAs for various radionuclides and environmental media are given in **Table 1** (see Data Tables section). 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 than' values, in which case no statistics are reported.

6.1 Airborne Emissions

Table 2 lists the airborne activity discharges for the 2006-07 financial year from the single stack at the NMC and 16 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 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 17.8% of the annual notification level and all other nuclides combined were below 22% of the annual notification level.

There was no detectable gross alpha radioactivity associated with airborne particles sampled from the LHSTC stacks and gross beta activity was less than 2% of annual notification levels for all stacks except building 20. This decontamination facility reached 83% of its annual gross beta notification level due to processing equipment removed from HIFAR.

In 2006-07 argon-41 discharges from stacks 15A and 15M (HIFAR) were significantly lower than in previous years due to the closure of the reactor, reaching just 35.2% and 29.5% of their respective annual notification levels. The airborne discharge of tritium from HIFAR stack 15A, which in past years accounted for the majority of the airborne tritium emissions at the LHSTC, reached just 27.4% of its annual notification level. However, operations to remove heavy water from HIFAR resulted in tritium discharges from HIFAR's other stack, 15M, reaching 131.6% of the (lower) annual notification level for this stack. These operations were reported to ARPANSA and had no environmental or health consequences.

Emissions from the main radiopharmaceutical production facilities (stacks 23A and 54) were also down from normal operational levels due to decreased production. Annual iodine-131 emissions from 23A reached just 7.3% and 0.3% of the annual notification levels, respectively, whilst fission-product noble gas releases (radio-xenons and -kryptons) from stack 54 were similarly low.

The off-site dose estimates for 2006-07 were the lowest seen in ten years due to substantial reduction in the airborne emissions - argon-41 from HIFAR and noble gases

from radiopharmaceutical production - which usually make the largest contribution to the small dose associated with LHSTC airborne discharges.(see **Figure 9**).

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. From October 2006 to January 2007 the HIFAR and OPAL reactors operated simultaneously which resulted in extra cooling tower water being received at the effluent plant. The total volume of treated liquid effluent discharged in 2006-07 was 95,188 cubic metres.

Table 3 shows the average gross alpha, gross beta and tritium radioactivity in liquid effluent at discharge, calculated from all the samples collected each month. The monthly combined activity quotient for alpha, beta and tritium activity ranged from 0.03 to 0.29, with a median value of 0.19, *i.e.* less than 20% 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 2006 to June 2007.

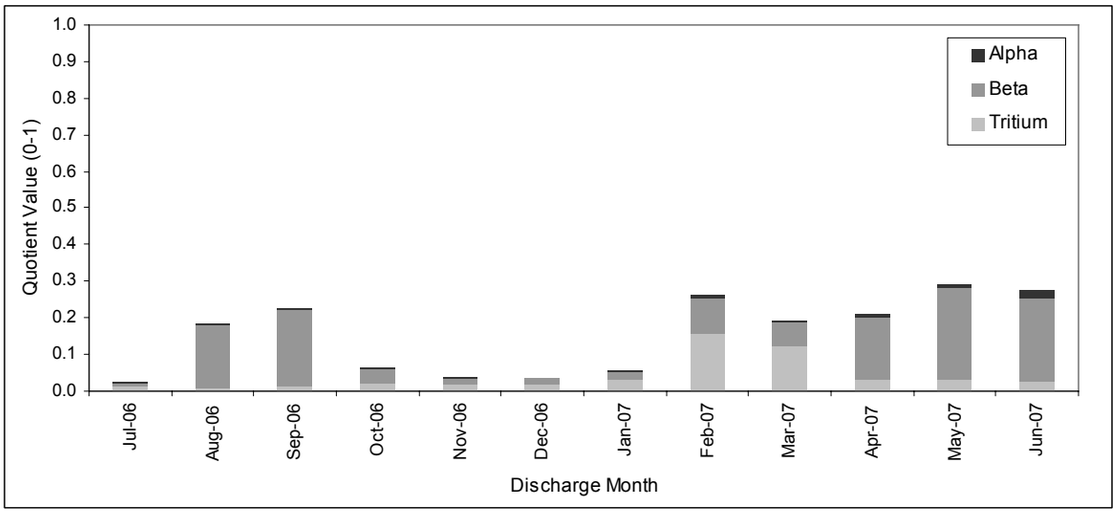

Figure 5: Monthly quotients for alpha, beta and tritium radioactivity in liquid effluent, LHSTC, July 2006 to June 2007.

The activities of gamma-emitting radionuclides in the monthly pipeline composite samples are given in **Table 4**. Of the radionuclides listed, only caesium-137 and iodine-131 were detected consistently, with caesium-137 levels slightly higher than in previous years due to decontamination activities.

Alpha-spectrometry was also performed on the monthly composites to check for the alpha-emitter polonium-210, which was found at low levels ranging from 0.01 Bq/L to 0.05 Bq/L.

The results for non-radioactive parameters of the liquid effluent (pH, ammonia, biological oxygen demand, 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. Whilst all the median values were within the acceptance standards, indicating 100% compliance, some samples had a pH less than 7, reflecting the slight acidity of water supplied to the site.

Whilst the concentrations of zinc, total dissolved solids and biological oxygen demand in the liquid waste discharges remained below the limits, the increased flows meant that the maximum daily mass limit was exceeded for these substances from November 2006 to February 2007. All other radioactive and non-radioactive substances 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 discharged to sewer from the NMC are shown in **Table 6**, along with the monthly (total) volume discharged. Four or more liquid effluent discharges were made each month, and the total volume discharged during the year was 68.4 cubic metres. The liquid effluent discharges contained variable amounts of radioactivity depending upon the radiopharmaceutical production schedule. However, the highest average activity discharged per month of thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65 and iodine-123 were 31%, 6%, 1%, 3%, 3% and 26% 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, which 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 two studies conducted in April and June 2007 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 16 daily composite samples from the UV Inlet during the April and June studies was 65 ± 1 Bq/L. The minimum in-line dilution ratio at the UV Inlet from the April study was 86:1 with an average dilution over the study period of 185:1. Consistent with results in previous years, this study demonstrated compliance with the agreed dilution factor of 25. During the June 2007 study high flows entering Cronulla STP following heavy rainfall led to bypassing of the tertiary treatment system and additional dilution of ANSTO effluent.

The 2007 effluent studies have again shown that 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 April study, the flow-weighted average tritium value in the final effluent stream was 10.2 Bq/L. This value, which is dependent on the recent history of ANSTO releases and the dynamics of the water flow through the plant, is very low compared with the ADWG guideline of 7600 Bq/L.

6.2.4 Gamma-emitting Radionuclides in Effluent and Biosolids at Cronulla STP

A non-routine study of gamma-emitting radionuclides in treated sewage effluent and biosolids from Cronulla STP was conducted in parallel with the effluent dilution study in April 2007. Eleven daily composite effluent samples from the UV Inlet were analysed by gamma spectrometry during a period of higher than average discharges of caesium-137 from ANSTO. Gamma spectrometry was also performed on four biosolids samples collected between April and June 2007 (see **Table 7**).

No caesium-137 was detected in any of the effluent or biosolids samples. This is likely to be due to the fact that caesium tends not to be particle-associated. All of the Cronulla STP

biosolids samples contained iodine-131, with a median activity of 55 ± 32 Bq/kg. In addition, one of the biosolids samples had a cobalt-60 activity of 13 ± 1 Bq/kg and another contained 48 ± 7 Bq/kg of the short-lived medical radioisotope thallium-201.

Iodine-131 was detected in 8 of the 11 effluent samples with a median value of 1.05 ± 0.28 Bq/L. It should be noted that this isotope has a relatively short half-life of approximately 8 days. A study by Davis (2006), which examined effluent samples collected from four Sydney sewage treatment plants outside the ANSTO sewer catchment, found that twenty, 24-hour composite effluent samples collected between August and October 2006 by Sydney Water showed iodine-131 activities ranging from <MDA to 150 ± 11 Bq/L, with a median of 6.9 ± 10.8 Bq/L. Iodine-131 levels at Cronulla STP in the ANSTO April 2007 study were therefore, by comparison, at the lower end of the scale seen in the Sydney area. This is likely to be due to the lack of major nuclear medicine facilities in the Cronulla STP catchment.

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 (see **Figure 2**). The results are given in **Table 8**. No iodine-131 was detected in 2006-07, with 100% of weekly results below the minimum detectable level. The median MDA value for iodine-131 was 0.0012 Bq/m^3.

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 6072 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 were divided by the equivalent sampling volume to obtain the concentration in air. Beryllium and plutonium-239/240 were below the minimum detectable levels 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, at three private residences in nearby suburbs (**Figure 1**) and at the Cronulla STP.

The external gamma data include the contribution from natural background radioactivity and the annual effective doses 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 the LHSTC and off-site at the LFBG and landfill depot were in the range 0.77 to 1.67 mSv/year for 2006-07.

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 0.95 to 1.67 mSv/year for 2006-07, 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 (0.77 mSv/year) 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, which is on a sewage holding tank approximately two metres above ground level, and the shielding effects of the sewage.

TLDs were also deployed outdoors at the NMC, and results for 2006-07 are given in **Table 11**. The median external dose-rate was 1.81 $\pm$ 0.07 mSv/year. Whilst these readings 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 2006 calendar year.

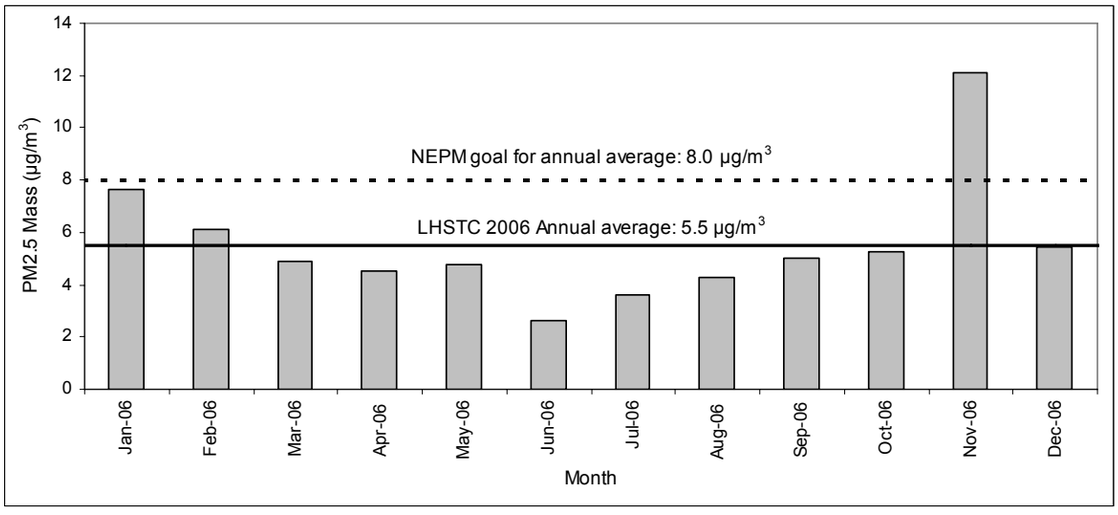

Figure 6: Average monthly mass of fine aerosol particles (less than 2.5 µm in diameter) collected over 24-hour periods at the LHSTC, January to December 2006.

The 24-hour maximum mass of 40 μg/m^3 PM2.5 in air was measured on November 22, 2006, affecting the monthly average. This maximum was associated with unusual levels of soil and organic matter, most likely from dust generated by construction activities and heavy vehicle movements near the sampling site. A National Environmental Protection Measure (NEPM) for fine particles in Australia has been set at an annual average of 8 μg/m^3 and the LHSTC annual average of 5.5 μg/m^3 for 2006 was 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 were transported in from surrounding areas across the Sydney Basin and beyond. The summary data can be found on the ANSTO web-site (ANSTO 2008c).

6.4 Surface Waters

Surface waters comprise of stormwater runoff as well as discharges of near-surface groundwater, with the proportion of each depending on the weather in the preceding days. Concrete bunds (of about 6 cubic metre capacity) on the three main stormwater outlets at the LHSTC (A, B and C on **Figure 3**) temporarily retain surface waters before their release off-site. These bunds are inspected, and emptied if necessary, each week-day morning to facilitate on-site containment and treatment of any small accidental releases of contaminated liquid. The bunds are also used as environmental monitoring points. Sedimentation basins, designed to capture surface water runoff and sediment from the OPAL construction site, are situated to the North and South West of OPAL (**Figure 3**). Waters flowing out of these two sediment basins are sampled quarterly provided sufficient water is available.

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 therefore 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 20 to 1130 Bq/L, with a median activity of 120 ± 120 Bq/L. Quarterly samples of water draining from the OPAL sediment basins showed low levels of tritium, ranging from less than the MDA to 70 Bq/L, with a median activity of 15 ± 25 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 4930 Bq/L, with a median activity of 115 ± 120 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 10 to 1830 Bq/L, with a median of 90 ± 50 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 less than MDA to 280 Bq/L, with a median activity of 60 ± 80 Bq/L.

The range of tritium activities recorded in these water samples from July 2006 to June 2007 was typical of recent years at the LHSTC. The maximum tritium activity in any of the samples from stormwater bunds and nearby sampling points was less than 65 percent of the ADWG level of 7600 Bq/L (NHMRC and NRMMC 2004), given here for context only as this water is not collected and supplied as potable water. The median tritium activities for surface waters at LHSTC range from 15 to 120 Bq/L, *i.e.* they are typically less than 2% of the ADWG levels.

