Environmental and Effluent Monitoring at ANSTO Sites

2002-2003

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Photography	Mark Alcorn

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INIS Descriptors

The following descriptors have been selected from the INIS Thesaurus to describe the subject matter of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS Manual for Indexing) and IAEA-INIS-13 (INIS Thesaurus) published in Vienna by the International Atomic Energy Agency. Airborne Particulates, Algae, Alpha Decay Radioisotopes, Alpha Particles, ANSTO, Argon-41, Australia, Cesium-137, Cobalt-60, Contamination, Cyclotrons, Dose-Constraint, Dose Limits, Drinking Water, Environmental Exposure Pathway, Environmental Impacts, Fishes, Fission Product Release, Gaseous Wastes, Ground Water, Iodine-123, Iodine-131, Iodine-132, Iodine-133, Liquid Wastes, Noble Gases, Public Health, Radiation Doses, Radiation Monitoring, Radioactive Effluents, Sampling, Seawater, Sediments, Soils, Stack Disposal, Standards, Strontium-90, Surface Waters, Thermoluminescent Dosimetry, Tritium, Uranium-238, Water Quality, Wind.

Environmental and Effluent Monitoring at ANSTO Sites, 2002–2003

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Abstract

This report presents the results of environmental and effluent monitoring at the Lucas Heights Science and Technology Centre (LHSTC) and the National Medical Cyclotron (NMC) from January 2002 to June 2003. Potential effective dose rates to the general public from airborne discharges from the LHSTC site were less than 0.01 mSv/year, well below the 1 mSv/year dose rate limit for long term exposure that is recommended by the Australian National Occupational Health and Safety Commission. The effective dose rates to hypothetical individuals potentially exposed to radiation in routine liquid effluent discharges from the LHSTC were recently calculated to be less than 0.001 mSv/year. This is much less than dose rates estimated for members of public potentially exposed to airborne emissions. The levels of tritium detected in groundwater and stormwater at the LHSTC were less than the Australian drinking water guidelines. The airborne and liquid effluent emissions from the NMC were below the ARPANSA-approved notification levels and NSW EPA limits, respectively. ANSTO's routine operations at the LHSTC and the NMC make only a very small addition to the natural background radiation dose experienced by members of the Australian public.

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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
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
DDT	Dichloro-diphenyl-trichloroethane
EPA	Environment Protection Authority
HIFAR	High Flux Australian Reactor
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INIS	International Nuclear Information System
IQR	Interquartile range (range from 25^{th} to 75^{th} percentile)
ISO	International Organisation for Standardisation
LFBG	Little Forest Burial Ground
LHSTC	Lucas Heights Science and Technology Centre
MDA	Minimum Detectable Activity
MDP	Main Disposal Pipeline
LFBG	Little Forest Burial Ground
ML	Mega Litre
NHMRC	National Health and Medical Research Council
NMC	National Medical Cyclotron
NOHSC	National Occupational Health and Safety Commission
NSW	New South Wales
PM	Particulate Matter
RRR	Replacement Research Reactor
SPCC	The former State Pollution Control Commission (now the NSW Environment Protection Agency)
STP	Sewage Treatment Plant
TLD	Thermo-Luminescent Dosimeters
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) operates several national facilities, including Australia's only research reactor, HIFAR (the High Flux Australian Reactor), produces radioisotopes and radiopharmaceuticals and carries out research in nuclear science and technology. ANSTO is an agency of the Commonwealth Government of Australia. Most of the ANSTO facilities are located at the Lucas Heights Science and Technology Centre (LHSTC), some 40 km south west of the Sydney city centre. The LHSTC occupies 70 hectares and is surrounded by a 1.6 km buffer zone (see **Figure 1**, section 5). ANSTO also operates the National Medical Cyclotron (NMC), located in the grounds of the Royal Prince Alfred Hospital in Camperdown, Sydney, to produce certain short-lived radioisotopes for medical investigations. ANSTO activities are regulated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) under the *Australian Radiation Protection and Nuclear Safety Act (1998)*.

ANSTO is committed to undertaking its activities in a manner that protects human health and the environment and is consistent with national and international standards. This commitment is described in the ANSTO Health, Safety and Environment Policy. ANSTO provides verifiable evidence of the fulfilment of the environmental commitment through a program of monitoring and audit, and publication of these results in its annual Environmental and Effluent Monitoring reports. The monitoring program is also designed to detect and quantify any accidental releases of radioactive materials, should they occur.

This report summarises the results from the environmental and effluent surveys carried out at the LHSTC and the NMC from January 2002 to June 2003, and assesses the potential effects of radioactive discharges, particularly as they might affect local residents. The eighteen-month period covered by this report represents a transition from calender to fiscal year-end reporting. Data published in previous years are publicly available either from the Sutherland Shire Central Library or by request from ANSTO's Communications Manager.

2. ANSTO Facilities

2.1 HIFAR

The HIFAR research reactor produces radioisotopes for medical and industrial use and employs neutrons for research applications. HIFAR is authorised by ARPANSA to release low levels of radionuclides to the atmosphere via stacks. The main radionuclides are tritium and argon-41 (a noble gas). There are small quantities of iodine-131, arsenic-76, bromine-82, mercury-197 and mercury-203. The tritium occurs as tritiated water vapour that can exchange with rainwater, resulting in the presence of tritium at very low levels in stormwater. Low level liquid waste is treated on-site by ANSTO Waste Operations and Technology Development and discharged via the Sydney Water Corporation sewer (see below).

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. ARPANSA regulates the atmospheric releases of radionuclides including iodine-131, xenon-133, xenon-135 and krypton-85 from stacks in the radioisotope and radiopharmaceutical production area at the LHSTC. Low level liquid waste is treated on-site by ANSTO Waste Operations and Technology Development and discharged via the Sydney Water Corporation sewer (see below).

2.3 NATIONAL MEDICAL CYCLOTRON

ANSTO also manufactures radiopharmaceuticals at the NMC (Camperdown, Sydney). Airborne emissions from the NMC are regulated by ARPANSA under the ANSTO Airborne Radioactivity Discharge Authorisation. The liquid waste discharges from the NMC to the sewer are covered by a trade wastewater agreement with Sydney Water Corporation that incorporates limits set by the New South Wales Environment Protection Authority (NSWEPA) for specific radionuclides in the discharges. The radiopharmaceutical products made at the NMC are short-lived, with half-lives ranging from minutes to hours. Consequently, a system of delayed liquid effluent releases allows

radionuclides to decay significantly prior to being released to the sewer. The radionuclides produced by the NMC include thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65 and iodine-123. Atmospheric releases of radionuclides include iodine-123, fluorine-18, thallium-201 and gallium-67, all of which are very short-lived.

2.4 WASTE OPERATIONS AND TECHNOLOGY DEVELOPMENT

Waste Operations and Technology Development, within the Nuclear Technology Division of ANSTO, is responsible for radioactive waste treatment at the LHSTC. All liquid effluent generated on-site is analysed and treated if necessary before authorised discharge to the sewer. The total annual discharge is typically 100 ML/year - 50 ML of sewage, 45 ML of non-active trade waste effluent and 5 ML of low level active wastewater from laboratories where radioactive materials are routinely handled.

The allowable levels of radioactivity in the effluent released to the sewer are governed by a trade wastewater agreement and are independently checked for compliance by Sydney Water Corporation and ARPANSA (ANSTO and Sydney Water Corporation, 2002a). The effluent contains low levels of radionuclides, mainly tritium, and also cobalt-60, chromium-51, cesium-137, strontium-90, radium-226, and occasionally iodine-131 and cesium-134. The sewage, 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.

The acceptable limits for eleven radioisotopes (tritium, cobalt-60, strontium-89, strontium-90, iodine-131, cesium-134, cesium-137, radium-226, radium-228, uranium-238 and plutonium-239) are based on the 1993 World Health Organisation "Guidelines for Drinking Water Quality" (WHO 1993), as specified in the Sydney Water Corporation trade wastewater agreement with ANSTO. Radioisotopes, which decay by alpha or beta emissions and do not belong to the above set of eleven, are classified as "unspecified" radioisotopes - these are considered to be present as the most restrictive isotopes for each decay type, *ie* radium-226 (alpha decay) and strontium-90 (beta decay).

Typical monthly effluent discharges for gross-alpha and gross-beta emitting radionuclides are < 0.8 Bq/L and 7.0 Bq/L, respectively – significantly lower than the limits set by Sydney Water Corporation. The major contributing radioisotopes to the gross-alpha activities are uranium-238, uranium-234, thorium-230, thorium-228, polonium-210 and radium-226 (all naturally-occurring). The major contributors to the gross-beta activities are cobalt-60, chromium-51, cesium-137 and iodine-131. As specified in the Sydney Water Corporation trade wastewater agreement with ANSTO the wastewaters are analysed for certain non-radionuclide components (pH, ammonia, biological oxygen demand, grease, suspended solids, total dissolved solids and zinc) and are further processed if necessary to meet the acceptance criteria before discharge to the sewer.

2.5 LITTLE FOREST BURIAL GROUND

Between 1960 and 1968 the Australian Atomic Energy Commission (AAEC, the precursor to ANSTO) used a small area locally known as Little Forest (see **Figure 1**, section 5) for the disposal, by burial, of solid waste with low levels of radioactivity and beryllium oxide (non-radioactive) that was generated predominantly at the LHSTC. Regular surveillance and monitoring of the Little Forest Burial Ground (LFBG) is designed to detect any off-site transport of radionuclides by windborne transport of soil particles or surface or ground waters.

3. Regulatory and Legal Framework

The Australian Nuclear Science and Technology Organisation (ANSTO) was formed in 1987 and is a Commonwealth Government Statutory Authority. It superseded the AAEC, which originated 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)	ARPANSA	Regulates facility licence conditions at all ANSTO sites; specifies exemption levels for radioactive materials.
Airborne Radioactive Discharge Authorisation (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 LHSTC and NMC (ARPANSA 2001).
Trade Wastewater Agreement (No. 4423, 2001/2002) (ANSTO and Sydney Water Corporation 2002a)	Sydney Water Corporation	Authorisation to discharge treated liquid effluent from LHSTC to the sewer.
Trade Wastewater Agreement (No. 13966, 2001/2002) (ANSTO and Sydney Water Corporation 2002b)	Sydney Water Corporation	Authorisation to discharge treated liquid effluent from the NMC to the sewer.
NSW Protection of the Environment Operations Act (1997)	NSW EPA	Provides radiological limits for Class C stormwater/surface water drainage.
Crown Lands Act (1989)	Commonwealth Government	Environmental protection principles are observed in relation to the management and administration of ANSTO sites.
Environment Protection and Biodiversity Conservation Act (1999)	Commonwealth Government	Environmental assessment of projects having national importance (Replacement Research Reactor).
National Biodiversity Strategy (1996)	Commonwealth Government	Integration of biodiversity conservation with natural resource management.
Native Vegetation Conservation Act (1997)	Commonwealth Government	Conservation and management of native vegetation.
Rural Fires Act (1997)	State 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 notification levels for discharges. Annual notification levels for the LHSTC and NMC are such that the effective dose rate to the public would not exceed the ALARA objective of 0.02 mSv/year, even if all releases from a site were at the notification level. The ALARA objective is 2% of the 1 mSv/year limit for annual effective dose to members of the public recommended by the National Occupational Health and Safety Commission, NOHSC, (ARPANSA 2002). Notification levels are applied to individual discharge points on the basis of radionuclide type. Four-weekly, quarterly and annual notification levels are effectively trend indicators that, if reached, trigger further investigation of airborne emissions from a particular stack. Notification levels are considered in more detail in the Licence Conditions Handbook issued by ARPANSA (31 May 2001).

Routine discharges of treated, low-level liquid effluent from the LHSTC and NMC are made to the sewer under the terms of trade wastewater agreements, negotiated with Sydney Water Corporation. 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. Liquid effluent discharges from the NMC are subject to limits set for specific radionuclides stipulated in the trade wastewater agreement with Sydney Water Corporation.

Stormwater from the LHSTC flows into small local streams that are classified as Class C surface waters under regulations associated with the *NSW Protection of the Environment Operations Act (1997)*. The act sets out relevant limits for gross alpha and beta radioactivity in these waters. The Australian Drinking Water Guidelines (ADWG; NHMRC and ARMCANZ, 1996) are used to provide context for the presence of tritium and some other radionuclides in surface and groundwaters, although there are no legal or other requirements to meet these levels.

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 (~1.5 mSv/year; Webb *et al*. 1999) consists of ~0.9 mSv/year from external radiation sources (such as terrestrial and cosmic radiation) and ~0.6 mSv/year from internal radiation sources (such as potassium-40 and radon). Natural background radiation varies from place to place on the earth (*eg* with rock type and altitude) and is affected by lifestyle (*eg* choice of building materials, ventilation of homes, frequency of flying). The radiation dose from natural background is estimated at ~3.5 mSv/year, averaged worldwide, but can be greater than 50 mSv/year (see http://www.arpansa.gov.au/baseline.htm).

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 rate is 1 mSv/year (ARPANSA 2002). ANSTO has a site dose rate constraint of 0.3 mSv/year (LHSTC) and a much lower ALARA objective for dose rate 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 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;
- wash-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 Corporation sewage treatment system and into the sea, leading to exposure of workers at the sewage treatment plant, uptake by fish and accidental ingestion of seawater by swimmers; and
- contamination of groundwater or soil used for drinking or food production leading to exposure by ingestion/inhalation.

Impact assessments due to any activity associated with a nuclear facility are estimated as radiation doses to members of the public. A critical group is defined as a reasonably homogeneous group of members of the public typical of individuals who are likely to receive the highest radiation dose via a given exposure pathway from a given source (IAEA 1996). The size of a critical group will usually be up to a few tens of persons but may consist of a single hypothetical individual (ICRP 1984). In order to satisfy the homogeneity criterion the ratio of the maximum to minimum dose values should not exceed an order of magnitude across the critical group.

A recent study, based on previous effluent and environmental monitoring, identified critical groups for assessing the potential impact of ANSTO's releases by (a) reviewing internationally recognised principles, (b) convening expert focus groups to consider possible airborne and aqueous effluent pathways and exposure and (c) estimating realistic doses from airborne and liquid discharges. Hypothetical individuals (excluding ANSTO employees) were identified for routine airborne discharges to the environment from the LHSTC. These included adults living at the Steven's Hall Motel (near ANSTO's front gate) and adults living in Engadine or Barden Ridge (near the boundary of ANSTO's 1.6 km radius buffer zone) who also work at the Lucas Heights Waste Management Centre (located adjacent to the LHSTC) and use the nearby bike track for recreation (within ANSTO's buffer zone) (**Figure 1**). Children and infants were also considered - children living in Engadine or Barden Ridge who attend Engadine Primary School or Lucas Heights Community School and also use the bike track for recreation, and infants living in Engadine or Barden Ridge.

The transport and dose-estimation model PC-CREAM was used to estimate the doses for these individuals. These calculations showed that the small ANSTO contribution to public dose was largely in the form of an external dose due to gamma radiation from the passing airborne plume

of radionuclides (primarily the noble gas argon-41). The assessed dose rates for the hypothetical individuals ranged from 0.0008 to 0.003 mSv/year, with the maximum potential dose rate to those individuals resident at the Stevens Hall Motel (see **Figure 2**, section 5), who could therefore be considered the Critical Group. However, the full range of doses covers less than a factor of ten and so it would be in keeping with international practice to consider all the hypothetical individuals as a single Critical Group, potentially affected by airborne releases. Note that the recent study used more realistic exposure scenarios than the conservative ones routinely used for calculating dose from airborne emissions and reported here (see below). For example, the routinely estimated dose from airborne emissions to people living at the Stevens Hall Motel assumes that a hypothetical individual is outdoors (i.e. unshielded from gamma radiation) for 100% of a year and so estimates a higher dose than is realistic, given that people spend significant time indoors. Also note that the routine dose estimation for airborne emissions does include residents at Stevens Hall.

Sydney Water Corporation has upgraded the Cronulla STP to provide tertiary treatment of sewage. Operational plans include recycling the sewage sludge for application as a slow release fertiliser (biosolids) on agricultural land, and use of the treated water for non-potable purposes. Hypothetical individuals potentially exposed to radiation associated with ANSTO's liquid effluent discharge were therefore identified on the basis of the potential exposure pathways relevant to routine liquid discharges from the LHSTC and with consideration of the Cronulla STP's operational plans. These hypothetical individuals included an STP worker handling biosolids, a farmer with child and infant whose food is grown on land with the allowed single application of biosolids and a person eating seafood (30 kg of fish and 10 kg of shellfish) taken near the Potter Point ocean outfall. Dose assessments for the liquid effluent discharge were made using either the generic model described in the International Atomic Energy Agency's Safety Report Series 19 (IAEA 2001) or the ANSTO-developed RadCon model (Crawford *et al*. 2000). The assessed dose rates ranged from 0.000001 to 0.0002 mSv/year and were all much less than those estimated for the critical group identified, above, for routine airborne releases. Note that dose assessment for hypothetical individuals potentially exposed to radiation from liquid effluent discharges from the LHSTC is not routinely carried out or reported in the Effluent and Environmental Monitoring Report.

5. Sampling of Emissions and Environment

The ANSTO routine monitoring program for the 2001-2002 and 2002-2003 financial years 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 6000 samples were taken and some 10,000 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 are passed through HEPA-filters to remove particles and charcoal filters to remove vapour, prior to discharge through 'stacks'. The stacks were sampled continuously by drawing off a proportion of the airflow and accumulating weekly data for specific radionuclides from either real-time measurement or after physico-chemical trapping over a week. Tritiated water vapour was trapped from air bubbled through a series of water-filled bottles. Radio-iodine was sampled using charcoal-filled 'Maypack' cartridges, also fitted with particle filters. Noble gases were measured in situ using a gamma detector and recording daily accumulations of counts. Airflow through each stack was measured on a quarterly basis using a hot-wire anemometer. Combined, these measurements enable reporting of total radionuclide releases from each stack.

The different liquid waste streams at the LHSTC (treated low-activity liquids, trade effluent and sewage) are combined in holding tanks at the on-site liquid effluent plant prior to discharge into the Sydney Water Corporation sewer. Proportional samples of all liquid effluent discharges were collected and analysed for gross alpha and gross beta radioactivity, pH, biological oxygen demand, grease, suspended solids, ammonia and zinc. A volume-weighted composite sample was also produced from all pipeline samples each month and analysed for gross alpha/beta, tritium and gamma radioactivity.

Table B. Summary of environmental monitoring at ANSTO sites, July 2001 to June 2003

SAMPLE	TYPES	ANALYSES	LOCATIONS	SAMPLING FREQUENCY	ESTIMATED SAMPLES	ESTIMATED ANALYSES
				per year	per year	per year
SOURCE MONITORING						
Airborne	Gases & particles (Maypacks)	GA, GB, Gamma	15 Stacks (LHSTC); 1 Stack (NMC)	Daily (work; NMC) and Weekly(LHSTC)	2050	5170
	Air flow	Flow	15 Stacks (LHSTC)	Weekly(Maypacks) and Quarterly(Stack)	840	840
	Gases	Gamma	3 Stacks (LHSTC); 1 Stack (NMC)	Daily(work)	980	980
	Gas (water vapour)	HTO	4 Stacks (LHSTC)	Weekly	208	208
Liquid	Wastewater	HTO, GA, GB	1-2 Holding Tanks (LHSTC Waste Optns)	Daily(work)	368	1104
	Wastewater	HTO, GA, GB, Chem	1 Sample Tank (LHSTC Waste Optns)	Every 3-4 Days	104	416
	Wastewater	HTO, GA, GB, Gamma	1 Sample Tank (LHSTC Waste Optns)	Monthly(from pipeline composites)	12	48
ENVIRONMENTAL MONITORING						
Waters	Rainfall	volume	1 Site (LHSTC)	15 minute intervals		
	Stormwater	HTO	3 Bunds (A, B, C)	Daily(work) to give Monthly composite	735	36
	Stormwater	HTO, GA, GB, Gamma	1 Bund (C); 1 Site (MDP+60m)	Weekly and Monthly composite (from weekly samples)	128	512
	Creek or river or estuary	HTO	3 Sites (Barden's Ck, Forbes Ck, Woronora R)	Weekly(B Ck) and Monthly(F Ck, W R)	76	76
	Creek or river or estuary	GA, GB	4 Sites (B Ck, MDP Ck, Strassman Ck, B&Mill Cks jnctn)	Monthly(B, M & S Cks) and Yearly(B&M Cks jnctn)	37	74
	Creek or river or estuary	Gamma	1 Site (B&Mill Cks jnctn)	Yearly	1	1
	Seawater	HTO	1 Site (Potter Pt; ~12 samples)	6 Monthly (*ie* twice per year)	24	24
	Wastewater	HTO	1 Sewage Treatment Plant (Cronulla; ~24 samples)	6 Monthly	48	48
	Groundwater	HTO, GA, GB, Gamma	15 Bores (LFBG)	6 Monthly	30	120
	Groundwater	HTO, GA, GB, Gamma, Chem	~20 Bores (LHSTC & Buffer Zone)	Yearly	20	100
	Groundwater	WQ	~20 Bores (LHSTC & Buffer Zone)	Quarterly	80	80
	Sump water	HTO, Gamma	1 Sump (B27)	Monthly	12	24
Air	Wind	speed & direction	1 Site (LHSTC at 10 and 49m)	15 minute intervals		
	Air	temperature, humidity	1 Site (LHSTC at 2, 10 and 49m)	15 minute intervals		
	Gases (Maypacks)	Gamma	4 Stations (LHSTC)	Weekly	208	208
	Particles	Pu, Be	1 Site (LFBG)	Quarterly(Be) and Yearly(Pu)	5	5
Soil/Sediment	Sediment	GA, GB, Gamma	3 Bunds (A, B, C); 2 Cks (Bardens, Mill Ck)	Yearly	5	15
Biota	Algae & fish & barnacles	Gamma	2 Sites (Potter Pt, RNP)	6 Monthly	12	12
Dosimetry		Rate survey	2 Sites (Effluent Pipeline, LFBG)	6 Monthly(E-pipe) and Yearly(LFBG)	3	3
		TLD	19 Sites (LHSTC, Suburbs, Cronulla STP)	Quarterly	76	76
INVESTIGATIONS						
Soil/Sediment	Soil/Sediment	Gamma	2 Areas (LFBG, Effluent Pipeline)	As indicated by dose-rate survey		
APPROXIMATE TOTALS				APPROXIMATE TOTALS	6100	10200

Notes: Working days assumed to be 245, excluding weekends and public holidays

Analyses: HTO = tritium analysis (after distillation)
GA = Gross Alpha counting; GB = Gross Beta counting
Gamma = Gamma spectrometry that varies in number of nuclides targetted (can include specific noble gases like Ar-41 or individual radionuclides like I-131)
Chem = non-radiological analysis that varies in number of analytes (can include major ions, selected metals, organics, plant nutrients, pH, conductivity, suspended solids)
Water Quality (WQ) = field WQ parameters (*eg* water level, pH, conductivity) Flow through Maypacks is measured using a floating ball gauge, and in stacks using a hot-wire anemometer

5.2 ENVIRONMENT

Environmental sampling is carried out primarily to determine where and in what quantities radioactive emissions from the LHSTC are found in the local environment. Environmental sampling is focussed according to our knowledge of potential radionuclide emission sources and the environmental pathways that may disperse radionuclides in a way conferring potential dose to the public. Samples of various media, including water, air and soil, plus some biota, are collected at locations in and around the LHSTC and these sample sites are shown in **Figures 1-5**. Sampling locations include local creeks (*eg* Mill, Bardens and Forbes Creeks), the Woronora River, the LFBG and Potter Point. Radioactive analyses of environmental samples include tritium analysis of water samples, gross alpha and beta analysis of surface water and groundwater, and gamma spectrometric measurements of various media.

Water sampling formed the greater part of the environmental sampling in the period from January 2002 to June 2003. The stormwater bunds at the LHSTC (A, B and C in **Figure 2**) were sampled on working days, prior to the bunds being emptied. These daily samples were combined to give representative monthly samples of stormwater. Weekly samples were taken at Bund C, on the main disposal pipeline (MDP) creek that drains ANSTO's waste operations area, and at a natural pool some 60 metres further downstream. Weekly samples were also collected at the Bardens Creek weir, downstream of the stormwater Bund A. For some analyses, weekly samples were combined into monthly composites. Monthly water samples were taken from the State Pollution Control Commission (SPCC) sampling points (named for having been selected by the then SPCC in 1975; see **Figure 2**) at Bardens Creek weir, Strassman Creek and MDP Creek weir. These sites lie on the drainage lines leaving the LHSTC but are within ANSTO's 1.6 km Buffer Zone. Sampling also occurs in the local area beyond the Buffer Zone, with monthly samples of estuarine water collected from Forbes Creek and the Woronora River. Samples were collected annually from near the junction of Mill and Bardens Creek, which drain the LFBG.

