ENVIRONMENTAL AND EFFLUENT MONITORING AT ANSTO SITES, 2001

LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE AND THE NATIONAL MEDICAL CYCLOTRON

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ABSTRACT

Results are presented of environmental surveillance and effluent monitoring conducted in the calendar year 2001 at the two sites owned and operated by ANSTO at the Lucas Heights Science and Technology Centre (LHSTC) and the National Medical Cyclotron (NMC) All low-level liquid and gaseous effluent discharges complied with existing discharge authorisations and relevant environmental regulations Potential effective doses to the general public from LHSTC-controlled airborne discharges were estimated for 2001 using the PC-Cream atmospheric dispersion and dosimetry code The potential effective doses to the public in 2001 were estimated to be less than 0 01 mSv/year for all receptor locations on the LHSTC 1 6 km buffer zone boundary or beyond This is well below the ALARA objective of 0 02 mSv per year for off-site doses that ANSTO has set and much lower than the public dose limit of 1 mSv per year (above natural background and medical doses) and the natural background dose in Australia of 1 5 mSv per year (Webb et al, 1999) It is concluded that there is no impact on the health of the community as a consequence of operations at the Lucas Heights Science and Technology Centre or the National Medical Cyclotron

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, Americium-241, ANSTO, Argon-41, Australia, Beryllium-7, Beta Decay Radioisotopes, Cesium-134, Cesium-137, Chemical Effluents, Cobalt-57, Cobalt-60, Contamination, Cyclotrons, Dose Equivalents, Dose-Constraint, Dose Limits, Drinking Water, Environmental Exposure Pathway, Environmental Impacts, Evaluated Data, Fishes, Fission Product Release, Gallium-67, Gamma Radiation, Gaseous Wastes, Ground Water, Iodine-123 Iodine-131, Iodine-132, Iodine-133, Liquid Wastes, Low Level Counting, Measuring Methods, Noble Gases, Plutonium-239, Potassium-40, Public Health, Radiation Doses, Radiation Monitoring, Radioactive Effluents, Natural Radioactivity, Rivers, Sampling, Seawater, Sediments, Soils, Stack Disposal, Standards, Statistics, Strontium-90, Surface Waters, Thallium-201, Thorium-232, Thermoluminescent Dosimetry, Tritium, Uranium-238, Water Quality, Wind, Zinc-65

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ENVIRONMENTAL AND EFFLUENT MONITORING AT ANSTO SITES, 2001

SUMMARY

The Australian Nuclear Science and Technology Organisation (ANSTO) is a science and technology agency of the Commonwealth Government of Australia. It has a staff of approximately 800 and is located at the Lucas Heights Science and Technology Centre (the LHSTC or Lucas Heights site), some 40 km south west of Sydney city centre. The science and technology centre occupies 70 hectares and is surrounded by a 1.6 km buffer zone.

ANSTO operates several national facilities including Australia's only nuclear reactor, the research reactor HIFAR (the High Flux Australian Reactor). The reactor is used to produce radioactive products for use in medicine and industry. The organisation also operates the National Medical Cyclotron (NMC), an accelerator facility used to produce certain short-life radioisotopes for nuclear medicine procedures. The NMC is located in the grounds of the Royal Prince Alfred Hospital in Camperdown, an inner west suburb of Sydney.

ANSTO operations are regulated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) under the *Australian Radiation Protection and Nuclear Safety Act 1998.*

ANSTO's Health, Safety and Environment Policy contains the principles that form the basis of its environmental management system. This policy commits ANSTO to undertaking its activities in a manner that protects human health and the environment and is consistent with national and international standards. In terms of environmental protection, ANSTO provides verifiable evidence of the fulfilment of the policy through a program of monitoring and audit, and publication of these results by means of 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.

Monitoring undertaken includes:

- liquid effluent prior to discharge to the sewer;
- airborne discharges;
- groundwater, soil and air from the "Little Forest Burial Ground[1]";
- external gamma radiation at the Lucas Heights site perimeter and local residences;
- meteorological measurements at Lucas Heights;
- stormwater run-off from the Lucas Heights site;
- water quality at local creeks; and
- seawater and marine biota at the Potter Point Ocean Outfall.

ANSTO is reviewing various aspects of its environmental monitoring and dose assessment program. This includes a re-evaluation of the potential exposure pathways and of the critical groups that might be affected by radiological doses from airborne and liquid effluent discharges.

Groundwater flow and quality are also being assessed at the Lucas Heights site, with a set of groundwater bores installed in 2000 and a monitoring program trialed in 2001. In addition, a program to monitor the non-radiological quality of stormwater flowing from the site has been

[1] See page 4 for an explanation of this term.

developed to cover the construction period of the Replacement Research Reactor. The results from these investigations will be included in future reports as they are integrated into the ANSTO environmental management system.

This report summarises the results from the environmental and effluent surveys carried out at the Lucas Heights and NMC sites during 2001, and assesses the environmental effects of radioactive discharges, focussing on any potential effect on local residents. Results obtained in previous years have been published in the annual monitoring reports, which are available from local libraries or on request from ANSTO's Communications Manager. ANSTO's contact details are included inside the front cover of this report.

In future, the results of ANSTO's environmental and effluent monitoring will be reported against fiscal years rather than calendar years. The next monitoring report in this series will cover the eighteen-month period running up to the end of the 2002-2003 fiscal year. In the interim, a "Health, Safety and Environment " brochure covering the 2001-2002 fiscal year will be published, and this will include an update on the monitoring data.

The environmental and effluent monitoring results for 2001 show that ANSTO operations complied with effluent discharge authorisations and relevant environmental regulations for both the Lucas Heights and the NMC sites.

Liquid Effluent from the Lucas Heights Site

ANSTO has an Agreement with Sydney Water Corporation that allows ANSTO to discharge treated liquid effluent from the Lucas Heights site to the sewer as long as the discharges comply with:

- drinking water quality concentrations for radioactivity at the Cronulla Sewage Treatment Plant and
- concentration limits for non-radiological components of the effluent.

During 2001, radionuclide concentrations in liquid effluent discharged to the sewer were below the limits specified in the Trade Wastewater Agreement with Sydney Water. The combined monthly concentration quotients for gross alpha, gross beta and tritium radioactivity in liquid effluent ranged from 0.12 to 0.30 with an average for the year of 0.18, which is less than 20% of the required limit. Concentrations of the non-radioactive components of liquid effluent discharged to the Sydney Water sewer also met the standards for acceptance specified in the discharge Agreement.

Airborne Discharges

Formal reporting to ARPANSA against a new Airborne Radioactive Discharge Authorisation commenced in July 2001. The authorisation 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). Annual notification levels are set for each discharge point at the Lucas Heights site and NMC, such that the maximum possible off-site dose to the public would be less than 0.02 mSv per year.

On-site and public doses resulting from airborne discharges from the Lucas Heights site continued to be very low in 2001. At the 1.6 km exclusion zone boundary the estimated doses based on stack emission and meteorological data were less than 0.01 mSv per year. This is well below the ALARA objective of 0.02 mSv per year and much lower than the public dose limit of 1 mSv per year and the natural background in Australia of around 1.5 to 2 mSv per year (Webb *et al*, 1999).

All airborne emissions were below the ARPANSA annual notification levels in 2001, and the calculated effective doses for the LHSTC confirm that ANSTO met the ALARA objective for doses to the public.

Stormwater and Surface Waters at the Lucas Heights Site

Stormwater drainage from the Lucas Heights site complied with the *NSW Protection of the Environment Operations Act (1997)* limits for gross alpha and gross beta radioactivity in Class C surface waters. Sampling included the on-site stormwater bunds and off-site sampling points on the three small creeks receiving most of the run-off from the site. Levels of tritium and gamma activity found in stormwater were also low in comparison with the relevant Australian drinking water guidelines (NH&MRC, 1996).

Surface water samples collected off-site at the confluence of Mill Creek and Bardens Creek, and from the Woronora River and Forbes Creek, contained only natural background levels of radioactivity.

Since the levels of detected activity are very low and stormwater does not enter any known human drinking water supply, it is concluded that there are no health consequences to humans from the measured radioactivity in the Lucas Heights site stormwater.

Little Forest Burial Ground

Between 1960 and 1968 the Australian Atomic Energy Commission (AAEC) used a small area locally known as Little Forest (see Figure 1) for the disposal by burial of solid waste with low levels of radioactivity and beryllium oxide (non-radioactive) that originated predominantly from the Lucas Heights site.

The environmental monitoring program at the Little Forest Burial Ground (LFBG) is based on the potential exposure pathways and includes the collection of groundwater, soil and airborne particles. Monitoring results at the LFBG in 2001 indicate that radioactivity levels were similar to those of previous years.

Tritium concentrations in LFBG groundwater were below levels considered safe for drinking water in Australia. The gross alpha and gross beta concentrations 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 were below the more restrictive level of 0.5 Bq/L set in the Australian drinking water guidelines.

Gamma spectrometry of the unfiltered LFBG groundwater samples showed only small concentrations of natural potassium-40 and uranium-238 progeny and, in one sampling hole, low levels of cobalt-60 (at less than 1% of the Australian drinking water guideline concentration). These extremely low levels of radioactivity are of no consequence to the health of humans.

A high-volume air sampler was used to collect airborne dust particles at the LFBG in 2001. Quarterly samples of air were collected on filters by sampling for approximately 4-6 hours every two weeks. Dry, relatively windy sampling days were chosen to maximise the collection of particles. The nuclides of interest are beryllium and plutonium; however, neither was detected in 2001.

Extra monitoring of soil and dose rates was undertaken at the LFBG in response to a trespassing incident. The results showed no measurable radioactivity above natural background levels. External gamma radiation doses over the disposal area were measured

using a hand-held meter and showed only background levels. The radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

External Gamma Radiation at the Lucas Heights Site

During the year, thermoluminescent dosimeters measured ambient gamma radiation at various locations around the Lucas Heights site perimeter fence and at three private residences in the nearby suburbs of Barden Ridge, Engadine and Woronora. Measurements at the three local residences showed an average external dose of about 0.75 mSv per year. The local absorbed doses in air were consistent with levels recorded in Australian capital cities (using similar dosimeters) in surveys carried out by the then Australian Radiation Laboratory and reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1993). These results indicate that the external gamma radiation levels at residential locations in the vicinity of the Lucas Heights site are not noticeably affected by ANSTO's operations.

The absorbed dose to air at Location 2 on the southern sector of the Lucas Heights site perimeter fence has in recent years been affected by nearby stored radioactive material. Comprehensive dose-rate surveys conducted inside and outside the perimeter fence, together with a consideration of occupancy factors, indicate that shielding of the storage building is appropriate. This part of the site is not readily accessed by the general public and is approximately 1.8 kilometres away from any residential areas. Other locations exhibited normal background dose rates.

Potter Point Ocean Outfall

Treated sewage effluent from the Sutherland Shire, including low-level effluent from the LHSTC, passes through the Cronulla Sewage Treatment Plant and is discharged at Potter Point. Seawater and biological sampling programs were continued at the Potter Point ocean outfall during 2001. This monitoring is aimed at assessing potential doses to members of the public who may swim in the ocean off Potter Point and/or eat fish caught in the vicinity of the outfall.

Fish, algae (seaweed) and barnacles are collected from Potter Point because these organisms represent different levels in the food chain leading to humans and also because algae and barnacles are known to concentrate a variety of elements from their environment.

The radioactivity measured in marine biota from Potter Point was of natural origin apart from the low concentrations of iodine-131 found in algae. No man-made radionuclides were detected in fish or barnacles from Potter Point in 2001 or in any samples collected from the reference site in the Royal National Park. The small concentrations of iodine-131 found in algae from Potter Point were of no radiological significance to humans.

The Cronulla Sewage Treatment Plant was upgraded to provide tertiary treatment from July 2001. Liquid effluent travelling between Lucas Heights and the sewage plant was studied on two occasions in 2001 to determine whether the upgrade had had any effect on dilution factors or transit times. During the first investigation the level of tritium in the effluent released was too low to permit its detection in the treatment plant or in seawater near the outfall. On the second occasion tritium was measured both in samples collected in the treatment plant and at the outfall. The estimated dilution factor for radionuclides between ANSTO and the outlet of the sewage treatment plant was 253. This compares with dilution factors of typically 25 prior to the plant upgrade. The enhanced values following the upgrade are consistent with an increase in the average residence time of sewage within the plant from a few hours to about 18 hours.