6.4.2 Gross Alpha and Gross Beta Radioactivity in Surface Waters

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

Gross alpha and gross beta data for monthly composite samples (combined weekly samples) at Bund C from July 2006 to June 2007 are given in **Table 17**. The gross alpha activities ranged from less than the MDA to 0.04 Bq/L, with a median of 0.02 ± 0.02 Bq/L. For gross beta, the range of activities was from 0.16 to 0.38 Bq/L and the median was 0.24 ± 0.09 Bq/L. Gross alpha and gross beta data for monthly composite samples (combined weekly samples) downstream of Bund C at MDP+60m are given in **Table 18**. The gross alpha activities ranged from less than the MDA to 0.05 Bq/L, with a median of 0.02 ± 0.02 Bq/L. For gross beta, the range of activities was from 0.06 to 0.20 Bq/L and the median was 0.13 ± 0.06 Bq/L. All of the measured gross alpha and gross 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 MDA to 0.06 Bq/L, with a median value of 0.02 ± 0.01 Bq/L. Gross beta radioactivity ranged from 0.01 to 0.39 Bq/L, with a median of 0.05 ± 0.07 Bq/L. Water samples collected annually 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 of water collected from the OPAL sedimentation basins are given in **Table 13**. Gross alpha activities ranged from 0.04 to 0.45 Bq/L, with a median value of 0.06 ± 0.08 Bq/L. Gross beta activities ranged from 0.07 to 0.42 Bq/L, with a median value of 0.11 ± 0.06 Bq/L. These results are consistent with data reported previously.

All results for surface waters from July 2006 to June 2007 were below the limits for gross alpha and gross beta activity in the relevant NSW regulations. In fact, 100% of gross alpha and gross 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 LHSTC buffer zone. Monthly samples were collected from MDP bund C and MDP+60m and the two OPAL sediment basins were sampled quarterly. 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 (combined weekly samples) from Bund C (**Table 17**) for 2006-07 show typical low levels of caesium-137 activity, ranging from 0.004 to 0.021 Bq/L, with a median of 0.010 ± 0.010 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.

In monthly composite samples (combined weekly 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 0.006 ± 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. 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 November 2006 contained no measurable quantities of gamma activity (**Table 20**).

6.5 River and Sea Waters

Samples of brackish water from the Woronora River estuary and fresh waters from two sites in the river's upper reaches (see **Figure 1**) were collected. The 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 2006-07, all tritium results for the freshwater sampling points were less than the MDA.

Sea water was collected in the vicinity of the Potter Point ocean outfall on two occasions, April 24 and June 26, 2007 (**Table 7**). On each occasion, samples were collected hourly from three locations at 20-30, 90 and 270 metres distant from the Potter Point outfall, at a depth of 1 metre below the surface. A total of 42 samples were collected. Seven samples were chosen at random from each date and analysed for tritium. Of the 14 samples, 9 were below the MDA and the remaining 5 all contained 4 ± 1 Bq/L of tritium. Both sampling occasions were timed to coincide with the Cronulla STP effluent study (section 6.2.3); however no Cronulla STP sample was provided by Sydney Water for 26 June 2007. 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** to **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 2006-07, quarterly pH measurements ranged from 3.8 to 6.6 with a median of 4.9 ± 1.1, and EC ranged between 166 and 1216 µS/cm with a median of 339 ± 97 µS/cm (**Tables 22** to **25**). The oxidation-reduction potential, Eh, had a positive median of 203 ± 114 mV, as would be expected of near-surface oxygenated waters. The lower Eh observed in piezometers such as MW1S and MW4S indicates less well oxygenated water. The median groundwater temperature was 18.8 ± 1.4°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 its trend of being the most saline piezometer and had the highest pH, consistent with its somewhat higher Ca, Mg, SO_4, and HCO_3 concentrations. This piezometer is located in a natural drainage line below a chlorinated swimming pool, and its groundwater chemistry may be influenced by past leakage of treated water from the pool.

6.6.2 Nutrients and Hydrocarbons in LHSTC Groundwater

The groundwater samples collected in November 2006 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 has been no 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 fertilizers, sewage or leachate from municipal waste.

Total phosphorus concentrations in unfiltered LHSTC groundwater ranged from 0.003 to 0.107 mg/L, with a median of 0.009 ± 0.001 mg/L in 2006-07. All but two of the samples were 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 phosphorus most readily available for biological uptake. Soluble reactive phosphorus levels in LHSTC groundwater in 2006-07 were close to, or below, the 0.002 mg/L limit of detection, which is 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, see **Table 27**. The values ranged from less than the combined detection limit (0.11 mg/L) to 2.44 mg/L, with only two piezometers (MW15D and MW10S) exceeding the ANZECC default target of 0.35 mg/L. At least 90% of the total nitrogen results were less than the detection limit and as such well below the default target

value. Oxidized nitrogen (nitrate and nitrite) results for LHSTC groundwater ranged from <0.01 to 1.41 mg/L, with a median concentration of 0.03 ± 0.12 mg/L, which is below the ANZECC 0.04 mg/L default target. There is a clear tendency for the shallow piezometers to show greater concentrations of nitrogen than the deeper ones.

Ammonia levels in LHSTC groundwaters were low, ranging from less than the detection limit to 0.13 mg/L, 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 ANSTO's 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 August 2006 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 MDA to 0.24 Bq/L, with a median of 0.06 ± 0.07 Bq/L. Gross beta activities were similar, ranging from 0.01 to 0.46 Bq/L, with a median of 0.06 ± 0.06 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. It should be noted 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 2006-07, nor 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 activities ranged from less than the MDA (3 Bq/L) to 68 Bq/L, with a median of 10.0 ± 15.5 Bq/L. These results are statistically indistinguishable from data reported since 2002-03. The maximum activity measured in LHSTC groundwater in 2006-07 was less than 1% of the ADWG guideline level (NHMRC and NRMMC 2004). Shallow piezometers showed higher tritium levels than their corresponding deeper ones for all but two piezometer pairs.

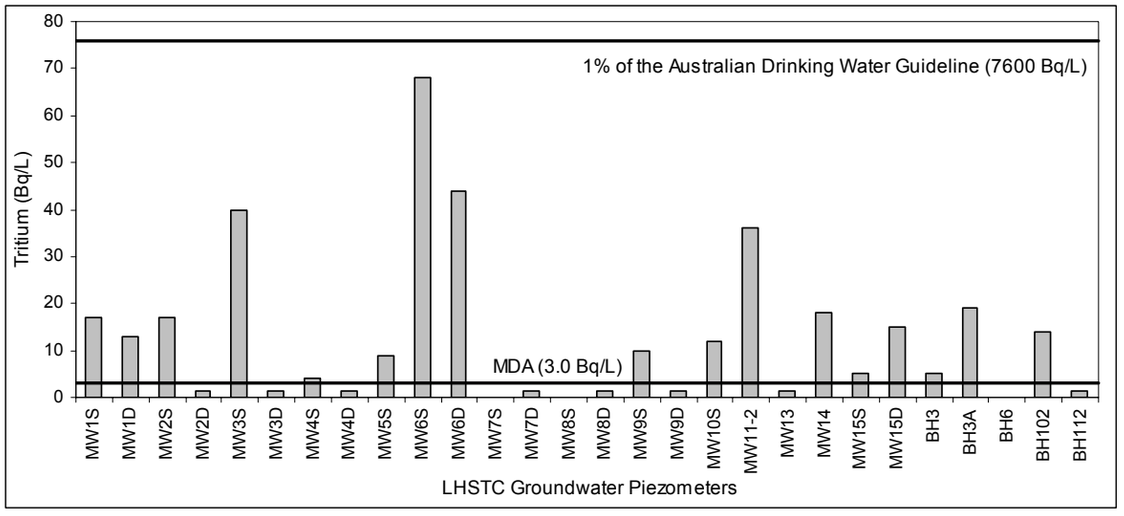

Figure 7: Tritium levels in LHSTC groundwater, August 2006.

6.7 Groundwater - Little Forest Burial Ground

Little Forest is located in a groundwater recharge area. Therefore, rain water moves down-gradient from the site along pathways of least resistance. For the LFBG, these pathways include surface water runoff and 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 the piezometer network at the LFBG.

At six-monthly intervals, the LFBG piezometer network is purged of standing water. Groundwater levels and field parameters are then measured and samples are collected for radioactivity analyses. The field parameter data are reported in **Tables 30** and **31**. In 2006-07, the groundwater pH ranged from 3.86 to 6.61 with a median of 5.69 ± 0.49, while electrical conductivity ranged between 176 and 15500 µS/cm with a median of 1541 ± 3157 µS/cm. These results show that 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 (Eh) measurements were generally positive, with a median of 98 ± 77 mV. Only three piezometers, (MB14, MB20 and BH10) displayed negative Eh values, indicating low oxygen concentrations.

The LFBG groundwater samples were settled and decanted prior to analysis, but not filtered. Results for tritium, gross alpha, gross beta and gamma-emitting radionuclides are shown in **Tables 32** and **33**. Tritium concentrations in groundwater from the LFBG for 2006-07 were 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 6920 Bq/L, 9% below the ADWG 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 one of two samples from piezometer MB16 at a concentration below 0.1 Bq/L, which is typical of the low levels reported in recent years. Americium-241 and caesium-137 were not detected in LFBG groundwater in 2006-07.

6.8 Rainwater

Since July 2004, the environmental monitoring program has included the collection and analysis of rainwater for tritium activity. 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 2006-07, 41 weekly rainwater composites were produced and analysed for tritium. The tritium analysis included distillation of the rainwater to remove possible interfering species, such as radioiodines, whenever sufficient sample volume was available. Distillations were performed on 73% of samples in 2006-07. The tritium levels in weekly composites of rainwater are shown in **Figure 8**, below. Results ranged from below the MDA for 68% of samples, to a maximum of 290 Bq/L in an undistilled sample. All samples contained less than 5% of the ADWG guideline for tritium of 7600 Bq/L.

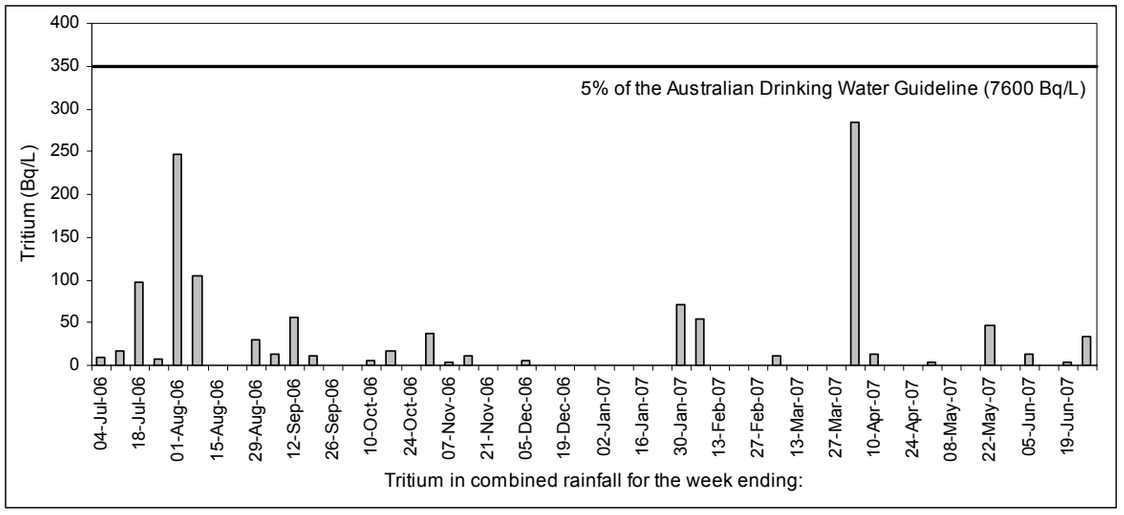

Figure 8: Tritium activity in LHSTC rainwater (weekly composites of daily samples), July 2006 to June 2007.

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 progeny of the uranium-238 and thorium-232 decay series were found in addition to traces of caesium-137 and cobalt-60, which have occasionally been detected at low levels in previous years. All of the measured activity concentrations were far below the relevant 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 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, beryllium-7 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 2007 using a hand-held meter at near-ground level (**Table 36**). Recorded dose-rates ranged from 0.08 to 0.20 µSv/hour and were consistent with background readings taken at the LFBG gate, approximately 200 metres away from the trench area.

6.10 Marine 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). Collection of fish, algae (seaweed) and barnacles continued at the Potter Point ocean outfall and a reference site at The Royal National Park from July 2006 to June 2007, with authorisation from the NSW Department of Primary Industries. 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 the samples were dried, ground and analysed for gamma-emitting radioisotopes (**Tables 37** to **39**).

The radioactivity measured in marine fish, algae and barnacles sampled at Potter Point in 2006-07 was of natural origin, apart from low levels of iodine-131 found in the algae. Iodine-131 is a medical radioisotope used in the treatment of thyroid cancer. As such, ANSTO's liquid effluent is 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 from 1997 to 2007 are summarised in **Table 40**. The meteorological statistics recorded 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 2006-07 was 1183.4 mm from 117 rainy days. Total rainfall for the previous decade, calculated as median ± interquartile range on a financial year basis was 880.7 ± 95.8 mm. The wettest month during 2006-07 was June 2007, with rainfall of 341.3 mm. The total evaporation for 2006-07 was 1256.2 mm, with a maximum 24-hour value of 16 mm recorded in January 2007.

6.11.2 Wind Speed and Direction

The winds (recorded at 10m) that predominated at Lucas Heights during summer and winter of 2006-07 are shown in **Table C**. Winds during autumn and spring represent a transition between those of summer and winter, with sea breezes observed later in the afternoon.

Table C. Seasonal prevailing winds at the LHSTC, recorded at 10m during 2006-07

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

For the period 2006-07 at Lucas Heights, the wind at 10m was blowing from the WSW-SSE sector approximately 47% 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 44% 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 are reported over periods of a year or less. However, the same data can provide a measure of ongoing trends and year to year variation. Examples of longer term datasets from ANSTO's environmental monitoring are set out below.