5.3 METEOROLOGY

In common with similar organisations operating nuclear facilities, ANSTO undertakes a program of meteorological measurements. The prime reason for such a program is to allow estimates to be made of the downwind concentration of any airborne pollutants, particularly radionuclides, released from the LHSTC through routine operations or under accident conditions. The data collected from this program provide the necessary input to the atmospheric dispersion and dose-estimation model, PC-CREAM, which is used to compute the effective dose to an individual due to the routine airborne release of radionuclides.

The on-site meteorological tower and associated laboratory are shown in **Figure 2**. Two off-site meteorological stations are also used to measure the influence of the local terrain on wind flow, dispersion patterns and temperatures. These stations (**Figure 1**) are located at the Boys Town School (Engadine) and at the "Shackels Estate" in the Woronora River valley. The meteorology program includes measurements of wind speed, direction and variability, as well as precipitation, evaporation, temperature, pressure and humidity. These data are collected and analysed continuously, and are displayed on ANSTO's web site in addition to being reported to the Australian Bureau of Meteorology. The long-term climatology data for the LHSTC are updated and published approximately every five years. The most recent report available is from 1975 to 1996 (Clark 1997).

6. Environmental Monitoring (January 2002-June 2003)

Monitoring data in this report covers an 18-month period from January 2002 to June 2003. For data routinely collated over financial years, the data tables for the full 2001-2002 period are included. For some environmental samples, analytical results were below the minimum detectable activity (MDA) for a radionuclide. The detection limit can differ for each individual analysis. Indicative, median, MDAs for various radionuclides and environmental media are given in **Table 1** (see Data Tables section, below). In general, data are summarised as median ± interquartile range (IQR), where IQR is the 75th minus the 25th percentile of the data, a similar concept to a standard deviation relative to the mean.

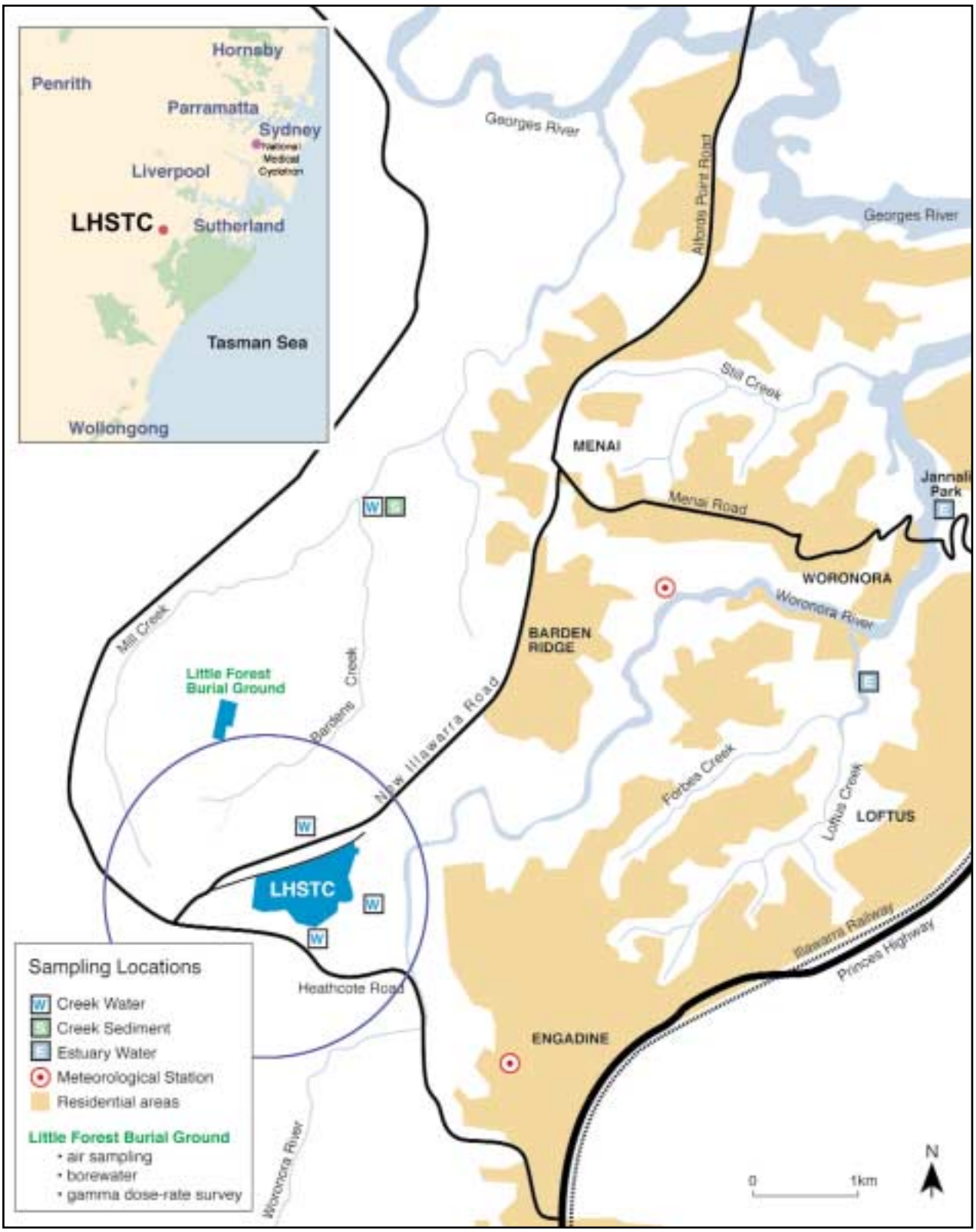


Figure 1. Location of the LHSTC & off-site sampling points

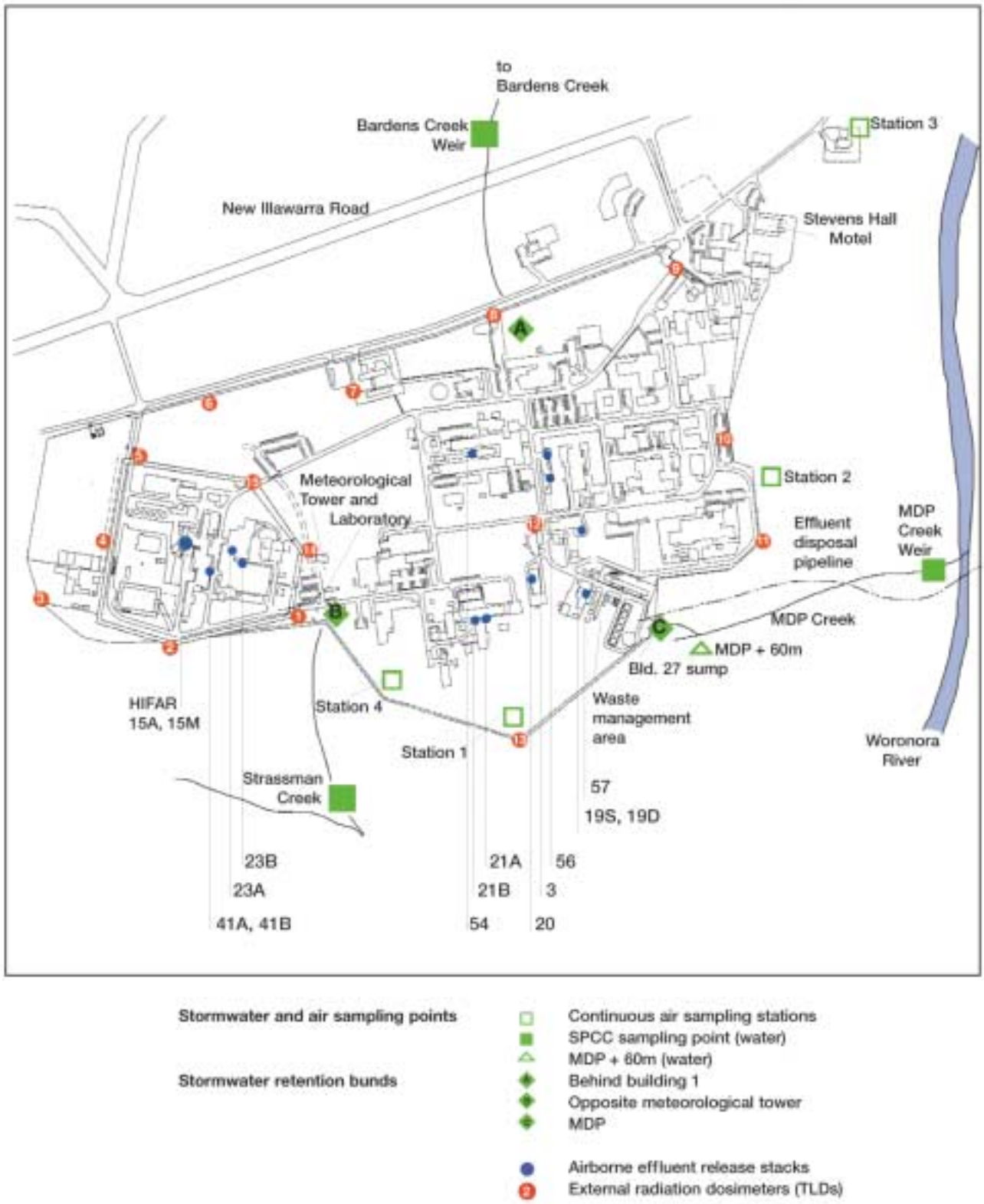


Figure 2. Location of stormwater, air & external radiation monitoring points at the LHSTC

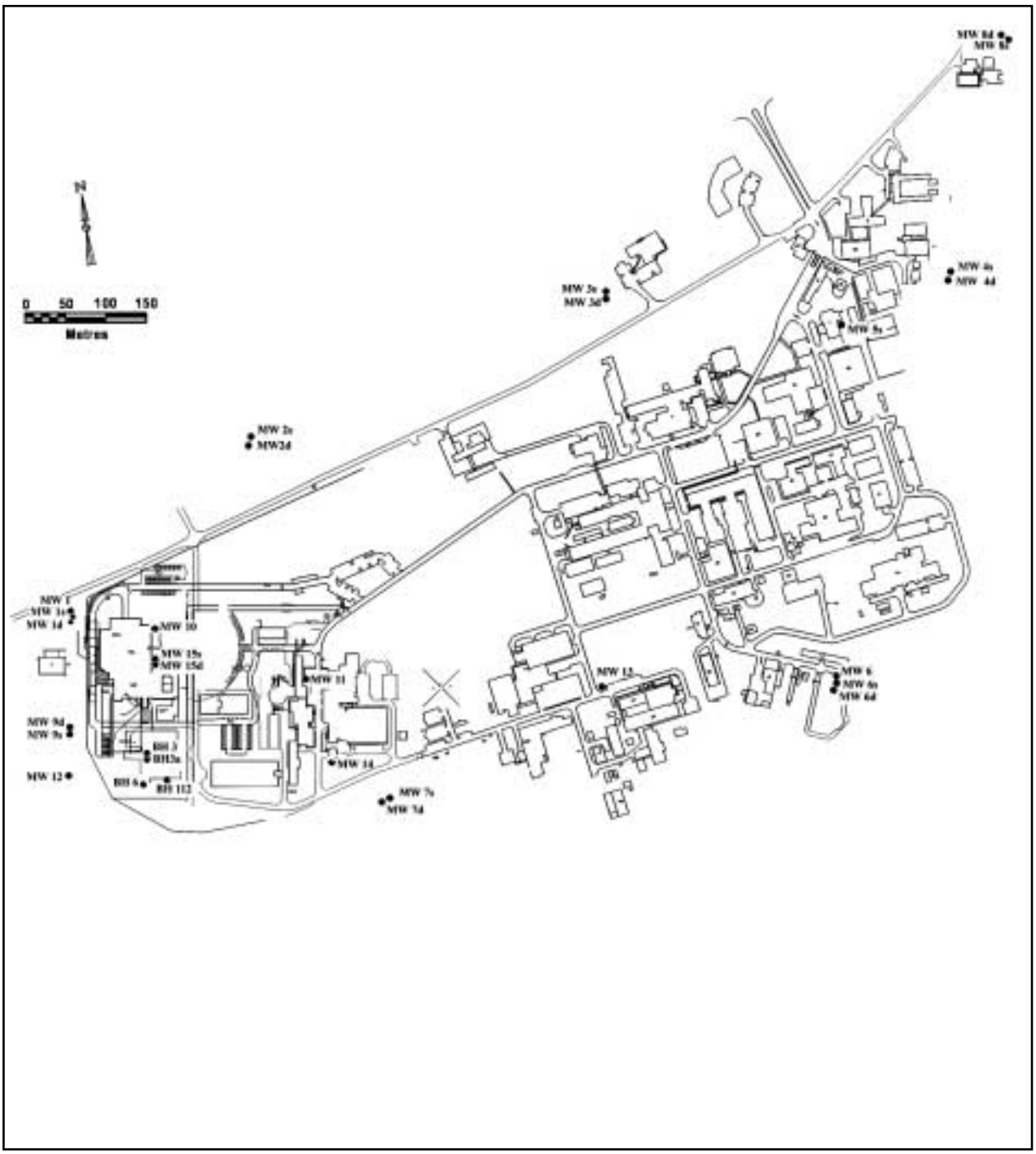


Figure 3. Location of groundwater monitoring piezometers at the LHSTC

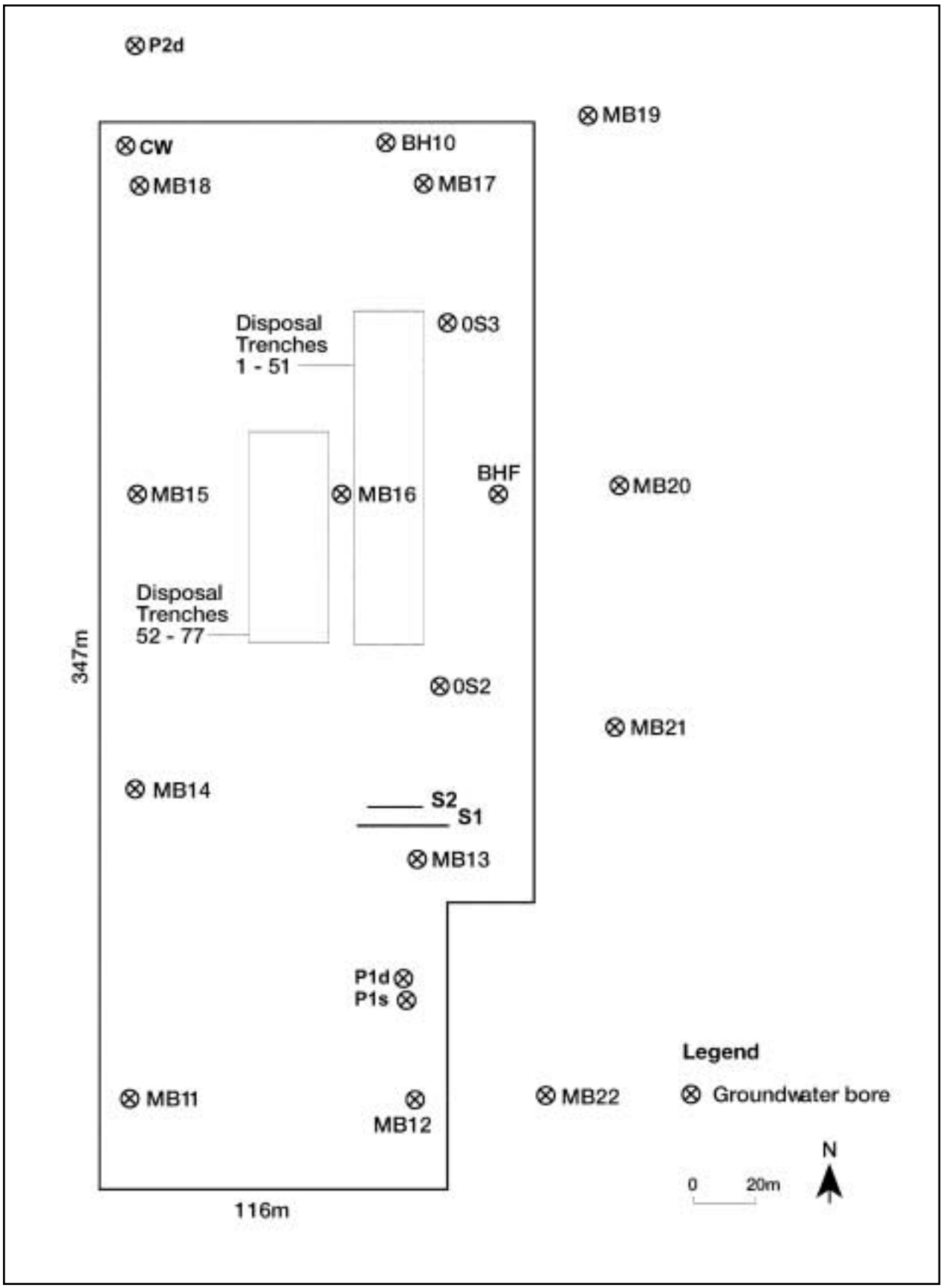


Figure 4. Little Forest Burial Ground – Configuration of bores currently sampled and location of the burial trenches including S1 and S2.

Figure 5. Location of the Cronulla Sewage Treatment Plant and sampling zones at Potter Point Ocean Outfall and The Royal National Park

6.1 AIRBORNE EMISSIONS

Tables 2 and **3** show the airborne activity discharges for the 2001-2002 and 2002-2003 financial years for the 15 stacks at the LHSTC and the single stack at the NMC. They show the total amount of radioactivity discharged and the discharges expressed as a percentage of the relevant annual notification levels. The "all other nuclides" column includes all radionuclides for which there is no specific notification level. Notification levels act as conservative triggers for follow-up investigation and are more fully explained in section 3, above.

In the 2001-2002 financial year, argon-41 emission from stack 15M, the least significant of the two HIFAR stacks, reached the annual notification level (**Table 2**) and the CEO ARPANSA was notified. In October 2002, ARPANSA agreed that the notification level for stack 15M should be increased to 20 TBq. Argon-41 emissions from stack 15M were at 53% of the revised notification level for 2002-2003 (**Table 3**).

In 2002-2003, annual notification levels were reached for specific radionuclides from two stacks and the CEO ARPANSA was notified. Tritium emissions from Building 20, the decontamination facility, reached 161% of the notification level. Noble gas emissions from Building 54 increased in the latter half of the 2002-2003 financial year and xenon-133 discharges reached 107% of the annual notification level (**Table 3**). In both cases there were appropriate investigations and follow-up.

6.2 LIQUID EFFLUENT

6.2.1 Lucas Heights Science and Technology Centre

A trade wastewater agreement with Sydney Water Corporation allows ANSTO to discharge treated liquid effluent from the LHSTC to the sewer (see section 3). The low activity 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. Prior to every discharge, the radioactive content and specified non-radiological water-quality parameters are measured.

Table 4 shows the average monthly activities of gross alpha, gross beta and tritium radioactivity in liquid effluent prior to discharge. The alpha values are all less than the minimum detectable activity, hence the combined quotients in the last column are also shown as less-than values. The combined monthly activity quotients for alpha, beta and tritium activity ranged from < 0.06 to < 0.19, with a median value of < 0.12, *ie* less than 12% of the allowed limit (*ie* a quotient of one). **Figure 6** charts the monthly quotients for alpha, beta and tritium activities in liquid effluent discharges for the period January 2002 to June 2003.

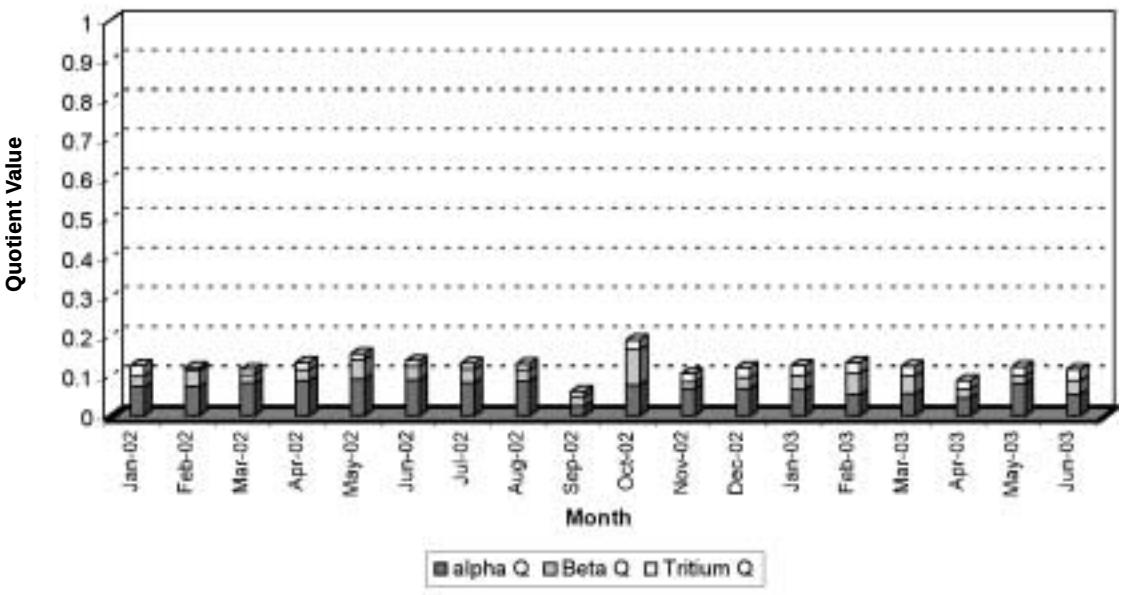


Figure 6. Monthly quotients for alpha, beta and tritium radioactivity in liquid effluent at the LHSTC, January 2002 to June 2003

The activities of gamma-emitting radionuclides in the monthly pipeline composite samples are given in **Table 5**. Of the radionuclides listed, only cobalt-60, cesium-137 and iodine-131 were detected in more than 50% of samples. The activity of cobalt-60 ranged from less than the minimum detectable activity (0.15 Bq/L) to 3.03 Bq/L, with a median (± IQR) of 0.66 ± 0.46 Bq/L. Cesium-137 ranged from less than the minimum detectable activity (0.11 Bq/L) to 4.0 Bq/L, with a median (± IQR) of 0.39 ± 0.45 Bq/L. Iodine-131 was detected in only 61% of samples, its overall range was from less than the minimum detectable activity (0.10 Bq/L) to 0.74 Bq/L, with a median (± IQR) of 0.22 ± 0.33 Bq/L.

The results for non-radioactive parameters of the liquid effluent (suspended solids, pH, ammonia, biological oxygen demand, grease and zinc) are shown in **Table 6**, along with the relevant standards for acceptance to the Sydney Water Corporation sewer. The range of values is reported, along with the mean and median. Of the samples analysed, 95% must be less than or equal to the relevant standards for acceptance. For the period January 2002 to June 2003, all median values were within acceptable bounds, although the ranges of pH, biological oxygen demand and grease indicate that occasional samples fell outside the standards.

A recent study was made of longer-term trends in liquid effluent radioactivity. The study found that discharge trends for unspecified alpha, beta-emitting nuclides and tritium, from January 1998 to March 2002 were within the limits for allowable discharge. The higher quotients in mid-2001 reflect ANSTO's operations and were attributed to HIFAR shut-down and subsequent contamination of effluent water by HIFAR-based operations. The tritium and beta activities in liquid discharges, during this period, increased the quotient-value. The average monthly discharge of tritium in liquid effluent during 2001 was 1.62×10^7 Bq/m^3 (range from 1.23×10^6 to 9.90×10^7 Bq/m^3) which was well below the limit of 1.95×10^8 Bq/m^3 as set out in the trade wastewater agreement. Release trends for tritium since 1998 show a number of maxima resulting from HIFAR shut-down activities, however all are well below the allowable limits. Typically, approximately 0.008 Bq/L of radium-226, an alpha-emitter, was found in liquid effluent samples, much less than the allowable limit (12.5 Bq/L) under the trade wastewater agreement.