The National Medical Cyclotron

The radiopharmaceutical products made at the National Medical Cyclotron are relatively short-lived, with half-lives ranging from minutes to hours. As a consequence, the small amounts of liquid effluent discharged to the sewer and airborne emissions from the NMC have limited impact on the environment or humans. All airborne and liquid emissions met the prescribed discharge levels in 2001.

Conclusions

It is concluded that there is no adverse impact on the health of the community as a consequence of ANSTO's operations at the Lucas Heights Science and Technology Centre or at the National Medical Cyclotron.

The estimated potential doses to members of the general public from airborne discharges at the Lucas Heights site are only a very small fraction, less than half a per cent, of the radiation dose received by everyone each year from naturally occurring sources of radiation. The monitoring results from the Potter Point Ocean Outfall confirm that the potential radiation dose to members of the general public as a result of ANSTO's discharges to the sewer is very low. The potential dose is less than 0.2% of the National Health and Medical Research Council recommended dose limits for members of the public. The levels of detected radioactivity in stormwater from the Lucas Heights site are low in comparison with the relevant Australian drinking water guidelines and have no health consequences.

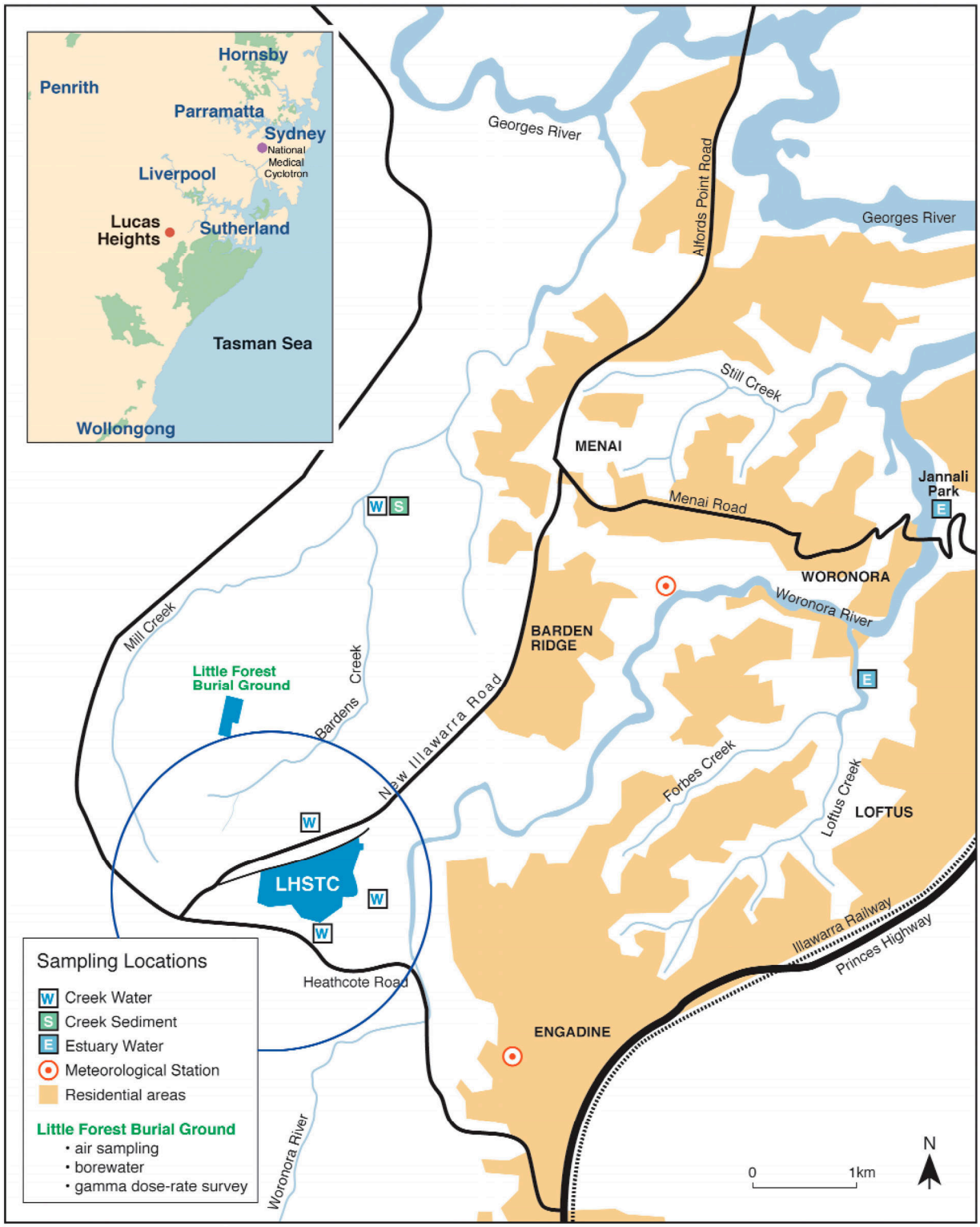

FIGURE 1
Location of LHSTC & Offsite Sampling points

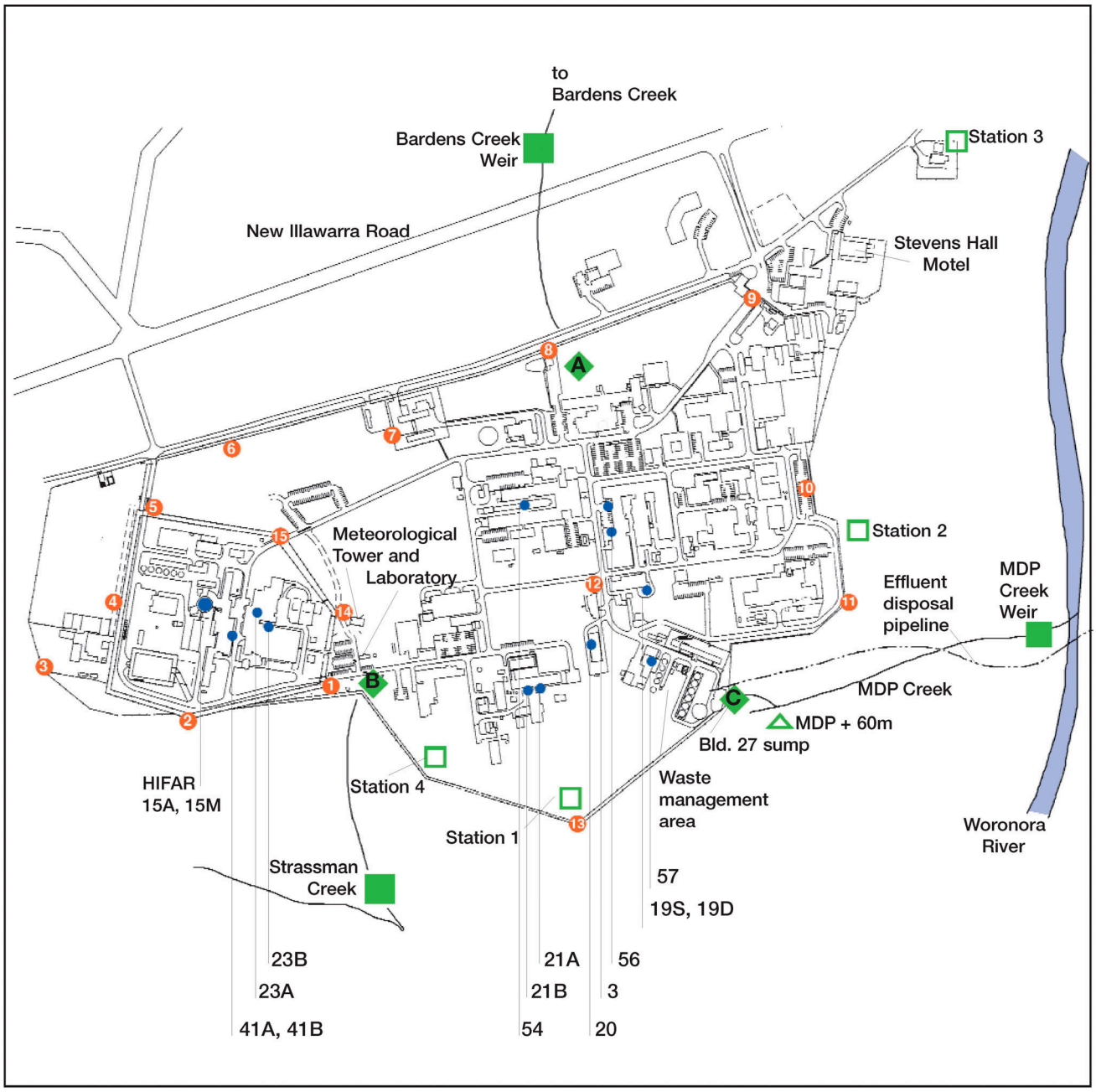

FIGURE 2

Locations of Stormwater, Air and External Radiation Monitoring Points at LHSTC

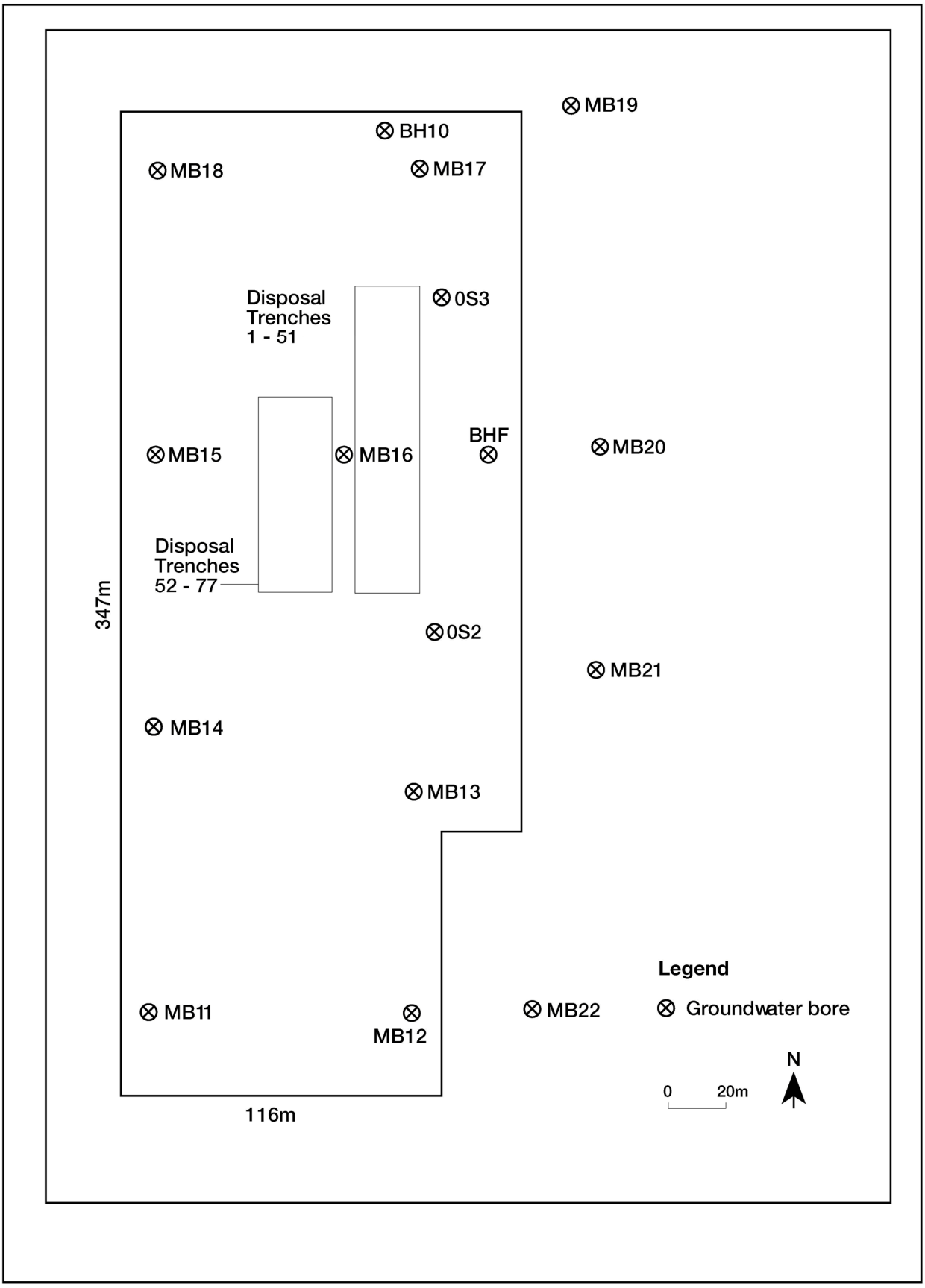

FIGURE 3
Little Forest Burial Ground - Location of Trenches & Groundwater Bores

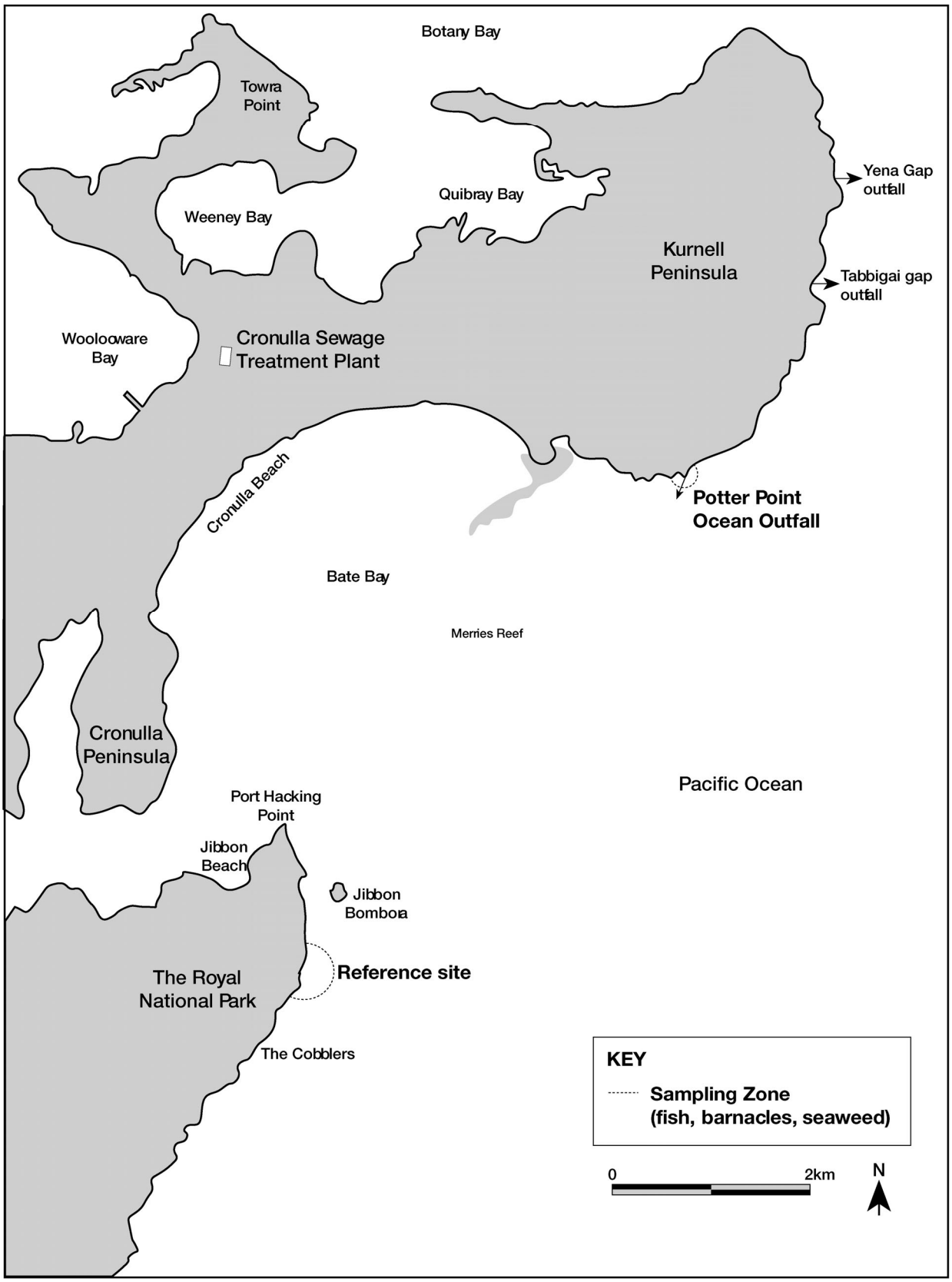

FIGURE 4
Location of Sampling Zones at Potter Point Ocean Outfall and the Royal National Park

1 INTRODUCTION

The Australian Nuclear Science and Technology Organisation (ANSTO) is a science and technology agency of the Commonwealth Government of Australia. It has a staff of approximately 800 and is located at the Lucas Heights Science and Technology Centre (the LHSTC or Lucas Heights site), some 40 km south west of Sydney city centre. The science and technology centre occupies 70 hectares and is surrounded by a 1.6 km buffer zone (see Figure 1).

ANSTO operates several national facilities including Australia's only nuclear reactor, the research reactor HIFAR (the High Flux Australian Reactor). The reactor is used to produce radioactive products for use in medicine and industry. The organisation also operates the National Medical Cyclotron (NMC), an accelerator facility used to produce certain short-life radioisotopes for nuclear medicine procedures. The NMC is located in the grounds of the Royal Prince Alfred Hospital in Camperdown, an inner west suburb of Sydney (see inset, Figure 1).

- ANSTO's activities are supported by specialist nuclear science and technological capabilities that include: the operation of national scientific and technological facilities;
- the manufacture of radiopharmaceuticals;
- assessment of the structural integrity of materials;
- mineral and chemical processing technologies relevant to the nuclear fuel cycle.
- the application of radioisotopes, neutrons and radioanalytical techniques;
- monitoring and analysis of radionuclides in the environment;
- safety services associated with the nuclear fuel cycle; and
- the management of radioactive waste.

ANSTO operations that involve radiation or radioactive material are regulated under the Commonwealth Government's *Australian Radiation Protection and Nuclear Safety Act 1998*, which is implemented by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Under the Act, ARPANSA has the authority to undertake independent audit of the effluent and environmental monitoring programs at ANSTO sites. (Section 7 of this report describes the discharge authorisations that cover airborne or liquid effluent emissions from ANSTO sites.)

ANSTO's Health, Safety and Environment Policy contains the principles that form the basis of the Organisation's environmental management system. Its Health, Safety and Environment Policy commits ANSTO to undertaking its activities in a manner that protects human health and the environment, and is consistent with national and international standards. ANSTO provides verifiable evidence of the fulfilment of the policy through a program of monitoring and audit. In addition, the monitoring program is designed to detect and quantify any accidental releases of radioactive materials, should they occur.

ANSTO is reviewing various aspects of its environmental monitoring and dose assessment program. This includes a re-evaluation of the potential exposure pathways and of the critical groups that might be affected by radiological doses from airborne and liquid effluent discharges.

Groundwater flow and quality are also being assessed at the Lucas Heights site, with a set of groundwater bores installed in 2000 and a monitoring program trialed in 2001. In addition, a program to manage the quality of stormwater flowing from the site is being developed