7.1 Airborne Dose

The modelling of airborne dose to the public integrates airborne emissions data 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 the maximum annual airborne effective dose to the critical group at the 1.6 km boundary of ANSTO's buffer zone for the past decade. 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 seven years. The 2006-07 figure was particularly low, due to the HIFAR reactor being shut down and decreased production of radiopharmaceuticals.

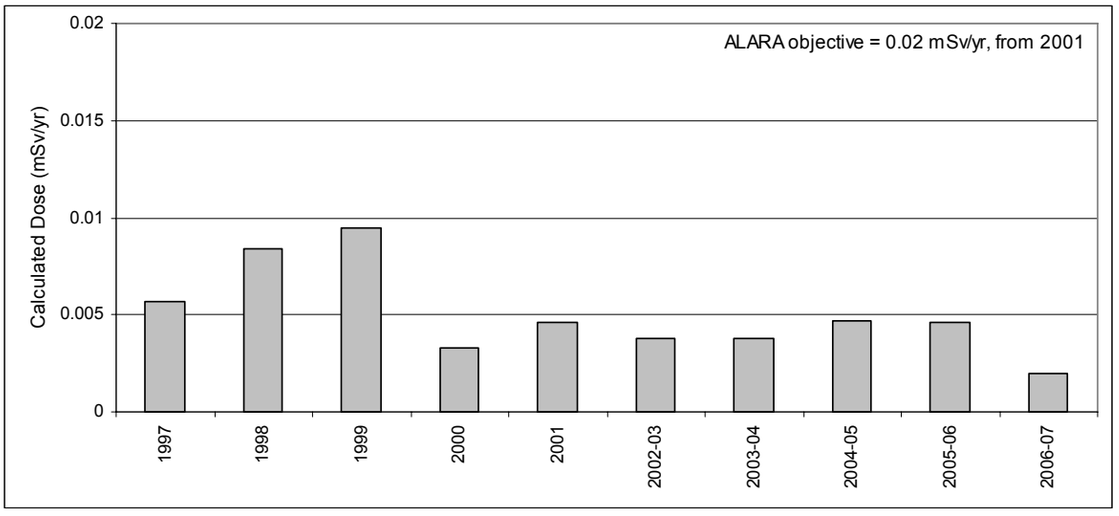

Figure 9: Maximum annual effective dose from LHSTC airborne discharges at the 1.6 km boundary of ANSTO's buffer zone, January 1997 to June 2007.

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).

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.

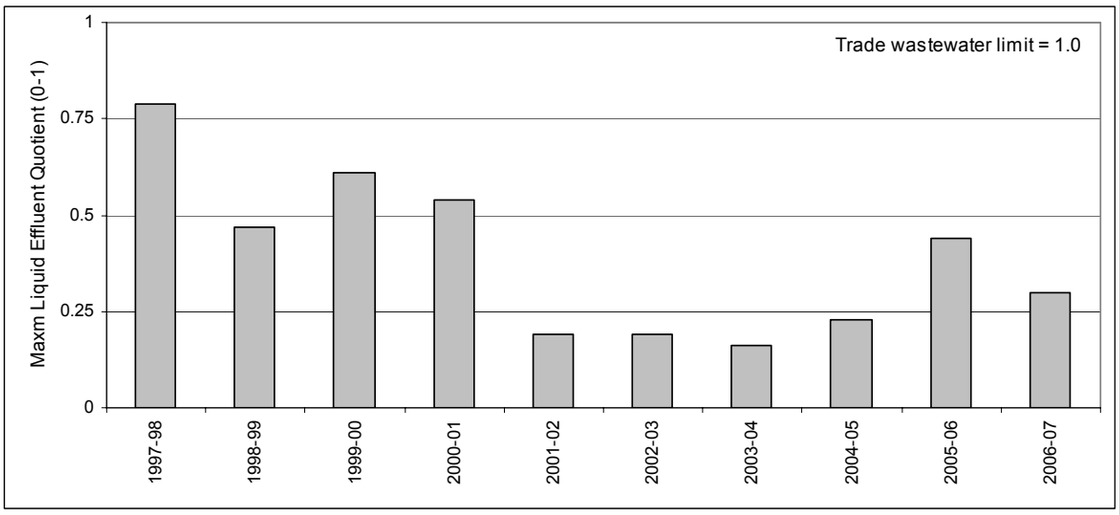

Figure 10: Maximum annual radioactivity concentration quotient in liquid effluent discharges from the LHSTC, July 1997 to June 2007.

7.3 Alpha and Beta Radioactivity in Stormwater

The gross alpha and gross 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. **Figures 11** and **12** show the annual maximum monthly gross alpha and gross beta data for the SPCC sampling points. The gross alpha and gross beta levels in these creeks have easily complied with the radioactivity limits for Class C waters in relevant state legislation (*Protection of the Environment Operations Act* 1997) over the past decade.

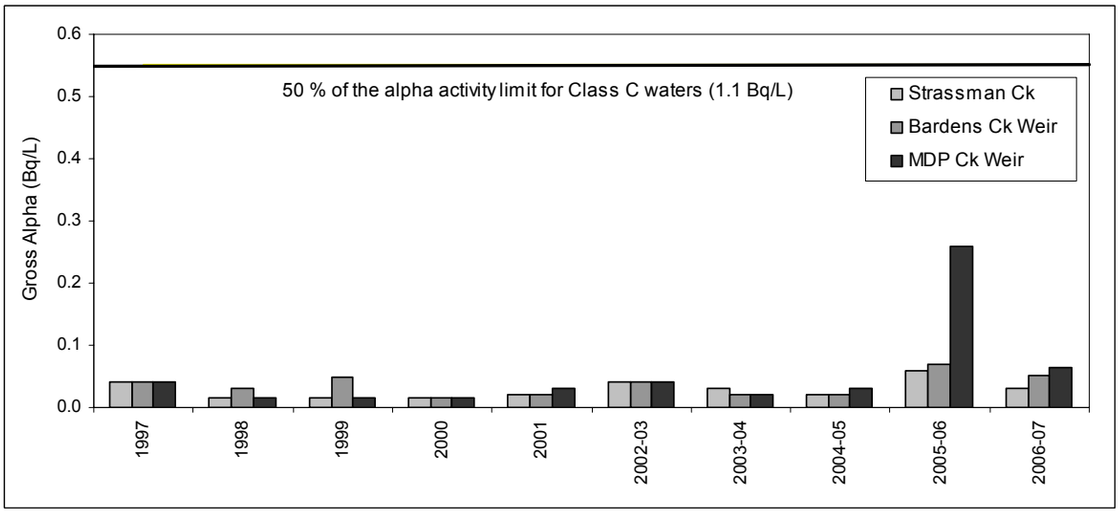

Figure 11: Annual maximum of monthly alpha radioactivity in stormwater at SPCC sampling points, January 1997 to June 2007.

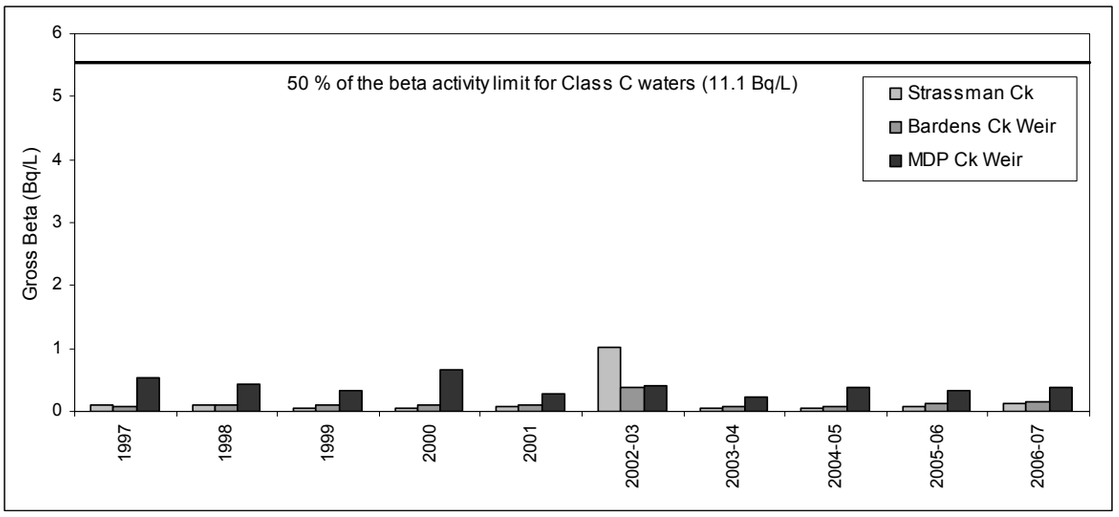

Figure 12: Annual maximum of monthly beta radioactivity in stormwater at SPCC sampling points, January 1997 to June 2007.

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-model are explained in Hoffmann and Loosz (2002).

During the period covered by this report there was 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. However, ANSTO is participating in an 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 2007) 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 2006-07 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 ANSTO's routine airborne releases comprises hypothetical individuals living around the 1.6 km buffer zone boundary. **Table 41** presents the estimated effective doses for various on-site locations and at radial distances of 1.6 and 4.8 km from HIFAR/OPAL. The estimated effective doses from routine airborne emissions to the critical group at 1.6 km ranged from 0.0004 to 0.0020 mSv/year, with a median of 0.0007 $\pm$ 0.0004 mSv/year.

Figure 13 shows the 2006-07 directional dose from LHSTC airborne emissions estimated for the critical group at 1.6 km. The maximum estimated dose was 0.0020 mSv/year to the north and this represents 10% of the ALARA objective of 0.02 mSv/year. The 2006-07 maximum off-site dose was around half that of recent years which is directly attributable to the closure of HIFAR and the consequent reduction in argon-41 emissions.

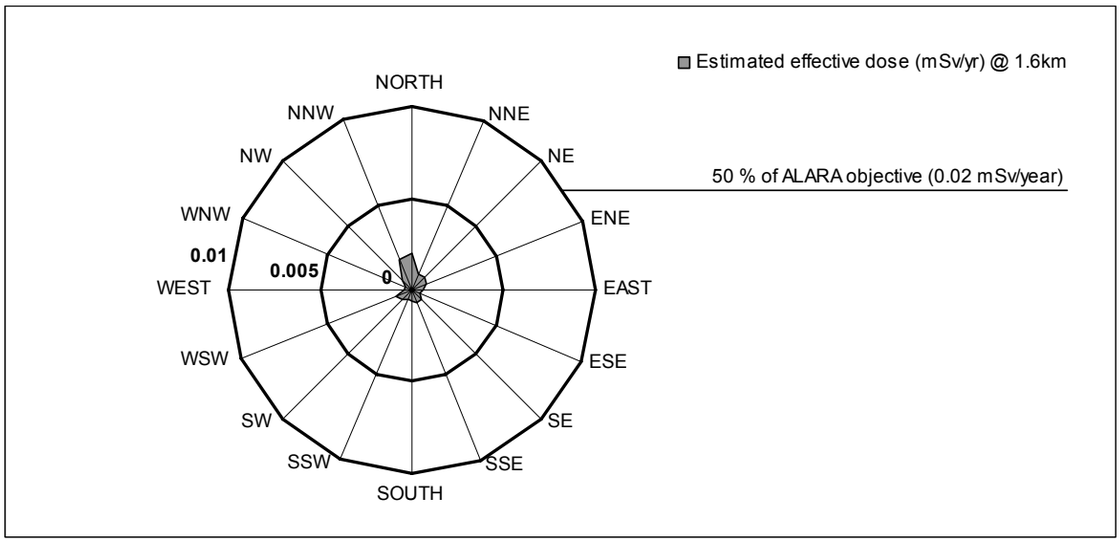

Figure 13: Estimated effective dose to the public (mSv/year) at a 1.6 km radius from HIFAR, from routine LHSTC airborne discharges, July 2006 to June 2007.

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. In **Figure 14**, the potential annual dose to ANSTO's nearest neighbours at 1.6 km is placed in the context of doses that Australians receive from other sources such as natural background radiation (~1.5 mSv/year) and averaged medical exposure (~0.8 mSv/year) (Webb *et al*. 1999).

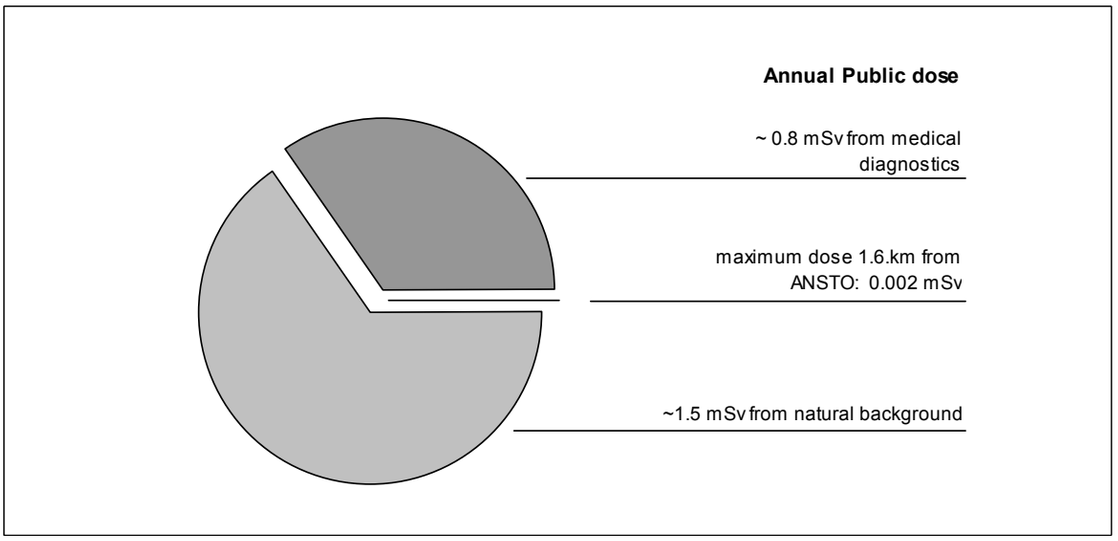

Figure 14: Comparison of the maximum potential off-site dose from ANSTO's airborne discharges (mSv/year) with the average dose Australians receive from natural background and medical procedures.