The non-radioactive components of the liquid effluent were also studied recently, over a 6–9 month period in 2002. The chemicals of interest were soluble ionic species, plus organic-based residues arising from waste treatment activities within the local area. There was no endeavour to analyse for contaminants in liquid effluent that would be relevant to other industries. All analyses were conducted by an independent, NATA registered, laboratory.

Although past operations on-site have involved quantities of tellurium, arsenic and mercury, the levels of these soluble species in discharged effluent are detectable at extremely low concentrations (< 1 μg/L). Chromium is of particular interest because of its past use as an anodic corrosion inhibitor in HIFAR cooling towers and because of the environmental toxicity of hexavalent chromium; however it has been replaced by phosphate since July 2000. Zinc is currently used as a cathodic corrosion inhibitor in the cooling towers. The replacement of chromium is reflected in the reduced concentrations of this soluble metal species found in the ANSTO effluent.

All organic-based residues in ANSTO effluent were below the level of detection and reporting for specific pesticide and herbicide residues. Pesticides were typically below a concentration of 0.5 μg/L (limit imposed < 10 μg/L total pesticides). The once popular organochlorine-pesticides, Aldrin, Dieldrin and Endrin were below 0.5 μg/L and DDT (dichlorodiphenyltrichloro ethane) pesticide was less than 2 μg/L. Herbicide defoliant residues were typically < 10 μg/L (limit < 100 μg/L).

Levels of radioactivity and non-radioactive components of all liquid effluent discharges to the sewer from January 2002 to June 2003 met the standards for acceptance specified in the trade wastewater agreement with Sydney Water Corporation.

6.2.2 Effluent Dilution – LHSTC to the Cronulla STP

The Cronulla STP receives sewage and wastewaters from the Sutherland Shire, including treated effluent from the LHSTC. ANSTO is required to comply with the Sydney Water Corporation trade wastewater agreement, which nominates a minimum value of 25 for the dilution factor between the ANSTO discharge tanks and the Cronulla STP. Compliance is confirmed at least twice each year by direct measurement of tritium levels in the plant. The Cronulla STP was upgraded to provide tertiary treatment from July 2001 and two additional effluent dilution studies were

undertaken (**Table C**). There were some problems with sampling equipment and low levels of tritium in the effluent released which meant that the dilution factors were only calculable for two of four studies attempted. The maximum activity of tritium observed in the Cronulla STP was 204 Bq/L and the minimum dilution factor was 61.

Table C. Effluent dilution studies at Cronulla Sewage Treatment Plant, January 2002 to June 2003

Date [1]	Tritium activity at LHSTC release point (Bq/L)	Maximum tritium activity in Cronulla STP [2] (Bq/L)	Dilution Factor	Comments
July 8 2002 (12.00 pm)	4630 Bq/L	70 Bq/L	61	The transit time to the interstage within the plant was 18 hours. A second release commenced at 15:15 hours (8 July 02). This did not affect the calculation of the dilution factor.
June 17 2003 (9.00 am)	18,300 Bq/L	204 Bq/L	90	The effluent transit time from LHSTC to Cronulla STP was 10 hours.

Notes:
1. In each case, 210 kL of effluent was released from the LHSTC, over 3 hours.
2. The data relates to samples collected at the 'interstage' location in the Cronulla STP, *ie* following the sedimentation tank, in the vicinity of the interstage lift pump.

The levels of tritium observed within the Cronulla STP are an order of magnitude less than those stipulated in the Sydney Water Corporation trade wastewater agreement. This confirms that ANSTO is in full compliance with its obligations under the agreement. During June 2003, samples were collected at the plant exit over a 48 h period commencing 1500 hr 17 June 2003. Over this period, the mean tritium value was 16 ± 1 Bq/L. This value is very low compared with the Australian drinking water guideline (NHMRC and ARMCANZ 1996) of 7600 Bq/L, and will depend on the history of ANSTO releases over the previous couple of days and the dynamics of the water flow through the plant.

6.2.3 National Medical Cyclotron

Liquid effluent is discharged from the NMC to the Sydney Water Corporation sewer under the terms of a trade wastewater agreement that incorporates limits set by the NSW EPA for specific radionuclides. The radiopharmaceutical products made at the NMC are relatively short-lived, with half-lives ranging from minutes to hours in most cases. Consequently, a system of delayed liquid effluent releases ensures that most radionuclides have decayed significantly prior to being released.

The average levels of radionuclides discharged to sewer each month from the NMC are shown in **Table 7**, along with calculated mean and median values. The average discharges contained very low levels of radionuclides, 5% or less of the NSW EPA monthly limits for thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65 and iodine-123. Liquid effluent discharges from the NMC were therefore well within the required limits in the period from January 2002 to June 2003.

6.3 AIR

6.3.1 Ambient I-131

No iodine-131 was detected in ambient air sampled continuously at four locations on the LHSTC boundary fence during the reporting period (**Table 8**). All results for the 78 weekly measurements were below the minimum detectable level of 0.0025 Bq/m^3.

6.3.2 LITTLE FOREST BURIAL GROUND – AIRBORNE PARTICULATES

Quarterly samples of airborne particles were collected on windy days (to maximise particulate collection) using a mobile high-volume air sampler (**Table 9**). The total volume of air sampled during the period was 2617 m^3. The exposed filters were analysed for stable beryllium and plutonium-239/240; however, neither was detected within the 18-month reporting period.

6.3.3 External Gamma Radiation

Thermoluminescent dosimeters were used to measure ambient gamma radiation (including the

contribution from natural background radioactivity) at various locations around the LHSTC (**Figure 2**), at three private residences in the nearby suburbs of Barden Ridge, Engadine and Woronora and at the Cronulla STP (**Figure 1**). Measurements at the three local residences, which can be taken as indicative of local background for the LHSTC, showed median external dose rates of 1.04 ± 0.20 and 1.09 ± 0.13 mSv/year for the 2001-2002 and 2002-2003 financial years, respectively (**Table 10**). The local absorbed dose rates in air were 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 absorbed dose to air at one site on the southern sector of the LHSTC perimeter fence (Location 2, see **Figure 2**) is affected by nearby stored radioactive material. An annual dose rate of 3.23 mSv/year was recorded at the site for 2001-2002 and 2.94 mSv/year for the 2002-2003 financial year - this part of the site is not readily accessed by the general public. The dose rates for other locations were in the ranges 0.80 to 1.54 mSv/year and 0.93 to 2.15 mSv/year for the two years (**Table 10**) *ie* generally within the local background range.

6.3.4 Aerosol Particles (PM 2.5)

ANSTO has been measuring and characterising fine aerosol particles at the LHSTC 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 with aerodynamic diameters less than 2.5 microns (1 micron is one 1 millionth of a metre) often referred to as PM2.5. At high levels, fine aerosol particles affect human health, reduce visibility and have been shown to play a key role in global climate change processes.

Particles in the PM2.5 size range mainly originate from anthropogenic combustion sources such as motor vehicle exhausts, fossil fuel burning and other high temperature industrial processes, producing sulphates, lead, bromine, organics, potassium and heavy metals. Some natural aerosol sources such as airborne soils and sea spray will have size components below and above 2.5 μm in diameter.

Figure 7 shows the average monthly mass of PM2.5 particles collected at the LHSTC in the 2002 calendar year.

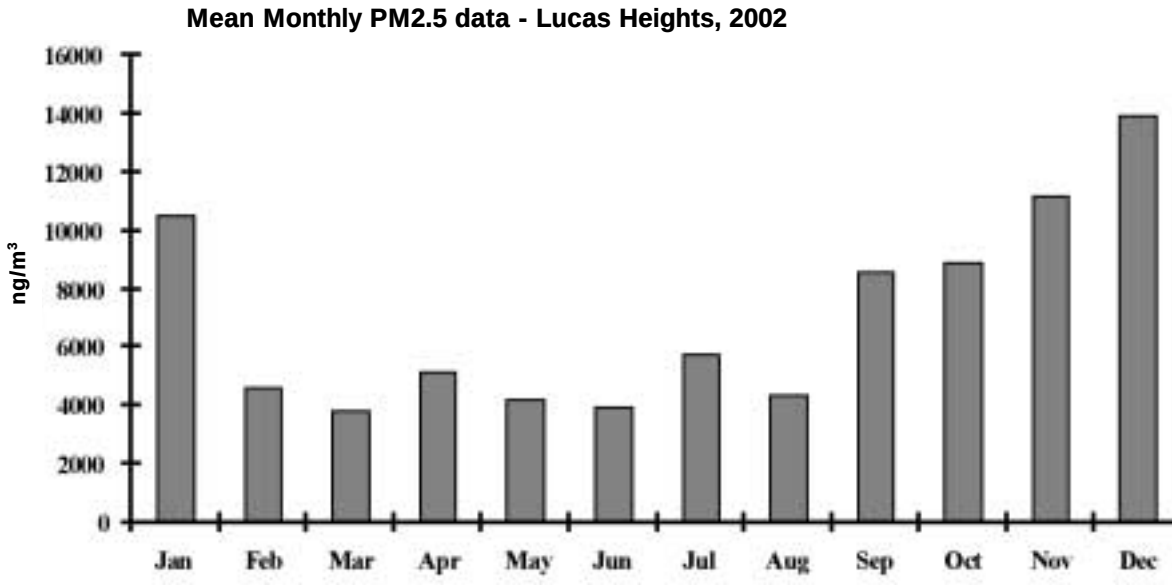


Figure 7. Average monthly mass of fine aerosol particles (less than 2.5 microns in diameter) collected over 24-hour periods, Lucas Heights, 2002

Currently there is no Australian or NSW standard for PM2.5 fine particles. However, in July 1997 the United States Environmental Protection Agency introduced a national air quality standard for PM2.5 particulates (USEPA 2002). This standard is mainly based on health-related issues and specifies an annual average of 15,000 ng/m^3 with a maximum 24-hour average, at the 2nd percentile, of no more than 65,000 ng/m^3 (depending on the sampling frequency). Thus, for

weekly sampling no more than two exceedances per year of 65,000 ng/m^3 would be allowed in order to comply with the standard. The levels of PM2.5 fine particles observed at the LHSTC in the calendar year 2002 were well within the requirements of the US EPA air quality standard. Analyses of the particulate composition demonstrates that most of the aerosol particles do not originate from ANSTO.

6.3.5 Radiological Characterisation of the LHSTC and Buffer Zone

Under site licence and Environmental Impact Statement (EIS) conditions for the Replacement Research Reactor (RRR), ANSTO was required to establish a radiological characterisation of the RRR site and Buffer Zone, to provide a fundamental basis for ongoing radiological monitoring programs and the detection of radiological trends over time. An extensive survey, using a helicopter equipped with an airborne gamma detection system, was supported by ground-based, more intensive gamma surveys of areas of interest. The ground-based studies also covered areas where the helicopter was not permitted to fly, *ie* the HIFAR security area.

Since gamma ray emissions are affected by groundwater content, soil moisture analyses at representative locations in the buffer zone established the conditions under which any future airborne surveys should be conducted. These soil samples were also subjected to gamma spectroscopy analysis to determine the presence of natural and man-made radionuclides. The studies revealed that all man-made radionuclides were contained within, or close to, the LHSTC boundary. The locations of man-made radionuclides in the LHSTC could be related to various processing and waste operations. The locations of naturally occurring radionuclides (potassium-40, uranium-238 and thorium-232) were consistent with the geological rock structures and soil types in the region.

6.4 SURFACE WATERS

Surface waters include stormwater runoff as well as flows of near-surface groundwater, with the proportion depending on the weather in the preceding days. Concrete bunds (of about 2 m^3 capacity) on the three main stormwater outlets at the LHSTC (A, B and C in **Figure 2**) temporarily retain surface water before its release off-site. These bunds are inspected and emptied 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.

6.4.1 Tritium in surface waters

Tritiated water vapour released to air from HIFAR operations, readily exchanges with rainwater and other surface waters and is present in stormwater and groundwater at the LHSTC. Tritium was detected in monthly composite water samples (work-daily samples combined) from Bunds A, B and C (**Table 11**) at levels ranging from less than the minimum detectable activity (10 Bq/L) to 610 ± 20 Bq/L, with a median activity (± IQR) of 120 ± 148 Bq/L.

Weekly samples from Bund C, situated at the top of MDP Creek, were analysed for tritium and the results are shown in **Table 12**. Tritium activity ranged from less than the minimum detectable activity (10 Bq/L) to 2550 ± 50 Bq/L, with a median activity (± IQR) of 175 ± 220 Bq/L. Weekly samples were also collected from a natural pool on the same drainage line but some 60 m downslope from Bund C – this was the stormwater sampling point prior to 1994 when the bunds were constructed. The tritium levels in weekly samples from this site, MDP+60 m (**Table 13**), ranged from less than the minimum detectable activity (10 Bq/L) to 1920 Bq/L, with a median (± IQR) of 100 ± 120 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 2**). The results are given in **Table 14**. The tritium activity in weekly samples from Bardens Creek weir ranged from less than the minimum detectable activity (10 Bq/L) to 250 Bq/L, with a median activity (± IQR) of 50 ± 70 Bq/L.

The range of tritium activities recorded in these water samples from January 2002 to June 2003 were 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 40% of the ADWG level of 7600 Bq/L (NHMRC and ARMCANZ 1996), given here for context only - this water is not collected and supplied as potable water. The median (50th percentile) tritium activities for surface waters at LHSTC are much lower, in the range from 50 to 175 Bq/L, *ie* they are typically less than 3% of the ADWG levels (NHMRC and ARMCANZ 1996).

6.4.2 Gross alpha and beta radioactivity in surface waters

Stormwater from the LHSTC flows into three small streams (Bardens, Strassman and MDP Creeks; **Figure 2**), that are classified as Class C waters under the regulations associated with the *NSW Protection of the Environment Operations Act (1997*). As such, there are regulatory limits for gross alpha and beta radioactivity (*ie* total measures of alpha and beta activity, without discriminating between contributing radionuclides).

Gross alpha and beta data for monthly composite samples (combined weekly samples) at Bund C are given in **Table 15** from January 2002 to June 2003. The gross alpha activities ranged from 0.017 to 0.081 Bq/L, with a median (± IQR) of 0.034 ± 0.009 Bq/L. For gross beta, the range of activities was from 0.24 to 1.54 Bq/L and the median (± IQR) was 0.68 ± 0.36 Bq/L. Gross alpha and beta data for monthly composite samples (combined weekly samples) at MDP+60 m are given in **Table 16** from January 2002 to June 2003. The gross alpha activities ranged from less than the minimum detectable activity to 0.091 Bq/L, with a median (± IQR) of 0.03 ± 0.02 Bq/L. For gross beta, the range of activities was from 0.17 to 0.42 Bq/L and the median 0.30 ± 0.11 Bq/L.

The results of gross alpha and gross beta analyses of monthly samples from Bardens Creek weir, Strassman Creek and MDP Creek weir (the SPCC sampling points) are given in **Table 17**. **Figures 8** and **9** graph these results. Taking the three creeks together, gross alpha levels ranged from less than the minimum detectable activity to 0.043 Bq/L, with a median value (± IQR) of 0.016 ± 0.008 Bq/L. Gross beta radioactivity ranged from 0.024 to 1.01 Bq/L, with a median of 0.081 ± 0.132 Bq/L. The maximum gross beta activity was found for Strassman Creek in September 2002. This was an outlier (more than ten times the median value) due to sampling turbid water in very dry conditions when only a very shallow pool remained (samples were analysed unfiltered). The enhanced beta activity almost certainly resulted from incorporation of natural radioactivity associated with uranium thorium series nuclides or potassium-40. Water samples collected near the junction of Mill and Bardens Creeks, which drain the LFBG, showed only natural background levels of gross alpha, gross beta, gamma and tritium activity (**Table 18**).

All results from January 2002 to June 2003 were well below the limits for gross alpha and gross beta activity in the relevant NSW regulations (1.1 Bq/L for gross alpha activity and 11.1 Bq/L for gross beta activity).

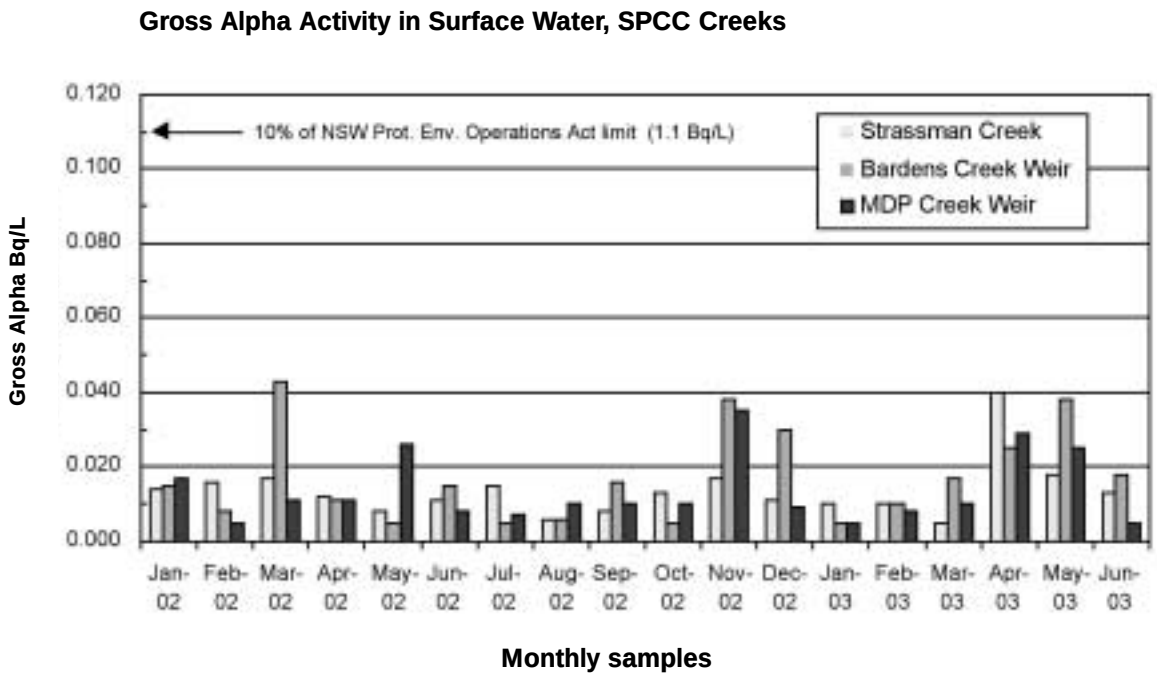


Figure 8. Gross alpha activity in surface water at the LHSTC, January 2002 to June 2003

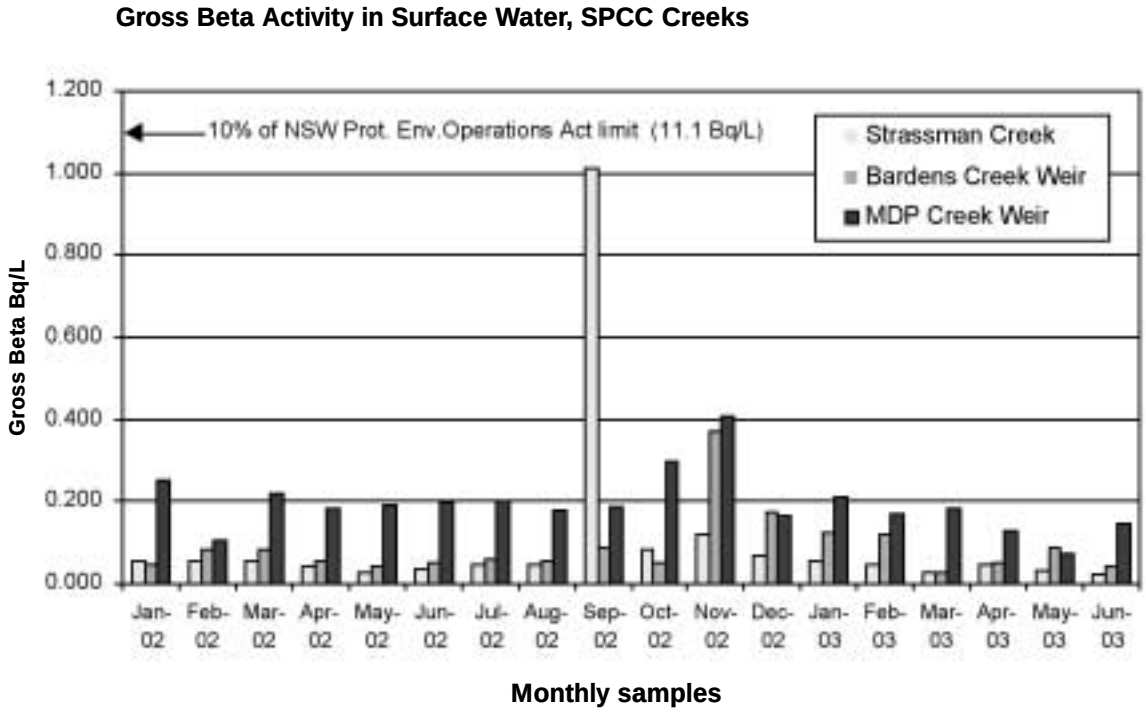


Figure 9. Gross beta activity in surface water at the LHSTC, January 2002 to June 2003

6.4.3 Gamma-emitting radionuclides in surface waters

Gamma spectrometry of monthly composite samples from Bund C (**Table 15**) showed low but detectable levels of cesium-137, ranging from less than the minimum detectable activity (0.021 Bq/L) to 0.153 Bq/L and, less often, cobalt-60 ranging from less than the minimum detectable activity (0.019 Bq/L) to 0.045 Bq/L. The only other gamma-emitters detected were potassium-40 and beryllium-7, both of natural origin. Cesium-137 was detected with a median activity of 0.01 ± 0.01 Bq/L in monthly composite samples (January 2002 to June 2003) from MDP+60 m (**Table 16**). Low levels of the natural gamma-emitters, potassium-40 and beryllium-7 were also detected in some samples. No other gamma-emitters were detected. Similarly low levels of cesium-137 and cobalt-60 have been reported in previous years.

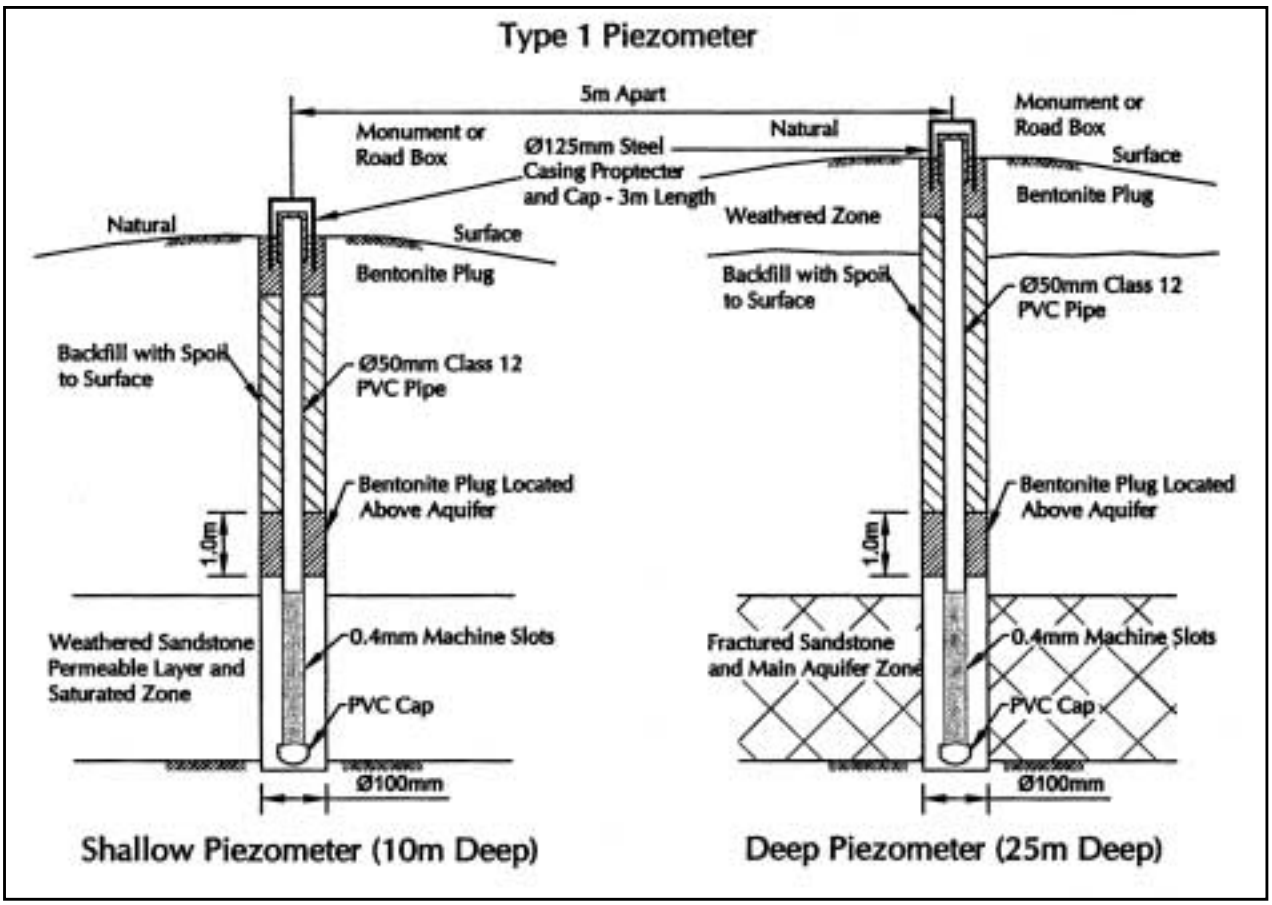
6.5 ESTUARINE AND SEA WATERS

Monthly samples of brackish/estuarine waters were collected from Forbes Creek (a tributary of the Woronora River) and the Woronora River and analysed for tritium however, as in previous years, none was detected (< 10 Bq/L). The results are presented in **Table 19**. Offshore sampling for tritium was also conducted near the Potter Point ocean outfall on 9 July 2002 between 0800 and 1500 hr at three locations 10, 90 and 270 m from the outfall in a line bearing 182 degrees. All tritium activities were below the MDA except the following: 10 m from the outfall at 08:00 and 13:00 h (25 Bq/L and 1.1 Bq/L, respectively); 90 m from the outfall at 09:00 and 10:00 h (5.0 and 3.6 Bq/L, respectively); 270 m from the outfall at 10:00 h (5.5 Bq/L). These data indicate the further dilution that occurs between the Cronulla STP and the nearshore area at Potter Point.