particularly to cover the construction period of the Replacement Research Reactor. The results from these investigations will be included in future reports, as they are integrated into the ANSTO Environmental Management System.

This report summarises the results from the environmental and effluent surveys carried out at the LHSTC and NMC sites during 2001, and assesses the environmental effects of radioactive discharges, focusing on any potential effect on local residents. Results obtained in previous years have been published annually as public documents within the series *Environmental and Effluent Monitoring at ANSTO Sites*, copies of which are available from the Sutherland Shire Central Library or on request from ANSTO's Communications Manager.

In future, the results of ANSTO's environmental and effluent monitoring will be reported against fiscal years rather than calendar years. The next monitoring report in this series will cover the eighteen month period running up to the end of the 2002-2003 fiscal year. In the interim, a "Health, Safety and Environment " brochure covering the 2001-2002 fiscal year will be published and this will include an update of the monitoring data.

ANSTO's contact details are included inside the front cover of this report while units and prefixes are printed inside the back cover. Definitions of terms used throughout this report may be found in the Glossary.

2 POTENTIAL ENVIRONMENTAL EXPOSURE PATHWAYS AND CRITICAL GROUPS

The concepts of *exposure pathways* (the possible avenues by which members of the public could be exposed to radioactivity originating from nuclear sites) and *critical groups* (the individuals most likely to be exposed to radiation) have been used at AAEC/ANSTO since the mid-1960s. The concepts have broad acceptance and are applied internationally for radiological dose estimation. Discharge levels are derived following consideration of all potential environmental exposure pathways, and are set so that dose rates to the critical group do not exceed prescribed limits. This approach has formed the basis for determining approved levels for both airborne and liquid discharges of radioactive effluent at the Lucas Heights facility over many years (see Hoffmann and Loosz, 1994).

The main ways in which radionuclides from ANSTO sites can enter the environment and lead to radiation exposure, particularly of members of the general public, are by:

- atmospheric emissions that primarily result in external radiation doses from short-lived, radioactive gases;
- wash-out or deposition of airborne radionuclides that can enter the food chain, for example in drinking water or on foodstuffs;
- discharge of low-level liquid effluent into the sea via Sydney's sewerage system. These radionuclides may then be taken up by marine plants and animals such as fish, or be accidentally ingested by swimmers or surfers; and
- direct or indirect contamination of groundwater or soil.

The same general pathways would apply to any abnormal atmospheric or liquid releases.

2.1 ATMOSPHERIC DISCHARGES FROM THE LUCAS HEIGHTS SITE

Atmospheric discharges from the Lucas Heights site have been regulated since 1968 when expansion of radioisotope production made it necessary to consider possible exposure

pathways for airborne releases of radionuclides, such as noble (inert) gases and iodine-131. Noble gases, including argon-41 from HIFAR, and radioisotopes of xenon (Xe-133, Xe-135 and Xe-135m) and krypton (Kr-85) from production of radiopharmaceuticals, are the major contributors to the small public dose arising from ANSTO's operations. (See Section 7 for more detail on discharge authorisations and applicable limits.)

Typical exposure pathways for potential transfer of deposited airborne radioactivity to humans usually include ingestion of contaminated drinking water and foodstuffs. However, in the case of ANSTO's airborne discharges, the ingestion pathway for deposited airborne radioactivity to humans is not considered to be significant, for the following reasons:

- the (small) ANSTO contribution to public dose is dominated by external radiation from short-lived noble gases, which are inert and cannot be concentrated in the food chain;
- there is little or no commercial food production or processing in the immediate neighbourhood of the Lucas Heights site; and
- the small creeks receiving run-off from the site are not used as sources of drinking water.

The computer code PC-CREAM (see Section 7.2) has been approved by ARPANSA for modelling the movement of ANSTO's airborne effluent releases and assessing the resulting dose to people. Dose assessments using PC-CREAM have shown that the small ANSTO contribution to public dose is largely due to external radiation from noble gases. Nevertheless, other exposure pathways, such as inhalation of radionuclides and ingestion of locally grown vegetables, are included in the dose assessment.

There is the potential for iodine-131 and other radionuclides to be deposited onto grazing land and concentrated in the food chain that gives rise to milk production. The levels of radioactivity in locally produced milk were routinely assessed in the past (see Hoffmann and Loosz, 1994) but, with the nearest registered dairy herd now some thirteen kilometres from ANSTO, this pathway is no longer considered significant.