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 was 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 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.

Estimates of radiological dose-rates to marine biota at the Potter Point ocean outfall over the reporting period have been made, based on the measured radionuclide concentrations in ANSTO's liquid effluent reported in **Tables 3** and **4** and assuming realistic but precautionary exposure scenarios (Twining and Hughes 2008). The estimates were, in all cases, much less than even the most conservative of the internationally recognised criteria recommended for the protection of biota from radiological hazards (Garnier-Laplace et al. 2006). On this basis, the effluent released by ANSTO during the 2006-07 monitoring period can be considered to be of negligible radiological risk to biota in the receiving environment at Potter Point.

9. CONCLUSION

For the period from July 2006 to June 2007, the estimated potential doses to members of the public from airborne discharges at the LHSTC were below the ALARA and regulatory limits, and were significantly lower than in previous years due to the closure of the HIFAR reactor in January 2007. Dose estimates based on the monitoring results for liquid effluent releases and seawater at Potter Point confirm that the potential radiation dose to marine biota and members of the public as a result of ANSTO's liquid effluent discharges to the sewer is also very low. Tritium levels in stormwater and groundwater at the LHSTC were less than the Australian drinking water guidelines. Airborne and liquid effluent emissions from the NMC 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 background radiation dose received by Australians each year from naturally-occurring sources of radiation.

10. ACKNOWLEDGEMENTS

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APPENDIX A – Corrections to Previous Reports

Corrections are listed below for the previous report in this series, ANSTO E-761 *Environmental and Effluent Monitoring at ANSTO Sites, 2005-06:*

- Page 27, Section 6.8, line 1: the date is incorrect. The sentence should read as follows:

  In July 2004, the collection and analysis of rainwater for tritium activity was incorporated into the environmental monitoring program.

- Page 31, Figures 11 and 12, the captions are incorrect: Figure 11 actually shows the gross beta data and Figure 12 shows the gross alpha data.

- Page 40, Table 4, second footnote: I-123 should read I-131.

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 (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 2006 to June 2007

	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)	I-123 (GBq)	All Other Nuclides (MBq)
3	N.D.	N.D.																	1.658
	-	-																	0.3%
15A	N.D.	599.6	6.56	2737	63.3	53.3	3.44	54.1	2.26										
	-	1.0%	16.4%	27.4%	35.2%	19.0%	8.6%	21.6%	9.0%										
15M	N.D.	N.D.	2.13	592	5.89														
	-	-	21.3%	131.6%	29.5%														
19S	N.D.	N.D.	4.58																
	-	-	9.2%																
19D	N.D.	N.D.	0.135																
	-	-	0.3%																
20	N.D.	57.8		83.9															1.66
	-	82.6%		38.1%															0.3%
20B	N.D.	N.D.																	2.26
	-	-																	0.5%
21A	N.D.	N.D.																	0.142
	-	-																	0.0%
23A	N.D.	4398	2424																N.D.
	-	1.3%	7.3%																-
23B	N.D.	N.D.	8.51																
	-	-	7.7%																
41A	N.D.	N.D.																	41.4
	-	-																	8.3%
41B	N.D.	N.D.																	4.31
	-	-																	0.9%
54	N.D.	N.D.	72.6							984.1	23.7	5.49	0.318	0.362	1.28E-03	N.D.	4.80E-06		
	-	-	0.3%							0.4%	0.2%	2.0%	0.1%	0.1%	0.0%	-	0.0%		
56	N.D.	N.D.																	2.26
	-	-																	0.5%
57	N.D.	N.D.		179.3															2.47
	-	-		81.5%															0.5%
80		N.D.	N.D.	9.36	N.D.						N.D.	N.D.	N.D.		N.D.	N.D.	N.D.		
		-	-	6.0%	-						-	-	-		-	-	-		
NMC																		17.79	104.7
																		17.8%	21.3%

Notes:
• ND = not detected. Percentages reported are the discharge as a percentage of the annual Notification Level (rounded to nearest 0.1%).
• 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 2006 to June 2007

Month	Total Volume Discharged (m^3)	Radioactivity Average Concentration in Discharges (Bq/m3)			Concentration Quotient
		Alpha	Beta	Tritium	
Jul 2006	6405	2.89×10^1	1.26×10^3	2.50×10^6	0.03
Aug 2006	7787	2.94×10^1	2.12×10^4	1.84×10^6	0.18
Sep 2006	10604	7.03×10^1	2.60×10^4	2.91×10^6	0.23
Oct 2006	6597	5.02×10^1	5.29×10^3	4.08×10^6	0.07
Nov 2006	6267	3.15×10^1	2.28×10^3	3.32×10^6	0.04
Dec 2006	7873	1.43×10^1	1.99×10^3	3.73×10^6	0.04
Jan 2007	8755	2.90×10^1	2.63×10^3	6.09×10^6	0.05
Feb 2007	4796	1.10×10^2	1.18×10^4	3.06×10^7	0.26
Mar 2007	9087	4.55×10^1	8.37×10^3	2.36×10^7	0.19
Apr 2007	7156	1.29×10^2	2.13×10^4	5.78×10^6	0.21
May 2007	7404	1.34×10^2	3.16×10^4	6.00×10^6	0.29
Jun 2007	12457	2.91×10^2	2.85×10^4	4.97×10^6	0.28
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 discharge agreement.

• Alpha-emitting nuclides are assumed to be all radium-226 and beta-emitters are assumed to be all strontium-90 (*ie* possible worst case) when calculating the concentration quotient.

Table 4. GAMMA-EMITTERS IN LIQUID EFFLUENT, MONTHLY PIPELINE COMPOSITE SAMPLES, LHSTC, July 2006 to June 2007

	Gamma-emitters (Bq/L)								
Month	**Cr-51**	**Co-60**	**Cs-134**	**Cs-137**	**Ce-144**	**I-131**	**Pb-210**	**Ra-226**	**Ra-228**
Jul 2006	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA
Aug 2006	< MDA	< MDA	< MDA	13.69 ± 0.14	< MDA	0.59 ± 0.04	< MDA	6.34 ± 0.51	< MDA
Sep 2006	< MDA	< MDA	< MDA	16.89 ± 1.01	< MDA	0.39 ± 0.04	< MDA	< MDA	< MDA
Oct 2006	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA
Nov 2006	2.37 ± 0.24	< MDA	< MDA	2.00 ± 0.06	0.60 ± 0.13	0.33 ± 0.04	< MDA	2.20 ± 0.51	< MDA
Dec 2006	2.25 ± 0.23	< MDA	< MDA	2.23 ± 0.04	< MDA	1.17 ± 0.05	< MDA	< MDA	< MDA
Jan 2007	5.54 ± 0.28	< MDA	< MDA	2.74 ± 0.08	0.65 ± 0.13	2.46 ± 0.05	< MDA	< MDA	< MDA
Feb 2007	< MDA	< MDA	< MDA	5.34 ± 0.11	< MDA	0.90 ± 0.05	< MDA	< MDA	< MDA
Mar 2007	< MDA	< MDA	< MDA	6.34 ± 0.13	< MDA	0.37 ± 0.04	< MDA	< MDA	< MDA
Apr 2007	< MDA	< MDA	< MDA	12.35 ± 0.12	< MDA	0.55 ± 0.04	< MDA	< MDA	< MDA
May 2007	< MDA	< MDA	< MDA	18.05 ± 0.18	< MDA	< MDA	< MDA	< MDA	< MDA
Jun 2007	6.62 ± 0.33	0.28 ± 0.05	< MDA	15.06 ± 0.15	< MDA	0.73 ± 0.04	< MDA	< MDA	< MDA

Notes:

• Gamma spectrometry was performed on the “monthly pipeline composite”, which is made up of volume-proportional samples from all treated liquid effluent discharges during a given month.

• < MDA indicates that the results was below the minimum detectable activity, calculated with 95% confidence. Median MDA values for the relevant radionuclides were as follows: 0.51 for Cr-51, 0.11 for Co-60, 0.07 for I-131, 0.09 for Cs-134, 0.12 for Cs-137, 0.38 for Ce-144, 1.41 for Pb-210, 1.62 for Ra-226 and 0.37 for Ra-228.

Table 5. NON-RADIOACTIVE COMPONENTS OF LIQUID EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, LHSTC, July 2006 to June 2007

Parameter	**Concentration** (mg/L)			**Standard for Acceptance** (mg/L)
	Mean	Median	Range	
pH	7.2	7.2	6.6 - 8.1	**7 – 10**
Ammonia	6.0	5.1	0.7 -18.4	**100**
Biological Oxygen Demand	19	15	2 - 74	**NA**
Zinc	0.9	0.5	0.1 - 3.5	**5**
Suspended Solids	25	24	2 - 89	**600**
Total Dissolved Solids	501	503	198 - 708	**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.

• NA: Not applicable.

Table 6. RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO THE SEWER, NMC, July 2006 to June 2007

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 2006	4.9	8.0	2.55	2.71	0.97	3.39	0.77	ND
Aug 2006	4.0	7.5	62.50	2.18	0.30	1.73	0.42	ND
Sep 2006	5.0	7.4	0.88	0.49	ND	1.20	0.22	0.18
Oct 2006	4.0	8.0	3.27	5.09	3.75	7.03	2.68	0.03
Nov 2006	4.7	7.4	0.40	2.93	0.06	10.50	2.35	0.01
Dec 2006	5.8	7.7	3.31	2.38	0.91	4.94	1.59	ND
Jan 2007	5.0	7.4	0.86	3.89	1.49	4.88	1.61	0.01
Feb 2007	5.7	8.5	1.49	1.50	0.78	2.47	0.61	0.01
Mar 2007	7.1	7.0	6.19	3.82	0.74	1.94	0.36	0.01
Apr 2007	8.2	7.2	1.05	1.15	0.39	1.52	0.28	0.09
May 2007	7.0	7.3	5.17	4.36	5.22	1.56	0.43	1.58
Jun 2007	7	7.0	9.93	6.04	0.91	1.15	0.30	ND
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, April 2007 to June 2007

LHSTC AND CRONULLA SEWAGE TREATMENT PLANT - Summary

Date	Effluent released from LHSTC			Maximum CSTP tritium activity (Bq/L)	Average CSTP tritium activity (Bq/L)	Estimated minimum dilution ratio LHSTC:CSTP	Average dilution ratio LHSTC:CSTP
	Number of tanks released	Total volume (kL)	Average tritium activity (Bq/L)				
18-4-07 to 29-4-07	10	3836	4817	65 ± 1	14.9	86:1	185:1
18-6-07 to 29-6-07	8	6795	232	6 ± 1	4.5*	92:1	

CRONULLA SEWAGE TREATMENT PLANT - Effluent

Date	CSTP tritium (Bq/L)	Date	CSTP tritium (Bq/L)	Date	CSTP I-131 (Bq/L)	Date	CSTP I-131 (Bq/L)
19-4-07	36 ± 1	27-4-07	5 ± 1	19-4-07	0.9 ± 0.1	27-4-07	1.1 ± 0.1
20-4-07	65 ± 1	28-4-07	5 ± 1	20-4-07	ND	28-4-07	1.0 ± 0.2
21-4-07	51 ± 1	29-4-07	5 ± 1	21-4-07	1.4 ± 0.1	29-4-07	1.2 ± 0.1
22-4-07	20 ± 1	19-6-07	6 ± 1	22-4-07	1.6 ± 0.2		
23-4-07	8 ± 1	20-6-07	< MDA	23-4-07	0.5 ± 0.1		
24-4-07	19 ± 1	21-6-07	< MDA	24-4-07	ND		
25-4-07	4 ± 1	22-6-07	6 ± 1	25-4-07	1.0 ± 0.2		
26-4-07	6 ± 1	29-6-07	5 ± 1	26-4-07	ND		

CRONULLA SEWAGE TREATMENT PLANT - Biosolids

Date	I-131 (Bq/kg)	Co-60 (Bq/kg)	Tl-201 (Bq/kg)
18-4-07	120 ± 6	13 ± 1	ND
1-5-07	64 ± 3	ND	ND
7-5-07	46 ± 2	ND	48 ± 7
28-6-07	46 ± 2	ND	ND

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)
24-4-07	8:00	14:00	7	4 ± 1	4 ± 1	19 ± 1
26-6-07	8:00	14:00	7	< MDA	< MDA	No sample

Notes:

• Effluent at the CSTP was sampled at a location known as the UV Inlet. All CSTP 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 April 2007 was 3 Bq/L and for June 2007 was 4.7 Bq/L.

* Flow data missing from 20 to 22-6-07. Estimated flow used for this calculation.