6.6 GROUNDWATER

6.6.1 Lucas Heights Science and Technology Centre

Groundwater level and quality monitoring at the LHSTC was established in 2000 with the installation and development of a groundwater piezometer network (**Figure 3**) followed by collection of preliminary data during 2001. Installation of additional piezometers took place in 2002. General piezometer construction details are outlined in **Figure 10**, illustrating Type 1 (shallow and deep) and Type 2 (open) piezometer construction. There are 28 type 1 piezometers and three Type 2 piezometers within the groundwater monitoring network, which has been designed to monitor some specific facilities, cover all areas within and adjacent to the LHSTC,



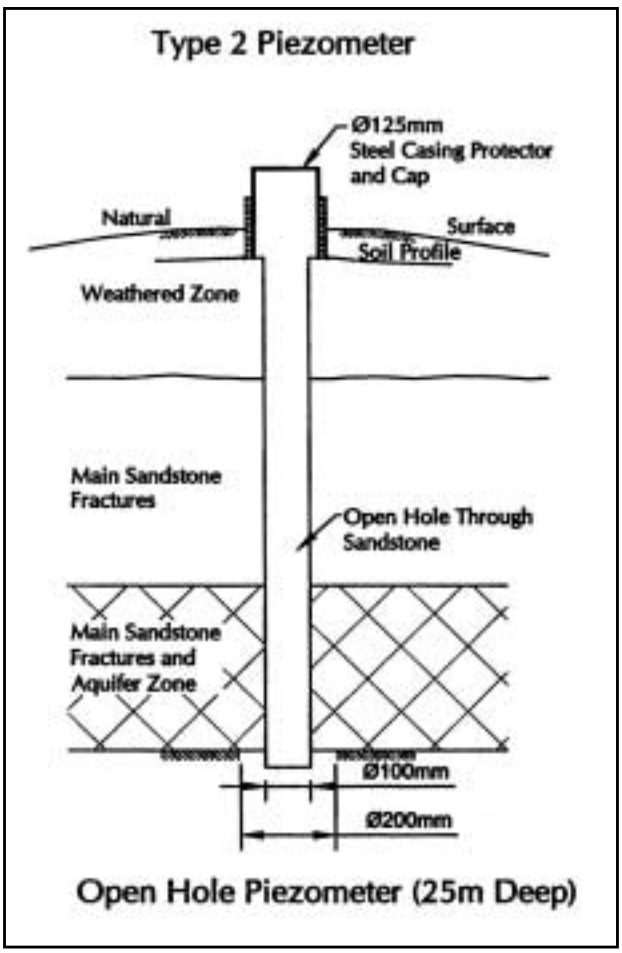
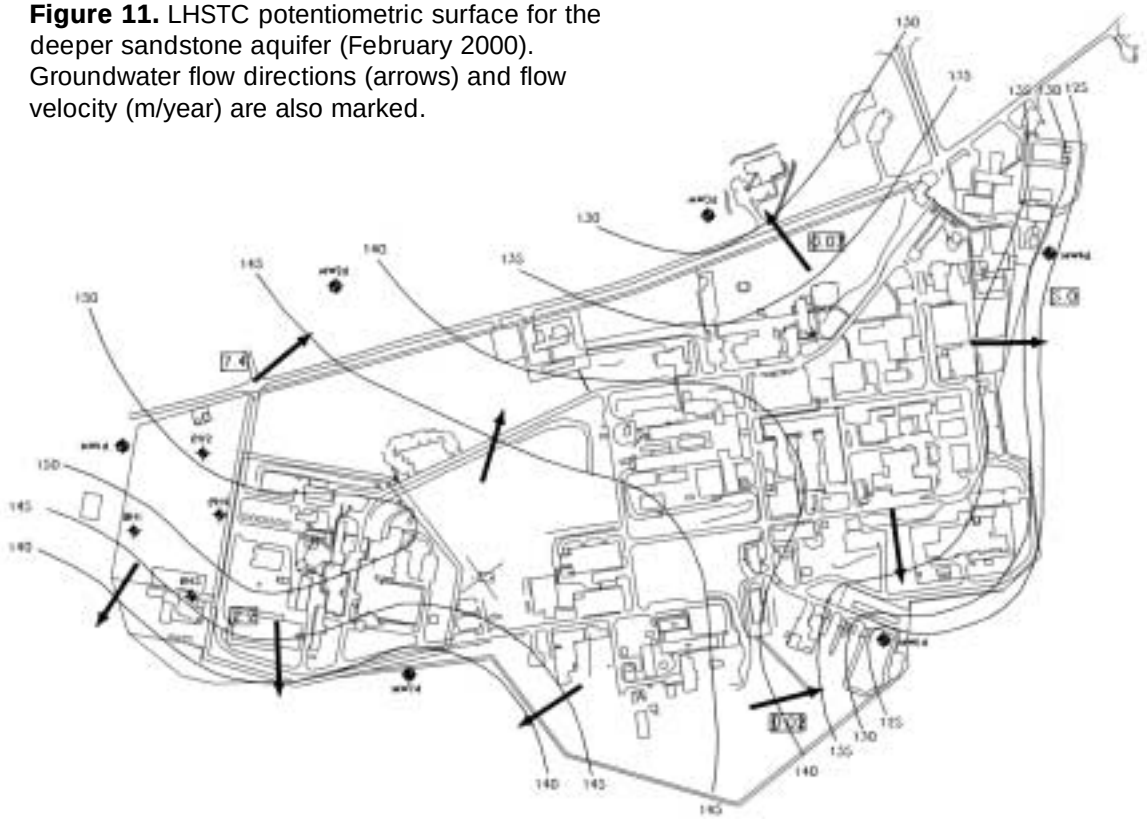


Figure 10. General construction details of Type 1 and Type 2 piezometers at the LHSTC

Groundwater flow at the LHSTC is primarily dependent on topographic features. LHSTC is situated on top of a gently north-sloping ridge, with several steep gullies draining into the Woronora River on the eastern side, and shallow depressions forming the headwaters of Bardens and Mill creeks to the west (**Figure 11**). A significant proportion of the LHSTC site has building and road cover, with the remainder covered by grass or sparse native vegetation. After heavy rain, the stormwater system receives surface flows from roads, buildings and surface drainage lines, and the soil absorbs rain falling on the vegetated portion of LHSTC. For several days following heavy rain, water seeps from the soil into the heads of the gullies surrounding the LHSTC. Discharge via a deeper groundwater path, over a much longer time scale and further down the gullies, ultimately forms the base-flow of the Woronora River. The response of the LHSTC groundwater to heavy rainfall has also been assessed.

Groundwater seepage from the general vicinity of the intermediate waste storage facility (Building 27) is routinely collected. The samples were measured each month for gamma-emitting isotopes (americium-241, cesium-137, cobalt-60 and potassium-40) and tritium (**Table 20**). Cesium-137 was detected occasionally, at levels within the range reported for LHSTC surface water samples (see section 6.4.3) and naturally occurring potassium-40. Tritium activities were stable and well below drinking water guideline levels, with a median (± IQR) of 415 ± 85 Bq/L.

Figure 11. LHSTC potentiometric surface for the deeper sandstone aquifer (February 2000). Groundwater flow directions (arrows) and flow velocity (m/year) are also marked.



Hydrogeochemistry

The data for field parameters and major ions for September 2002 are presented in **Tables 21** and **22**. Groundwater quality at LHSTC is typical of what would be expected for a sandstone aquifer. Groundwaters are acidic to slightly acidic, ranging in pH from 3.88 to 6.30. The aquifer is low in total dissolved solids as reflected by the electrical conductivity values, which range from 300 to1000 µS/cm. The pH and electrical conductivity values reflect fresh groundwater originating from local rainfall, flowing through the system at a slow rate (ranging from 0.01 to 4 m/year, depending on hydraulic conductivity at the location). The LHSTC groundwaters are predominantly sodium-chloride-sulphate type waters. The source of these ions in these waters would be from marine aerosol input (*ie* from rainfall originating from the sea). Piezometers monitoring groundwater to the north and north east (*ie* MW2s,d, MW3s,d, MW4s,d, and MW5s) show a predominance of magnesium with some calcium and bicarbonate type waters. This could

reflect a more calcite rich source, possibly from the cementing material of the sandstone in this area. Furthermore, there are no significant trace elements or nutrients identified from the analysis of groundwaters at the LHSTC.

In summary, the field chemical data and major ion data confirms that the rate of groundwater movement from rainfall to discharge is small, as also reflected in the generally low ionic concentrations of the groundwater in the area.

Radioactivity

Groundwater samples were collected at the LHSTC in September 2002, following purging of the wells. These samples were then analysed for alpha, beta, tritium and gamma radioactivity (americium-241, cesium-137 and cobalt-60 in particular). Radioactivity data are given in **Table 23**. Levels of alpha, beta and gamma radioactivity were found to be negligible in groundwaters in the LHSTC. The few small detections of radioactivity are attributed to natural background levels in particular potassium-40, uranium-238 and thorium-232. Potassium-40 and uranium-238 are commonly associated with the clay fractions of the sediments, while thorium-232 is associated with heavy minerals found in the sand fraction of sediments.

Tritium activity in the LHSTC groundwaters ranged from 2.6 to 611 Bq/L. Shallower piezometers (represented as 'S' series) display higher tritium levels than the deep piezometers in nested sets. This reflects a vertical downward hydraulic gradient with tritium levels in recent rainwater decaying as it moves downward and also mixing with less tritiated (older) water. The tritium activities are higher than normal rainfall background in Australian waters, which is approximately 0.4 Bq/L, but the maximum activity is less than 10% of the ADWG (NHMRC and ARMCANZ 1996). The elevated levels of tritium in these waters reflect the contribution from emissions of tritiated water vapour to air associated with HIFAR operations. Rain that falls in the vicinity of the reactor can contain elevated tritium levels.

The groundwater regime at the LHSTC can be described in terms of three layers consisting of:

- a near-surface soil and regolith layer, typically less than 2 metres deep;
- a weathered sandstone layer of variable thickness and degree of weathering, from around 1-10 m; and
- an unweathered sandstone layer, greater than 10 metres.

A seismic survey showed variability for these three layers, both in their thickness and in their degree of definition. In places, there is no clear distinction between the layers. These heterogeneities in structure result in variations in hydraulic conductivity throughout the geological profile. Generally, at the surface, a thin highly permeable soil layer absorbs rain. Most of this water then rapidly drains laterally to the topographic lows at the heads of the gullies surrounding the LHSTC. Percolating rainwater cannot effectively flow downward in the sandstone groundwater system because of zones of low hydraulic conductivity, resulting in lateral flow. The contrast in hydraulic conductivity between these layers forms an effective barrier to vertical flow.

The characteristic response of the LHSTC groundwater to heavy rainfall is an immediate local rise in groundwater level (caused by saturated soil contributing water directly to the borehole) followed by the falling head as this water is redistributed into the aquifer within a few hours. The hydrograph data for a borehole located near the head of a gully (MW6s), along with concurrent rainfall, is displayed in **Figure 12**. The data show that groundwater flow from the plateau to the gully peaked a few days after the rainfall event and that the groundwater level returned to its original height after about 10 days.

The hydrograph data are consistent with the conceptual model for the LHSTC groundwater developed from earlier seismic and geophysical data. That is, an imperfect multi-layer groundwater flow regime, exhibiting a decrease in flow rate through each layer due to decreasing hydraulic conductivities with depth.

Rain and evaporation data for the LHSTC from 1992 to 2003 are summarised in **Table 24**. These data are used in the interpretation of groundwater hydrology for the LHSTC site. Monthly total rainfall (R Total; mm), the number of days on which rain fell (R Days), monthly total evaporation (E Total; mm) and the maximum daily evaporation (E max; mm) are given.

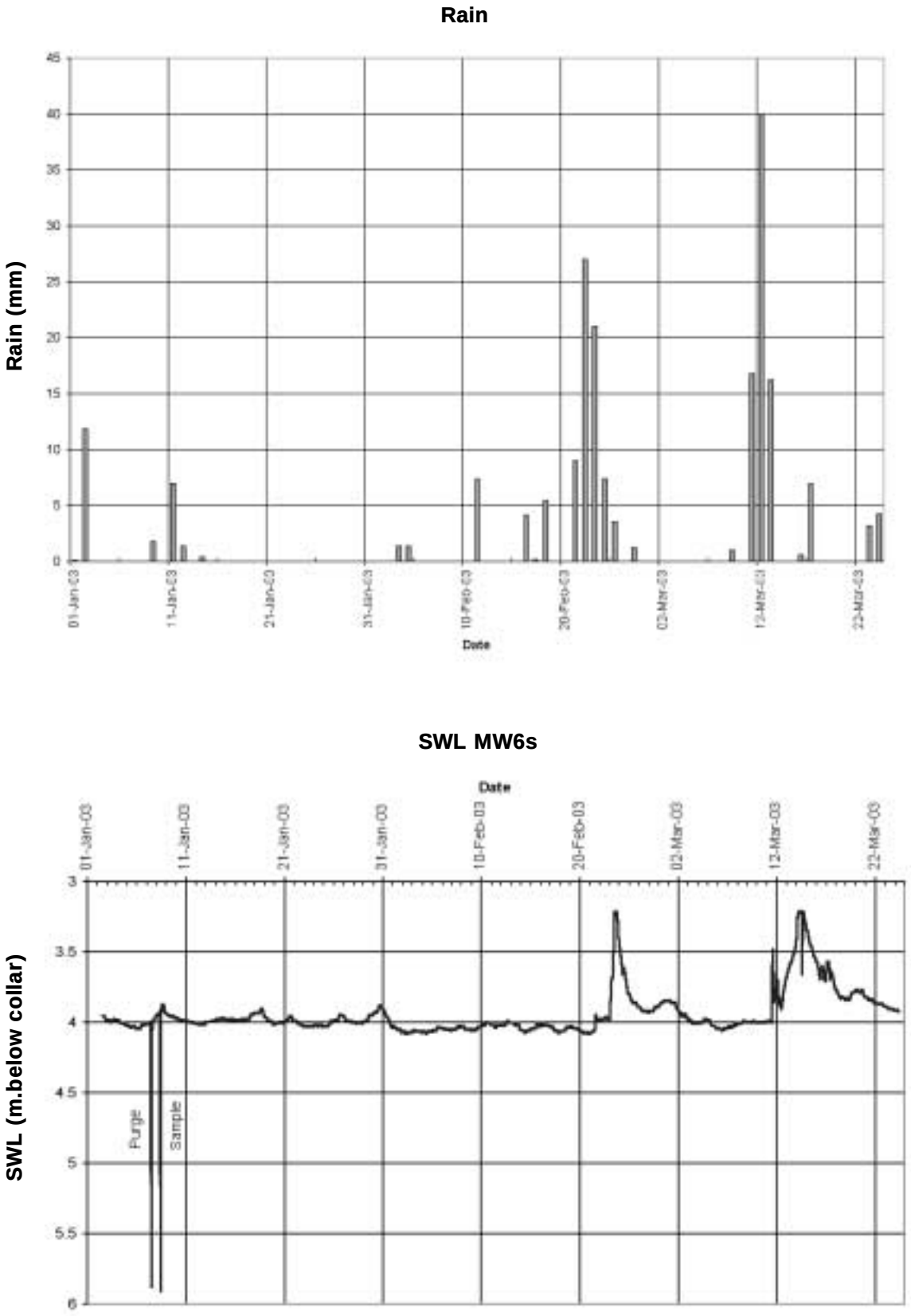


Figure 12. Groundwater hydrograph for piezometer MW 6s and concurrent rainfall at the LHSTC.

6.6.2 Little Forest Burial Ground

Routine six-monthly groundwater level monitoring and sampling from the Little Forest Burial Ground (**Figure 4**) bore network is undertaken to measure field parameters, tritium, and gross alpha, gross beta and gamma emitting radionuclides. Results of this monitoring are shown in **Tables 25-30**.

Tritium activities in groundwater from the LFBG were below levels considered safe for drinking water in Australia. The gross alpha and gross beta activities in the groundwater were below the levels prescribed for surface waters in New South Wales. In fact, the majority of gross alpha and gross beta results (**Tables 28-30**) were below the more restrictive level of 0.5 Bq/L recommended in the ADWG (NHMRC and ARMCANZ 1996). Note that this comparison is made simply to provide context and that these guidelines are not applicable to groundwaters that do not contribute to public water supply. Gamma spectrometry of the unfiltered LFBG groundwater samples showed only low levels of natural potassium-40 and uranium-238 progeny and, in one well, occasional low levels of cobalt-60, americium-241 or cesium-137.

Measurement of LFBG groundwater field parameters included pH, electrical conductivity, redox potential and temperature (**Tables 25-27**). The electrical conductivity of groundwater bores in a direct line with the groundwater flow paths reflect fresh groundwater influence, while bores located away from these paths are more saline and probably reflect older waters. Distinct groundwater flow pathways at the LFBG have been identified to provide a better understanding of movement of radionuclides from the source to the surrounding environment. Little Forest is located in a groundwater recharge area, whereby rain water moves down-gradient from the site. Groundwater will move along pathways of least resistance and for the LFBG these pathways include:

- Surface water runoff
- The zone of aeration and saturation in the Ashfield Shale layer,
- Infiltration into the Hawkesbury Sandstone beneath the shale layer,
- Streamflow into Bardens and Mill Creeks, and ultimately the George's River.

Elevated tritium levels have, currently and historically, been identified in the LFBG groundwaters and are attributed to the buried waste. The tritiated water is not an environmental problem and in fact has been useful in identifying the groundwater flow paths associated with Little Forest. Based on these data, groundwater appears to flow away from the burial trenches in two directions, perpendicular from an east-west groundwater divide that runs through the central position of the burial trenches. Groundwater flows from this recharge zone to discharge areas (surface springs) at lower elevations. **Figure 13** illustrates the groundwater flowpaths.

The variation in tritium activity through time can be explained in terms of a simple decay process from a point source moving along a flow path with overlying sporadic variations, due to evaporative concentration and rain dilution. Hydrogeological data gathered historically and in recent times indicate that waste products and radionuclides from burial at Little Forest in the 1960's have not travelled any significant distance in the groundwater and are not a public health issue.

6.7 SOIL AND SEDIMENT

6.7.1 Bund sediments

Sediment that accumulates in the stormwater bunds is removed at least once each year. These sediments are analysed, prior to their removal, for gross alpha, gross beta and gamma radioactivity (**Table 31**). Measured gross alpha/beta activities correspond to background levels for similar sandy soils of the Sydney region. Gamma-emitters that were detected include naturally-occurring potassium-40 and members of the uranium-238 and thorium-232 decay series. As in previous years, levels of fission or activation products were also detected at low levels, far below the relevant ARPANSA exemption levels for classification of radioactive materials.

6.7.2 Sediment from local streams

Sediment was collected off-site near the confluence of Mill and Bardens creeks, which ultimately drain the LFBG area. Levels of gross alpha, gross beta and gamma radioactivity were measured (see **Table 18**) and showed only low levels of natural activity attributable to progeny of the uranium-238 and thorium-232 decay series, and potassium-40.

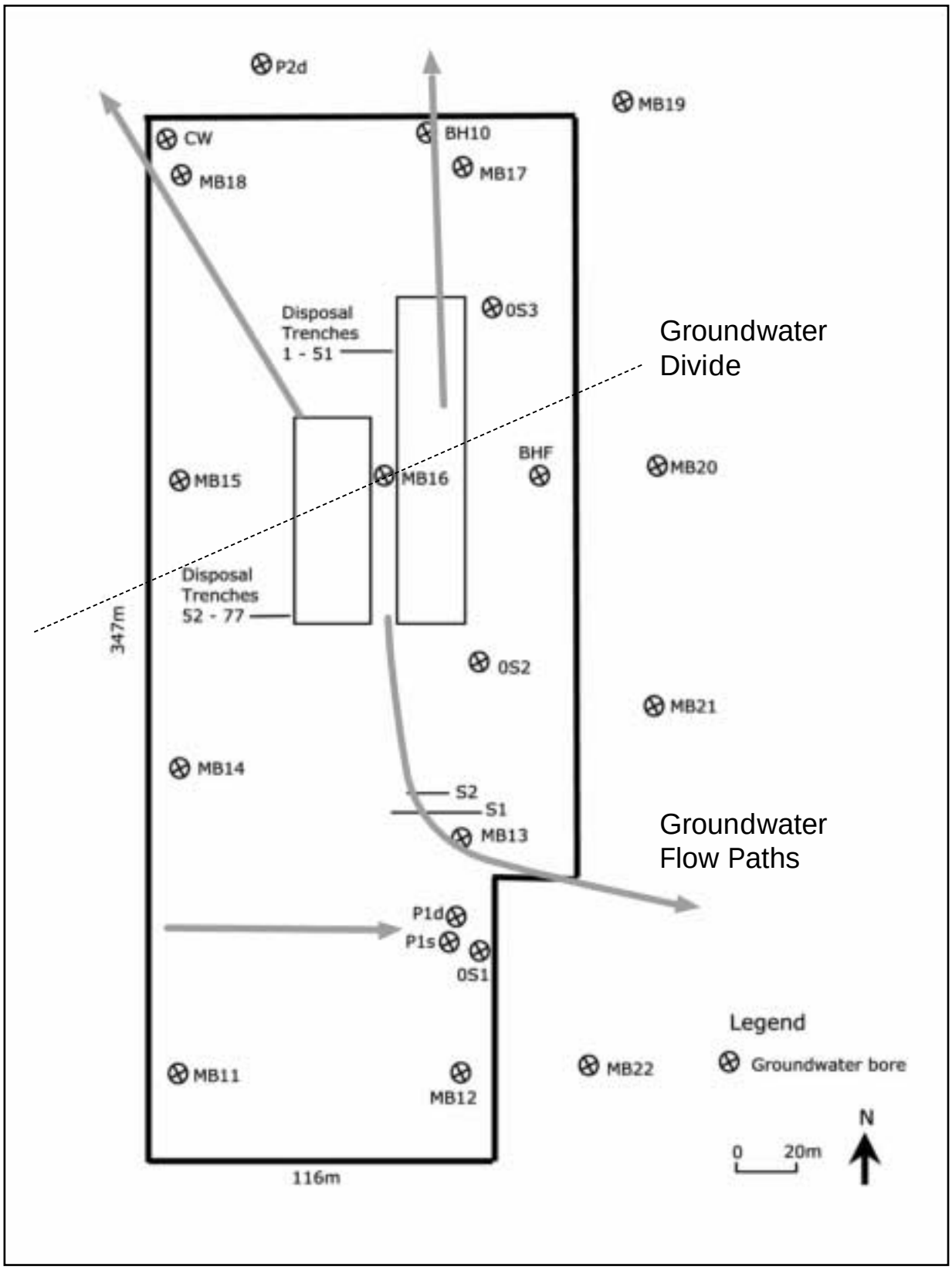


Figure 13. Little Forest Burial Ground – Groundwater flow paths

6.7.3 Gamma Dose Survey – Little Forest Burial Ground

Levels of gamma radiation over the burial area at the LFBG are surveyed annually to monitor surface soil dose-rates. Routine maintenance of the grassy area includes regular mowing and monitoring, then filling any shallow depressions with clay/shale of local origin. Dose rates over all of the trenches, including S1 and S2, were measured in December 2002 using a hand-held meter (**Table 32**). Recorded dose rates ranged from 0.08 to 0.15 μSv/hour and were consistent with previous measurements and background readings taken at the LFBG gate, approximately 200 metres away from the trench area. The potential radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

6.7.4 Gamma Dose Survey - Liquid Effluent Pipeline

The pipeline through which liquid effluent from the LHSTC is discharged to the Sydney Water Corporation sewer is shown, in part, on **Figure 2**. In addition to the regular inspection and maintenance of the pipeline, surveys of the dose rates along the accessible sections of pipeline were carried out in order to detect any past or present leaks. The results for January 2002 to June 2003 are summarised in **Table 33**. The measured dose rates ranged from 0.05 to 0.16 μSv/hour and were principally due to natural background radiation. No pipeline leaks were detected during the reporting period.