The major critical group for exposure to airborne activity is people living close to the Lucas Heights site perimeter at the Stevens Hall Motel. Continuous samplers (to monitor ambient levels of iodine-131 in air) are positioned near the site perimeter fence at locations near both the motel and the closest suburban residences. (See Figure 2 for the location of Stevens Hall Motel and the air sampling stations, and Section 3.8 for results.) Levels of integrated external radiation at the Lucas Heights site and in nearby suburban locations were also measured during 2001 using dosimeters issued by ARPANSA. (Results of this monitoring are discussed in Section 3.10.)

2.2 LOW-LEVEL LIQUID EFFLUENT DISCHARGES FROM THE LUCAS HEIGHTS SITE

The AAEC/ANSTO released liquid effluent containing low levels of radioactivity into the upper reaches of the Woronora Estuary from 1961 to 1980. Since then, low-level liquid effluent from the Lucas Heights site has been pumped to the sewer. Along with other effluent from the Sutherland Shire, this effluent passes through the Cronulla Sewage Treatment Plant (Cronulla STP) and is discharged into the sea at the Potter Point outfall. In July 2001 the Cronulla STP was upgraded to provide tertiary treatment of sewage, which has greatly reduced the levels of plant nutrients in discharges to the ocean at the Potter Point outfall.

Various activities at the Lucas Heights site produce radioactive liquid waste. After treatment and storage, the major contributor to radioactivity in the low-level effluent discharged to the sewer is typically tritium. (See Appendix 1 for more information on tritium and other relevant

radionuclides. The liquid effluent discharge authorisations and applicable limits are discussed in Section 7.)

The major critical groups for exposure to radiation in liquid effluent are workers at the Cronulla STP and people eating fish (30 kg per annum) caught near the Potter Point outfall. In order to assess the possible exposures of these groups, external gamma radiation dose has been measured at the Cronulla STP since 1999. The measured doses have been similar to or less than background doses measured at residences in Barden Ridge, Engadine and Woronora. Further, a program of biological monitoring, begun in 1995, has included measurement of gamma-emitting radionuclides in the edible flesh of blackfish caught at Potter Point. The potential dose from consuming these fish was estimated (Hoffmann *et al*., 1996) to be at least a thousand times less than a realistic intake limit for people, based on the International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources (IAEA, 1996). Section 3.3 of this report presents the results of biological monitoring conducted at Potter Point in 2001.

Studies conducted in 1993 (Hoffmann *et al*., 1995) and periodically confirmed since then have demonstrated that ANSTO's liquid effluent is diluted on its way to the Cronulla STP to the extent that it meets World Health Organisation (WHO 1993) drinking water guidelines for radioactivity. There is further dilution before the sewage is discharged at Potter Point. Offshore studies in 1995 and 1997 showed that the discharge could be modelled as it dispersed off Potter Point (Hoffmann *et al*., 1996 and 1998), thus supporting dose estimation for recreational swimmers/surfers in that area, should this be considered necessary. (Refer to Section 6 for the results of offshore monitoring at Potter Point in 2001.)

2.3 THE LITTLE FOREST BURIAL GROUND (LFBG)

Between 1960 and 1968 the Australian Atomic Energy Commission (AAEC) used a small area locally known as Little Forest (see Figure 1) for the disposal by burial of solid waste with low levels of radioactivity and beryllium oxide (non-radioactive) that originated predominantly from the Lucas Heights site.

Site selection and disposal operations followed the international guidelines and accepted practice of that time. Various government agencies and private companies have used areas adjacent to LFBG for the disposal of liquid industrial wastes, solid municipal wastes and nightsoil. Some nearby areas were quarried for clay and shale until the closure of the quarries in December 1998.

Potential exposure pathways to members of the general public from the wastes buried at LFBG would be associated with the off-site transport of radionuclides by surface or groundwater, or by windborne movement of contaminated particles from the surface of the burial area. Direct exposure to external radiation from buried waste would only become a consideration if the waste were exposed by some means (for example, through erosion or subsidence of the soil cover) or if dissolved radionuclides were transported to the surface by groundwater. The airborne particulate pathway also requires non-radiological analysis at LFBG because the site was used for the disposal of beryllium, which, though not radioactive, is chemically toxic if inhaled as a fine dust. Groundwater and surface water associated with the LFBG and surrounding area are not used as drinking water for people or for irrigating crops. The hydrogeological conditions at LFBG also ensure that, with the exception of tritium, most radionuclides in groundwater are chemically trapped by the clay subsoil and retained close to the burial trenches.

Radiological dose assessments are not routinely conducted for the LFBG, however the environmental monitoring program, begun in 1966 (Cook *et al*., 1969), is based on the potential exposure pathways. The monitoring at LFBG has included measurement of

radioactivity in soil, plants, groundwater, and airborne dust sampled from the site, as well as surface water from creeks draining the area (see Hoffmann, 1990). These samples have shown no detectable beryllium in windborne dust, or tritium in water sampled from creeks draining the area, for at least a decade. External gamma radiation dose over the disposal area has been surveyed, using a hand-held meter, since 1993. Soil sampling is triggered only when a dose three times background is recorded; this last occurred at a point over the burial trenches in 1993. The plants and soil covering burial trenches at LFBG are regularly inspected and any sign of deterioration is remedied.

2.4 THE NATIONAL MEDICAL CYCLOTRON

The National Medical Cyclotron (NMC) provides isotopes for research, clinical evaluations and routine nuclear medicine procedures. It is owned and operated by ANSTO and is located adjacent to the Royal Prince Alfred Hospital in Camperdown, Sydney (see Figure 1 inset).

The NMC is primarily used to produce radiopharmaceuticals for use in two diagnostic imaging systems - positron emission tomography (PET) and single photon emission computed tomography (SPECT). The radionuclides produced by the NMC are typically of a very short half-life (particularly for PET), ranging from minutes to a number of days, and must be administered to the patient very soon after they are produced. The NMC was therefore located physically close to major Sydney hospitals to minimise the delay between production and patient use.

SPECT radiopharmaceuticals produced at the NMC include:

- gallium-67, used to diagnose soft-tissue tumours and some inflammatory lesions, with a half-life of 78 hours;
- thallium-201, used to assess heart conditions, with a half-life of 74 hours; and
- iodine-123, used to diagnose certain thyroid diseases, with a half-life of 13 hours.

PET radiopharmaceuticals produced at the NMC include:

- fluorine-18, used to diagnose brain disease and to assess the spread of cancers, with a half-life of 110 minutes;
- nitrogen-13, used for the early detection of coronary disease, with a half-life of 10 minutes; and
- oxygen-18, used to study oxygen metabolism, with a half-life of 2 minutes.

The pathways through which radionuclides from the NMC may enter the environment are very similar to those discussed with relation to the Lucas Heights site, namely:

- atmospheric discharges of short-lived isotopes such as iodine-123;
- discharges to the Sydney Water sewerage system of low-level liquid effluent, typically containing thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65 and iodine-123.

The longest-lived radioisotope discharged to air from the NMC is gallium-67 with a half-life of 78 hours. In the case of liquid effluent, cobalt-57 has the longest half-life at around 271 days. Liquid effluent discharged to the Sydney sewerage system ultimately enters the sea offshore via the deep ocean outfalls. There is therefore not likely to be any significant environmental pathway to humans, such as through the consumption of seafood.

3 ENVIRONMENTAL MONITORING AT THE LUCAS HEIGHTS SITE

The monitoring program at Lucas Heights involves measurement of the radioactivity in local environmental samples, as well as the liquid and airborne effluent discharged from the site. (Details of the effluent monitoring programs are presented in Section 4 of this report. Effluent monitoring at the National Medical Cyclotron site is reported in Section 5.)

Samples of sediment, groundwater, biota, air and surface water were collected during 2001 at the sites shown in Figures 1 to 4 and analysed for radioactivity. Sampling locations included the Woronora River, Mill Creek, Bardens Creek, Forbes Creek, Potter Point ocean outfall, stormwater outlets, creeks draining the Lucas Heights site and the Little Forest Burial Ground. The on-site meteorological station has been in operation since 1958 and collects data all year round. External gamma radiation levels at the perimeter of the Lucas Heights site, as well as local residences, have been measured since 1994.

The environmental sample collection and preparation schedule is shown in Table 1. Further detail about the collection, preparation and analysis of environmental samples was published in Hoffmann *et al*., 2001. For information on the major radionuclides detected, including naturally occurring radioactivity in environmental samples, please refer to Appendix 1. Appendix 2 lists the radionuclide symbols and half-lives used throughout this report.

Environmental survey results for 2001 are presented in Tables 2 to 18b. Results are interpreted against state or national guidelines, such as:

- The NSW Regulations associated with the *Protection of the Environment Operations Act,* 1997; and
- The National Health and Medical Research Council and Australian Water Resources Council (NH&MRC and AWRC) *Australian Drinking Water Guidelines,* 1996.

It should be noted that the environmental water samples discussed in this section are not required to meet guidelines for radioactivity concentrations in drinking water. Such guidelines are used as indicative levels simply to provide context for the results of tests for the presence of tritium and other radionuclides in non-class C waters. In previous years, results were compared with the WHO 1993 guidelines. Both the Australian and WHO guidelines use a similar methodology to assess the dose from radioisotopes present in drinking water.

3.1 WORONORA RIVER

Water samples were collected monthly from the Woronora River at the boat ramp in Jannali Reserve and analysed for tritium. No tritium was detected in these samples during 2001. (The data are listed in Table 2.)

3.2 FORBES CREEK

Sampling at Forbes/Loftus Creek was initiated in 1994, in response to the concerns of local residents that occasional overflows from the upstream sewer mains during periods of heavy rainfall might contain radioactivity of LHSTC origin. Tritium is the radionuclide most likely to be detectable under such circumstances.

Water from the confluence of Forbes and Loftus Creeks (tributaries of the Woronora River) was sampled monthly in 2001 and analysed for tritium. Results are presented in Table 3. The samples were taken after rain (when possible) from the point at which the Sydney Water supply pipeline crosses Forbes Creek, shown on Figure 1. No statistically significant tritium concentrations have been observed in any samples collected at this location.

3.3 POTTER POINT BIOLOGICAL MONITORING

The biological monitoring at Potter Point is designed to give the best chance of detecting human-produced radionuclides in the marine environment. Fish, algae (seaweed) and barnacles are collected because these organisms represent different levels in the food chain leading to humans (ie. water to seaweed to fish to people) and also because the algae and barnacles are efficient at concentrating a variety of radionuclides from the water.

The sampling locations at Potter Point and the reference (background) site in the Royal National Park are shown in Figure 4, and the results for fish flesh, green algae and barnacles are given in Tables 4, 5 and 6. See Section 6 for details of the offshore monitoring program conducted at Potter Point.

The species collected from Potter Point were blackfish or luderick (*Girella sp*.), green algae (mainly *Enteromorpha sp*. or *Ulva sp*.) and surf barnacles (mainly *Tesseropera rosea*).

The approximate quantities collected in 2001 were blackfish, 0.6 kg fresh weight; green algae, 1.6 kg; and barnacles, 1.2 kg. Collections were conducted with authorisation from the NSW Department of Fisheries.

Fish were filleted and skinned, while the algae and barnacles were left whole and unwashed. Samples were dried, ground and analysed for gamma-emitting radioisotopes. The upgrading of the Cronulla Sewage Treatment Plant to remove important plant nutrients (tertiary treatment) affected sampling by greatly reducing the amount of algae (*Enteromorpha sp*.) growing near the outfall. In October 2001, *Ulva sp.* was the main type of green alga sampled at Potter Point and in the Royal National Park.

The radioactivity of the biological samples is expressed as becquerels per kilogram fresh weight. Gamma spectrometry of samples collected from Potter Point and the comparison site some 6.5 kilometres away, showed typical levels of naturally occurring radioisotopes, which are commonly found in marine specimens. These included beryllium-7, potassium-40 (found in all biological samples) and progeny of the uranium-238 and thorium-232 decay series, such as lead-210 and thorium-234.