Table 8. AMBIENT IODINE-131 IN AIR, LHSTC PERIMETER, July 2006 to June 2007

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
4-7-06	< MDA	< MDA	< MDA	< MDA	2-1-07	< MDA	< MDA	< MDA	< MDA
11-7-06	< MDA	< MDA	< MDA	< MDA	9-1-07	< MDA	< MDA	< MDA	< MDA
18-7-06	< MDA	< MDA	< MDA	< MDA	16-1-07	< MDA	< MDA	< MDA	-
25-7-06	< MDA	< MDA	< MDA	< MDA	23-1-07	< MDA	< MDA	< MDA	< MDA
1-8-06	< MDA	< MDA	< MDA	< MDA	30-1-07	< MDA	< MDA	< MDA	< MDA
8-8-06	< MDA	< MDA	< MDA	< MDA	6-2-07	< MDA	< MDA	< MDA	< MDA
15-8-06	< MDA	< MDA	< MDA	< MDA	13-2-07	< MDA	< MDA	< MDA	< MDA
22-8-06	< MDA	< MDA	< MDA	< MDA	20-2-07	< MDA	< MDA	< MDA	< MDA
29-8-06	< MDA	< MDA	< MDA	< MDA	27-2-07	< MDA	-	< MDA	< MDA
5-9-06	< MDA	< MDA	< MDA	< MDA	6-3-07	< MDA	< MDA	< MDA	< MDA
12-9-06	< MDA	< MDA	-	< MDA	13-3-07	< MDA	< MDA	< MDA	< MDA
19-9-06	< MDA	< MDA	< MDA	< MDA	20-3-07	< MDA	< MDA	< MDA	< MDA
26-9-06	< MDA	< MDA	< MDA	< MDA	27-3-07	< MDA	< MDA	< MDA	< MDA
3-10-06	< MDA	< MDA	< MDA	< MDA	3-4-07	< MDA	< MDA	< MDA	< MDA
10-10-06	< MDA	< MDA	< MDA	< MDA	10-4-07	< MDA	< MDA	< MDA	< MDA
17-10-06	< MDA	< MDA	< MDA	< MDA	17-4-07	< MDA	< MDA	< MDA	< MDA
24-10-06	< MDA	< MDA	< MDA	< MDA	26-4-07	< MDA	< MDA	< MDA	< MDA
31-10-06	< MDA	< MDA	< MDA	< MDA	1-5-07	< MDA	< MDA	< MDA	< MDA
7-11-06	< MDA	< MDA	< MDA	< MDA	8-5-07	< MDA	< MDA	< MDA	< MDA
14-11-06	< MDA	< MDA	< MDA	< MDA	15-5-07	< MDA	< MDA	< MDA	< MDA
21-11-06	< MDA	< MDA	< MDA	< MDA	22-5-07	< MDA	< MDA	< MDA	< MDA
28-11-06	< MDA	< MDA	< MDA	< MDA	29-5-07	< MDA	< MDA	< MDA	< MDA
5-12-06	< MDA	< MDA	< MDA	< MDA	5-6-07	< MDA	< MDA	< MDA	< MDA
12-12-06	< MDA	< MDA	< MDA	< MDA	12-6-07	< MDA	< MDA	< MDA	< MDA
19-12-06	< MDA	< MDA	< MDA	< MDA	19-6-07	< MDA	< MDA	< MDA	< MDA
28-12-06	< MDA	< MDA	< MDA	< MDA	26-6-07	< MDA	< MDA	< MDA	< MDA

Notes:

- Four continuous air samplers are located along the eastern boundary of the LHSTC site, see Figure 2.
- Dash (-) indicates missing data due to power or pump failure.
- < 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 2006 to June 2007

Sampling Period	Equivalent Volume	Beryllium		Pu-239/240	
	(m^3)	(µg total)	(µg/m^3)	(Bq total)	(Bq/m^3)
Jul – Sep 2006	403	< 0.08	< 2.0×10^{-4}	< 0.001	< 2.5×10^{-6}
Oct – Dec 2006	406	< 0.03	< 7.4×10^{-5}	< 0.001	< 2.5×10^{-6}
Jan – Mar 2007	392	< 0.02	< 5.1×10^{-5}	< 0.001	< 2.6×10^{-6}
Apr – Jun 2007	317	< 0.02	< 6.3×10^{-5}	< 0.001	< 3.2×10^{-6}

Notes:

• Airborne particulate samples were accumulated over a period of 3 months using a high-volume air sampler. The sampling duration and frequency was approximately 4 hours, every 2 weeks. The equivalent sampling volume is based on the proportion of the sample taken for analysis (25%).

• '<' indicates that the result was below the stated minimum detectable activity, which was divided by the volume of air sampled to give the Be and Pu concentrations in air.

Table 10. ANNUAL EFFECTIVE DOSE FROM EXTERNAL GAMMA RADIATION, LHSTC AND LOCAL AREA, July 2006 to June 2007

	ANSTO Environmental Thermoluminescent Dosimeters	
	Dosimeter Location: LHSTC site	**Annual Effective Dose** (mSv/year) **2006-07**
1	HIFAR fence - south east	0.99 ± 0.04
2	HIFAR fence - south	2.87 ± 0.11
3	Perimeter fence - west	2.61 ± 0.10
4	HIFAR fence - west	1.20 ± 0.05
5	HIFAR fence - north west	1.03 ± 0.04
6	Perimeter fence - north A	0.96 ± 0.04
7	Internal fence - north	0.97 ± 0.04
8	Perimeter fence - north B	0.92 ± 0.03
9	Perimeter fence - north east	0.94 ± 0.04
10	Perimeter fence - east	0.97 ± 0.04
11	Perimeter fence - south east	0.92 ± 0.03
12	Corner of Curie and Roentgen St	1.06 ± 0.04
13	Perimeter fence - south	0.79 ± 0.03
14	HIFAR fence - east	1.09 ± 0.04
15	HIFAR fence - north east	1.24 ± 0.05
	Dosimeter Location: off-site	
16	Private house - Barden Ridge	1.30 ± 0.05
17	Private house - Yarrawarra	0.95 ± 0.04
18	Private house - Woronora	1.67 ± 0.06
19	Cronulla Sewage Treatment Plant	0.77 ± 0.03
20	LFBG - on trenches	1.05 ± 0.04
21	LFBG - background	1.20 ± 0.05
22	Lucas Heights Waste Management Centre - Depot	1.09 ± 0.04

Notes:

• Refer to Figure 2 for the locations of the environmental dosimeters at the LHSTC.

• 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 2006 to June 2007

ANSTO Environmental Thermoluminescent Dosimeters		
	Dosimeter Location	**Annual Effective Dose** (mSv/year) **2006-07**
1	Front entrance	1.95 ± 0.07
2	East wall	1.66 ± 0.06
3	Stair on north wall	1.88 ± 0.07
4	West wall	1.74 ± 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 2006 to June 2007

	Tritium (Bq/L)		
Month	**Bund A**	**Bund B**	**Bund C**
Jul 2006	1130 ± 30	90 ± 10	90 ± 10
Aug 2006	380 ± 20	80 ± 10	890 ± 30
Sep 2006	350 ± 20	50 ± 10	180 ± 10
Oct 2006	20 ± 10	140 ± 10	70 ± 10
Nov 2006	120 ± 10	60 ± 10	130 ± 10
Dec 2006	80 ± 10	30 ± 10	80 ± 10
Jan 2007	160 ± 10	80 ± 10	140 ± 10
Feb 2007	140 ± 10	90 ± 10	120 ± 10
Mar 2007	340 ± 10	260 ± 10	70 ± 10
Apr 2007	360 ± 10	470 ± 20	90 ± 10
May 2007	940 ± 20	150 ± 10	150 ± 10
Jun 2007	90 ± 10	40 ± 10	90 ± 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 2006 to June 2007

Location	Date	Gross Alpha (Bq/L)	Gross Beta (Bq/L)	RADIOACTIVITY (Bq/L) Gamma-emitters					Tritium (Bq/L)
				Am-241	Be-7	Cs-137	Co-60	K-40	
OPAL- North	11-9-06	0.05 ± 0.01	0.10 ± 0.01	< MDA	0.433 ± 0.093	< MDA	< MDA	< MDA	30 ± 10
	13-2-07	0.07 ± 0.01	0.10 ± 0.01	< MDA	0.426 ± 0.077	< MDA	< MDA	< MDA	70 ± 10
	24-4-07	0.06 ± 0.01	0.13 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA
OPAL - South West	11-9-06	0.16 ± 0.02	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	0.64 ± 0.19	< MDA
	13-2-07	0.45 ± 0.05	0.42 ± 0.02	< MDA	1.448 ± 0.129	< MDA	< MDA	0.52 ± 0.15	< MDA
	24-4-07	0.04 ± 0.01	0.07 ± 0.01	< MDA	0.149 ± 0.051	< MDA	< MDA	< MDA	30 ± 10

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 2006 to June 2007

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
4-7-06	50 ± 10	7-11-06	140 ± 10	13-3-07	< MDA
11-7-06	100 ± 10	14-11-06	80 ± 10	20-3-07	80 ± 10
18-7-06	< MDA	21-11-06	180 ± 20	27-3-07	60 ± 10
25-7-06	50 ± 10	28-11-06	180 ± 10	3-4-07	200 ± 10
1-8-06	140 ± 10	5-12-06	90 ± 10	10-4-07	100 ± 10
8-8-06	170 ± 10	12-12-06	20 ± 10	17-4-07	50 ± 10
15-8-06	4930 ± 60	19-12-06	40 ± 10	24-4-07	< MDA
22-8-06	250 ± 20	28-12-06	160 ± 10	1-5-07	90 ± 10
29-8-06	400 ± 20	2-1-07	< MDA	8-5-07	100 ± 10
5-9-06	280 ± 20	9-1-07	130 ± 10	15-5-07	110 ± 10
12-9-06	50 ± 10	16-1-07	150 ± 10	22-5-07	110 ± 10
19-9-06	320 ± 20	23-1-07	170 ± 10	29-5-07	410 ± 20
26-9-06	190 ± 20	30-1-07	150 ± 10	5-6-07	170 ± 10
3-10-06	360 ± 20	6-2-07	180 ± 10	12-6-07	120 ± 10
10-10-06	120 ± 10	13-2-07	50 ± 10	19-6-07	90 ± 10
17-10-06	220 ± 20	20-2-07	90 ± 10	26-6-07	40 ± 10
24-10-06	100 ± 10	27-2-07	30 ± 10		
31-10-06	200 ± 20	6-3-07	120 ± 10		

Notes:

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

• < 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 15. TRITIUM IN SURFACE WATER, MDP + 60m, LHSTC, July 2006 to June 2007

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
4-7-06	40 ± 10	7-11-06	110 ± 10	13-3-07	10 ± 10
11-7-06	80 ± 10	14-11-06	70 ± 10	20-3-07	60 ± 10
18-7-06	20 ± 10	21-11-06	90 ± 10	27-3-07	100 ± 10
25-7-06	40 ± 10	28-11-06	110 ± 10	3-4-07	90 ± 10
1-8-06	170 ± 10	5-12-06	80 ± 10	10-4-07	60 ± 10
8-8-06	110 ± 10	12-12-06	50 ± 10	17-4-07	40 ± 10
15-8-06	1830 ± 40	19-12-06	50 ± 10	24-4-07	< MDA
22-8-06	280 ± 20	28-12-06	80 ± 10	1-5-07	90 ± 10
29-8-06	220 ± 20	2-1-07	< MDA	8-5-07	90 ± 10
5-9-06	160 ± 10	9-1-07	90 ± 10	15-5-07	70 ± 10
12-9-06	50 ± 10	16-1-07	90 ± 10	22-5-07	90 ± 10
19-9-06	270 ± 20	23-1-07	90 ± 10	29-5-07	300 ± 10
26-9-06	150 ± 10	30-1-07	80 ± 10	5-6-07	170 ± 10
3-10-06	200 ± 10	6-2-07	100 ± 10	12-6-07	110 ± 10
10-10-06	120 ± 10	13-2-07	30 ± 10	19-6-07	80 ± 10
17-10-06	170 ± 10	20-2-07	70 ± 10	26-6-07	50 ± 10
24-10-06	70 ± 10	27-2-07	40 ± 10		
31-10-06	90 ± 10	6-3-07	90 ± 10		

Notes:

• Refer to Figure 3 for the location of this sampling point, 60m downstream of Bund C.

• < 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 16. TRITIUM IN SURFACE WATER, BARDENS CREEK WEIR, LHSTC
July 2006 to June 2007

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
4-7-06	110 ± 10	7-11-06	90 ± 10	13-3-07	130 ± 10
11-7-06	280 ± 20	14-11-06	100 ± 10	20-3-07	130 ± 10
18-7-06	130 ± 10	21-11-06	30 ± 10	27-3-07	80 ± 10
25-7-06	130 ± 10	28-11-06	50 ± 10	3-4-07	110 ± 10
1-8-06	180 ± 10	5-12-06	30 ± 10	10-4-07	120 ± 10
8-8-06	150 ± 10	12-12-06	30 ± 10	17-4-07	20 ± 10
15-8-06	110 ± 10	19-12-06	120 ± 10	24-4-07	50 ± 10
22-8-06	120 ± 10	28-12-06	30 ± 10	1-5-07	50 ± 10
29-8-06	60 ± 10	2-1-07	< MDA	8-5-07	50 ± 10
5-9-06	70 ± 10	9-1-07	40 ± 10	15-5-07	80 ± 10
12-9-06	60 ± 10	16-1-07	30 ± 10	22-5-07	80 ± 10
19-9-06	70 ± 10	23-1-07	20 ± 10	29-5-07	50 ± 10
26-9-06	100 ± 10	30-1-07	130 ± 10	5-6-07	< MDA
3-10-06	60 ± 10	6-2-07	30 ± 10	12-6-07	20 ± 10
10-10-06	50 ± 10	13-2-07	20 ± 10	19-6-07	20 ± 10
17-10-06	50 ± 10	20-2-07	30 ± 10	26-6-07	20 ± 10
24-10-06	< MDA	27-2-07	100 ± 10		
31-10-06	20 ± 10	6-3-07	60 ± 10		

Notes:

• Refer to Figure 3 for the location of this sampling point.