6.8 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 5**). Sampling of fish, algae (seaweed) and barnacles continued at the Potter Point ocean outfall and a reference site at The Royal National Park in 2002 and 2003, with authorisation from NSW Fisheries. These organisms represent different levels in the food chain and are known to concentrate a variety of elements, including radionuclides, from their environment. Blackfish or luderick (*Girella sp*.) were filleted and skinned, green algae (mainly *Ulva sp*. or *Enteromorpha sp*.) and surf barnacles (*Tesseropera rosea*) were left whole and unwashed. All samples were dried, ground and analysed for gamma-emitting radioisotopes (**Table 34-36**).

The radioactivity measured in marine fish, algae and barnacles sampled at Potter Point from January 2002 to June 2003 was of natural origin, apart from the low levels of iodine-131 found in the algae. Only naturally occurring radionuclides were detected in samples collected from the reference site.

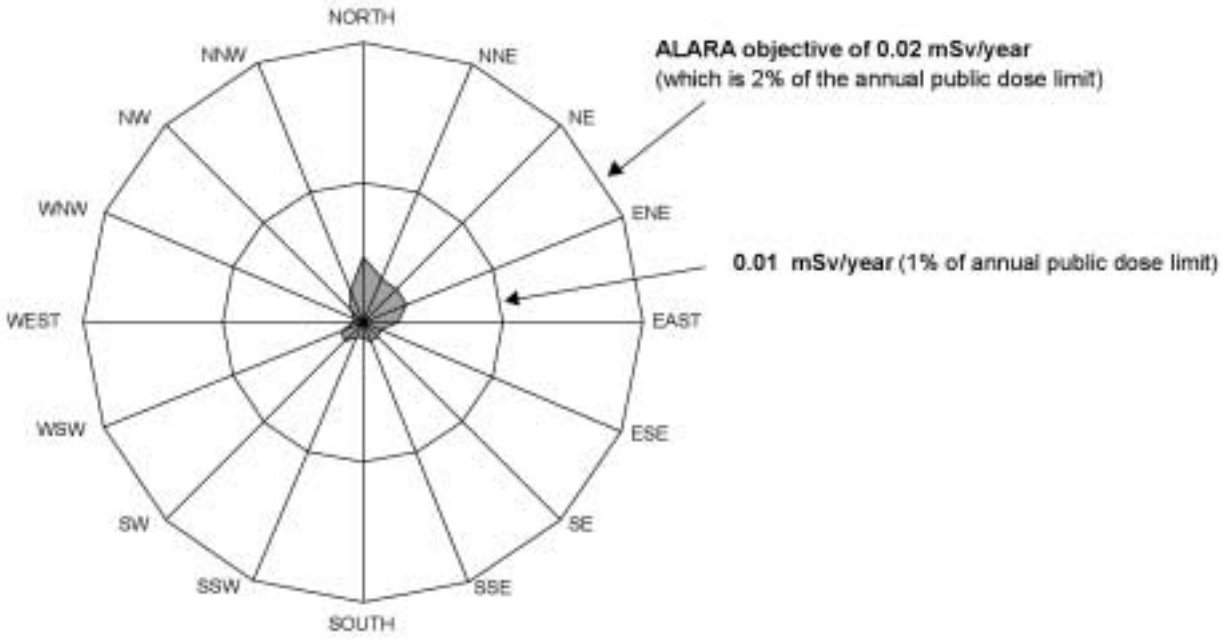
7. Potential Doses to the Public and Environment

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. ANSTO is committed to protecting the environment from the possible effects of ionising radiation and is actively participating in international forums that are supporting the development of a system to achieve this. Currently, there is no internationally agreed approach to assessing doses to non-human species and no established guidelines against which to determine the risks of such doses. Following the ICRP (1991), it is assumed here that demonstrating protection of humans from the potential effects of ionising radiation also demonstrates adequate protection of the environment.

7.1 AIRBORNE DISCHARGES

The effective doses to hypothetical individuals potentially exposed to radiation in routine airborne discharges from the LHSTC in 2001-2002 and 2002-2003 financial years were calculated to be less than 0.01 mSv/year (**Table 37**), based on the LHSTC stack discharge data and concurrent meteorological information. This is well below the ALARA objective of 0.02 mSv/year and much lower than the public dose rate limit of 1 mSv/year and the natural background in Australia of ~1.5 mSv/year (not including medical investigations; Webb *et al*. 1999). **Figure 14** shows the public dose from airborne emissions estimated for hypothetical individuals on a 1.6 km radius from HIFAR, relative to the ALARA objective for the 2001-2002 and 2002-2003 financial years.

2001-2002 Estimated Effective Dose from LHSTC Airborne Discharges (mSv/year) at 1.6km Radius from HIFAR



2002-2003 Estimated Effective Dose from LHSTC Airborne Discharges (mSv/year) at 1.6km Radius from HIFAR

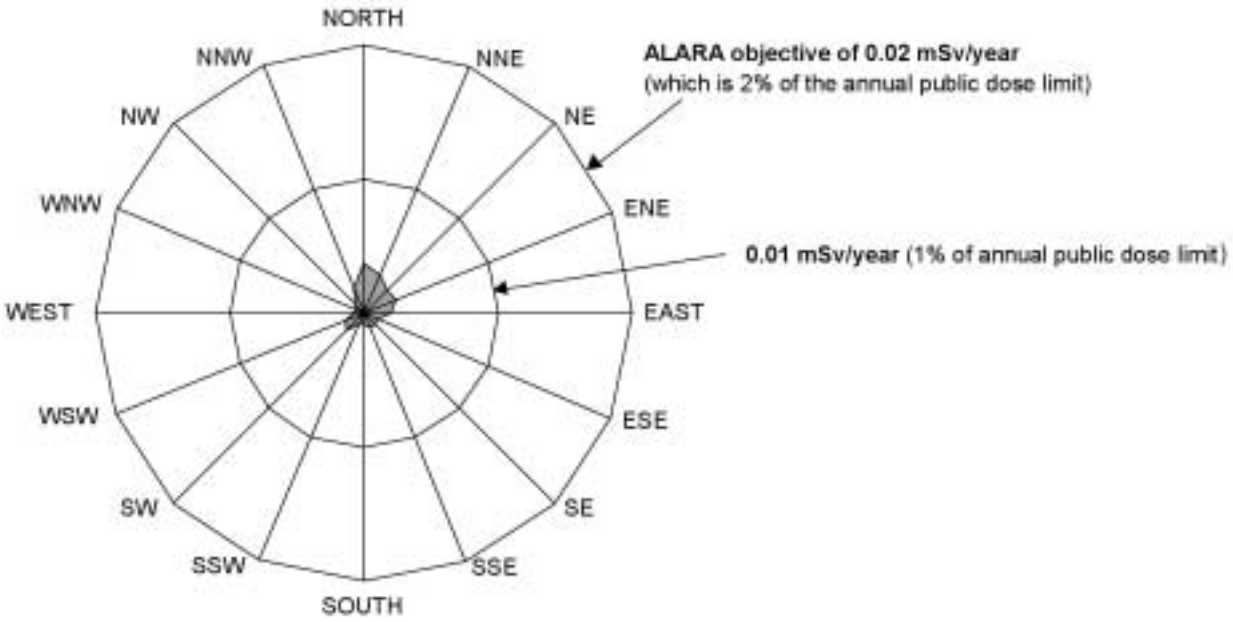


Figure 14. Estimated effective dose to the public from LHSTC airborne discharges on a 1.6 km radius from HIFAR, 2001-2002 and 2002-2003.

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

7.2 LIQUID EFFLUENT DISCHARGES

The effective dose rates to hypothetical individuals potentially exposed to radiation in routine liquid effluent discharges from the LHSTC were recently calculated, on the basis of previous effluent monitoring, to be less than 0.001 mSv/year. This is much less than the dose rates estimated for members of the public potentially exposed to airborne emissions (see section 4).

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

8. Conclusion

From January 2002 to June 2003 the estimated potential doses to members of the public from airborne discharges at the LHSTC are only a very small fraction of the radiation dose received by everyone each year from naturally-occurring sources of radiation. The monitoring results from Potter Point confirm that the potential radiation dose to members of the public as a result of ANSTO's liquid effluent discharges to the sewer is also very low. The levels of tritium in groundwater and stormwater at the LHSTC are less than Australian drinking water guidelines. The airborne and liquid effluent emissions from the NMC, from January 2002 to June 2003, were below the ARPANSA-approved notification levels and NSW EPA 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, even for the comparatively few members of the public identified as potentially exposed to radionuclides entering the environment from ANSTO sites.

9. Acknowledgements

The environmental and effluent monitoring program at ANSTO is very much a team effort. The following people are sincerely thanked for their contribution: Tom Loosz, Jenny Harrison, Kristy Falconer, Mark Alcorn, Ashley Gillen, Ashley Browne, Richard Barton, Werner Reynolds, Geoff Clark, Jim Pascoe, Peter Airey, Tom Kluss, John Bradd and Chris Waring. Thanks are also extended to those who made contributions to the text and/or provided constructive comments on text drafts.

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DATA TABLES

Table 1. MEDIAN DETECTION LIMITS FOR 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)	0.017	-	0.021	0.019	0.33	0.056	0.036	0.14	10	-	-
SOIL / SEDIMENT											
(Bq/g)	0.002	-	0.008	0.005	0.20	0.054	-	-	-	-	-
FISH											
(Bq/kg fresh weight)	0.41	0.36	0.60	0.55	162.6	2.8	-	-	-	-	-
ALGAE (seaweed)											
(Bq/kg fresh weight)	0.28	0.52	0.31	0.46	177.8	1.85	-	-	-	-	-
BARNACLES											
(Bq/kg fresh weight)	0.58	0.68	0.68	1.0	46.6	6.54	-	-	-	-	-
MAYPACKS											
(Bq/m^3)	-	0.0025	-	-	-	-	-	-	-	-	-
AIRBORNE PARTICLES											
(Hi-volume air filters)	-	-	-	-	-	-	-	-	-	0.001	0.035

Table 2 . ANNUAL AIRBORNE ACTIVITY DISCHARGE REPORT, LHSTC & NMC, July 2001 – June 2002

Start: 26-Jun-01 End: 25-Jun-02 Sampling period (days): 364 Year: 2001/2002

	Particulates		Gases and Vapours																	
STACK	Gross Alpha (MBq)	Gross Beta (MBq)	I-131 (MBq)	Tritium (GBq)	Ar-41 (TBq)	Hg-197 (MBq)	Hg-203 (MBq)	As-76 (MBq)	Br-82 (MBq)	I-132 (MBq)	I-133 (MBq)	Xe-133 (TBq)	Xe-135 (TBq)	Xe-135m (TBq)	Kr-85m (TBq)	Kr-87 (GBq)	Kr-88 (TBq)	F-18 (GBq)	I-123 (GBq)	All Other Nuclides (MBq)
3	N.D.	N.D.																		2.17
	-	-																		0.4%
15A	N.D.	0.72	4.45	1696.0	130.50	56.60	3.97	171.40	5.04											
	-	1.2%	11.1%	17.0%	72.5%	20.2%	9.9%	68.6%	20.2%											
15M	N.D.	N.D.	0.77	244.80	12.96															
	-	-	7.7%	54.4%	144.0%															
19S	N.D.	N.D.	6.91																	N.D.
	-	-	13.8%																	-
19D	N.D.	N.D.	0.16																	N.D.
	-	-	0.3%																	-
20	N.D.	N.D.		51.37																6.59
	-	-		23.4%																1.3%
21A	N.D.	N.D.																		0.17
	-	-																		0.0%
21B	N.D.	N.D.																		N.D.
	-	-																		-
23A	N.D.	3.06	2028																	N.D.
	-	0.9%	6.1%																	-
23B	N.D.	N.D.	1.80																	N.D.
	-	-	1.6%																	-
41A	N.D.	N.D.																		24.90
	-	-																		5.0%
41B	N.D.	N.D.																		9.90
	-	-																		2.0%
54	N.D.	N.D.	14970							94400	3886	190.60	42.90	33.01	9.21	N.D.	0.49			N.D.
	-	-	53.5%							39.3%	25.9%	68.1%	10.7%	8.3%	14.2%	-	8.2%			-
56	N.D.	N.D.																		2.43
	-	-																		0.5%
57	N.D.	N.D.		189.5																0.66
	-	-		86.1%																0.1%
NMC																		11.02	49.83	413.65
																		4.41%	49.83%	82.7%

Notes for tables 2 & 3: N.D. = None Detected. Percentages reported are the percentage of the annual notification level. The sampling period for NMC was 1 July 2001 to 28 June 2002. The "All Other Nuclides" column includes all nuclides for which no specific notification level exists.*ie* It may include the shaded nuclides.

Table 3. ANNUAL AIRBORNE ACTIVITY DISCHARGE REPORT, LHSTC & NMC, July 2002 – June 2003

Start: 25-Jun-02 End: 24-Jun-03 Sampling period (days): 364 Year: 2002/2003

	Particulates		Gases and Vapours																	
STACK	Gross Alpha (MBq)	Gross Beta (MBq)	I-131 (MBq)	Tritium (GBq)	Ar-41 (TBq)	Hg-197 (MBq)	Hg-203 (MBq)	As-76 (MBq)	Br-82 (MBq)	I-132 (MBq)	I-133 (MBq)	Xe-133 (TBq)	Xe-135 (TBq)	Xe-135m (TBq)	Kr-85m (TBq)	Kr-87 (GBq)	Kr-88 (TBq)	F-18 (GBq)	I-123 (GBq)	All Other Nuclides (MBq)
3	N.D.	N.D.																		2.92
	-	-																		0.6%
15A	N.D.	1.11	4.71	2634.00	96.90	102.10	6.89	134.80	5.58											
	-	1.9%	11.8%	26.3%	53.8%	36.5%	17.2%	53.9%	22.3%											
15M	N.D.	N.D.	0.19	305.90	10.49															
	-	-	1.9%	68.0%	52.5%															
19S	N.D.	N.D.	9.46																	N.D.
	-	-	18.9%																	-
19D	N.D.	N.D.	0.45																	N.D.
	-	-	0.9%																	-
20	0.13	0.15		354.60																26.84
	1.3%	0.2%		161.2%																5.4%
21A	N.D.	N.D.																		0.19
	-	-																		0.0%
21B	N.D.	N.D.																		0.03
	-	-																		0.0%
23A	N.D.	3.30	1597																	N.D.
	-	1.0%	4.8%																	-
23B	N.D.	N.D.	6.61																	N.D.
	-	-	6.0%																	-
41A	N.D.	N.D.																		13.76
	-	-																		2.8%
41B	N.D.	N.D.																		2.54
	-	-																		0.5%
54	N.D.	N.D.	10670							71600	1393	298.40	65.98	54.35	14.75	N.D.	0.09			N.D.
	-	-	38.1%							29.8%	9.3%	106.6%	16.5%	13.6%	22.7%	-	1.5%			-
56	N.D.	N.D.																		4.03
	-	-																		0.8%
57	N.D.	N.D.		144.3																2.27
	-	-		65.6%																0.5%
NMC																		15.12	50.68	256.45
																		6.05%	50.68%	51.3%

Notes for tables 2 & 3: N.D. = None Detected. Percentages reported are the percentage of the annual notification level. The sampling period for NMC was 25 June 2002 to 24 June 2003. The "All Other Nuclides" column includes all nuclides for which no specific notification level exists. *ie* It may include the shaded nuclides.

Table 4. RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, LHSTC, January 2002 - June 2003

MONTH	TOTAL VOLUME Discharged m^3	AVERAGE CONCENTRATION IN DISCHARGES			Average MONTHLY Concentration QUOTIENT (3)
		ALPHA (1) Bq/m^3	BETA (2) Bq/m^3	TRITIUM Bq/m^3	
January 2002	5932	$< 9.0 \times 10^2$	3.20×10^3	5.28×10^6	< 0.13
February 2002	9014	$< 9.0 \times 10^2$	5.07×10^3	1.58×10^6	< 0.12
March 2002	12219	$< 1.0 \times 10^3$	2.57×10^3	2.66×10^6	< 0.12
April 2002	10428	$< 1.1 \times 10^3$	3.50×10^3	3.57×10^6	< 0.13
May 2002	7502	$< 1.1 \times 10^3$	6.10×10^3	3.17×10^6	< 0.16
June 2002	6945	$< 1.1 \times 10^3$	4.36×10^3	2.77×10^6	< 0.14
July 2002	8242	$< 1.0 \times 10^3$	4.23×10^3	2.92×10^6	< 0.13
August 2002	7773	$< 1.1 \times 10^3$	3.73×10^3	2.99×10^6	< 0.13
September 2002	6211	$< 3.0 \times 10^2$	2.89×10^3	2.62×10^6	< 0.06
October 2002	7117	$< 9.5 \times 10^2$	1.13×10^4	4.75×10^6	< 0.19
November 2002	7593	$< 8.5 \times 10^2$	2.00×10^3	4.25×10^6	< 0.11
December 2002	6990	$< 8.5 \times 10^2$	3.40×10^3	5.10×10^6	< 0.12
January 2003	6054	$< 8.3 \times 10^2$	4.34×10^3	4.59×10^6	< 0.12
February 2003	8467	$< 6.6 \times 10^2$	6.76×10^3	5.34×10^6	< 0.13
March 2003	7602	$< 6.9 \times 10^2$	5.62×10^3	4.60×10^6	< 0.12
April 2003	8243	$< 5.5 \times 10^2$	2.70×10^3	4.13×10^6	< 0.09
May 2003	14278	$< 1.0 \times 10^3$	2.62×10^3	4.12×10^6	< 0.12
June 2003	8745	$< 6.6 \times 10^2$	4.20×10^3	5.73×10^6	< 0.12
Regulatory Limit: Activity Concentration Equivalent at ANSTO (4)		1.25×10^4 (as ^{226}Ra)	1.25×10^5 (as ^{90}Sr)	1.95×10^8	1.00

Notes:
1. A mixture of unidentified alpha-emitting nuclides, assumed to be all radium-226 (*ie*. possible worst case) when calculating the concentration quotient.
2. A mixture of unidentified beta-emitting nuclides, assumed to be all strontium-90 (*ie*. possible worst case) when calculating the concentration quotient.
3. Concentration Quotient: the sum of the average monthly concentrations of alpha, beta and tritium radioactivity in the liquid effluent divided by the Activity Concentration Equivalent for that radionuclide. The final quotient term must be no greater than one to comply with the requirements of the Sydney Water Trade Wastewater Agreement.
4. All discharges were below the required Activity Concentration Equivalents at ANSTO which are based on the WHO Guidelines for Drinking-Water Quality (WHO 1993).

Table 5. GAMMA-EMITTERS IN LIQUID EFFLUENT, MONTHLY PIPELINE COMPOSITE SAMPLES, LHSTC, January 2002 to June 2003

MONTH [1]	Gamma-emitters (Bq/L)								
	Ce-144	**Co-60**	**Cr-51**	**Cs-134**	**Cs-137**	**I-131**	**Ra-226**	**Pb-210**	**Ra-228**
January 2002	< MDA	1.04 ± 0.05	< MDA	< MDA	0.44 ± 0.06	0.26 ± 0.04	< MDA	< MDA	< MDA
February 2002	< MDA	0.75 ± 0.06	2.8 ± 0.4	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA
March 2002	< MDA	1.33 ± 0.07	< MDA	< MDA	< MDA	0.42 ± 0.05	< MDA	< MDA	< MDA
April 2002	< MDA	0.52 ± 0.05	< MDA	< MDA	0.37 ± 0.04	0.32 ± 0.04	< MDA	< MDA	< MDA
May 2002	< MDA	3.03 ± 0.09	< MDA	< MDA	1.15 ± 0.06	< MDA	< MDA	< MDA	< MDA
June 2002	< MDA	1.80 ± 0.09	< MDA	< MDA	< MDA	0.10 ± 0.02	< MDA	< MDA	< MDA
July 2002	< MDA	0.90 ± 0.05	< MDA	< MDA	0.3 ± 0.05	0.30 ± 0.04	< MDA	< MDA	< MDA
August 2002	< MDA	< MDA	< MDA	< MDA	0.4 ± 0.06	< MDA	< MDA	< MDA	< MDA
September 2002	< MDA	0.60 ± 0.05	< MDA	< MDA	0.2 ± 0.04	< MDA	< MDA	< MDA	< MDA
October 2002	< MDA	0.66 ± 0.05	< MDA	< MDA	4.04 ± 0.08	0.58 ± 0.03	7.16 ± 0.79	< MDA	< MDA
November 2002	< MDA	< MDA	< MDA	< MDA	0.31 ± 0.05	0.17 ± 0.03	< MDA	< MDA	< MDA
December 2002	< MDA	< MDA	< MDA	< MDA	2.05 ± 0.16	< MDA	< MDA	< MDA	< MDA
January 2003	< MDA	0.70 ± 0.04	< MDA	0.28 ± 0.03	0.41 ± 0.07	< MDA	< MDA	< MDA	< MDA
February 2003	< MDA	0.66 ± 0.05	< MDA	< MDA	0.68 ± 0.07	0.42 ± 0.05	< MDA	< MDA	< MDA
March 2003	< MDA	0.64 ± 0.06	< MDA	< MDA	2.28 ± 0.07	< MDA	6.35 ± 0.06	< MDA	< MDA
April 2003	< MDA	0.39 ± 0.04	< MDA	< MDA	0.31 ± 0.06	0.74 ± 0.05	< MDA	< MDA	< MDA
May 2003	< MDA	< MDA	2.0 ± 0.4	< MDA	< MDA	0.32 ± 0.04	< MDA	< MDA	< MDA
June 2003	< MDA	0.83 ± 0.05	< MDA	< MDA	0.67 ± 0.05	0.40 ± 0.04	< MDA	< MDA	< MDA

Notes:
1. 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.
2. < MDA: indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Median MDA values for the relevant radionuclides are as follows: 0.40 for Ce-144, 0.15 for Co-60, 0.6 for Cr-51, 0.09 for Cs-134, 0.11 for Cs-137, 0.10 for I-131, 1.8 for Ra-226, 1.7 for Pb-210, and 0.41 for Ra-228.

Table 6. NON-RADIOACTIVE COMPONENTS OF LIQUID EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, LHSTC, January 2002 to June 2003

Parameter	Concentration (mg/L) January 2002 – June 2003			Standard for Acceptance mg/L (2)
	Mean (1)	Median	Range	
Suspended Solids	24	16	< 1 - 93	**600**
pH	7.2	7.3	5.2 - 9.9	**7 – 10**
Ammonia	9.6	8.6	< 0.5 - 38.7	**100**
B.O.D. (3)	20.1	14	< 2 - 148	**85** (3)
Grease	7.6	5	< 5 - 57	**50**
Zinc	0.2	0.2	< 0.1 – 0.7	**5**

Notes:

1. The annual mean is conservative because results that were below the detection limits were included.
2. The sampling regime was every 4 days from 1 July 2002, when the Sydney Water Trade Wastewater Agreement was renegotiated. Of the samples analysed, 95% must be less than or equal to the Standards for Acceptance of Liquid Trade Wastes to Sewers, specified in the Sydney Water Trade Waste Policy and Management Plan (1995).
3. The standards for acceptance do not stipulate a specific limit for biological oxygen demand (BOD), therefore the agreed limit is applicable in this case.