Three fish samples were collected at Potter Point during the year (see Table 4). The filleted flesh was analysed by gamma spectrometry and all sample spectra were checked for the presence of anthropogenic (man-made) radionuclides. None were detected. The minimum detectable activities (95% confidence) are therefore quoted for relevant radionuclides such as iodine-131, cobalt-60 and caesium-137. Any other anthropogenic radionuclides would be reported and discussed if they were noted in the sample spectra.

Green algae sampled from the shore near the Potter Point ocean outfall in March and October 2001 contained iodine-131 as well as the expected natural radioactivity (see Table 5). No other anthropogenic radionuclides were detected. There was a decline in the amounts of both iodine-131 and cobalt-60 detected in green algae in 2001, compared with levels found over the past few years of sampling.

In 2001, no gamma radioactivity, other than that of natural origin, was detected in any of the four barnacle samples collected from Potter Point (see Table 6).

Iodine-131 is a beta- and gamma-emitting radionuclide with a relatively short half-life of about eight days. It is an important medical isotope used in hospitals for the treatment of thyroid cancer and is also produced at the Lucas Heights site by ANSTO's commercial arm, Australian Radiopharmaceuticals and Industrials. ANSTO's liquid effluent is not therefore the only source of iodine-131 entering the sewerage system in the Sutherland Shire, since local hospitals and medical practices using nuclear medicines may also be sources.

The small concentrations of iodine-131 found in green algae from Potter Point are considered of no health significance to humans. Even though blackfish are known to eat such algae, no iodine-131 was detected in the fish sampled in 2001.

As in previous years, since 1995 when the current biological sampling began at Potter Point, no human-produced radionuclides were detected in any of the biological samples collected from the site in the Royal National Park, where only natural levels of radiation are expected.

3.4 STORMWATER

Concrete stormwater retention dams (bunds) on the three main stormwater outlet points for the Lucas Heights site retain stormwater/groundwater seepage temporarily before its release off-site. They enable the on-site containment and treatment of any small accidental spills or releases of contaminated liquid that could otherwise enter the site stormwater system. They are also used as environmental monitoring points. The locations of the stormwater bunds are shown in Figure 2.

The stormwater bunds are inspected and discharged daily by Waste Operations staff.

Tritium in Stormwater Bunds

From February 1996 until March 2000 the stormwater bunds were sampled and analysed for tritium once per month. In March 2000 a more representative sampling protocol was applied to all three stormwater bunds. Daily samples were taken (except on weekends and public holidays) and combined to form a monthly composite. The volume sampled each month ranged from 16 to 23 litres. The composite samples were distilled and analysed for tritium. The tritium results for the 2001 composite samples appear in Table 7a.

Tritium was detected in monthly composite water samples from Stormwater Bunds A, B and C at levels well below the Australian (NH&MRC 1996) drinking water guideline concentration of 7600 Bq/L (see Table 7a). These bunds are situated on-site and stormwater passing through them clearly does not contribute to any public drinking water source.

The range of tritium values recorded in the twelve composite samples for 2001, typical for the Lucas Heights site, were as follows:

- Bund A: 30 – 340 Bq/L;
- Bund B: 30 – 140 Bq/L;
- Bund C: 50 – 210 Bq/L.

The detection of small but measurable quantities of tritium in stormwater and creeks draining the site is not unexpected at the LHSTC, since tritiated water vapour released to air from HIFAR operation exchanges with rainwater and other surface waters. (Further information on tritium is presented in Appendix 1.)

In 2001, as in previous years, discrete water samples were collected from the MDP Bund C each week. All of these samples were analysed for tritium and the results are shown in Table 7b. The tritium levels in MDP Bund C ranged from less than 20 up to 840 Bq/L with an average of 160 Bq/L, which are typical levels for the Lucas Heights site.

Radioactivity in Water from MDP Bund C - Monthly Composite

Weekly water samples from MDP Bund C, situated on the stormwater drain from the Waste Management area into MDP creek, were combined to make a monthly composite sample, which was analysed for gross alpha, gross beta and gamma radioactivity. The results are given in Table 7c.

The average gross alpha/beta activities of the monthly MDP Bund C composite samples for 2001 (including less-than values) were gross alpha less than 0.03 Bq/L; gross beta 0.73 Bq/L. These values are well below the relevant limits for Class C waters (gross alpha, 1.1 Bq/L and gross beta, 11.1 Bq/L) under the Protection of the Environment Operations Act (1997).

Gamma spectrometry performed on the monthly composite samples showed low but detectable caesium-137 concentrations in ten of the twelve samples. The only other significant gamma-emitters detected were potassium-40 and beryllium-7 (both of natural origin) and occasional traces of cobalt-60. The latter radionuclide was probably associated with suspended sediment in the unfiltered samples.

The average weekly concentration of caesium-137 in MDP bund water was less than 0.020 Bq/L, or 0.2% of the Australian guideline value for caesium-137 in drinking water (NH&MRC 1996). Similar low levels of caesium-137 have been detected in previous years.

Sediment from Stormwater Bunds

Sediment that has accumulated in the stormwater bunds is removed at least once each year. These sediments are analysed for gross alpha, gross beta and gamma radioactivity. Results pertaining to sediment collected from the three bunds in 2001 are given in Table 8. Gross alpha/beta activities found in 2001 corresponded to normal levels for similar sandy soils of the Sydney region. Gamma-emitters detected included naturally occurring potassium-40, beryllium-7 and progeny of the uranium-238 and thorium-232 decay series. Small concentrations of fission or activation products were also detected. The extremely low activities found do not have any health consequences for humans or the environment.

3.5 SURFACE WATERS

MDP Creek (MDP+60m)

Stormwater and groundwater from the southeast corner of the site drain into MDP creek (see Figure 2). Historically, the water from this area has been sampled from a natural pool about sixty metres below the actual stormwater outlet itself, known as MDP+60m.

The weekly MDP+60m sample was combined to make a composite sample for each month. The monthly samples were analysed for gross alpha, gross beta and gamma- emitters. Each weekly sample was also separately analysed for tritium.

Tritium in Water from MDP+60m - Weekly

Tritium results for the weekly MDP+60m water samples are shown in Table 9a and varied from less than 20 up to 470 Bq/L. The average tritium concentration of weekly samples for the year was 110 Bq/L, which is less than 2% of the Australian drinking water guideline concentration (NH&MRC 1996).

Radioactivity in MDP+60m - Monthly Composite

Gross alpha and gross beta radioactivity results for monthly composite MDP+60m water samples were at background levels throughout the year (see Table 9b). The average activities were less than 0.04 Bq/L for gross alpha and 0.33 Bq/L for gross beta. These are well below the relevant NSW regulations limits for Class C waters: 1.1 Bq/L for gross alpha and 11.1 Bq/L for gross beta activity.

Gamma spectrometry of the MDP+60m creek water composite samples showed low levels of the natural radionuclides potassium-40 and beryllium-7, as well as caesium-137 in nine of the twelve samples. The maximum observed concentration of caesium-137 represents less than

0.3% of the Australian drinking water guideline concentration (NH&MRC 1996). No other gamma-emitters were detected.

SPCC Creek Sampling Points

Sampling locations on Strassman Creek, Bardens Creek and MDP Creek (shown in Figure 2) are known as the "SPCC" creek sampling points because they were originally selected in 1975 by the State Pollution Control Commission [(1)]. Stormwater from the Lucas Heights site flows into these small local streams, which are classified as Class C waters under the regulations associated with the NSW *Protection of the Environment Operations Act*, 1997.

The results of gross alpha and gross beta analyses conducted on the SPCC creek samples are shown in Table 10. Note that the gross beta results include the contribution of natural potassium-40 activity. All results for 2001 were well below the limits for gross alpha and gross beta activity in the relevant NSW regulations. Although drinking water standards do not strictly apply to stormwater, the results were also below the more restrictive Australian guideline value of 0.5 Bq/L for gross alpha and gross beta activity in drinking water (NH&MRC 1996, as amended September 2001).

Bardens Creek Weir

In addition to the monthly sampling (see above), weekly water samples were also collected from the flume weir on Bardens Creek. The results of tritium analyses performed on these samples are shown in Table 11. The average weekly concentration at this location was less than 50 Bq/L, or less than 1% of the NH&MRC 1996 guideline concentration. It should be noted that water from Bardens Creek is not part of any known drinking water supply.

Surface-water and Stormwater Summary

Tritium and gamma activity concentrations found in stormwater at the Lucas Heights site and associated watercourses were consistently below 2% of the Australian drinking water guideline values. Gross alpha/beta results were substantially below the limits specified in the relevant NSW regulations for Class C waters. Since the levels of detected activity were minimal, and the stormwater does not enter any known human drinking water supply, it is concluded that there are no environmental or health consequences to humans from the measured radioactivity in stormwater from the Lucas Heights site.

3.6 GAMMA SURVEY OF EFFLUENT DISCHARGE PIPELINE

The pipeline through which liquid effluent from ANSTO is discharged to the Sydney Water sewer is shown in 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 2001 in order to detect any past or present leaks. The results are summarised in Table 12a. Gamma dose rates at pipe joints were recorded using an Eberline PRM-7 dose-rate meter. The measurement tolerance on such instruments is typically ± 20%. The measured dose rates ranged from 0.05 to 0.13 μSv/hour and were principally due to natural background radiation.

Staff observed a small weep in a pipe joint during routine environmental sampling on 30 July 2001. This was immediately repaired and the Environmental Monitoring Group collected soil samples and measured gamma dose rates around the pipe joint. The soils were analysed for gross alpha, beta and gamma activity and the results are given in Table 12b. Localised soil contamination of anticipated radionuclides, such as cobalt-60 and caesium-137 (less than 0.3

[1] Now the NSW Environment Protection Authority

Bq/g dry weight in each case) was found in samples from directly underneath the leak and at near-background levels a metre downhill. The maximum levels found were less than a tenth of the relevant IAEA exemption level (IAEA 1996).

A similar investigation was conducted on 15 October 2001 after an air bleed valve was found to be weeping slightly. The valve was corrected and shortly afterwards removed during scheduled maintenance to replace all the valves on the pipeline. Measurements taken near the valve showed no dose above background from a calibrated, hand-held dose-rate meter. More sensitive analyses showed no significant increase in gross alpha counts from soil sampled close to the valve, but an approximate 50% increase in gross beta activity. The levels of some gamma-emitting radionuclides (lead-210, caesium-137, cobalt-60 and potassium-40) appeared to be increased over background soil measurements but all were less than 0.25 Bq/g dry weight. Conservative dose estimations showed that radioactivity was well below levels of regulatory concern.

3.7 THE LITTLE FOREST BURIAL GROUND (LFBG)

Results of sampling at the LFBG are given in Tables 13, 14a, 14b, 15, and 16. The locations of the sampling points and the burial trenches are shown in Figure 3.

Non-routine monitoring of soil from the LFBG burial trench area was carried out following vandalism of the fence and LFBG compound. The vandalism resulted in minor disturbance of the grass cover on a small area of the trench zone (to a depth of no more than 5 cm), but there was no damage to the monitoring bores. Results are discussed below.

Routine maintenance of the LFBG area includes regular mowing and inspection of the trenches. During the year several depressions in the trench area were filled with clay/shale of local origin.

Soil Survey of LFBG

The annual survey of the burial trenches at LFBG is carried out using field dose-rate monitors to check for surface contamination. The dose-rate survey for 2001 was carried out in November (see Table 13). Dose rates over all the trenches ranged from 0.10 to 0.15 μSv/hour and were consistent with background readings taken approximately 200 metres away from the trench area, at the LFBG entrance gate.

Soil Samples from LFBG

No routine soil samples were collected at LFBG in 2001, because the dose-rate survey showed no gamma radiation above background levels; sampling is conducted at any point yielding a dose rate greater than three times background.

On 7 August 2001, in response to vandalism of the LFBG, two non-routine samples of soil were collected from the trench area. The samples were analysed for gross alpha, gross beta and gamma radioactivity. The results are given in Table 14a along with those for a comparison site outside the LFBG, collected in 2000. These results show background levels of natural radioactivity in the case of all the samples and indicate that there was no mobilisation of radioactivity as a result of this incident.