• < 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 17. RADIOACTIVITY IN STORMWATER, BUND C MONTHLY COMPOSITES, LHSTC, July 2006 to June 2007

Month	Gross Alpha (Bq/L)	Gross Beta (Bq/L)	Gamma-emitters (Bq/L) Am-241	Be-7	Cs-137	Co-60	K-40
Jul 2006	0.04 ± 0.01	0.28 ± 0.01	< MDA	0.080 ± 0.032	< MDA	< MDA	< MDA
Aug 2006	< MDA	0.24 ± 0.01	< MDA	< MDA	0.004 ± 0.002	< MDA	< MDA
Sep 2006	0.02 ± 0.01	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	0.12 ± 0.05
Oct 2006	0.03 ± 0.01	0.20 ± 0.01	< MDA	< MDA	< MDA	< MDA	0.21 ± 0.04
Nov 2006	0.02 ± 0.01	0.25 ± 0.01	< MDA	0.216 ± 0.029	0.020 ± 0.003	< MDA	< MDA
Dec 2006	0.04 ± 0.01	0.38 ± 0.01	< MDA	0.578 ± 0.052	0.021 ± 0.003	< MDA	< MDA
Jan 2007	0.03 ± 0.01	0.31 ± 0.01	< MDA	0.075 ± 0.017	0.014 ± 0.002	< MDA	0.13 ± 0.05
Feb 2007	< MDA	0.38 ± 0.01	< MDA	0.093 ± 0.024	0.012 ± 0.003	< MDA	< MDA
Mar 2007	< MDA	0.22 ± 0.01	< MDA	0.182 ± 0.027	0.007 ± 0.002	< MDA	< MDA
Apr 2007	0.02 ± 0.01	0.20 ± 0.01	< MDA	0.201 ± 0.048	0.011 ± 0.004	< MDA	< MDA
May 2007	< MDA	0.25 ± 0.01	< MDA	< MDA	0.008 ± 0.002	< MDA	0.09 ± 0.04
Jun 2007	0.03 ± 0.01	0.16 ± 0.01	< MDA	0.116 ± 0.040	< 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 2006 to June 2007

Month	Gross Alpha (Bq/L)	Gross Beta (Bq/L)	Gamma-emitters (Bq/L)				
			Am-241	Be-7	Cs-137	Co-60	K-40
Jul 2006	0.04 ± 0.01	0.19 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
Aug 2006	0.02 ± 0.01	0.15 ± 0.01	< MDA	< MDA	0.005 ± 0.002	< MDA	< MDA
Sep 2006	< MDA	0.12 ± 0.01	< MDA	0.052 ± 0.023	< MDA	< MDA	0.10 ± 0.05
Oct 2006	0.03 ± 0.01	0.10 ± 0.01	< MDA	< MDA	0.006 ± 0.002	< MDA	< MDA
Nov 2006	0.03 ± 0.01	0.09 ± 0.01	< MDA	0.076 ± 0.023	0.007 ± 0.002	< MDA	< MDA
Dec 2006	0.02 ± 0.01	0.13 ± 0.01	< MDA	0.089 ± 0.027	0.007 ± 0.002	< MDA	0.14 ± 0.05
Jan 2007	0.03 ± 0.01	0.12 ± 0.01	< MDA	0.057 ± 0.016	0.005 ± 0.002	< MDA	< MDA
Feb 2007	< MDA	0.20 ± 0.01	< MDA	< MDA	0.006 ± 0.002	< MDA	0.15 ± 0.05
Mar 2007	0.01 ± 0.01	0.17 ± 0.01	< MDA	0.295 ± 0.034	0.014 ± 0.002	< MDA	< MDA
Apr 2007	0.05 ± 0.01	0.10 ± 0.01	< MDA	0.093 ± 0.022	0.005 ± 0.002	< MDA	< MDA
May 2007	< MDA	0.16 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
Jun 2007	0.05 ± 0.01	0.06 ± 0.01	< MDA	0.139 ± 0.023	0.010 ± 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 2006 to June 2007

	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 2006	0.02 ± 0.01	0.05 ± 0.01	0.02 ± 0.01	0.06 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	0.02 ± 0.01	0.04 ± 0.01
Aug 2006	0.01 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	0.01 ± 0.01	0.16 ± 0.01	< MDA	0.05 ± 0.01
Sep 2006	0.03 ± 0.01	0.04 ± 0.01	0.01 ± 0.01	0.07 ± 0.01	0.01 ± 0.11	0.11 ± 0.01	< MDA	0.05 ± 0.01
Oct 2006	< MDA	0.04 ± 0.01	< MDA	0.02 ± 0.01	< MDA	0.17 ± 0.01	< MDA	0.04 ± 0.01
Nov 2006	0.01 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.16 ± 0.01	0.06 ± 0.02	0.39 ± 0.02	< MDA	0.07 ± 0.02
Dec 2006	0.03 ± 0.01	0.12 ± 0.01	0.02 ± 0.01	0.10 ± 0.01	0.02 ± 0.01	0.19 ± 0.01	< MDA	0.08 ± 0.01
Jan 2007	0.02 ± 0.01	0.04 ± 0.01	< MDA	0.01 ± 0.01	< MDA	0.18 ± 0.01	< MDA	0.04 ± 0.01
Feb 2007	0.01 ± 0.01	0.04 ± 0.01	0.05 ± 0.02	0.13 ± 0.01	0.02 ± 0.01	0.13 ± 0.01	< MDA	0.06 ± 0.01
Mar 2007	< MDA	0.02 ± 0.01	< MDA	0.03 ± 0.01	< MDA	0.13 ± 0.01	< MDA	0.06 ± 0.01
Apr 2007	< MDA	0.02 ± 0.01	< MDA	0.04 ± 0.01	0.02 ± 0.01	0.13 ± 0.01	< MDA	0.06 ± 0.01
May 2007	0.01 ± 0.01	0.03 ± 0.01	< MDA	0.04 ± 0.01	0.01 ± 0.01	0.12 ± 0.01	0.04 ± 0.02	0.05 ± 0.01
Jun 2007	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.09 ± 0.01	0.03 ± 0.01	0.09 ± 0.01	< MDA	0.05 ± 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 2006 to June 2007

WATER (Bq/L)

				Gamma-emitters				
Location	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
Mill Creek	13-11-06	0.02 ± 0.01	0.31 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
Bardens Creek	13-11-06	0.02 ± 0.01	0.12 ± 0.01	< MDA	< MDA	< MDA	< MDA	30 ± 10

SEDIMENT (Bq/g DW)

				Gamma-emitters				
Location	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Be-7**
Mill Creek	13-11-06	0.78 ± 0.13	0.17 ± 0.02	< MDA	< MDA	< MDA	0.066 ± 0.013	< MDA
Bardens Creek	13-11-06	0.68 ± 0.13	0.16 ± 0.02	< MDA	< MDA	< MDA	0.084 ± 0.010	0.007 ± 0.003

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 2006 to June 2007

	Tritium (Bq/L)		
Month	**Estuary: Station E5.9**	**Causeway**	**Heathcote Rd Bridge**
Jul 2006	< MDA	< MDA	< MDA
Sep 2006	< MDA	< MDA	< MDA
Sep 2006	< MDA	< MDA	< MDA
Oct 2006	< MDA	< MDA	< MDA
Nov 2006	< MDA	< MDA	< MDA
Dec 2006	< MDA	< MDA	< MDA
Jan 2007	< MDA	< MDA	< MDA
Mar 2007	< MDA	< MDA	< MDA
Mar 2007	< MDA	< MDA	< MDA
Apr 2007	< MDA	< MDA	< MDA
May 2007	< MDA	< MDA	< MDA
Jun 2007	< MDA	< MDA	< MDA

Notes:

• Figure 1 shows the sampling locations. Station E5.9 and the Causeway are downstream of ANSTO whilst the Heathcote Rd Bridge location is upstream.

• < MDA indicates that the result was below the minimum detectable activity, calculated with 95% confidence.

Table 22. FIELD PARAMETERS IN GROUNDWATER, LHSTC, August 2006

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	9.73	18.8	315	4.8	39
MW1D	21	9.79	18.9	428	4.0	344
MW2S	7	3.37	16.0	216	4.8	200
MW2D	12	3.95	17.4	344	4.4	293
MW3S	6	2.11	15.7	318	4.5	216
MW3D	10	5.90	17.6	446	5.8	39
MW4S	7	1.45	14.1	1216	6.6	-6
MW4D	12	4.89	16.7	303	5.3	116
MW5S	7	3.90	19.7	250	5.1	174
MW6S	8	4.29	16.9	263	6.2	145
MW6D	20	8.24	18.6	309	5.2	182
MW7S	-	-	-	-	-	-
MW7D	21	14.09	17.9	609	3.8	427
MW8S	-	-	-	-	-	-
MW8D	27	23.94	18.0	177	5.1	166
MW9S	18	11.89	18.5	346	4.2	383
MW9D	22	13.70	18.3	352	4.3	223
MW10S	8	4.08	17.6	312	5.0	224
MW11-2	20	13.02	19.8	390	4.9	227
MW13	23	16.19	20.2	369	4.0	284
MW14	24	13.90	19.4	498	5.4	111
MW15S	10	3.68	18.7	378	4.2	225
MW15D	12	3.76	18.9	522	5.9	190
BH3	23	16.38	21.2	403	5.4	113
BH3A	13	10.84	18.7	350	4.4	240
BH6	-	-	-	-	-	-
BH102	Hand Bailed	6.10	18.5	369	5.7	83
BH112	25	18.40	20.3	445	4.1	339

Notes:

• MW7S and MW8S were not sampled because these piezometers were dry, BH6 was damaged. BH102 was rehabilitated and these are the first measurements since December 2002.

• 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 2006

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	9.28	18.9	513	4.7	62
MW1D	23	9.44	18.7	349	4.2	249
MW2S	8	3.36	17.1	242	4.7	255
MW2D	23	6.93	17.7	292	4.9	254
MW3S	6	2.22	18.1	253	4.7	252
MW3D	22	3.56	18.6	335	5.6	134
MW4S	6	1.86	16.7	899	6.5	29
MW4D	23	4.75	17.5	270	5.6	92
MW5S	9	4.68	20.6	189	5.1	189
MW6S	10	4.20	18.7	183	5.9	139
MW6D	24	6.07	18.6	260	5.3	169
MW7S	-	-	-	-	-	-
MW7D	20	13.97	18.4	518	4.1	381
MW8S	-	-	-	-	-	-
MW8D	27	23.97	18.6	173	5.7	152
MW9S	16	11.61	19.4	303	4.4	274
MW9D	22	13.59	18.8	304	4.5	263
MW10S	10	3.67	19.2	270	5.1	188
MW11-2	20	12.73	21.0	327	4.6	251
MW13	24	16.10	19.9	319	4.2	252
MW14	25	13.91	20.0	396	5.1	191
MW15S	10	3.28	19.6	325	4.4	276
MW15D	12	4.93	19.1	334	5.4	192
BH3	20	16.15	19.8	359	5.6	82
BH3A	13	10.72	19.9	320	4.7	200
BH6	-	-	-	-	-	-
BH102	Hand Bailed	11.78	19.5	331	5.7	81
BH112	24	20.80	19.9	357	4.9	185

Notes:
• MW7S and MW8S were not sampled because these piezometers were dry, BH6 was damaged. BH102 was rehabilitated and these are the first measurements since December 2002.
• 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 2007

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	11	9.18	20.4	564	4.5	206
MW1D	15	9.36	20.0	373	4.2	295
MW2S	7	3.00	18.8	199	4.9	223
MW2D	10	4.31	18.3	316	4.6	235
MW3S	10	1.86	20.1	214	5.0	191
MW3D	10	5.20	18.7	350	5.6	168
MW4S	5	1.40	20.3	1130	6.6	18
MW4D	15	4.65	17.9	290	5.7	133
MW5S	6	2.42	22.8	183	5.4	238
MW6S	9	3.96	20.7	225	6.2	163
MW6D	20	5.73	19.9	269	5.3	190
MW7S	-	-	-	-	-	-
MW7D	20	13.99	19.2	569	4.1	297
MW8S	-	-	-	-	-	-
MW8D	28	24.01	18.9	183	6.4	131
MW9S	16	10.87	18.8	322	4.5	261
MW9D	20	13.52	18.7	325	4.6	287
MW10S	8	3.61	20.6	313	5.0	253
MW11-2	17	9.91	22.8	349	4.6	240
MW13	20	16.13	20.8	343	4.2	252
MW14	20	13.71	20.8	423	5.0	208
MW15S	10	3.27	19.6	363	4.4	267
MW15D	13	6.25	20.8	348	5.5	215
BH3	21	15.87	19.5	368	5.4	156
BH3A	13	10.50	19.5	353	4.7	212
BH6	-	-	-	-	-	-
BH102	Hand Bailed	8.27	19.7	336	5.5	125
BH112	21	19.25	19.4	387	4.8	221

Notes:
• MW7S and MW8S were not sampled because these piezometers were dry, BH6 was damaged. BH102 was rehabilitated and these are the first measurements since December 2002.
• 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 2007

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MW1S	10	8.56	19.7	366	5.0	30
MW1D	20	8.78	18.5	616	4.3	195
MW2S	6	2.53	18.0	564	4.4	192
MW2D	12	3.57	18.0	312	4.4	242
MW3S	5	1.91	18.7	283	4.4	215
MW3D	10	6.75	18.6	400	5.7	67
MW4S	5	1.30	17.0	1059	6.6	-28
MW4D	14	4.38	17.8	286	5.6	78
MW5S	7	3.95	21.9	190	5.0	197
MW6S	8	3.95	19.9	257	6.2	108
MW6D	14	5.68	19.3	271	5.2	163
MW7S	-	-	-	-	-	-
MW7D	20	13.79	18.0	557	3.9	401
MW8S	-	-	-	-	-	-
MW8D	28	24.05	17.6	166	5.4	171
MW9S	14	11.08	18.8	323	4.4	266
MW9D	21	12.97	18.4	322	4.4	263
MW10S	8	3.33	20.0	339	5.0	206
MW11-2	18	14.05	19.7	341	4.5	312
MW13	22	15.98	19.6	347	4.2	237
MW14	20	13.44	18.9	416	5.0	228
MW15S	8	3.00	19.8	355	4.3	217
MW15D	18	14.30	18.6	343	5.9	125
BH3	21	15.80	18.9	402	5.6	120
BH3A	12	10.38	19.4	329	4.5	242
BH6	-	-	-	-	-	-
BH102	Hand Bailed	10.90	19.3	339	5.5	106
BH112	24	19.47	18.6	389	4.4	261

Notes:

• MW7S and MW8S were not sampled because these piezometers were dry, BH6 was damaged. BH102 was rehabilitated and these are the first measurements since December 2002.