Table 7. AVERAGE ACTIVITY OF RADIONUCLIDES IN LIQUID EFFLUENT, NMC, January 2002 to June 2003

	Monthly Average Concentration in Liquid Effluent (MBq/m^3)					
	Tl-201	**Tl-202**	**Ga-67**	**Co-57**	**Zn-65**	**I-123**
Half-life (days)	**3.0**	**12.2**	**3.3**	**270.9**	**244.4**	**0.54**
January 2002	4.18	1.63	0.37	0.34	0.27	ND
February 2002	57.85	3.75	6.33	0.59	0.20	ND
March 2002	9.51	2.43	0.99	0.69	0.18	ND
April 2002	52.63	4.28	1.02	0.41	0.20	ND
May 2002	5.23	4.04	1.79	0.59	0.25	ND
June 2002	13.55	4.76	1.18	0.64	0.38	ND
July 2002	2.86	2.61	1.33	0.63	0.43	ND
August 2002	2.39	1.33	0.05	0.41	0.17	ND
September 2002	0.50	1.97	ND	1.88	6.23	ND
October 2002	0.38	0.38	0.03	0.60	0.37	0.02
November 2002	1.02	0.30	0.11	0.69	0.33	ND
December 2002	6.37	1.61	6.36	2.09	0.77	ND
January 2003	0.82	2.36	3.42	2.55	0.41	ND
February 2003	0.76	0.59	0.10	1.23	0.33	ND
March 2003	1.16	0.45	0.19	0.38	1.10	ND
April 2003	1.03	0.53	0.57	0.28	0.12	ND
May 2003	1.21	1.85	1.14	1.04	0.24	ND
June 2003	20.79	18.93	8.53	1.68	0.82	ND
Mean	10.12	2.99	1.86	0.93	0.71	0.02
Median	2.63	1.91	1.00	0.63	0.33	0.02
NSW EPA Monthly Limits	**200**	**100**	**600**	**400**	**100**	**6.00**

Table 8. AMBIENT IODINE-131 IN AIR AT LHSTC, January 2002 to June 2003

Sampled during the week ending:	**Iodine-131**(1,2) In Air (Bq/m^3)	Sampled during the week ending:	**Iodine-131**(1,2) In Air (Bq/m^3)	Sampled during the week ending:	**Iodine-131**(1,2) In Air (Bq/m^3)
2-1-02	< MDA	3-7-02	< MDA	30-12-02	< MDA
9-1-02	< MDA	9-7-02	< MDA	8-1-03	< MDA
15-1-02	< MDA	16-7-02	< MDA	14-1-03	< MDA
23-1-02	< MDA	23-7-02	< MDA	21-1-03	< MDA
29-1-02	< MDA	30-7-02	< MDA	28-1-03	< MDA
5-2-02	< MDA	6-8-02	< MDA	4-2-03	< MDA
12-2-02	< MDA	13-8-02	< MDA	11-2-03	< MDA
19-2-02	< MDA	20-8-02	< MDA	18-2-03	< MDA
26-2-02	< MDA	27-8-02	< MDA	25-2-03	< MDA
5-3-02	< MDA	3-9-02	< MDA	4-3-03	< MDA
12-3-02	< MDA	10-9-02	< MDA	11-3-03	< MDA
19-3-02	< MDA	17-9-02	< MDA	18-3-03	< MDA
26-3-02	< MDA	24-9-02	< MDA	25-3-03	< MDA
2-4-02	< MDA	1-10-02	< MDA	1-4-03	< MDA
9-4-02	< MDA	8-10-02	< MDA	8-4-03	< MDA
16-4-02	< MDA	15-10-02	< MDA	15-4-03	< MDA
23-4-02	< MDA	22-10-02	< MDA	22-4-03	< MDA
30-4-02	< MDA	29-10-02	< MDA	29-4-03	< MDA
7-5-02	< MDA	5-11-02	< MDA	6-5-03	< MDA
14-5-02	< MDA	12-11-02	< MDA	13-5-03	< MDA
21-5-02	< MDA	19-11-02	< MDA	20-5-03	< MDA
28-5-02	< MDA	26-11-02	< MDA	27-5-03	< MDA
4-6-02	< MDA	3-12-02	< MDA	3-6-03	< MDA
11-6-02	< MDA	10-12-02	< MDA	10-6-03	< MDA
18-6-02	< MDA	17-12-02	< MDA	17-6-03	< MDA
25-6-02	< MDA	23-12-02	< MDA	24-6-03	< MDA

Notes:

1. Four air samplers are located along the eastern boundary of the LHSTC site, see Figure 2.
2. < MDA indicates that the result was below the minimum detectable activity (0.0025 Bq/m^3). Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1.

Table 9. RADIOACTIVITY IN AIRBORNE PARTICLES, LFBG, January 2002 to June 2003

Sampling Period (1)	**Equivalent Volume** (2)	**Beryllium** (3)		**Plutonium-239/240** (4)	
	m^3	µg (total)	$\mu g/m^3$	Bq (total)	Bq/m^3
Jan – Mar 02 (5)	342.7	< MDA (6)	$< 1.0 \times 10^{-4}$	< MDA	$< 1.3 \times 10^{-6}$
Apr – Jun 02	428.8	< MDA	$< 8.2 \times 10^{-5}$		
July – Sept 02	437.2	< MDA	$< 8.0 \times 10^{-5}$	< MDA	$< 5.4 \times 10^{-7}$
Oct – Dec 02	461.1	< MDA	$< 7.6 \times 10^{-5}$		
Jan – Mar 03	492.9	< MDA	$< 7.1 \times 10^{-5}$		
Apr – Jun 03	454.5	< MDA	$< 7.7 \times 10^{-5}$		

Notes:

1. Airborne particulates were collected using a mobile high-volume air sampler and samples were accumulated on a single filter over a period of 3 months. The sampling duration and frequency was approximately 4 hours, every 2 weeks. The filter paper was then divided into four equal parts with one being used per Be & Pu analysis and two retained as duplicates.
2. The Equivalent Volume is 25% of the total volume of air sampled during the period, since one-quarter of the total filter was analysed.
3. The Worksafe Australia Exposure Standard for atmospheric contaminants such as beryllium in air is 2 $\mu g/m^3$ (applicable to workers exposed 8 hours per day, 50 weeks per year).
4. The limit of detection for plutonium-239/240 in Bq/m^3 would equate to a committed effective dose to adults of < 0.0002 mSv/year, or < 0.02% of the allowable public dose limit of 1 mSv/y.
5. The 2 quarterly samples for January to June 2002, and the 4 filters for the 2002-3 financial year, were combined for plutonium analyses.
6. < MDA: indicates that the result was below the minimum detectable activity, calculated with 95% confidence. Indicative (median) MDA values for various radionuclides and environmental media are listed in Table 1. The concentrations were calculated using the median MDA and the volume of air sampled.

Table 10. EXTERNAL GAMMA RADIATION, LHSTC and LOCAL AREA, ANNUAL EFFECTIVE DOSE for 2001-2002 and 2002-2003

ANSTO Environmental Thermoluminescent Dosimeters [1]			
Dosimeter Location: on-site [2]		**Annual Effective Dose** [3] (mSv / year)	
		2001-2	2002-3
1	HIFAR fence - south east	1.15 ± 0.04	1.13 ± 0.04
2	HIFAR fence - south	3.23 ± 0.10	2.94 ± 0.11
3	Perimeter fence - west	1.50 ± 0.05	2.15 ± 0.08
4	HIFAR fence - west	1.54 ± 0.05	1.45 ± 0.06
5	HIFAR fence - north west	1.31 ± 0.04	1.24 ± 0.05
6	Perimeter fence - north A	0.98 ± 0.03	1.05 ± 0.04
7	Internal fence - north	1.08 ± 0.03	1.09 ± 0.04
8	Perimeter fence - north B	1.07 ± 0.03	1.50 ± 0.06
9	Perimeter fence - north east	0.80 ± 0.03	0.93 ± 0.04
10	Perimeter fence - east	1.05 ± 0.03	0.93 ± 0.04
11	Perimeter fence - south east	0.98 ± 0.03	0.97 ± 0.04
12	Corner of Curie and Roentgen St	1.23 ± 0.04	1.15 ± 0.04
13	Perimeter fence - south	0.86 ± 0.03	0.94 ± 0.04
14	HIFAR fence - east	1.17 ± 0.04	1.03 ± 0.04
15	HIFAR fence - north east	1.27 ± 0.04	1.10 ± 0.04
	Dosimeter Location: off-site		
16	Private house - Barden Ridge	0.95 ± 0.03	0.98 ± 0.04
17	Private house - Engadine	1.33 ± 0.04	1.24 ± 0.05
18	Private house - Woronora	1.04 ± 0.03	1.09 ± 0.04
19	Cronulla Sewage Treatment Plant	0.65 ± 0.02	0.71 ± 0.03

Notes:
1. Refer to Figure 2 for the locations of thermoluminescent dosimeters 1 to 15.
2. The ANSTO environmental dosimeters contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters. 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.
3. The data were reported as absorbed dose to air (mGy) and converted to effective dose for adults (mSv) using a conservative conversion factor of 1. UNSCEAR (1993) uses a factor of 0.72 Sv per Gy for adults, 0.80 for children and 0.93 for infants.

Table 11. TRITIUM IN STORMWATER BUNDS, MONTHLY COMPOSITES, LHSTC
January 2002 to June 2003

	TRITIUM (Bq/L)		
Month (1)	**BUND A**	**BUND B**	**BUND C**
January 2002	300 ± 10	80 ± 10	50 ± 10
February 2002	440 ± 10	50 ± 10	60 ± 10
March 2002	310 ± 20	70 ± 20	370 ± 20
April 2002	390 ± 10	140 ± 20	320 ± 20
May 2002	120 ± 20	60 ± 10	260 ± 10
June 2002	200 ± 20	70 ± 10	130 ± 10
July 2002	120 ± 10	70 ± 10	410 ± 10
August 2002	120 ± 10	60 ± 10	610 ± 20
September 2002	70 ± 10	70 ± 10	130 ± 10
October 2002	< MDA	40 ± 10	50 ± 10
November 2002	30 ± 10	40 ± 10	130 ± 10
December 2002	140 ± 10	50 ± 10	120 ± 10
January 2003	80 ± 10	40 ± 10	80 ± 10
February 2003	260 ± 10	80 ± 10	420 ± 20
March 2003	210 ± 10	60 ± 10	580 ± 20
April 2003	160 ± 10	90 ± 10	260 ± 10
May 2003	110 ± 10	30 ± 10	190 ± 10
June 2003	150 ± 10	60 ± 10	190 ± 10

Notes:
1. Refer to Figure 2 for the locations of the bunds. One litre was collected daily from each bund before it was discharged (except weekends and public holidays). These daily samples were combined to form a monthly composite from each bund for tritium analysis.
2. The Australian guideline value for tritium in drinking water is 7600 Bq/L (NH&MRC 1996).
3. < 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 12. TRITIUM IN STORMWATER, BUND C, LHSTC, January 2002 to June 2003

Date	**Tritium** Bq/L	Date	**Tritium** Bq/L	Date	**Tritium** Bq/L	Date	**Tritium** Bq/L
02-01-02	110 ± 10	14-5-02	390 ± 20	1-10-02	120 ± 10	18-2-03	700 ± 20
09-01-02	210 ± 10	21-5-02	200 ± 10	8-10-02	90 ± 10	25-2-03	330 ± 10
15-01-02	60 ± 10	28-5-02	340 ± 10	15-10-02	140 ± 20	4-3-03	550 ± 20
22-01-02	90 ± 10	4-6-02	150 ± 20	22-10-02	140 ± 20	11-3-03	150 ± 10
29-01-02	100 ± 10	11-6-02	300 ± 20	29-10-02	120 ± 20	18-3-03	1480 ± 30
5-2-02	< MDA	18-6-02	240 ± 20	5-11-02	170 ± 10	25-3-03	970 ± 20
12-2-02	80 ± 10	25-6-02	250 ± 20	12-11-02	2550 ± 50	1-4-03	330 ± 10
19-2-02	70 ± 10	3-7-02	210 ± 20	19-11-02	180 ± 20	8-4-03	630 ± 20
26-2-02	60 ± 10	9-7-02	150 ± 10	26-11-02	100 ± 10	15-4-02	420 ± 10
5-3-02	150 ± 10	16-7-02	160 ± 10	3-12-02	150 ± 20	22-4-03	430 ± 10
12-3-02	1400 ± 30	23-7-02	1070 ± 30	10-12-02	20 ± 10	29-4-03	150 ± 10
19-3-02	200 ± 20	30-7-02	100 ± 10	17-12-02	110 ± 20	6-5-03	70 ± 10
26-3-02	180 ± 10	6-8-02	240 ± 10	23-12-02	120 ± 10	13-5-03	30 ± 10
2-4-02	2450 ±50	13-8-02	1750 ± 50	30-12-02	260 ± 10	20-5-03	220 ± 10
9-4-02	390 ± 10	20-8-02	1150 ± 20	7-1-03	220 ± 20	27-5-03	290 ± 10
16-4-02	330 ± 10	29-8-02	510 ± 10	14-1-03	120 ± 20	3-6-03	150 ± 10
23-04-02	240 ± 10	3-9-02	140 ± 20	21-1-03	110 ± 20	10-6-03	130 ± 10
30-4-02	280 ± 20	10-9-02	90 ± 10	28-1-03	120 ± 20	17-6-03	110 ± 10
7-5-02	290 ± 10	17-9-02	20 ± 10	4-2-03	20 ± 10	24-6-03	90 ± 10
		24-9-02	210 ± 10	11-2-03	830 ± 20		

Notes:
1. Refer to Figure 2 for the location of this sampling point. The weekly water samples were also combined into monthly composite samples and analysed for gross alpha/beta and gamma activity.
2. < 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 13. TRITIUM IN SURFACE WATER, MDP + 60m, LHSTC, January 2002 to June 2003

Date	**Tritium** Bq/L	Date	**Tritium** Bq/L	Date	**Tritium** Bq/L	Date	**Tritium** Bq/L
02-01-02	90 ± 20	14-5-02	110 ± 10	1-10-02	60 ± 10	18-2-03	240 ± 10
09-01-02	70 ± 20	21-5-02	190 ± 10	8-10-02	70 ± 10	25-2-03	900 ± 20
15-01-02	100 ± 20	28-5-02	160 ± 20	15-10-02	70 ± 10	4-3-03	220 ± 10
22-01-02	90 ± 10	4-6-02	270 ± 10	22-10-02	70 ± 10	11-3-03	140 ± 10
29-01-02	100 ± 10	11-6-02	130 ± 10	29-10-02	60 ± 10	18-3-03	440 ± 10
5-2-02	< MDA	18-6-02	220 ± 20	5-11-02	60 ± 10	25-3-03	240 ± 10
12-2-02	60 ± 10	25-6-02	80 ± 10	12-11-02	70 ± 10	1-4-03	220 ± 10
19-2-02	50 ± 10	3-7-02	100 ± 10	19-11-02	80 ± 10	8-4-03	220 ± 10
26-2-02	60 ± 10	9-7-02	70 ± 10	26-11-02	70 ± 10	15-4-03	160 ± 10
5-3-02	130 ± 10	16-7-02	70 ± 10	3-12-02	70 ± 10	22-4-03	320 ± 10
12-3-02	250 ± 20	23-7-02	1070 ± 10	10-12-02	60 ± 10	29-4-03	160 ± 10
19-3-02	140 ± 20	30-7-02	100 ± 10	17-12-02	100 ± 10	6-5-03	30 ± 10
26-3-02	140 ± 10	6-8-02	120 ± 10	23-12-02	90 ± 10	13-5-03	30 ± 10
2-4-02	1920 ±10	13-8-02	450 ± 20	30-12-02	120 ± 10	20-5-03	190 ± 10
9-4-02	300 ± 10	20-8-02	160 ± 20	7-1-03	90 ± 10	27-5-03	70 ± 10
16-4-02	230 ± 10	29-8-02	100 ± 10	14-1-03	70 ± 10	3-6-03	130 ± 10
23-04-02	190 ± 10	3-9-02	100 ± 10	21-1-03	80 ± 10	10-6-03	100 ± 10
30-4-02	130 ± 20	10-9-02	60 ± 20	28-1-03	70 ± 10	17-6-03	110 ± 10
7-5-02	100 ± 10	17-9-02	40 ± 10	4-2-03	30 ± 10	24-6-03	100 ± 10
		24-9-02	70 ± 10	11-2-03	360 ± 10		

Notes:
1. Refer to Figure 2 for the location of this sampling point, 60m downstream of the MDP Bund. The weekly water samples above were also combined into monthly composite samples and analysed for gross alpha, beta and gamma activity
2. < 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 SURFACE WATER, BARDENS CREEK WEIR, LHSTC, January 2002 to June 2003

Date	**Tritium** Bq/L	Date	**Tritium** Bq/L	Date	**Tritium** Bq/L	Date	**Tritium** Bq/L
2-1-02	140 ± 20	14-5-02	70 ± 20	1-10-02	20 ± 10	18-2-03	130 ± 10
9-1-02	110 ± 20	21-5-02	60 ± 10	8-10-02	30 ± 10	25-2-03	120 ± 10
15-1-02	100 ± 20	28-5-02	60 ± 20	15-0-02	30 ± 20	4-3-03	140 ± 10
22-1-02	80 ± 10	4-6-02	140 ± 30	22-10-02	30 ± 10	11-3-03	60 ± 10
29-1-02	110 ± 10	11-6-02	40 ± 10	29-10-02	30 ± 10	18-3-03	160 ± 10
5-2-02	40 ± 10	18-6-02	30 ± 10	5-11-02	20 ± 10	25-3-03	100 ± 10
12-2-02	80 ± 20	25-6-02	50 ± 10	12-11-02	20 ± 10	1-4-03	100 ± 10
19-2-02	70 ± 20	3-7-02	< MDA	19-11-02	30 ± 10	8-4-03	30 ± 10
26-2-02	180 ± 10	9-7-02	20 ± 10	26-11-02	30 ± 10	15-4-03	90 ± 10
5-3-02	50 ± 10	16-7-02	20 ± 10	3-12-02	50 ± 10	22-4-03	90 ± 10
12-3-02	40 ± 10	23-7-02	30 ± 10	10-12-02	50 ± 10	29-4-03	50 ± 10
19-3-02	< MDA	30-7-02	90 ± 10	17-12-02	40 ± 10	6-5-03	50 ± 10
26-3-02	60 ± 10	6-8-02	30 ± 10	23-12-02	40 ± 10	13-5-03	100 ± 10
2-4-02	120 ± 10	13-8-02	20 ± 10	30-12-02	60 ± 10	20-5-03	40 ± 10
9-4-02	100 ± 10	20-8-02	30 ± 10	7-1-03	40 ± 10	27-5-03	50 ± 10
16-4-02	120 ± 10	29-8-02	60 ± 20	14-1-03	110 ± 10	3-6-03	40 ± 10
23-04-02	90 ± 10	3-9-02	40 ± 10	21-1-03	100 ± 10	10-6-03	30 ± 10
30-4-02	100 ± 20	10-9-02	30 ± 20	28-1-03	90 ± 20	17-6-03	30 ± 10
7-5-02	70 ± 10	17-9-02	30 ± 10	4-2-03	100 ± 10	24-6-03	50 ± 10
		24-9-02	20 ± 10	11-2-03	250 ± 10		

Notes:
1. Refer to Figure 2 for the location of this sampling point.
2. < 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. RADIOACTIVITY IN STORMWATER, BUND C MONTHLY COMPOSITES, LHSTC, January 2002 to June 2003

Month	Gross Alpha	Gross Beta	Gamma-Emitters Bq/L				
	Bq/L	Bq/L	Am-241	Be-7	Cs-137	Co-60	K-40
January 2002	0.04 ± 0.01	0.74 ± 0.01	< MDA	0.122 ± 0.025	0.079 ± 0.008	0.009 ± 0.003	0.10 ± 0.01
February 2002	0.03 ± 0.01	0.35 ± 0.01	< MDA	0.128 ± 0.031	< MDA	< MDA	< MDA
March 2002	0.03 ± 0.01	0.33 ± 0.01	< MDA	0.069 ± 0.032	0.046 ± 0.006	0.045 ± 0.006	< MDA
April 2002	0.03 ± 0.01	0.37 ± 0.01	< MDA	0.109 ± 0.025	0.009 ± 0.002	< MDA	0.10 ± 0.03
May 2002	0.03 ± 0.01	0.75 ± 0.02	< MDA	< MDA	0.046 ± 0.005	0.033 ± 0.005	0.18 ± 0.03
June 2002	0.02 ± 0.01	0.68 ± 0.02	< MDA	< MDA	0.014 ± 0.003	< MDA	< MDA
July 2002	0.02 ± 0.01	0.72 ± 0.02	< MDA	0.065 ± 0.016	0.038 ± 0.004	0.009 ± 0.003	< MDA
August 2002	0.02 ± 0.01	0.87 ± 0.02	< MDA	0.065 ± 0.021	0.028 ± 0.004	< MDA	0.11 ± 0.04
September 2002	0.08 ± 0.01	0.68 ± 0.02	< MDA	0.115 ± 0.026	0.029 ± 0.004	< MDA	0.24 ± 0.05
October 2002	0.07 ± 0.01	1.54 ± 0.03	< MDA	< MDA	0.153 ± 0.015	0.020 ± 0.005	0.32 ± 0.10
November 2002	0.03 ± 0.01	0.85 ± 0.02	< MDA	0.050 ± 0.021	0.052 ± 0.006	< MDA	0.23 ± 0.05
December 2002	0.04 ± 0.01	0.43 ± 0.01	< MDA	0.197 ± 0.030	0.053 ± 0.006	< MDA	< MDA
January 2003	0.02 ± 0.01	0.58 ± 0.01	< MDA	< MDA	0.027 ± 0.004	< MDA	0.12 ± 0.04
February 2003	0.04 ± 0.01	0.36 ± 0.01	< MDA	0.463 ± 0.052	0.030 ± 0.004	< MDA	< MDA
March 2003	0.03 ± 0.01	1.17 ± 0.02	< MDA	0.137 ± 0.030	0.095 ± 0.010	0.024 ± 0.005	0.10 ± 0.05
April 2003	0.05 ± 0.01	0.47 ± 0.01	< MDA	< MDA	0.016 ± 0.003	< MDA	0.41 ± 0.05
May 2003	0.04 ± 0.01	0.69 ± 0.01	< MDA	0.390 ± 0.051	0.100 ± 0.001	0.025 ± 0.006	0.15 ± 0.05
June 2003	0.03 ± 0.01	0.24 ± 0.01	< MDA	< MDA	0.013 ± 0.003	< MDA	1.38 ± 0.15

Notes:
1. Refer to Figure 2 for the MDP Bund C sampling location. The weekly samples were analysed for tritium then combined to make the monthly composites, reported above.
2. The NSW Regulations (Prot. Env. Operations Act, 1997) limits for radioactivity in class C waters are: Gross alpha 1.1 Bq/L; Gross beta 11.1 Bq/L.
3. The gross beta results include the contribution from K-40 (a natural beta-gamma emitter). Be-7 is also of natural origin.
4. < 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. RADIOACTIVITY IN SURFACE WATER, MDP+60m MONTHLY COMPOSITES, LHSTC, January 2002 to June 2003