Groundwater Monitoring at LFBG

Groundwater from fifteen monitoring bores located both inside and outside the fenced LFBG area was collected in June and November 2001. The bores were first purged and allowed to recover for a week prior to sampling. As in previous years, the groundwater was not filtered

prior to analysis, which meant that any radioactivity (natural or otherwise) bound to suspended sediments in the samples would be included in the analysis.

The MB series of bores were drilled in 1986 and first sampled in 1988, whilst BHF, BH10, OS2 and OS3 are from a much older series of bores that are neither screened nor lined.

The groundwaters were analysed for tritium, gross alpha, gross beta and gamma radioactivity. Results are listed in Table 14b, with shaded areas indicating the three bores located outside the fenced area that were sampled. Note that there are no liquid or airborne emissions, as such, from the LFBG, therefore no discharge authorisation exists. For the purposes of comparison, however, national guidelines for surface waters and/or drinking water are provided.

Gamma-emitters in LFBG Groundwater

Apart from traces of cobalt-60 found in MB16, located in the centre of the trench area, only natural potassium-40 and progeny of the U-238 series were occasionally detected in LFBG bore waters. The maximum concentration of cobalt-60 was less than 1% of the Australian drinking water guideline value of 20 Bq/L (NH&MRC 1996).

Gross Alpha/Beta Activity in LFBG Groundwater

The gross alpha activity found in groundwater from LFBG ranged from less than 0.02 up to 0.16 Bq/L. The gross beta values ranged from 0.04 to 0.54 Bq/L. The results were all below the limits for Class C surface waters of 1.1 Bq/L (alpha) and 11.1 Bq/L (beta) under the NSW regulations associated with the *Protection of the Environment Operations Act*, 1997. The gross alpha and gross beta activity levels were also at or below the more restrictive Australian drinking water guideline level of 0.5 Bq/L.

Tritium in LFBG Groundwater

The range of tritium concentrations measured in 2001 was similar to values observed in previous years, with detectable tritium levels in thirteen out of fifteen bores sampled. Bores OS3, MB13 and MB16 usually display the most significant tritium concentrations, with MB16, located in the centre of the trenches, having the highest levels. However, in November 2001 the greatest concentration of tritium (5690 Bq/L) was observed in BH10. Similar levels were last recorded in this bore in 1997 and 1998. The tritium concentration in BH10 was still below the level of 7600 Bq/L, which is considered safe for Australian drinking water.

MB19 and MB21, two of the three bores sampled outside the fenced area contained very low, but detectable, levels of tritium.

Streams Draining the LFBG area

Samples of surface water and sediment were collected from Mill Creek and Bardens Creek, which drain the area around the LFBG, near their confluence. This sampling location is approximately two kilometres distant from the LFBG (see Figure 1). The results of gross alpha, gross beta, tritium and gamma analyses on these samples are given in Table 15. No radioactivity above environmental background levels was found.

Airborne Particle Sampling at the LFBG

The airborne particulate pathway requires special consideration at LFBG because the site was also used for the disposal of stable beryllium oxide from 1960 to 1968. This beryllium is not radioactive but would be chemically toxic if inhaled as a fine dust.

An Ecotech high-volume air sampler was operated at the Little Forest Burial Ground once every two weeks for four to six hours during normal working hours. Sampling was not performed during wet weather when airborne dust levels would have been negligible.

The results are given in Table 16. At the end of each three-month sampling period, the exposed filter was divided into four equal portions. Two of these were used for beryllium and plutonium analyses; the remaining two portions were stored. Beryllium and plutonium were not detected on the filter portions analysed in 2001.

Wind Conditions at the LFBG

Wind-speed conditions at the LFBG are assumed to be similar to those measured at the nearby Lucas Heights meteorological tower. In 2001, during periods of air sampling at the LFBG, the average wind speed at Lucas Heights was 3.4 metres per second. This information was obtained from 15-minute averages of wind-speed data recorded at a height of 10 metres on the ANSTO meteorological tower during the actual periods that sampling was undertaken. For further information on the meteorological monitoring carried out at Lucas Heights see Section 3.9.

The wind-speed threshold for increased re-suspension of dust particles from the ground in temperate Australian conditions is normally considered to be about 5 to 6 metres per second. However, this depends on local conditions, including soil moisture, age of the particles and their bonding to the ground surface, vegetation cover and local turbulence. Nigel Holmes and Associates (1991) reported that 5.6 metres per second was the critical wind-speed threshold for dust generation from an exposed surface, such as the nearby Lucas Heights Waste Management Centre.

The LFBG has an established vegetation cover consisting of grass and scattered shrubs, which minimises the potential for dust generation. Analysis of all wind-speed data from Lucas Heights for the period April 1991 to April 2002 showed that wind speeds exceeded 5.6 metres per second in only 3.3% of the time during that period (Clark, G.H., 1997 and Clark, G.H., unpublished data, 2002).

The LFBG is a stable, grass-covered area that rarely experiences winds capable of significant dust generation. Under ordinary circumstances, the possibility that contaminated airborne particles could be transported off-site is remote. Radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

3.8 IODINE-131 IN AIR

Four continuous air-sampling stations are situated along the eastern boundary of the site (where suburban residences are closest) to monitor concentrations of ambient iodine-131 in air. The locations of these samplers are shown in Figure 2. Iodine-131 is a nuclide of particular interest since it can be incorporated into the food chain, unlike inert noble gases.

At each station the air is sampled by means of a vacuum pump that draws air through a pair of Maypacks (activated charcoal filter cartridges), so that duplicate samples are available. Air is sampled at a rate of approximately 35 cubic metres per day. Filters are replaced and analysed weekly, with airflow rates through the filters being checked at the same time. Calculations of iodine-131 activity give maximum levels of activity using a conservative set of assumptions. The Maypacks are screened for iodine-131 activity using an 8 x 4 inch sodium iodide gamma detector.

No iodine-131 was detected in ambient air at the site boundary during 2001. All results were below the detectable level of 0.0025 Bq/m^3 (see Table 17). The minimum detectable level would correspond to an annual dose of less than 0.01 mSv per year[(2)] to a member of a hypothetical critical group living at Stevens Hall Motel and receiving continuous exposure to iodine-131 at a concentration of 0.0025 Bq/m^3. Since the fifty-two measurements in 2001 showed no detectable iodine-131, the average annual dose to the public from iodine-131 is clearly far less than 0.01 mSv.

3.9 METEOROLOGICAL MONITORING

In common with many other nuclear facilities, ANSTO undertakes an extensive program of meteorological measurements. The prime reason for such a program is to allow estimates to be made of the downwind concentration of any airborne pollutants, particularly radionuclides, released from the Lucas Heights site through routine operations or under accident conditions. The data collected from this program provide the necessary input to the atmospheric dispersion model called PC-CREAM, which is used to compute the effective dose to an individual due to the routine airborne or accidental release of radionuclides from the Lucas Heights site. (See Section 7.2 for further information regarding PC-CREAM.)

The meteorological data are collected and analysed continuously. The long-term climatology data for Lucas Heights are updated and published approximately every five years. The most recent report available is Clark, G.H., *An Updated Analysis of the Lucas Heights Climatology – 1975 to 1996*, 1997. 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 (shown in Figure 1) are located at the Boys Town School (Engadine) and at the "Shackels Estate" in the Woronora River valley.

Wind Speed and Direction

Annual average wind speeds recorded at Lucas Heights from 1991 to 1996 were approximately 2.5 metres per second (Clark, 1997). The winds that predominate at Lucas Heights during summer and winter are shown in the table below.

Prevailing Winds at Lucas Heights		
Season	*Time of Day*	*Wind Direction*
Summer	Daytime (sea-breeze) Night / early morning	From NE - ENE sectors From SSE – SSW sector
Winter	Daytime Night / early morning	From W - NW and S - SE sectors From S – WSW sectors

[2] Based on the Committed Effective Dose per Unit Activity given in the International Basic Safety Standards (IAEA 1996).

Winds during autumn and spring represent a transition between those of summer and winter seasons, with sea breezes observed later in the afternoon.

The influence of local topography on wind speeds and directions is very marked in the Lucas Heights area. Low wind speeds at the Woronora River valley floor are associated with the drainage of cool air into the valley at night (Clark, 1997). Winds on the plateau and ridges are stronger and steadier.

Rainfall and Evaporation

The total rainfall at Lucas Heights during the year 2001 was 898 mm recorded on 120 rain days. The wettest month was January with 191 mm, and the maximum 24-hour rainfall was 147 mm recorded on 31 January. The total annual rainfall measured at Lucas Heights since 1958 has varied from 556 mm to 1658 mm. The total evaporation for the year, measured using a Class A evaporation pan, was 1162 mm with a maximum 24-hour value of 10.8 mm.

Temperature

There are only small differences in recorded temperature between the stations on the ridges and plateau above the Woronora River valley. However, the valley generally has higher daytime temperatures due to trapping of warm air, and lower night temperatures due to cool air drainage.

The coldest month at Lucas Heights during 2001 was July with an average midday temperature of 15.6 °C, while the warmest month was January when the average midday temperature was 26.8 °C. The minimum temperature was 3.1 °C recorded in July and the maximum was 41.6 °C recorded in January.

3.10 EXTERNAL GAMMA RADIATION

Thermoluminescent dosimeters (TLD) were used to measure the external gamma radiation in and around the Lucas Heights site during 2001.

The dosimeters, issued by ARPANSA, are the same as those used for personal monitoring and consist of calcium sulphate thermoluminescent material with three filtered areas and an open window.

Figure 2 shows the locations of Dosimeters 1 to 15 at the Lucas Heights site.

ARPANSA Thermoluminescent Dosimeter Results

Table 18a shows the integrated annual absorbed doses to air, in millisieverts, as monitored by the ARPANSA dosimeters for the calendar year 2001, and compares these figures with results obtained since 1997. Measurements were made over quarterly monitoring periods, the dosimeters were returned to ARPANSA for measurement, and the readings were reported to ANSTO as annual absorbed dose to air in terms of milligrays (mGy). The absorbed dose was then converted to effective dose (millisieverts) using the conservative conversion factor of one [3].

Annual doses measured at or within the Lucas Heights site perimeter fence in 2001, apart from those at Location 2, ranged from 0.56 mSv to 1.21 mSv. The external gamma dose at

[3] UNSCEAR (1993) use conversion factors of 0.72 Sv per Gy for adults, 0.80 for children and 0.93 for infants.

Location 2 (on the inner perimeter fence) has been slightly elevated since 1997, when stored radioactive materials were relocated to the area. Comprehensive dose-rate surveys conducted inside and outside the perimeter fence, together with a consideration of occupancy factors, indicate that shielding of the storage building is appropriate. This location is about 1.8 kilometres away from any residential areas and there is no public occupancy of the area.

Table 18a also shows the annual absorbed dose to air measured outside three homes in the vicinity of the Lucas Heights site (Locations 16, 17 and 18). This dose, due to environmental radiation, averaged 0.75 mSv at the three locations in 2001. The annual doses measured at these local residences have remained constant (within measurement tolerances) since the introduction of TLD monitoring in 1994.

In July 1999 an additional dosimeter was placed at the Cronulla Sewage Treatment Plant (Location 19) and the annual effective doses measured at this location have remained at background levels since monitoring commenced.

When converted to an hourly rate, the local environmental dose figures (Table 18a) correspond with the average hourly absorbed dose rate to air from terrestrial gamma radiation, recorded in Australian capital cities in surveys carried out by the Australian Radiation Laboratory (now ARPANSA) and reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993). This means that the external gamma dose rates at residences near the Lucas Heights site are at normal background levels.

ANSTO Thermoluminescent Dosimeter Results

Dual monitoring was carried out using two sets of dosimeters placed at the same locations. The environmental dosimeters used by ANSTO contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters. They were analysed at ANSTO using a Harshaw 6600 TLD reader. Table 18b shows the data obtained from the ANSTO and ARPANSA dosimeters. As in previous years, the results from the two types of TLD show no significant difference.

4 EFFLUENT MONITORING AT THE LUCAS HEIGHTS SITE

Descriptions of the liquid and airborne effluent sampling and analysis programs are given in the following sections and results are discussed. Refer to Section 7 for information on the airborne and liquid effluent discharge authorisations applicable to the Lucas Heights and NMC sites.