• Field parameters were measured five times (the average reading is given) using a flowcell and a calibrated water quality analyser probe.

• SWL - Standing water level.

• mBTOC - metres below the top of the piezometer casing.

• EC - electrical conductivity, measured in micro Siemens per centimetre.

• Eh - oxidation/reduction potential measured in millivolts.

Table 26. MAJOR IONS IN GROUNDWATER, LHSTC, August 2006

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	29.3	2.28	4.92	1.77	57	11	8
MW1D	40.2	0.26	5.51	0.23	84	10	<1
MW2S	28.9	0.34	3.84	5.29	52	48	<1
MW2D	35.9	1.28	9.10	4.92	70	8	36
MW3S	23.0	0.28	3.34	0.53	43	8	<1
MW3D	33.2	0.90	5.73	1.42	70	7	<1
MW4S	37.9	1.10	25.2	141	55	200	354
MW4D	28.9	0.59	5.58	1.44	61	8	3
MW5S	24.3	0.68	3.67	2.33	43	13	6
MW6S	10.6	0.89	2.71	24.0	17	23	51
MW6D	34.1	0.68	3.23	4.48	60	6	10
MW7S	-	-	-	-	-	-	-
MW7D	52.5	0.83	7.74	0.95	107	13	<1
MW8S	-	-	-	-	-	-	-
MW8D	16.6	0.61	1.75	4.93	32	5	6
MW9S	36.2	0.43	4.43	0.97	67	11	<1
MW9D	34.5	0.56	5.65	1.38	72	9	<1
MW10S	33.0	0.63	3.63	4.30	59	10	6
MW11-2	43.8	0.87	6.15	0.94	81	10	5
MW13	30.7	0.48	3.98	0.50	68	10	<1
MW14	47.2	1.40	7.97	2.27	90	20	18
MW15S	40.7	0.59	4.46	0.78	77	13	<1
MW15D	60.6	14.10	3.42	9.65	76	42	28
BH3	33.6	2.73	6.12	4.00	75	12	13
BH3A	35.6	0.37	3.58	1.10	63	20	<1
BH6	-	-	-	-	-	-	-
BH102	28.3	2.52	5.64	4.72	66	15	30
BH112	40.8	1.07	7.60	2.52	94	9	<1

Notes:
- Cation concentrations (Na, K, Mg, Ca) are for dissolved ions.
- Anion concentrations (Cl^-, SO_4^{2-}, HCO_3^-) include dissolved and undissolved ions.
- MW7S and MW8S were not sampled as these piezometers were dry.
- BH6 was not sampled because the piezometer was damaged.

Table 27. NUTRIENTS IN GROUNDWATER, LHSTC, August 2006

Piezometer	Ammonia: NH_3-N (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Oxidized Nitrogen: NO_x-N (mg/L)	Total Nitrogen (calculated max.) (mg/L)	Soluble Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)
MW1S	-	-	-	-	-	-
MW1D	< MDL	< MDL	0.16	0.26	< MDL	0.003
MW2S	< MDL	< MDL	0.01	0.11	< MDL	0.009
MW2D	< MDL	< MDL	< MDL	0.11	< MDL	0.004
MW3S	< MDL	< MDL	0.02	0.12	< MDL	0.024
MW3D	0.02	< MDL	< MDL	0.11	< MDL	0.010
MW4S	0.11	0.26	0.03	0.29	< MDL	0.013
MW4D	< MDL	< MDL	< MDL	0.11	< MDL	0.005
MW5S	< MDL	< MDL	0.14	0.24	< MDL	0.006
MW6S	< MDL	< MDL	0.23	0.33	0.002	0.021
MW6D	0.01	< MDL	0.01	0.11	< MDL	0.047
MW7S	-	-	-	-	-	-
MW7D	< MDL	< MDL	0.01	0.11	< MDL	0.008
MW8S	-	-	-	-	-	-
MW8D	0.03	< MDL	0.12	0.22	0.002	0.009
MW9S	< MDL	< MDL	0.10	0.20	< MDL	0.009
MW9D	< MDL	< MDL	0.03	0.13	< MDL	0.005
MW10S	< MDL	< MDL	0.50	0.60	< MDL	0.011
MW11-2	< MDL	0.15	0.18	0.33	< MDL	0.005
MW13	< MDL	< MDL	0.02	0.12	< MDL	0.004
MW14	0.01	< MDL	< MDL	0.11	< MDL	0.016
MW15S	< MDL	< MDL	0.06	0.16	< MDL	0.004
MW15D	0.01	1.03	1.41	2.44	0.013	0.107
BH3	0.01	0.12	< MDL	0.13	0.002	0.016
BH3A	0.01	< MDL	0.12	0.22	< MDL	0.008
BH6	-	-	-	-	-	-
BH102	0.13	< MDL	< MDL	0.11	< MDL	0.014
BH112	0.01	< MDL	< MDL	0.11	0.002	0.006

Notes:

- MW7S and MW8S were not sampled as these piezometers were dry, MW1s had insufficient sample to test and BH6 was damaged.
- 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 nitrogen; 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, including MDA values.

Table 28. HYDROCARBONS IN GROUNDWATER, LHSTC, 31 August 2006

	HYDROCARBONS (µg/L)								
	Monocyclic Aromatic Hydrocarbons					**Volatile TPH**	**Total Petroleum Hydrocarbons**		
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 for the analysis. The EQL for the monocyclic aromatic hydrocarbon analyses was 1µg/L, except for meta- and para-xylene with an EQL of 2 µg/L. The EQL for total petroleum hydrocarbons analyses was 50 µg/L, except for the C_{15}-C_{28} fraction with an EQL of 200 µg/L.

Table 29. RADIOACTIVITY IN GROUNDWATER, LHSTC, August 2006

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MW1S	30-08-06	0.04 ± 0.01	0.09 ± 0.01	< MDA	< MDA	< MDA	< MDA	17 ± 1
MW1D	1-09-06	0.14 ± 0.01	0.15 ± 0.01	< MDA	< MDA	< MDA	< MDA	13 ± 1
MW2S	30-08-06	0.02 ± 0.01	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	17 ± 1
MW2D	30-08-06	0.04 ± 0.01	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW3S	30-08-06	0.06 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	40 ± 1
MW3D	30-08-06	0.03 ± 0.01	0.04 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW4S	30-08-06	< MDA	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	4 ± 1
MW4D	30-08-06	0.04 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW5S	31-08-06	0.05 ± 0.01	0.04 ± 0.01	< MDA	< MDA	< MDA	< MDA	9 ± 1
MW6S	31-08-06	0.01 ± 0.01	0.12 ± 0.01	< MDA	< MDA	< MDA	< MDA	68 ± 1
MW6D	1-09-06	< MDA	0.01 ± 0.01	< MDA	< MDA	< MDA	< MDA	44 ± 1
MW7S	-	-	-	-	-	-	-	-
MW7D	1-09-06	0.22 ± 0.02	0.15 ± 0.01	< MDA	< MDA	< MDA	0.40 ± 0.13	< MDA
MW8S	-	-	-	-	-	-	-	-
MW8D	30-08-06	0.02 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW9S	1-09-06	0.08 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	0.45 ± 0.12	10 ± 1
MW9D	1-09-06	0.18 ± 0.01	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW10S	30-08-06	0.10 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	12 ± 1
MW11-2	1-09-06	0.06 ± 0.01	0.04 ± 0.01	< MDA	< MDA	< MDA	0.59 ± 0.12	36 ± 1
MW13	1-09-06	0.19 ± 0.01	0.12 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MW14*	1-09-06	0.06 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	18 ± 1
MW15S	30-08-06	0.21 ± 0.01	0.12 ± 0.01	< MDA	< MDA	< MDA	< MDA	5 ± 1
MW15D	5-09-06	0.16 ± 0.02	0.46 ± 0.01	< MDA	< MDA	< MDA	0.80 ± 0.14	15 ± 1
BH3	1-09-06	0.08 ± 0.01	0.09 ± 0.01	< MDA	< MDA	< MDA	< MDA	5 ± 1
BH3A	30-08-06	0.06 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	0.39 ± 0.13	19 ± 1
BH6	-	-	-	-	-	-	-	-
BH102	5-09-06	< MDA	0.06 ± 0.01	< MDA	< MDA	< MDA	0.55 ± 0.13	14 ± 1
BH112	5-09-06	0.07 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA

Notes:

• Gross beta activity includes any contribution from natural K-40. Tritium analyses were performed in ANSTO's low-level facility for greater sensitivity (MDA was 3 Bq/L).

• MW7S and MW8S were not sampled as these piezometers were dry, whilst BH6 was damaged.

• MW14 gross alpha/beta results from field duplicate sample.

• < 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 2006

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MB11	7	4.72	18.2	1541	5.7	40
MB12	5	3.22	17.6	385	5.7	180
MB13	5	1.76	16.9	260	5.4	170
MB14	6	3.70	17.6	2621	5.9	30
MB15	6	4.40	18.1	1008	5.7	80
MB16	5	2.00	17.5	291	5.7	100
MB17	5	1.88	17.1	285	5.7	100
MB18	6	4.83	19.2	1367	6.4	40
MB19	6	4.19	16.8	3062	6.2	130
MB20	5	2.36	14.8	749	6.3	90
MB21	4	1.87	15.7	616	6.4	130
BH10	4	1.88	16.4	411	6.0	-10
BHF	6	2.54	17.7	3467	5.4	130
OS2	-	-	-	-	-	-
OS3	7	1.35	17.3	200	5.5	140
P1S	5	3.35	17.9	7492	3.9	320
P1D	15	3.20	18.5	15000	5.5	70
P2D	20	13.78	18.9	4573	5.7	120
CW	9	4.69	19.0	2356	5.7	90

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, May 2007

Piezometer	Sampling Depth (mBTOC)	SWL (mBTOC)	Temperature (°C)	EC (µS/cm)	pH	Eh (mV)
MB11	7	4.67	20.3	3761	5.3	100
MB12	5	2.80	20.2	224	5.7	150
MB13	5	1.20	20.0	179	5.4	190
MB14	6	3.70	19.1	3564	5.9	-20
MB15	6	4.54	19.8	2188	5.4	100
MB16	6	2.55	19.7	310	5.6	80
MB17	4	1.93	20.5	299	5.5	140
MB18	6	4.18	20.0	2255	5.9	70
MB19	6	4.32	17.8	4764	6.1	10
MB20	6	3.04	16.8	1000	6.6	-90
MB21	4	3.36	18.1	527	6.4	50
BH10	4	2.32	19.8	1884	5.7	20
BHF	7	2.80	18.5	3987	5.5	130
OS2	1	0.96	19.6	212	6.5	60
OS3	3	1.57	20.3	176	5.4	180
P1S	6	3.29	20.2	1597	4.7	230
P1D	15	4.39	19.0	15500	5.2	120
P2D	22	14.23	18.4	5314	5.8	70
CW	10	4.90	19.3	2615	5.7	120

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.

Table 32. RADIOACTIVITY IN GROUNDWATER, LFBG, October 2006

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MB11	19-10-06	< MDA	0.06 ± 0.02	< MDA	< MDA	< MDA	< MDA	< MDA
MB12	19-10-06	< MDA	0.01 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB13	19-10-06	0.14 ± 0.02	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	930 ± 30
MB14	19-10-06	< MDA	0.17 ± 0.03	< MDA	< MDA	< MDA	0.34 ± 0.13	240 ± 20
MB15	19-10-06	< MDA	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	160 ± 10
MB16	20-10-06	0.18 ± 0.02	0.38 ± 0.01	< MDA	< MDA	< MDA	< MDA	3770 ± 60
MB17	19-10-06	0.14 ± 0.02	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	410 ± 20
MB18	19-10-06	< MDA	0.10 ± 0.02	< MDA	< MDA	< MDA	< MDA	570 ± 20
MB19	19-10-06	< MDA	0.30 ± 0.04	< MDA	< MDA	< MDA	0.92 ± 0.13	280 ± 20
MB20	19-10-06	< MDA	0.19 ± 0.01	< MDA	< MDA	< MDA	0.75 ± 0.14	10 ± 10
MB21	19-10-06	0.04 ± 0.02	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	20 ± 10
BH10	19-10-06	0.08 ± 0.02	0.09 ± 0.01	< MDA	< MDA	< MDA	0.32 ± 0.13	340 ± 20
BHF	19-10-06	0.18 ± 0.08	0.36 ± 0.04	< MDA	< MDA	< MDA	0.37 ± 0.15	5480 ± 70
OS2	-	-	-	-	-	-	-	-
OS3	19-10-06	0.11 ± 0.02	0.19 ± 0.01	< MDA	< MDA	< MDA	0.46 ± 0.12	450 ± 20
CW	19-10-06	0.20 ± 0.05	0.34 ± 0.04	< MDA	< MDA	< MDA	< MDA	730 ± 30
P1S	19-10-06	1.03 ± 0.19	0.64 ± 0.09	< MDA	< MDA	< MDA	0.47 ± 0.15	20 ± 10
P1D	20-10-06	0.46 ± 0.22	0.41 ± 0.20	< MDA	< MDA	< MDA	< MDA	130 ± 10
P2D	20-10-06	< MDA	1.05 ± 0.08	< MDA	< MDA	< MDA	0.57 ± 0.16	100 ± 10

Notes:

- See Figure 4 for the location of the sampling piezometers. OS2 was not sampled as the 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 33. RADIOACTIVITY IN GROUNDWATER, LFBG, May 2007

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
MB11	4-05-07	0.15 ± 0.07	0.16 ± 0.04	< MDA	< MDA	< MDA	0.33 ± 0.13	< MDA
MB12	7-05-07	< MDA	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB13	7-05-07	0.05 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	250 ± 10
MB14	4-05-07	< MDA	0.10 ± 0.04	< MDA	< MDA	< MDA	< MDA	290 ± 10
MB15	4-05-07	< MDA	0.11 ± 0.02	< MDA	< MDA	< MDA	0.31 ± 0.18	310 ± 10
MB16	7-05-07	0.26 ± 0.02	0.67 ± 0.02	< MDA	< MDA	0.051 ± 0.015	< MDA	4480 ± 50
MB17	4-05-07	0.09 ± 0.02	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	200 ± 10
MB18	4-05-07	< MDA	0.13 ± 0.03	< MDA	< MDA	< MDA	< MDA	800 ± 20
MB19	7-05-07	< MDA	0.38 ± 0.06	< MDA	< MDA	< MDA	0.71 ± 0.18	330 ± 10
MB20	7-05-07	0.09 ± 0.03	0.27 ± 0.02	< MDA	< MDA	< MDA	0.33 ± 0.15	20 ± 10
MB21	16-05-07	0.07 ± 0.02	0.08 ± 0.01	< MDA	< MDA	< MDA	< MDA	20 ± 10
BH10	4-05-07	< MDA	0.14 ± 0.02	< MDA	< MDA	< MDA	< MDA	6920 ± 60
BHF	4-05-07	< MDA	0.19 ± 0.05	< MDA	< MDA	< MDA	0.45 ± 0.17	5830 ± 60
OS2	7-05-07	0.12 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	< MDA	70 ± 10
OS3	4-05-07	0.06 ± 0.01	0.09 ± 0.01	< MDA	< MDA	< MDA	< MDA	260 ± 10
CW	4-05-07	< MDA	0.09 ± 0.03	< MDA	< MDA	< MDA	0.31 ± 0.13	660 ± 20
P1S	7-05-07	0.11 ± 0.05	0.16 ± 0.03	< MDA	< MDA	< MDA	< MDA	< MDA
P1D	7-05-07	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	140 ± 10
P2D	7-05-07	0.22 ± 0.1	0.33 ± 0.06	< MDA	< MDA	< MDA	0.57 ± 0.15	120 ± 10

Notes:

- See Figure 4 for the location of the sampling piezometers.
- 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 2006 to June 2007

Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)	Date	**Tritium** (Bq/L)
4-7-06	< MDA	7-11-06	< MDA	13-3-07	< MDA
11-7-06	20 ± 10	14-11-06	< MDA	20-3-07	< MDA
18-7-06	100 ± 10	21-11-06	< MDA	27-3-07	< MDA
25-7-06	< MDA	28-11-06	-	3-4-07	290 ± 10
1-8-06	250 ± 20	5-12-06	< MDA	10-4-07	10 ± 10
8-8-06	110 ± 10	12-12-06	-	17-4-07	< MDA
15-8-06	-	19-12-06	< MDA	24-4-07	< MDA
22-8-06	-	28-12-06	< MDA	1-5-07	< MDA
29-8-06	30 ± 10	2-1-07	< MDA	8-5-07	-
5-9-06	< MDA	9-1-07	< MDA	15-5-07	< MDA
12-9-06	60 ± 10	16-1-07	-	22-5-07	50 ± 10
19-9-06	< MDA	23-1-07	-	29-5-07	-
26-9-06	-	30-1-07	70 ± 10	5-6-07	< MDA
3-10-06	-	6-2-07	50 ± 10	12-6-07	< MDA
10-10-06	< MDA	13-2-07	-	19-6-07	< MDA
17-10-06	< MDA	20-2-07	< MDA	26-6-07	30 ± 10
24-10-06	< MDA	27-2-07	< MDA		
31-10-06	40 ± 10	6-3-07	< MDA		

Notes:

• Refer to Figure 2 for the location of this sampling point.

• Dashes (-) indicate insufficient sample for analysis.

• < 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 2006 to June 2007

		RADIOACTIVITY (Bq/g DW)						
				Gamma-emitters				
Bund Location	**Date**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Be-7**	**Cs-137**	**Co-60**	**K-40**
Bund A	2-4-07	0.32 ± 0.11	0.34 ± 0.02	< MDA	0.047 ± 0.005	0.001 ± 0.001	< MDA	0.320 ± 0.025
Bund B	2-4-07	0.27 ± 0.11	0.34 ± 0.02	< MDA	0.033 ± 0.007	< MDA	0.003 ± 0.001	0.199 ± 0.021
Bund C	2-4-07	0.31 ± 0.11	0.21 ± 0.02	< MDA	0.053 ± 0.005	0.021 ± 0.002	< MDA	0.105 ± 0.011

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 2007

Date of Survey	**Location**	**Dose-rate** (μSv/hour)
26-5-07 to 13-6-07	Background reading (outside LFBG gate)	0.07 – 0.15
	Trenches 1-51	0.08 – 0.15
	Trenches 52-77	0.08 – 0.20
	Trenches S1 and S2	0.09 – 0.15

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

Table 37. RADIOACTIVITY IN FISH, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2006 to June 2007

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	21-09-06	< MDA	< MDA	< MDA	< MDA	< MDA	168 ± 12
The Royal National Park Reference Site	22-09-06	< MDA	< MDA	< MDA	< MDA	< MDA	138 ± 11

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.
- Radioactivity is in units of becquerels per kilogram of fresh (wet) sample weight.

MDA
values for various radionuclides and environmental media are listed in Table 1.

Table 38. RADIOACTIVITY IN ALGAE, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2006 to June 2007

Location	Date Sampled	Gamma-emitters in Algae (Bq/kg FW)					
		Am-241	**Be-7**	**I-131**	**Cs-137**	**Co-60**	**K-40**
Potter Point	21-09-06	< MDA	< MDA	24 ± 1.7	< MDA	< MDA	178 ± 13
Ocean Outfall	18-04-07	< MDA	< MDA	1.9 ± 0.2	< MDA	< MDA	158 ± 12
The Royal National Park Reference Site	22-09-06	< MDA	< MDA	< MDA	< MDA	< MDA	272 ± 20

Table 39. RADIOACTIVITY IN BARNACLES, POTTER POINT AND THE ROYAL NATIONAL PARK, July 2006 to June 2007

Location	Date Sampled	Gamma-emitters in Barnacles (Bq/kg FW)					
		Am-241	**Be-7**	**I-131**	**Cs-137**	**Co-60**	**K-40**
Potter Point	21-09-06	< MDA	< MDA	2.76 ± 0.54	< MDA	< MDA	35 ± 6
Ocean Outfall	21-09-06	< MDA	< MDA	2.56 ± 0.61	< MDA	< MDA	28 ± 5
	18-04-07	< MDA	< MDA	< MDA	< MDA	< MDA	26 ± 6
The Royal National Park Reference Site	22-09-06	< MDA	< MDA	< MDA	< MDA	< MDA	36 ± 5

Table 40. RAINFALL AND POTENTIAL EVAPORATION at the LHSTC, July 1997 to June 2007

		1997-98	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07
Jul	R Total	48.2	86.8	163.3	31.4	109.2	26.4	35.5	37.4	53.2	61.3
	R Days	6	12	12	9	14	2	8	8	6	14
	E Total	52.7	50.1	47.4	52.1	44.3	57.0	49.7	52.8	55.6	44.0
	E Max	2.6	3.8	4.1	3.8	2.3	3.3	3.8	4.2	3.9	4.1
Aug	R Total	18.7	316.3	31.2	19.2	49.4	14.3	30.0	68.3	4.0	41.8
	R Days	5	15	8	11	6	7	7	5	4	6
	E Total	82.4	51.0	65.6	59.6	75.4	73.0	75.4	74.9	77.2	70.9
	E Max	6.9	3.3	3.2	4.3	5.5	5.9	5.8	4.4	4.4	4.1
Sep	R Total	105.6	37.7	20.7	37.2	18.2	7.0	4.4	35.9	41.0	161.0
	R Days	15	9	5	6	10	4	2	8	9	7
	E Total	78.7	82.5	82.5	120.6	82.9	118.4	113.8	87.4	95.8	90.1
	E Max	6.0	5.5	4.4	7.5	5.0	8.5	6.8	5.8	6.0	7.1
Oct	R Total	60.2	26.7	211.0	55.1	39.8	1.4	62.4	219.1	76.2	6.1
	R Days	8	8	13	9	8	4	13	10	11	5
	E Total	136.9	121.1	104.1	117.2	128.9	149.8	102.5	119.0	120.9	126.8
	E Max	7.6	6.8	6.3	6.8	7.6	8.5	6.6	8.4	7.8	11.0
Nov	R Total	21.7	110.3	32.7	150.3	57.1	14.5	50.0	71.2	139.2	38.2
	R Days	9	15	9	17	11	6	10	14	14.0	12
	E Total	150.2	113.6	112.1	100.5	129.6	157.1	133.2	130.9	126.0	137.4
	E Max	7.5	7.2	5.4	6.0	9.4	10.3	7.0	10.8	7.1	8.0
Dec	R Total	27.3	37.8	112.8	46.4	15.9	59.8	45.9	67.0	24.3	89.6
	R Days	7	9	13	11	8	9	8	10	4	11
	E Total	162.9	148.9	140.4	170.5	150.5	177.2	142.9	156.7	189.7	138.5
	E Max	11.2	9.6	6.8	10.1	10.8	12.7	9.0	14.2	12.0	7.2
Jan	R Total	75.0	111.9	29.6	191.0	55.2	22.5	38.9	41.4	82.9	92.0
	R Days	11	14	12	9	10	6	8	13	13	5
	E Total	163.9	165.4	138.0	151.3	176.6	173.2	163.9	149.5	127.8	189.1
	E Max	10.1	10.0	8.0	10.1	13.4	11.0	9.2	8.5	7.2	16.0
Feb	R Total	56.0	196.5	11.0	110.6	295.1	89.1	92.5	81.7	96.2	148.4
	R Days	8	14	9	11	18	12	9	6	5	11
	E Total	154.7	113.1	149.6	108.4	103.4	118.2	138.6	133.1	141.2	119.2
	E Max	10.0	6.6	9.3	6.4	8.7	8.0	7.8	8.3	10.1	9.0
Mar	R Total	15.5	40.2	217.6	122.0	143.3	89.0	52.8	93.7	34.7	74.4
	R Days	8	10	14	20	15	8	5	10	8	14
	E Total	127.8	94.3	94.6	110.1	90.2	118.1	109.3	112.2	104.8	100.6
	E Max	7.7	5.1	5.1	7.9	5.5	8.5	7.5	6.7	7.7	11.5
Apr	R Total	161.3	94.3	31.9	70.2	15.4	147.2	107.4	20.2	2.4	107.3
	R Days	10	17	12	7	6	16	7	6	2	12
	E Total	94.9	72.0	65.3	78.0	68.8	69.0	73.4	80.3	106.1	81.3
	E Max	8.1	4.0	4.0	5.0	3.5	4.9	5.6	8.1	7.7	7.5
May	R Total	203.7	48.7	34.5	105.3	50.6	358.8	9.2	27.1	17.6	22.0
	R Days	13	10	9	10	11	17	1	5	6	4
	E Total	61.8	44.7	54.9	58.1	61.6	71.7	69.8	57.0	68.9	68.4
	E Max	4.9	3.4	3.4	4.5	3.7	6.8	3.8	4.0	5.1	9.4
Jun	R Total	80.2	66.6	34.2	9.3	18.1	58.0	5.4	78.3	92.3	341.3
	R Days	11	14	9	6	5	7	3	10	11	16
	E Total	45.5	45.9	45.7	44.4	49.1	49.3	58.4	48.0	41.0	89.9
	E Max	4.1	2.8	4.5	2.4	3.1	3.5	3.7	5.2	3.0	9.2
Annual	**R Total**	**873.4**	**1173.8**	**930.5**	**948.0**	**867.3**	**888.0**	**534.4**	**841.3**	**664.0**	**1183.4**
	R Days	**111**	**147**	**125**	**126**	**122**	**98**	**81**	**105**	**93**	**117**
	E Total	**1312.4**	**1102.6**	**1100.2**	**1170.8**	**1161.3**	**1332.0**	**1230.9**	**1201.8**	**1255.0**	**1256.2**

Notes:

• Rainfall (R) and potential evaporation (E) are measured in millimetres. E Max is the 24-hour maximum potential evaporation.

Table 41. ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, July 2006 to June 2007

Receptor Location	2006-07 Estimated Effective Dose (mSv/year)
Nearest Resident	0.0005
LHSTC Library	0.0009
LHSTC Building 9	0.0017
LHSTC Main gate	0.0005
Stevens Hall Motel	0.0016
LH Waste Management Centre	0.0006
BMX track	0.0005
Woronora Valley	0.0002
At 1.6 kilometre radius from HIFAR	
NORTH	0.0020
NNE	0.0010
NE	0.0010
ENE	0.0008
EAST	0.0006
ESE	0.0005
SE	0.0007
SSE	0.0008
SOUTH	0.0006
SSW	0.0005
SW	0.0008
WSW	0.0010
WEST	0.0004
WNW	0.0004
NW	0.0007
NNW	0.0019
At 4.8 kilometre radius from HIFAR	
NORTH	0.0004
NNE	0.0002
NE	0.0002
ENE	0.0002
EAST	0.0001
ESE	0.0001
SE	0.0001
SSE	0.0002
SOUTH	0.0001
SSW	0.0001
SW	0.0002
WSW	0.0002
WEST	0.0001
WNW	0.0001
NW	0.0001
NNW	0.0004

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)