Month	Gross Alpha	Gross Beta	Gamma-Emitters Bq/L				
	Bq/L	Bq/L	Am-241	Be-7	Cs-137	Co-60	K-40
January 2002	0.02 ± 0.01	0.34 ± 0.01	< MDA	0.039 ± 0.015	0.015 ± 0.003	< MDA	0.09 ± 0.04
February 2002	0.04 ± 0.01	0.42 ± 0.01	< MDA	0.194 ± 0.044	0.032 ± 0.005	< MDA	0.14 ± 0.05
March 2002	0.03 ± 0.01	0.33 ± 0.01	< MDA	< MDA	0.008 ± 0.004	< MDA	< MDA
April 2002	0.05 ± 0.01	0.33 ± 0.01	< MDA	< MDA	0.006 ± 0.003	< MDA	< MDA
May 2002	0.05 ± 0.01	0.35 ± 0.01	< MDA	0.047 ± 0.022	0.012 ± 0.003	0.015 ± 0.003	0.18 ± 0.03
June 2002	0.03 ± 0.01	0.40 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
July 2002	< MDA	0.31 ± 0.01	< MDA	0.049 ± 0.015	0.007 ± 0.002	< MDA	< MDA
August 2002	0.03 ± 0.01	0.20 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
September 2002	0.05 ± 0.01	0.29 ± 0.01	< MDA	0.050 ± 0.019	0.010 ± 0.003	< MDA	< MDA
October 2002	0.03 ± 0.01	0.19 ± 0.01	< MDA	< MDA	0.010 ± 0.003	< MDA	0.12 ± 0.04
November 2002	0.01 ± 0.01	0.17 ± 0.01	< MDA	< MDA	0.009 ± 0.003	< MDA	< MDA
December 2002	0.04 ± 0.01	0.23 ± 0.01	< MDA	0.085 ± 0.021	0.011 ± 0.003	< MDA	< MDA
January 2003	0.02 ± 0.01	0.18 ± 0.01	< MDA	< MDA	0.009 ± 0.003	< MDA	< MDA
February 2003	0.01 ± 0.01	0.29 ± 0.01	< MDA	0.163 ± 0.030	0.022 ± 0.004	< MDA	< MDA
March 2003	0.02 ± 0.01	0.28 ± 0.01	< MDA	0.089 ± 0.025	0.019 ± 0.003	< MDA	< MDA
April 2003	0.04 ± 0.01	0.32 ± 0.01	< MDA	< MDA	0.015 ± 0.002	< MDA	< MDA
May 2003	0.09 ± 0.01	0.40 ± 0.01	< MDA	0.169 ± 0.024	0.039 ± 0.005	0.018 ± 0.004	0.08 ± 0.05
June 2003	0.03 ± 0.01	0.24 ± 0.01	< MDA	< MDA	0.009 ± 0.003	0.006 ± 0.003	< MDA

Notes:
1. Refer to Figure 2 for the location of this sampling point, 60m downstream of the MDP Bund. The weekly samples were analysed for tritium, then combined to make the monthly composites, reported above.
2. The NSW Regulations (Prot. Env. Operations Act, 1997) limits for radioactivity in class C waters are: Gross alpha 1.1 Bq/L; Gross beta 11.1 Bq/L.
3. The gross beta results include the contribution from K-40 (a natural beta-gamma emitter). Be-7 is also of natural origin.
4. < 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 SURFACE WATER, SPCC SAMPLING POINTS, January 2002 to June 2003

	Strassman Creek		Bardens Creek Weir		MDP Creek Weir	
Date Sampled	**Gross Alpha** Bq/L	**Gross Beta** Bq/L	**Gross Alpha** Bq/L	**Gross Beta** Bq/L	**Gross Alpha** Bq/L	**Gross Beta** Bq/L
15-1-02	0.01± 0.01	0.05 ± 0.01	0.02 ± 0.01	0.05 ± 0.01	0.02 ± 0.01	0.25 ± 0.01
27-2-02	0.02 ± 0.01	0.06 ± 0.01	0.01 ± 0.01	0.08 ± 0.01	< MDA	0.11 ± 0.01
26-3-02	0.02 ± 0.01	0.06 ± 0.01	0.04 ± 0.01	0.08 ± 0.01	0.01 ± 0.01	0.22 ± 0.01
23-4-02	0.01 ± 0.01	0.04 ± 0.01	0.01 ± 0.01	0.06 ± 0.01	0.01 ± 0.01	0.19 ± 0.01
29-5-02	0.01 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.19 ± 0.01
25-6-02	0.01 ± 0.01	0.04 ± 0.01	0.02 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.20 ± 0.01
23-7-02	0.02 ± 0.01	0.04 ± 0.01	< MDA	0.06 ± 0.01	0.01 ± 0.01	0.20 ± 0.01
13-8-02	0.01 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.18 ± 0.01
20-9-02	0.01 ± 0.01	1.01 ± 0.01	0.02 ± 0.01	0.09 ± 0.01	< MDA	0.19 ± 0.01
28-10-02	0.01 ± 0.01	0.08 ± 0.01	< MDA	0.05 ± 0.01	< MDA	0.30 ± 0.01
29-11-02	0.02 ± 0.01	0.12 ± 0.01	0.04 ± 0.01	0.37 ± 0.01	0.04 ± 0.01	0.41 ± 0.01
10-12-02	0.01 ± 0.01	0.07 ± 0.01	0.03 ± 0.01	0.18 ± 0.01	0.01 ± 0.01	0.17 ± 0.01
28-1-03	< MDA	0.05 ± 0.01	< MDA	0.12 ± 0.01	< MDA	0.21 ± 0.01
25-2-03	0.01 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.12 ± 0.01	0.01 ± 0.01	0.17 ± 0.01
7-3-03	0.01 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	< MDA	0.18 ± 0.01
11-4-03	0.04 ± 0.01	0.05 ± 0.01	0.03 ± 0.01	0.05 ± 0.01	0.03 ± 0.01	0.13 ± 0.01
25-5-03	0.02 ± 0.01	0.03 ± 0.01	0.04 ± 0.01	0.09 ± 0.01	0.03 ± 0.01	0.08 ± 0.01
12-6-03	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	< MDA	0.15 ± 0.01

Notes:
1. See Figure 2 for the location of the SPCC sampling points.
2. < 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.
3. All gross beta results include the beta activity due to natural potassium-40.
4. The NSW Clean Waters Regulations (1972) specify limits for radioactivity in class C waters: gross alpha: 1.1 Bq/L; gross beta: 11.1 Bq/L.

Table 18. RADIOACTIVITY IN CREEKS NORTH OF THE LFBG, January 2002 to June 2003

WATER (Bq/L)

Sample Location	Date Sampled	Gross Alpha	Gross Beta	Gamma-emitters				Tritium
				Am-241	Cs-137	Co-60	K-40	
Mill Creek	16-12-02	0.04 ± 0.01	0.25 ± 0.01	< MDA	< MDA	< MDA	0.54 ± 0.08	< MDA
Bardens Creek	16-12-02	0.01 ± 0.01	0.20 ± 0.01	< MDA	< MDA	< MDA	0.60 ± 0.11	< MDA

SEDIMENT (Bq/g DW)

Sample Location	Date Sampled	Gross Alpha	Gross Beta	Gamma-emitters			
				Am-241	Cs-137	Co-60	K-40
Mill Creek	16-12-02	0.57 ± 0.08	0.08 ± 0.02	< MDA	< MDA	< MDA	0.033 ± 0.007
Bardens Creek	16-12-02	1.00 ± 0.09	0.20 ± 0.02	< MDA	< MDA	< MDA	0.067 ± 0.010

Notes:
1. See Figure 1 for the location of these sampling points.
2. The creeks were each sampled approximately 20m upstream from their confluence.
3. < 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. TRITIUM IN WATERS, WORONORA RIVER ESTUARY AND FORBES CREEK, January 2002 to June 2003

	Tritium (Bq/L)	
	Woronora Estuary	
Date Sampled	Station E5.9	Forbes Creek
16-1-02	< MDA	< MDA
7-2-02	< MDA	< MDA
20-3-02	< MDA	< MDA
30-4-02	< MDA	< MDA
21-5-02	< MDA	< MDA
26-6-02	< MDA	< MDA
23-7-02	< MDA	< MDA
30-8-02	< MDA	< MDA
30-9-02	< MDA	< MDA
28-10-02	< MDA	< MDA
3-12-02	< MDA	< MDA
23-12-02	< MDA	< MDA
22-1-03	< MDA	< MDA
14-2-03	< MDA	< MDA
13-3-03	< MDA	< MDA
1-4-03	< MDA	< MDA
6-5-03	< MDA	< MDA
10-6-03	< MDA	< MDA

Notes:
1. Figure 1 shows the sampling locations.
2. < 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 GROUNDWATER FROM THE VICINITY OF BUILDING 27, January 2002 to June 2003

	GAMMA-EMITTERS Bq/L				Tritium
Date Sampled	Am-241	Cs-137	Co-60	K-40	Bq/L
11-1-02	< MDA	< MDA	< MDA	< MDA	380 ± 20
27-2-02	< MDA	< MDA	< MDA	< MDA	460 ± 10
26-3-02	< MDA	< MDA	< MDA	< MDA	390 ± 10
29-4-02	< MDA	< MDA	< MDA	< MDA	470 ± 10
28-5-02	< MDA	< MDA	< MDA	1.76 ± 0.36	380 ± 20
28-6-02	< MDA	< MDA	< MDA	< MDA	390 ± 20
31-7-02	< MDA	< MDA	< MDA	< MDA	300 ± 20
30-8-02	< MDA	< MDA	< MDA	< MDA	430 ± 10
30-9-02	< MDA	< MDA	< MDA	< MDA	440 ± 20
31-10-02	< MDA	< MDA	< MDA	< MDA	480 ± 20
29-11-02	< MDA	< MDA	< MDA	< MDA	400 ± 20
23-12-02	< MDA	< MDA	< MDA	< MDA	460 ± 20
23-1-03	< MDA	0.071 ± 0.030	< MDA	< MDA	480 ± 20
20-2-03	< MDA	< MDA	< MDA	< MDA	560 ± 20
25-3-03	< MDA	0.068 ± 0.020	< MDA	< MDA	480 ± 20
30-4-03	< MDA	< MDA	< MDA	< MDA	390 ± 20
26-5-03	< MDA	< MDA	< MDA	< MDA	210 ± 10
26-6-03	< MDA	< MDA	< MDA	< MDA	370 ± 10

Notes:
1. Building 27 is the intermediate waste and spent fuel storage facility.
2. The NH&MRC and AWRC (1996) guideline level for tritium in drinking water is 7600 Bq/L.
3. < 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. FIELD PARAMETERS IN GROUNDWATER, LHSTC, September 2002

Piezometer	Sample Depth m	SWL (mBTOC)	pH	EC µS/cm	Eh mV	Temperature °C
MW1s	11.5	8.67	5.54	300	195.5	21.71
MW1d	23	8.97	3.88	600	353.2	22.30
MW2s	7.5	3.57	5.09	500	297.8	20.80
MW2d	25	3.22	5.62	800	294.8	23.12
MW3s	5	2.00	4.04	700	393.9	19.16
MW3d	23.5	1.54	5.75	700	349.2	20.19
MW4s	5	1.90	6.30	1000	336.8	20.47
MW4d	18	5.34	5.28	600	331.6	24.58
MW5s	7	2.91	4.87	500	311.7	23.55
MW6s	8	3.74	5.34	400	328.3	21.05
MW6d	23	6.93	5.69	600	348.2	21.43
MW7s	5.5	2.97	4.71	600	404.7	18.34
MW7d	20	13.04	3.88	1000	494.0	19.31
MW8s	dry	-	-	-	-	-
MW8d	~ 25.74	22.74	4.91	600	474.1	24.54
MW9s	17	10.67	4.32	400	462.7	18.62
MW9d	28	12.56	4.19	400	477.7	20.61
MW10s	11.5	6.08	4.56	300	417.0	19.77
MW11	11	8.40	4.42	500	357.8	23.57
MW13	23.5	14.28	4.17	400	400.7	22.54
MW14	24	13.04	5.68	600	163.3	20.67
MW15s	11	5.12	4.07	400	338.3	21.97
MW15d	18	5.84	4.98	500	350.5	21.62
BH3	23.5	15.70	5.06	500	278.5	23.67
BH3A	dry	-	-	-	-	-
BH6	14.5	10.60	4.16	400	368.0	22.40
BH112	~ 21.76	19.26	4.92	500	285.2	24.05
BH102	~ 8.26	7.26	6.27	700	288.9	18.54

Notes:
1. SWL, mBTOC - Standing water level measured in metres below the top of the bore casing.
2. Field parameters were measured using a calibrated YeoKal probe. EC is electrical conductivity, measured in micro Siemens per centimetre; Eh is the oxidation/reduction potential measured in millivolts.
3. ~ Denotes samples collected with hand bailer, therefore, approximate depths only.

Table 22. MAJOR IONS IN GROUNDWATER, LHSTC, September 2002

Piezometer	Na mg/L	K mg/L	Mg mg/L	Ca mg/L	Cl mg/L	SO_4 mg/L	HCO_3 mg/L
MW1s	21.8	1.29	2.7	0.7	37.1	17.1	2.7
MW1d	59.8	0.35	8.0	1.0	130.3	25.2	< 0.1
MW2s	20.3	0.33	4.7	0.3	39.6	13.2	1.1
MW2d	38.4	1.29	8.6	1.8	76.6	14.9	6.1
MW3s	36.6	0.32	4.7	0.2	73.0	48.2	< 0.1
MW3d	42.8	1.53	10.9	4.4	79.8	18.3	29.0
MW4s	29.7	2.53	20.2	99.0	41.5	52.1	343.8
MW4d	37.4	0.64	7.1	4.9	62.4	16.3	23.6
MW5s	26.2	0.70	4.1	0.8	38.7	36.9	2.4
MW6s	13.6	0.60	2.6	8.9	13.8	62.4	16.3
MW6d	65.1	1.17	4.6	5.7	74.8	62.4	55.1
MW7s	49.7	1.68	6.7	3.7	71.1	84.8	< 0.1
MW7d	64.4	1.04	11.2	0.9	160.1	58.1	< 0.1
MW8d	21.3	0.91	2.6	2.6	38.9	13.6	3.7
MW9s	35.2	0.53	5.0	0.8	74.5	27.7	< 0.1
MW9d	36.8	0.69	5.5	0.7	78.0	42.9	< 0.1
MW10s	32.9	0.99	2.2	2.0	47.9	40.2	< 0.1
MW11	47.9	0.59	3.7	1.6	45.3	65.6	< 0.1
MW13	42.6	0.50	4.7	0.9	83.1	38.6	< 0.1
MW14	58.6	1.10	6.8	7.0	32.4	126.9	28.7
MW15s	41.9	0.56	5.7	0.6	89.9	36.4	< 0.1
MW15d	48.7	1.89	8.3	1.5	84.7	150.4	10.6
BH3	42.3	3.23	7.8	6.7	91.8	21.2	9.5
BH6	37.4	0.83	6.8	4.2	24.7	130.5	< 0.1
BH112	48.3	3.91	8.6	5.8	90.1	52.9	17.3
BH102	37.6	7.20	7.4	22.2	48.8	47.1	61.8

Notes:
1. Concentrations quoted are for dissolved ions.

Table 23. RADIOACTIVITY IN GROUNDWATER, LHSTC, September 2002

	RADIOACTIVITY (Bq/L)						
			Gamma-Emitters				
Piezometer	**Gross Alpha**	**Gross Beta**	**K-40**	**Am-241**	**Cs-137**	**Co-60**	**Tritium**
MW1s	0.03 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	23.6
MW1d	0.14 ± 0.01	0.15 ± 0.01	< MDA	< MDA	< MDA	< MDA	7.7
MW2s	0.02 ± 0.01	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	54.9
MW2d	0.07 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	2.7
MW3s	0.13 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	< MDA	34.2
MW3d	0.03 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	4.5
MW4s	< MDA	0.11 ± 0.01	< MDA	< MDA	< MDA	< MDA	7.3
MW4d	0.02 ± 0.01	0.01 ± 0.01	< MDA	< MDA	< MDA	< MDA	3.0
MW5s	0.04 ± 0.01	0.04 ± 0.01	< MDA	< MDA	< MDA	< MDA	32.8
MW6s	0.01 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	128.6
MW6d	< MDA	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	3.6
MW7s	0.06 ± 0.01	0.13 ± 0.01	< MDA	< MDA	< MDA	< MDA	53.7
MW7d	0.21 ± 0.02	0.26 ± 0.01	< MDA	< MDA	< MDA	< MDA	4.0
MW8d	0.02 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	2.6
MW9s	0.06 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	12.5
MW9d	0.20 ± 0.01	0.19 ± 0.01	< MDA	< MDA	< MDA	< MDA	12.8
MW10s	0.06 0.01	0.10 ± 0.01	< MDA	< MDA	< MDA	< MDA	46.7
MW11	0.04 ± 0.01	0.04 ± 0.01	0.26 ± 0.10	< MDA	< MDA	< MDA	611.1
MW13	0.07 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	3.9
MW14	< MDA	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	107.6
MW15s	0.12 ± 0.01	0.14 ± 0.01	< MDA	< MDA	< MDA	< MDA	2.6
MW15d	0.10 ± 0.01	0.16 ± 0.01	0.28 ± 0.10	< MDA	< MDA	< MDA	8.0
BH3	0.08 ± 0.01	0.17 ± 0.01	< MDA	< MDA	< MDA	< MDA	2.6
BH6	0.05 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	< MDA	44.7
BH112	0.03 ± 0.01	0.07 ± 0.01	0.38 ± 0.12	< MDA	< MDA	< MDA	10.9
BH102	0.02 ± 0.01	0.23 ± 0.01	< MDA	< MDA	< MDA	< MDA	38.0

Notes:
1. Gross beta activity includes any contribution from natural potassium-40. Tritium analyses performed by the low-level ANSTO facility.
2. < 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 24. Rainfall (R) and Evaporation (E) Data from LHSTC, January 1992 to June 2003

		1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Jan.	R Total	123.2	50.2	11.2	122.1	136.0	113.2	75.0	111.9	29.6	191.0	55.2	22.5
	R Days	12	10	7	12	13	11	11	14	12	9	10	6
	E Total	137.5	149.0	205.2	135.8	125.2	151.8	163.9	165.4	138.0	151.3	176.6	173.2
	E Max	7.1	9.1	12.6	7.9	7.6	7.8	10.1	10.0	8.0	10.1	13.4	11.0
Feb.	R Total	300.4	88.5	47.3	47.6	64.1	127.7	56.0	196.5	11.0	110.6	295.1	89.1
	R Days	12	11	8	12	15	10	8	14	9	11	18	12
	E Total	104.4?	133.4	147.6	122.9	137.5	118.5	154.7	113.1	149.6	108.4	103.4	118.2
	E Max	7.9	8.0	10.2	7.6	7.8	11.3	10.0	6.6	9.3	6.4	8.7	8.0
Mar.	R Total	80.2	144.6	151.7	205.4	33.7	61.2	15.5	40.2	217.6	122.0	143.3	89.0
	R Days	9	17	17	16	9	10	8	10	14	20	15	8
	E Total	99.0	117.0?	118.3?	123.7	101.7	124.0	127.8	94.3	94.6	110.1	90.2	118.1
	E Max	6.1	10.4?	8.2?	8.4	6.1	6.2	7.7	5.1	5.1	7.9	5.5	8.5
April	R Total	93.6	30.3	95.5	14.2	33.2	0.5	161.3	94.3	31.9	70.2	15.4	147.2
	R Days	13	7	8	2	6	1	10	17	12	7	6	16
	E Total	77.0	83.0	85.9	91.0	99.2	91.9	94.9	72.0	65.3	78.0	68.8	69.0
	E Max	4.7	4.5	5.8	5.5	6.4	7.0	8.1	4.0	4.0	5.0	3.5	4.9
May	R Total	37.8	15.8	25.5	199.9	143.5	96.5	203.7	48.7	34.5	105.3	50.6	358.8
	R Days	9	4	5	16	14	16	13	10	9	10	11	17
	E Total	47.2	55.3	82.0	67.7	60.1	64.7	61.8	44.7	54.9	58.1	61.6	71.7
	E Max	2.7	4.9	6.6	6.0	3.9	4.7	4.9	3.4	3.4	4.5	3.7	6.8
June	R Total	70.5	34.3	39.5	40.4	51.8	51.0	80.2	66.6	34.2	9.3	18.1	58.0
	R Days	8	6	7	8	9	10	11	14	9	6	5	7
	E Total	48.7	53.3	51.1	44.1	58.9	54.7	45.5	45.9	45.7	44.4	49.1	49.3
	E Max	3.2	3.4	3.5	3.3	3.8	6.4	4.1	2.8	4.5	2.4	3.1	3.5
July	R Total	11.2	64.8	7.4	1.0	78.4	48.2	86.8	163.3	31.4	109.2	26.4	
	R Days	5	10	8	4	6	6	12	12	9	14	2	
	E Total	59.0	42.1	56.7	52.7	60.0	52.7	50.1	47.4	52.1	44.3	57.0	
	E Max	3.5	2.6	3.1	3.5	3.2	2.6	3.8	4.1	3.8	2.3	3.3	
Aug.	R Total	19.2	69.0	8.4	0.0	129.9	18.7	316.3	31.2	19.2	49.4	14.3	
	R Days	8	9	2	0	6	5	15	8	11	6	7	
	E Total	76.3	76.6	85.5	86.1	76.0	82.4	51.0	65.6	59.6	75.4	73.0	
	E Max	5.7	6.6	6.0	5.2	5.0	6.9	3.3	3.2	4.3	5.5	5.9	
Sept.	R Total	17.8	81.8	10.4	249.3	74.8	105.6	37.7	20.7	37.2	18.2	7.0	
	R Days	9	10	2	13	7	15	9	5	6	10	4	
	E Total	96.9	89.4	130.8	85.8	120.0	78.7	82.5	82.5	120.6	82.9	118.4	
	E Max	5.2	5.0	6.6	7.0	7.5	6.0	5.5	4.4	7.5	5.0	8.5	
Oct.	R Total	33.4	54.6	35.1	34.4	31.2	60.2	26.7	211.0	55.1	39.8	1.4	
	R Days	12	7	9	10	10	8	8	13	9	8	4	
	E Total	106.3	138.2	139.0	121.9	118.1	136.9	121.1	104.1	117.2	128.9	149.8	
	E Max	7.4	9.9	7.2	6.6	6.8	7.6	6.8	6.3	6.8	7.6	8.5	
Nov.	R Total	143.4	57.3	94.2	135.4	70.8	21.7	110.3	32.7	150.3	57.1	14.5	
	R Days	18	9	14	15	12	9	15	9	17	11	6	
	E Total	127.3	142.4?	164.6	126.4	146.5	150.2	113.6	112.1	100.5	129.6	157.1	
	E Max	7.9	13.6?	10.5	7.2	7.3	7.5	7.2	5.4	6.0	9.4	10.3	
Dec.	R Total	186.0	40.7	50.7	93.9	68.8	27.3	37.8	112.8	46.4	15.9	59.8	
	R Days	18	12	9	13	6	7	9	13	11	8	9	
	E Total	125.8	167.3	163.7	155.0	160.6	162.9	148.9	140.4	170.5	150.5	177.2	
	E Max	7.6	8.8	11.6	8.5	8.2	11.2	9.6	6.8	10.1	10.8	12.7	
Annual	**R Total**	**1116.7**	**731.9**	**576.2**	**1143.6**	**916.2**	**731.8**	**695.8**	**1129.9**	**698.4**	**898.0**	**701.1**	
	R Days	**133**	**112**	**87**	**121**	**113**	**108**	**129**	**139**	**128**	**120**	**97**	
	E Total	**1105.4**	**1247.0**	**1430.4**	**1220.4**	**1260.5**	**1269.4**	**1215.8**	**1087.5**	**1168.6**	**1161.9**	**1282.2**	

Note: Data labelled with ? denotes uncertainty in evaporation measurement.

Table 25. FIELD PARAMETERS IN GROUNDWATER, LFBG, May 2002

	SWL	pH	EC	Eh	Temp
Piezometer	mBTOC	pH	µS/cm	mV	°C
MB 11	316	7.5	739	141	21.0
MB 12	191	4.64	154	214	20.9
MB 13	131	4.96	58	129	20.7
MB 14	275	5.6	435	54	21.3
MB 15	351	5.02	199	186	22.0
MB 16	182	4.7	170	108	20.6
MB 17	101	4.96	166	112	21.7
MB 18	307	5.78	613	122	21.8
MB 19	167	5.97	2212	72	19.7
MB 20	143	5.64	540	183	18.4
MB 21	116	5.66	565	86	19.6
BH10	75	4.97	1782	85	21.6
BHF	170	4.92	470	129	19.8
OS 2	105	5.96	116	106	21.2
OS 3	86	5.04	85	126	21.4

Notes:
1. SWL, mBTOC - Standing water level measured in metres below the top of the bore casing.
2. Field parameters were measured in triplicate (the average reading is given) using a calibrated YeoKal probe. EC is Electrical conductivity, measured in micro Siemens per centimetre; Eh is the oxidation/reduction potential measured in millivolts.