In 2001, results of ANSTO's effluent monitoring programs were also checked by the Environmental and Radiation Health Branch of ARPANSA, based in Melbourne.

4.1 AIRBORNE EFFLUENT STACK DISCHARGES

Airborne emissions from ANSTO are subject to regulation by ARPANSA. A new airborne discharge authorisation was issued by ARPANSA in May 2001 and reporting against the Facility Licence Conditions and associated stack notification system commenced from 1 July 2001. The stack notification system includes four-weekly, quarterly and annual notification levels of radioactivity for each emission source.

In 2001, as in previous years, the authorised airborne emissions from LHSTC stacks were sampled continuously, with weekly analysis and data collection. The effluent airstream samples were analysed for gamma-emitters, noble (inert) gases, tritiated water vapour and

gross alpha/beta activity and the results were reported to ARPANSA on a four-weekly and quarterly basis. The locations of the discharge stacks are shown in Figure 2.

Lucas Heights Site Stack Sampling and Analysis

During 2001, fifteen sampling points on twelve discharge stacks at the Lucas Heights site were monitored on a weekly basis. The effluent airstreams were sampled using filter cartridges (Maypacks) connected to vacuum pumps. The Maypacks consist of a charcoal section to trap gases and vapours, and a particulate filter. Critical orifices are used to standardise the flow of air through Maypack sampling assemblies.

The Maypack cartridges are initially analysed by gamma spectrometry, and the particulate filters for gross alpha/beta activity. The cartridges and the filters are then stored for four weeks. Some of the particulate filters are measured again for gross alpha and gross beta activity to confirm whether any particulate activity previously measured was principally due to short-lived radioisotopes.

Tritiated water in the airborne discharges is sampled using a tritium trap. A proportion of the stack airstream is drawn through a series of four Dreschel bottles filled with demineralised water, trapping the tritiated water. A liquid scintillation counter is then used to measure the tritium activity in the sample. Noble gases in airborne effluent are measured in situ by a gamma spectrometer as the effluent passes through a 250 mL sampling flask.

Lucas Heights Airborne Emission Data

Tables 19a, 19b, 19c and 19d present the 2001 airborne emission data for the individual stack release points at the Lucas Heights site, showing total releases over quarterly periods. The information contained in the above tables is drawn from the quarterly reports sent to ARPANSA.

The emission of noble gases from radiopharmaceutical production (Stack 54) remained low in 2001 due to process modification that was carried out in the latter half of 2000. Tritium discharges returned to usual levels after the HIFAR major maintenance shutdown in 2000. There have been no formal notifications to ARPANSA during the reporting period, however ANSTO and ARPANSA negotiated the merging of the notification levels for HIFAR Stacks 15A and 15M (essentially argon-41 releases) to reflect normal operating conditions.

The possible doses to members of the public as a result of airborne releases from the Lucas Heights site were estimated from the airborne discharge data for the 2001 calendar year using the PC-CREAM atmospheric dispersion model. See Section 7.2 for further information on PC-CREAM, and Section 8 for discussion of the potential public doses from ANSTO operations.

It should be noted that the on-site and public doses resulting from the discharges are very low. At the 1.6 km exclusion zone boundary the estimated doses were less than 0.01 mSv per year, well below the annual 0.2 mSv ALARA objective for off-site doses and much lower than the public dose limit of 1 mSv/year, and the natural background in Australia of 1.5 to 2 mSv/year (Webb *et al*, 1999).

Independent Check of Stack Monitoring Program

ANSTO monitored the Lucas Heights site stack discharges on a weekly basis, with four-weekly and quarterly reporting to ARPANSA. Independent confirmation of these measurements was undertaken by a peer laboratory, the Environmental and Radiation Health Branch, ARPANSA. These independent checks confirmed that ANSTO's stack monitoring system operated correctly in 2001.

4.2 LOW-LEVEL LIQUID EFFLUENT DISCHARGES

The Waste Operations group at ANSTO is responsible for the handling, treatment, monitoring and authorised discharge of liquid effluent arising from operations at the Lucas Heights site. The Waste Operations facilities are located on the southeast corner of the site (see Figure 2).

Liquid effluent at the Lucas Heights site falls into the following categories:

- liquids from radioactive laboratories, which have a low level of radioactivity;
- trade effluent from laboratories and workshops in which radioactive and toxic materials are not handled;
- leachate from the nearby Waste Services NSW land-fill operations; and
- sewage.

Treatment and Discharge

The low-activity liquid effluent produced at The Lucas Heights site goes through an alum-based chemical treatment process for removal of radionuclides. The trade waste effluent is tested and chemically treated if necessary. Waste Services effluent is tested for ammonia levels before being accepted as trade waste. Sewage is partially treated at the on-site plant.

The trade waste effluent, treated low-activity effluent and sewage are then combined in the effluent plant holding tanks. The levels of radioactivity in each holding tank are checked for compliance with the current Trade Wastewater Agreement, prior to discharge into the Sydney Water sewer. Such discharges are made almost every working day.

The effluent from the Lucas Heights site, along with sewage from the rest of the Sutherland Shire, passes through the Cronulla Sewage Treatment Plant, which was upgraded to provide tertiary treatment from July 2001. Section 5 discusses the subsequent changes to effluent flows and residence times within the upgraded plant.

Sampling

All effluent is sampled and analysed prior to discharge to the sewer to ensure compliance with the Trade Wastewater Agreement. Pipeline composite samples are also collected during discharge to the effluent pipeline as specified in the Trade Wastewater Agreement. The sampling period for collection of these "pipeline composite" samples changed in July 2001 when a revised Trade Wastewater Agreement came into effect. Previously, one composite sample was collected every fifteen discharge-days, but from July the sampling period was decreased to one every four discharge-days.

Groundwater in the Vicinity of Building 27

Purely as a precaution, groundwater seepage from the general vicinity of the intermediate waste and spent fuel storage facility (Building 27) is routinely collected and pumped into the effluent holding tanks. The levels of gamma-emitting isotopes and tritium in the groundwater are monitored monthly for gamma and tritium radioactivity (see Table 20). Consistent with results in previous years, no statistically significant gamma activity was detected in groundwater from Building 27 Sump in 2001. Tritium levels remained stable with an average of 340 Bq/L, which is less than 5% of the Australian drinking water guideline level of 7600 Bq/L (NH&MRC 1996).

Radioactivity in Liquid Effluent

Radioactivity levels in liquid effluent discharged to the Sydney Water sewer in 2001 are summarised in Table 21. The average gross alpha, gross beta and tritium concentrations in effluent were calculated from the individual pipeline composite results for each month. The

total volume of liquid effluent discharged per month is also given; the average was 7568 cubic metres.

Table 21 also shows the monthly average concentration quotients for gross alpha, gross beta and tritium activity in the effluent, calculated as required by the relevant Trade Wastewater Agreement (see Section 7.3). The concentrations of alpha-emitters found were below the detection limits and, for this reason, alpha quotients are reported as "less-than" values.

The levels of radioactivity in liquid effluent discharges from the Lucas Heights site were well below the concentrations required, ensuring that drinking water quality guidelines were met at the Cronulla STP.

Non-Radioactive Components of Liquid Effluent

The pipeline composite samples were all analysed for the following non-radioactive components: suspended solids; pH; ammonia; biological oxygen demand, grease and zinc.

The non-radiological liquid effluent results are listed in Table 22 as yearly averages recorded from 1997 through to 2001. The maximum and minimum values observed are given in brackets where possible. The concentration limits are also listed against each component.

From 29 March 2001 ANSTO recommenced acceptance of the leachate waste stream from the nearby Waste Services NSW land-fill site, which increased the average ammonia levels in ANSTO discharges from 15% to 19% of the 100 ppm limit.

Liquid Effluent Compliance with Trade Wastewater Agreement

Proportional samples of all liquid effluent discharges were collected and analysed for gross alpha and gross beta radioactivity, pH, biological oxygen demand (BOD), grease, suspended solids, ammonia and zinc to confirm compliance with the Sydney Water Trade Wastewater Agreement. A volume-weighted composite sample was also produced from all pipeline samples each month. This monthly composite sample was analysed for gross alpha/beta, tritium and gamma radioactivity and also assessed for compliance with the Agreement.

Under the terms of the Sydney Water Trade Wastewater Agreement, the average monthly quotient term (based on the Activity Concentration Equivalents at the ANSTO discharge point, see Section 7.3) for gross alpha, gross beta and tritium radioactivity in liquid effluent must be less than 1. In 2001, the average quotient was less than 0.18, representing less than 20% of the authorised limit. Individual monthly quotients ranged from less than 0.12 to less than 0.30. All quotients for 2001 samples were below the limit, demonstrating compliance with the Sydney Water discharge agreement.

Analysis of the monthly composite effluent samples for the year 2001 for the beta-emitting radionuclides, radium-228 and lead-210, showed that concentrations of these nuclides were just at or below detectable levels. Therefore, as permitted under the discharge agreement, the gross alpha and gross beta activities continue to be reported in terms of the less restrictive radionuclides, radium-226 and strontium-90.

In the case of non-radiological components of the effluent, 95% of all samples analysed must be less than or equal to the Sydney Water Standards for Acceptance of Liquid Trade Wastes to Sewers (shown in Table 22). All samples in 2001 complied with these standards.

Compliance Auditing of Liquid Effluent Discharges

In 2001 ARPANSA obtained random retention samples of the monthly pipeline composite from ANSTO's Waste Operations section and carried out independent analyses. These analyses confirmed that discharges were in compliance with the Sydney Water Trade Wastewater Agreement. In addition, Sydney Water also collected random liquid effluent

samples from the ANSTO discharge pipeline at Lucas Heights, to independently assess compliance with its requirements for the acceptance of liquid trade waste. No non-conformances were raised as a result of these audits in 2001, by either Sydney Water or ARPANSA.

5 EFFLUENT MONITORING AT THE NATIONAL MEDICAL CYCLOTRON

The airborne and liquid effluent monitoring results for the NMC in 2001 are detailed in Tables 23a and 23b, respectively. The tables also list the ARPANSA notification levels for airborne discharges and liquid effluent discharge limits as prescribed by the NSW Environment Protection Authority (EPA) and in the Trade Waste Agreement with Sydney Water. See Section 7 for discussion of the relevant discharge authorisations.

The NMC airborne emissions are monitored daily using Maypack charcoal filters. Total monthly iodine-123 activity discharged to air from the NMC ranged from 0.86 to 6.7 GBq (Table 23a). The total iodine-123 activity discharged in 2001 was less than 32% of the annual notification level. The total amounts of fluorine-18, gallium-67 and thallium-201 discharged over the year were orders of magnitude below the relevant annual notification levels.

For liquid effluent discharges from the NMC, the average concentrations of radionuclides discharged to sewer each month were all less than 8% of the NSW EPA limits for thallium-201, thallium-202, gallium-67, zinc-65 and iodine-123.

All the individual airborne and liquid effluent emissions from the NMC during 2001 were well within the prescribed concentration limits.

The airborne and liquid effluent emissions from the National Medical Cyclotron during 2001 were also below the ARPANSA-approved notification levels and NSW EPA limits, respectively. Due to the short-lived nature of the radioisotopes concerned, the impact on humans and the environment from NMC emissions is considered to be negligible.

6 OFFSHORE MONITORING AT POTTER POINT

Treated effluent from the upgraded Cronulla Sewage Treatment Plant is discharged from a submerged cliff-face outfall at Potter Point, located at the northern end of Bate Bay on the Southern Sydney coastline of NSW (see Figure 4).

Some public interest groups have in the past expressed concern that treated liquid effluent discharged to the sewer from the Lucas Heights site may have radiological implications for swimmers and surfers in the vicinity of the Potter Point ocean outfall.

In order to address these concerns ANSTO has carried out a program of investigations at Potter Point since 1995, with the following objectives:

- to measure the transit times and dilution factors for liquid effluent travelling between Lucas Heights and the Cronulla Sewage Treatment Plant (Cronulla STP);
- to study the dispersion of tritium in the vicinity of the outfall; and
- to continue the biological monitoring program at Potter Point outfall.