Table 26. FIELD PARAMETERS IN GROUNDWATER, LFBG, October 2002

Piezometer	Sampling Depth m	SWL mBTOC	pH	EC µS/cm	Eh mV	Temp °C
MB 11	6.5	3.62	5.27	538	168	22.09
MB 12	4.0	2.92	5.32	156	186	25.95
MB 13	5.0	1.87	5.15	111	154	22.32
MB 14	5.2	3.31	5.86	311	-179	22.79
MB 15	6.5	4.38	5.44	111	179	22.07
MB 16	5.0	2.54	5.24	142	111	21.78
MB 17	4.0	1.78	5.19	130	154	24.11
MB 18	5.0	3.91	6.45	316	95	25.00
MB 19	5.0	2.94	6.03	846	46	21.66
MB 20	4.0	2.31	6.18	159	45	18.62
MB 21	3.5	2.04	6.02	205	119	21.6
BH10	5.0	1.59	5.25	402	166	20.87
BHF	8.0	2.45	4.94	197	203	20.6
OS 2	2.5	1.90	6.21	82	115	19.46
OS 3	3.0	1.67	5.08	70	193	22.07
P1S	5.0	3.12	4.74	476	195	22.1
P1D	20.0	3.46	5.29	430	107	22.1
P2D	26.0	12.46	6.22	1956	-55	19.5
CW	11.0	4.66	5.91	509	95	20.4

Notes:
1. SWL, mBTOC - Standing water level measured in metres below the top of the bore casing.
2. Field parameters were measured in triplicate (the average reading is given) using a calibrated YeoKal probe. EC is Electrical conductivity, measured in micro Siemens per centimetre; Eh is the oxidation/reduction potential measured in millivolts.

Table 27. FIELD PARAMETERS IN GROUNDWATER, LFBG, April - June 2003

Piezometer	Sampling Depth m	SWL mBTOC	pH	EC µS/cm	Eh mV	Temp °C
MB 11	5.0	4.15	5.98	109	147	22.83
MB 12	3.8	1.47	6.02	27.3	180	17.61
MB 13	4.8	0.47	6.05	34.3	141	18.00
MB 14	5.5	3.93	6.51	64	48	20.27
MB 15	6.0	4.67	6.05	83	121	20.34
MB 16	5.0	3.04	5.69	68	91	20.52
MB 17	4.0	2.40	5.86	84	151	19.53
MB 18	5.5	4.02	7.11	168	108	19.42
MB 19	4.5	0.35	6.81	70	77	19.95
MB 20	4.0	0.57	6.17	64	57	16.81
MB 21	3.0	0.23	6.55	76	111	17.92
BH10	5.5	1.81	5.98	430	93	18.4
BHF	10.0	3.14	5.91	204	97	17.82
OS 2	2.3	2.03	7.46	45	136	18.57
OS 3	3.0	1.88	5.75	39	178	20.07
P1S	5.0	2.55	4.94	59	192	19.57
P1D	10.0	2.94	6.72	86	107	18.49
P2D	15.5	11.95	5.86	913	163	17.64
CW	11.0	4.57	6.25	535	135	19.25

Notes:
1. SWL, mBTOC - Standing water level measured in metres below the top of the bore casing.
2. Field parameters were measured in triplicate (the average reading is given) using a calibrated YeoKal probe. EC is Electrical conductivity, measured in micro Siemens per centimetre. Eh is the oxidation/reduction potential measured in millivolts.

Table 28. RADIOACTIVITY IN GROUNDWATER, LFBG, May 2002

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	Date Sampled	Gross Alpha	Gross Beta	Am-241	Cs-137	Co-60	K-40	Tritium
BHF	9-5-02	0.16 ± 0.02	0.22 ± 0.02	< MDA	< MDA	< MDA	0.34 ± 0.10	160 ± 20
BH10	9-5-02	< MDA	0.25 ± 0.04	< MDA	< MDA	< MDA	0.29 ± 0.13	6860 ± 50
OS2	9-5-02	0.03 ± 0.01	0.10 ± 0.01	< MDA	< MDA	< MDA	0.44 ± 0.09	660 ± 10
OS3	9-5-02	0.02 ± 0.01	0.28 ± 0.01	< MDA	< MDA	< MDA	0.27 ± 0.08	920 ± 20
MB11	9-5-02	0.09 ± 0.01	0.20 ± 0.01	< MDA	< MDA	< MDA	0.24 ± 0.09	< MDA
MB12	9-5-02	< MDA	0.05 ± 0.01	< MDA	< MDA	< MDA	0.27 ± 0.09	< MDA
MB13	9-5-02	0.02 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	0.34 ± 0.09	900 ± 30
MB14	9-5-02	< MDA	0.09 ± 0.01	< MDA	< MDA	< MDA	0.37 ± 0.09	< MDA
MB15	9-5-02	0.02 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	0.39 ± 0.08	< MDA
MB16	9-5-02	0.10 ± 0.01	0.51 ± 0.01	< MDA	< MDA	0.16 ± 0.01	0.31 ± 0.08	3000 ± 20
MB17	9-5-02	0.06 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	0.35 ± 0.08	610 ± 10
MB18	9-5-02	0.18 ± 0.03	0.34 ± 0.03	< MDA	< MDA	< MDA	0.58 ± 0.10	140 ± 10
MB19	9-5-02	0.11 ± 0.05	0.57 ± 0.06	< MDA	< MDA	< MDA	0.39 ± 0.15	120 ± 10
MB19 DUP	9-5-02	0.11 ± 0.05	0.30 ± 0.04	< MDA	< MDA	< MDA	0.99 ± 0.15	50 ± 20
MB20	9-5-02	0.07 ± 0.01	0.37 ± 0.02	< MDA	< MDA	< MDA	0.57 ± 0.10	< MDA
MB21	9-5-02	0.06 ± 0.01	0.22 ± 0.01	< MDA	< MDA	< MDA	0.39 ± 0.09	< MDA
Wash Blank	9-5-02	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA

Notes for Tables 28, 29 and 30:

1. See Figure 4 for the location of the sampling bores. A "less than" value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).
2. The wash blank was collected in the field after MB16 was sampled. It consists of water (purified by reverse osmosis) that was pumped through the equipment then filtered.
3. The Australian drinking water guideline (NH&MRC and AWRC, 1996) for tritium in is 7600 Bq/L, and the screening level for gross alpha and gross beta activity is 0.5 Bq/L (less K-40).
4. Gross beta results include the contribution from natural potassium-40.
5. < 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 29. RADIOACTIVITY IN GROUNDWATER, LFBG, October 2002

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
BHF	23-10-02	0.03 ± 0.02	0.22 ± 0.02	< MDA	< MDA	< MDA	< MDA	270 ± 20
BH10	23-10-02	0.08 ± 0.03	0.21 ± 0.03	< MDA	< MDA	< MDA	< MDA	4890 ± 50
OS2	23-10-02	0.13 ± 0.01	0.17 ± 0.01	< MDA	< MDA	< MDA	< MDA	620 ± 20
OS3	23-10-02	0.10 ± 0.02	0.37 ± 0.02	< MDA	< MDA	< MDA	0.45 ± 0.02	1330 ± 30
MB11	23-10-02	0.02 ± 0.01	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB12	23-10-02	0.02 ± 0.01	0.07 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB13	23-10-02	0.06 ± 0.01	0.19 ± 0.02	< MDA	< MDA	< MDA	< MDA	2220 ± 30
MB14	23-10-02	0.25 ± 0.05	0.28 ± 0.03	< MDA	< MDA	< MDA	0.39 ± 0.12	40 ± 10
MB15	23-10-02	0.10 ± 0.02	0.17 ± 0.01	< MDA	< MDA	< MDA	0.22 ± 0.09	10 ± 10
MB16	23-10-02	0.27 ± 0.03	0.67 ± 0.02	< MDA	< MDA	0.30 ± 0.03	< MDA	4230 ± 60
MB17	23-10-02	0.05 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA	720 ± 10
MB18	23-10-02	0.03 ± 0.02	0.12 ± 0.02	< MDA	< MDA	< MDA	0.24 ± 0.11	140 ± 10
MB19	24-10-02	< MDA	0.58 ± 0.09	< MDA	< MDA	< MDA	0.58 ± 0.14	160 ± 20
MB20	24-10-02	0.04 ± 0.02	0.33 ± 0.02	< MDA	< MDA	< MDA	0.42 ± 0.13	< MDA
MB21	24-10-02	< MDA	0.26 ± 0.02	< MDA	< MDA	< MDA	0.45 ± 0.09	< MDA
Wash Blank	23-10-02	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA

Table 30. RADIOACTIVITY IN GROUNDWATER, LFBG, April - June 2003

		RADIOACTIVITY (Bq/L)						
				Gamma-emitters				
Piezometer	**Date Sampled**	**Gross Alpha**	**Gross Beta**	**Am-241**	**Cs-137**	**Co-60**	**K-40**	**Tritium**
BHF	1-5-03	0.12 ± 0.02	0.18 ± 0.01	< MDA	< MDA	< MDA	< MDA	360 ± 20
BH10	1-5-03	0.05 ± 0.03	0.10 ± 0.02	< MDA	0.015 ± 0.006	< MDA	< MDA	7180 ± 60
OS2	7-5-03	0.12 ± 0.01	0.13 ± 0.01	< MDA	< MDA	< MDA	< MDA	220 ± 10
OS3	1-5-03	0.09 ± 0.01	0.12 ± 0.01	< MDA	< MDA	< MDA	< MDA	230 ± 10
MB11	28-4-03	0.02 ± 0.01	0.03 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB12	6-6-03	0.01 ± 0.01	0.02 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB13	6-6-03	0.02 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	< MDA	640 ± 20
MB14	28-4-03	0.05 ± 0.01	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB15	28-4-03	0.13 ± 0.02	0.14 ± 0.01	< MDA	< MDA	< MDA	< MDA	15 ± 5
MB16	28-4-03	0.16 ± 0.02	0.35 ± 0.01	0.017 ± 0.006	0.015 ± 0.007	0.098 ± 0.019	< MDA	5530 ± 50
MB17	1-5-03	0.11 ± 0.02	0.06 ± 0.01	< MDA	< MDA	< MDA	< MDA	760 ± 20
MB18	1-5-03	0.12 ± 0.03	0.18 ± 0.02	< MDA	< MDA	< MDA	0.31 ± 0.11	220 ± 10
P1s	6-6-03	3.2 ± 0.3	3.0 ± 0.2	< MDA	< MDA	< MDA	< MDA	< MDA
P1d	6-6-03	0.09 ± 0.03	0.04 ± 0.02	< MDA	< MDA	< MDA	< MDA	30 ± 10
CW	1-5-03	0.40 ± 0.07	0.37 ± 0.03	< MDA	< MDA	< MDA	< MDA	820 ± 20
MB19	6-6-03	0.04 ± 0.01	0.11 ± 0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB20	6-6-03	0.08 ± 0.01	0.26 ±0.01	< MDA	< MDA	< MDA	< MDA	< MDA
MB21	6-6-03	0.14 ± 0.02	0.32 ± 0.02	< MDA	< MDA	< MDA	< MDA	< MDA
P2d	6-6-03	< MDA	0.33 ± 0.05	< MDA	< MDA	< MDA	< MDA	60 ± 10
Wash Blank	28-4-03	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA
Wash Blank	6-6-03	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA

Table 31. RADIOACTIVITY IN SEDIMENT, LHSTC STORMWATER BUNDS, January 2002 to June 2003

Location [1]	Date Sampled	Gross Alpha Bq/g DW	Gross Beta Bq/g DW	Gamma-emitters (Bq/g DW)				
				Am-241	Be-7	Cs-137	Co-60	K-40
BUND A	28-2-02	0.36 ± 0.07	0.40 ± 0.02	< MDA	0.176 ± 0.018	0.0059 ± 0.0008	< MDA	0.22 ± 0.02
	24-6-03	0.24 ± 0.01	0.26 ± 0.01	< MDA	0.083 ± 0.009	0.0024 ± 0.0005	< MDA	0.18 ± 0.02
BUND B	28-2-02	0.24 ± 0.07	0.26 ± 0.02	< MDA	0.129 ± 0.014	0.0015 ± 0.0006	0.0049 ± 0.0009	0.16 ± 0.02
	24-6-03	0.24 ± 0.01	0.22 ± 0.01	< MDA	0.062 ± 0.007	0.0017 ± 0.0004	0.0083 ± 0.0001	0.15 ± 0.02
BUND C	28-2-02	0.40 ± 0.08	0.30 ± 0.02	0.0010 ± 0.0004	0.025 ± 0.006	0.060 ± 0.006	0.0046 ± 0.0008	0.06 ± 0.01
	24-6-03	0.23 ± 0.01	0.20 ± 0.01	0.0010 ± 0.0003	0.028 ± 0.004	0.018 ± 0.002	0.0044 ± 0.0007	0.08 ± 0.01

Notes:
1. See Figure 2 for the locations of the stormwater bunds.
2. Radioactivity units are becquerels per gram (dry weight) of sample.
3. < 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 32. GAMMA DOSE-RATE SURVEY, LFBG TRENCHES, December 2002

Date of Survey	**Location** (1,2)	**Dose-rate** (μSv/hour)
13 December 2002	Background reading	
	(at LFBG gate)	0.08 – 0.15
	Trenches 1-51	0.10 – 0.15
	Trenches 52-77	0.08 – 0.15
	Trenches S1 and S2	0.10 – 0.15

Notes
1. See Figure 4 for the location of the waste burial trenches and sampling points.
2. The survey was performed using a calibrated Eberline PRM-7 gamma dose-rate meter, held at ground level.

Table 33. GAMMA DOSE-RATE SURVEYS, LIQUID EFFLUENT PIPELINE, LHSTC, January 2002 to June 2003

Date	**Location** (1,2)	**Dose-rate** (μSv/hour)		**Background Dose-rate** (μSv/hour)
		Ground Below Joint	**Pipe Joint**	
27/28-2-02	Joints #1-22	0.07 – 0.13	0.07 – 0.13	0.07 – 0.13
9-10-02	Joints #1-22	0.07 – 0.12	0.06 – 0.13	0.06 – 0.12
25-3-03	Joints #1-22	0.06 – 0.11	0.06 – 0.11	0.05 – 0.16

Notes:
1. Survey of exposed portions of pipeline between LHSTC and the Sydney Water sewer connection, using a calibrated Eberline PRM-7 gamma dose-rate meter.
2. The survey excluded joints numbered 18 & 19 which are inaccessible.

Table 34. RADIOACTIVITY IN FISH, POTTER POINT AND THE ROYAL NATIONAL PARK, January 2002 to June 2003

Sampling Location	Date Sampled (1)	Gamma-emitters in Blackfish (2) Bq/kg FW (3)					
		Be-7 (4,5)	K-40	Am-241	Co-60	Cs-137	I-131
POTTER POINT Ocean Outfall	7-5-02	< MDA	155 ± 15	< MDA	< MDA	< MDA	< MDA
	11-6-03	< MDA	150 ± 20	< MDA	< MDA	< MDA	< MDA
	11-6-03	< MDA	140 ± 15	< MDA	< MDA	< MDA	< MDA
The Royal National Park	21-11-02	< MDA	150 ± 15	< MDA	< MDA	< MDA	< MDA
Reference Site	21-11-02	< MDA	110 ± 15	< MDA	< MDA	< MDA	< MDA

Notes for Tables 34, 35 and 36:

1. Samples were split to form duplicates, where possible. See Figure 5 for sampling locations at the Potter Point ocean outfall and the reference site.
2. The whole, unwashed samples of algae (Ulva sp.) and barnacle (Tesseropera rosea) were dried and ground prior to gamma spectrometry analysis. The fish, Luderick (Girella sp.), were cut into flesh fillets.
3. Radioactivity is in units of becquerels per kilogram of fresh (wet) sample.
4. U &Th Series, Be-7 and K-40 are of natural origin. The U & Th Series column indicates the unquantified presence of decay products from the natural uranium-238 or thorium-232 series.
5. < 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 ALGAE, POTTER POINT AND THE ROYAL NATIONAL PARK, January 2002 to June 2003

Sampling Location	Date Sampled (1)	Gamma-emitters in Algae (2) Bq/kg FW (3)						
		U&Th Series (4)	Be-7 (5)	K-40	Am-241	Co-60	Cs-137	I-131
POTTER	6-5-02	Th-234	< MDA	195 ± 20	< MDA	< MDA	< MDA	31.5 ± 3.0
POINT	6-5-02	Th-234	< MDA	195 ± 20	< MDA	< MDA	< MDA	31.3 ± 3.0
Ocean Outfall	8-5-03	Th-234	< MDA	110± 10	< MDA	< MDA	< MDA	7.2 ± 0.7
The Royal	21-11-02	Th-234	< MDA	250 ± 25	< MDA	< MDA	< MDA	< MDA
National Park	21-11-02	Th-234	< MDA	250 ± 25	< MDA	< MDA	< MDA	< MDA
Reference	13-6-03	Th-234	2.8 ± 0.7	125 ± 15	< MDA	< MDA	< MDA	< MDA
Site	13-6-03	Th-234	3.0 ± 0.8	135 ± 15	< MDA	< MDA	< MDA	< MDA

Table 36. RADIOACTIVITY IN BARNACLES, POTTER POINT AND THE ROYAL NATIONAL PARK, January 2002 to June 2003

Sampling Location	Date Sampled (1)	Gamma-emitters in Barnacles (2) Bq/kg FW (3)					
		Be-7 (4,5)	K-40	Am-241	Co-60	Cs-137	I-131
POTTER	6-5-02	< MDA	35 ± 5	< MDA	< MDA	< MDA	< MDA
POINT	6-5-02	< MDA	45 ± 5	< MDA	< MDA	< MDA	< MDA
Ocean Outfall	8-5-03	< MDA	35 ± 6	< MDA	< MDA	< MDA	< MDA
The Royal	21-11-02	< MDA	25 ± 10	< MDA	< MDA	< MDA	< MDA
National Park	21-11-02	< MDA	20 ± 10	< MDA	< MDA	< MDA	< MDA
Reference	13-6-03	< MDA	30 ± 5	< MDA	< MDA	< MDA	< MDA
Site	13-6-03	< MDA	24 ± 5	< MDA	< MDA	< MDA	< MDA

Table 37. ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, 2001-2002 and 2002-2003

Receptor Location	2001-2 Estimated Effective Dose mSv/yr	2002-3 Estimated Effective Dose mSv/yr
Nearest resident	0.00263	0.00191
LHSTC Library	0.00325	0.00268
LHSTC Building 9	0.00464	0.00310
LHSTC Main gate	0.00219	0.00180
Stevens Hall Motel	0.00617	0.00503
Waste Services Centre	0.00099	0.00075
BMX track	0.00054	0.00047
Woronora Valley	0.00059	0.00045
At 1.6 kilometre radius from HIFAR		
NORTH	0.00401	0.00378
NNE	0.00297	0.00308
NE	0.00319	0.00249
ENE	0.00334	0.00254
EAST	0.00285	0.00207
ESE	0.00141	0.00115
SE	0.00133	0.00124
SSE	0.00142	0.00121
SOUTH	0.00104	0.00089
SSW	0.00101	0.00100
SW	0.00168	0.00185
WSW	0.00155	0.00156
WEST	0.00074	0.00071
WNW	0.00068	0.00059
NW	0.00123	0.00093
NNW	0.00216	0.00189
At 4.8 kilometre radius from HIFAR		
NORTH	0.00097	0.00103
NNE	0.00059	0.00053
NE	0.00074	0.00057
ENE	0.00076	0.00057
EAST	0.00062	0.00045
ESE	0.00030	0.00024
SE	0.00027	0.00025
SSE	0.00031	0.00027
SOUTH	0.00021	0.00017
SSW	0.00021	0.00022
SW	0.00039	0.00043
WSW	0.00034	0.00033
WEST	0.00016	0.00016
WNW	0.00015	0.00013
NW	0.00028	0.00022
NNW	0.00050	0.00049

Notes:
1. The annual effective dose is estimated using actual stack discharge data as input to the computer model, PC-Cream.
2. The annual dose limit for members of the public is 1 mSv/year (NH&MRC, 1995).

Appendix A – Quality Assurance and Control

APPENDIX A – QUALITY ASSURANCE AND CONTROL

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 audits, client surveys and other management tools. ANSTO's environmental management system includes the external verification of analytical results from the environmental and effluent monitoring program, as agreed with ARPANSA. ANSTO's environmental monitoring includes a variety of radioanalytical techniques applied to a range of environmental media and with determination of many different radionuclides. Some basic statistics and simple decision rules have been applied in order to summarise this multi-factorial comparison.

Method of comparing analytical results

Comparative statistics are based on the difference between paired analyses (as absolute % of the ANSTO value) and presented as the median ± IQR. Data below the various detection limits ("less than" data) were replaced with a value of half the detection limit for the individual analysis. Where more than half the data were 'less thans', no comparison was attempted. The quality of comparison is broadly categorized, based on the median difference, as follows: a difference of 10% or less represents a 'good' agreement between the ANSTO data and those of the independent laboratory; 30% or less difference is considered a 'fair' agreement, and anything greater than a median difference of 30% is considered a 'poor' agreement. It should be noted that many of the radionuclides, particularly those determined by gamma spectrometry of environmental samples, were being measured close to the detection limits where the comparative statistics used (*ie* percentage differences) are sensitive to small variations. The problem of dealing with data less than the detection limits also contributes to variation in the comparative statistics.

Airborne discharges

At least twenty samples of airborne effluent were submitted to ARPANSA (Environmental Radiation and Health Branch) for measurement of either tritium (trapped in water) or iodine-131 (trapped on charcoal). Both tritium and iodine measurements were in fair agreement for 2002-2003, with median differences of 26 ± 50% for tritium and 23 ± 10% for iodine.

Liquid effluent discharges

Six samples (monthly pipeline composites) of liquid effluent were submitted to ARPANSA (Environmental Radiation and Health Branch) for measurement of gross alpha and beta activity, tritium activities and various radionuclides determined via gamma spectrometry. More than half of the gross alpha measurements returned 'less than' values, so no comparison of statistics was made. Gross beta measurements were in fair agreement for 2002-2003, with a median difference of 11 ± 11%. Tritium data were in good agreement for 2002-2003, with a median difference of 6 ± 6% – this comparison is based on few data. However, of the eleven radionuclides reported from gamma spectrometry by at least one of the two laboratories, only two (cesium-137 and cobalt-60) were commonly detected. Cesium-137 analyses were in poor agreement, differing by 51 ± 148%. Cobalt-60 analyses were in fair agreement, with a median difference of 24 ± 10%.

Environmental sampling and analysis

In 2002-2003, more than 20 environmental samples (ground- and surface-waters and biota) were submitted to ARPANSA (Environmental Radiation and Health Branch) for parallel determination of radioactivity including gross alpha and beta activity, tritium activity and various radionuclides determined via gamma spectrometry (americium-241, cesium-137, beryllium-7, cobalt-60 and potassium-40). Most gross alpha measurements of waters returned 'less than' values, so no comparison of statistics was made. Gross beta measurements of waters were in fair agreement, with a median difference of 12 ± 11%. A median difference of 14 ± 11% also indicated fair

agreement for tritium measurements of waters. The repeatability of these measurements was also tested using multiple aliquots from two samples of varying tritium activity – the median difference between laboratories (0.4 ± 2%) showed that there was good agreement. Cesium-137 measurements of waters were in fair agreement, with a median difference of 15 ± 25%. Beryllium-7 measurements of waters were in poor agreement, differing by 45 ± 60%. Americium-241, cobalt-60 and potassium-40 were detected in too few samples for comparative analysis.

External gamma radiation

ARPANSA-supplied personal thermoluminescent dosimeters (TLDs) were placed at the 19 locations where ANSTO environmental TLDs were situated in 2001-2002 and 2002-2003. Three locations were in nearby suburbs and one set of TLDs was placed at the Cronulla STP. The ARPANSA personal TLDs systematically underestimate the effective dose by around 20% compared with ANSTO's environmental TLDs (20 ± 9% for 2001-2 and 18 ± 13% for 2002-2003), as a result of their different design and purpose. Accounting for this, the two sets of TLDs were in good agreement for both 2001-2 and 2002-2003, with median differences of 6 ± 5% and 9 ± 11%, respectively.

Conclusion

In conclusion, external verification of ANSTO's environmental monitoring measurements indicates acceptable agreement between ANSTO analytical results and independent analyses. This applies across the range of analytical techniques, environmental media and for most radionuclides determined.

SI* units

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

Note: For a fuller explanation of the terms used in this table, refer to the Glossary.

*SI stands for Système International

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)