See Section 3.3 of this report for the results of the Potter Point biological monitoring program.

6.1 MODELLING OF EFFLUENT TRANSPORT

The University of NSW Water Research Laboratory (WRL) has modelled effluent transport from all offshore sewage outfalls serving Sydney, including Potter Point. The model is based on sea conditions monitored at the Ocean Reference Station off Bondi. A detailed account of the WRL modelling of the Potter Point transport plume was published in 1998 in ANSTO/ E-732.

Using the WRL model, it is possible to calculate the concentrations of tritium at any location at sea and at any time since the implementation of the model, given:

- the concentration and times of effluent release at ANSTO;
- the average transit times and dilution factors between ANSTO and Potter Point; and
- offshore dilution factors calculated from the model.

Any concerns over historical releases may therefore be addressed.

6.2 EFFLUENT STUDIES IN 2001

Two routine effluent releases from the Lucas Heights site were monitored during 2001. Samples of the effluent passing through the Cronulla STP were collected by a contractor, GM Laboratories. These samples were collected every hour for twenty-four hours from midnight of the day of release. The samples were then delivered to ANSTO where they were subjected to a sterilising dose of gamma radiation before submission to the Environmental Chemistry tritium laboratory for tritium assay. (Gamma sterilisation has absolutely no effect on the tritium levels.)

Releases of ANSTO treated liquid effluent were monitored in November and December 2001. The effluent was sampled at three stages: prior to its release from Lucas Heights; within the Cronulla STP; and in the sea off Potter Point near the ocean outfall. Details are summarised in the following table:

Liquid effluent releases	**1 November 2001**	**19 and 20 December 2001**
Duration of discharge	3 hours (from 22:00 on 31-10-01)	3 hours (from 19:00 on 19-12-01)
Tritium concentration at the Lucas Heights site	0.33 kBq/L	11.6 kBq/L
Effluent volume discharged	210 kL	210 kL
Number of seawater samples collected near Potter Point ocean outfall	24*	24

* Due to the low level of tritium released at ANSTO, the concentrations of tritium in all twenty-four samples from the Cronulla STP were below the detectable limit. Hence only six marine samples selected at random were assayed. As expected, none showed any tritium.

Investigation on 1 November 2001

The level of tritium in the wastewater available for release was a low value of 0.33 kBq/L. Since the upgrade of the Cronulla STP, the in-line dilution factor has increased to around 250. Therefore, the maximum expected tritium concentration at the Cronulla STP would be around 1.3 Bq/L, which is well below the limit of detection (10 Bq/L). It is therefore not surprising that no tritium was observed in the effluent samples collected at the treatment plant. Clearly there is further dilution and dispersion between the treatment plant and the outfall, and between the outfall and the sampling point in the ocean. For the record, six of the twenty-four seawater samples were assayed. No tritium was found.

Investigation on 19-20 December 2001

The effluent, with a tritium concentration of 11.6 kBq/L, was discharged between 19:00 and 22:00 hours on 19 December 2001. Twenty-four samples were collected for tritium assay at hourly intervals commencing at midnight on 19 December. Seawater samples were collected at three sites at hourly intervals between 08:10 and 15:00 hours (twenty-four samples in total) on 20 December. The locations were as follows:

- Site 1: 34 degrees 02.518 minutes S 151 degrees 12.836 minutes E (+/-15 metres);
- Site 2: 34 degrees 02.599 minutes S 151 degrees 12.809 minutes E (+/- 15 metres);
- Site 3: 34 degrees 02.689 minutes S 151 degrees 12.816 minutes E (+/- 16 metres).

These locations equate to distances of 72 metres, 144 metres and 306 metres at a bearing of 178 degrees (almost due south) from the Potter Point ocean outfall.

The tritium released from ANSTO was first detected within the Cronulla STP at 09:00 hours on 20 December and reached a peak of 46 Bq/L at 18:00 hours. There was still measurable tritium in the plume when sampling ceased at 24:00 hours. This corresponds to a transit time between Lucas Heights and the sampling point within the Cronulla STP of about 21 hours and a dilution factor of 11600/46, or 253. These values compare with typically 11 hours transit time and dilution factors of around 25, prior to the plant upgrade. The apparent increase in the transit time from 11 to 21 hours was due to the relocation of the sample collection point within the re-engineered plant.

Since the upgrading of the plant to permit tertiary treatment, the mean residence time of sewage and LHSTC effluent within the Cronulla STP has increased from a few hours to about 18 hours. Dilution of the effluent has also substantially increased.

7 DISCHARGE AUTHORISATIONS

To ensure protection of the public and the environment in general, liquid and airborne emissions from ANSTO sites are subject to regulation by ARPANSA. ANSTO holds licences issued by ARPANSA for specific conducts at controlled facilities and for dealing with radioactive sources. The licences contain conditions to ensure that discharges to the environment are effectively controlled. Compliance with these requirements also ensures early detection and notification of increases in emissions to the environment.

In 2001 ANSTO complied with:

- Site Facility Licence conditions, reporting requirements and any special conditions prescribed by its regulator, ARPANSA;
- the ANSTO Airborne Radioactive Discharge Authorisation, May 2001;

- all provisions of relevant NSW acts and regulations; and
- in the case of liquid effluent, provisions of the Sydney Water Trade Waste Service Agreements Nos. 4423 (1999 and 2001) and 13966 (1994) for the LHSTC and NMC sites, respectively.

Summaries of annual levels of radioactivity in authorised discharges from the LHSTC and NMC sites are presented in this and previous environmental monitoring reports. The airborne and liquid effluent discharge authorisations are discussed below.

7.1 AIRBORNE DISCHARGE AUTHORISATION

In May 2001 ARPANSA issued ANSTO with an Airborne Radioactive Discharge Authorisation, applicable to all airborne emissions from ANSTO controlled sites, ie. the Lucas Heights site and the NMC. The discharge authorisation is subject to review by ARPANSA after 31 December 2001 following receipt and consideration of public comment. For further information on licence conditions, refer to the ANSTO Licence Conditions Handbook, Section 2.4, issued by ARPANSA.

The purpose of the discharge authorisation is to ensure that the radiation dose to a member of the public, arising from routine airborne radioactive discharges at the Lucas Heights site and the NMC, is as low as reasonably achievable (the ALARA principle) and below the relevant ALARA objectives agreed with the Chief Executive Officer (CEO) of ARPANSA.

The ALARA objective for radiation dose to a member of the public from all operations at either the LHSTC or NMC sites, is 0.020 mSv per year. This is 2% of the annual effective dose limit for members of the general public recommended by the NH&MRC (1995) and specified in the NSW Radiation Control Regulation (1993).

In the case of the Lucas Heights site, the ALARA objective is subdivided as follows:

- 0.010 mSv per year due to the HIFAR research reactor operation;
- 0.010 mSv per year due to radiopharmaceutical production;
- less than 0.001 mSv per year due to all other activites at the Lucas Heights site.

The licence holder (ANSTO) is also required to demonstrate through monitoring, performance assessments or other evidence, that they are effectively controlling airborne discharges to the environment. For practical implementation of the ALARA objectives the airborne discharge authorisation incorporates a system of notification levels for discharge sources. A notification level is:

- a level set well below the agreed dose constraint to ensure the regulator is informed of any change in emission with the potential to significantly impact on public exposure;
- subject to periodic review to maintain relevance in the face of changing technology and operations.

The discharge authorisation incorporates requirements for formal systems of reporting and the requirement to make application for approval of changes.

7.2 APPLICATION OF THE ANNUAL NOTIFICATION LEVELS

Annual notification levels for each discharge location at the Lucas Heights site and NMC are set such that the maximum possible exposure to a member of the public from all sources at Lucas Heights would be less than 0.02 mSv per year. This is more than ten times less than the site dose constraint of 0.3 mSv per year, that was applicable prior to July 2001 and ensures that any event reported to ARPANSA will still be well below the agreed ALARA objective.

The following periodic notification levels, based on a fraction of the annual level, also apply:

Periodic Notification Level	Percentage of Annual Level
Quarterly	50%
4-weekly	20%

These periodic notification levels add a further level of conservatism to the system of public radiation protection.

The contribution of each stack and radionuclide to public dose has also been evaluated to determine the relative importance of the emission sources. Based on this assessment, the emission sources have been prioritised into three groups:

- priority one emissions: relative contribution to public dose greater than 10%;
- priority two emissions: dose contribution 0.1 – 10%;
- priority three emissions: dose contribution less than 0.1%.

The priority three emissions by definition contribute less than 0.1% to the public dose from ANSTO's airborne discharges. Therefore when calculating notification levels for these sources a dose-based approach was not always possible. Specific levels have been set for routinely expected radionuclides, with a separate notification level set for the "total of all other nuclides."

This priority system allows the concentration of resources on high-priority emissions and effective scrutiny of ANSTO's emissions in a manner that is consistent with general radiation protection principles.

PC-CREAM Atmospheric Transport and Dispersion Model

For the highest priority (categories one and two) emissions, annual notification levels were calculated based on assigned doses and airborne dispersion monitoring.

PC-CREAM, an internationally accepted dispersion model, was used to calculate the potential public dose for each type of emission. ARPANSA has authorised the use of PC-CREAM to model environmental transport and dose estimation.

A number of assumptions are used by PC-CREAM when defining the critical groups of members of the public. These assumptions are generally conservative and may lead to some overestimation of the dose received. The following user-defined assumptions are included:

- a hypothetical person is assumed to be outdoors, at the boundary of the buffer zone, 100% of the time for an entire year, so there is no assumed shielding;
- 25% of the hypothetical person's diet of green vegetables (47 kg/annum), root vegetables (84 kg/annum) and fruit (148 kg/annum) is assumed to be grown at the buffer zone boundary, and all other food is grown away from the local area. (Diet is based on Australian Bureau of Statistics data);
- only adult doses are included, but note that the calculated child and infant doses are approximately the same as the adult dose due to the dominance of the contribution from noble gases.

Other assumptions are intrinsic to PC-CREAM and cannot be altered by the user; for example, that the effective release height for airborne effluent is the same as the stack height, so that buoyancy, velocity and building wake effects are not included.

7.3 LIQUID EFFLUENT AUTHORISATIONS

Routine discharges of treated, low-level liquid effluent from the LHSTC and NMC sites are made to the sewer under the terms of Trade Wastewater Agreements, negotiated with Sydney Water Corporation Pty. Ltd.

The Lucas Heights Site

In 2001, discharges from the Lucas Heights site complied with:

- acceptable discharge levels for radioactive pollutants listed in Schedule 1 of the Agreement (at the ANSTO composite sampling and discharge point);
- World Health Organisation (WHO) *Guidelines for Drinking-Water Quality* (1993) reference activity concentrations for radionuclides in drinking water (at the Cronulla Sewage Treatment Plant); and
- concentration limits for non-radioactive components of the effluent.

When monitoring liquid effluent at the ANSTO point of release to the sewer, all discharges must be below the relevant activity concentration equivalents (ACE) for specific radionuclides. These ACE values allow for dilution between the Lucas Heights site and the Cronulla STP.

Where more than one radionuclide is present, the sum is taken of the average concentrations of all radionuclides on release (expressed as a fraction of the relevant ACE). The monthly concentration quotient is calculated as the sum of a mixture of unspecified alpha and beta radionuclides and tritium, where the sum must be no greater than one. Refer to Table 21 for the ACE values and a summary of 2001 liquid effluent discharges.

Within the terms of the Trade Wastewater Agreement, it is assumed that all alpha and beta radioactivity comes from the most restrictive nuclide of each type as defined in the Schedule, unless that nuclide can be shown to be an insignificant fraction of the effluent. Therefore ANSTO also tests composite samples of liquid effluent (proportionately sampled from all discharges for the month) specifically for the beta-emitters radium-228 and lead-210. As in previous years, the results of these analyses were just at, or below, the limit of detection, indicating that these radionuclides are not present in ANSTO effluent in significant proportions. Therefore, reporting of the gross (unspecified) beta activity of liquid effluent continues, using the strontium-90 ACE, while the gross alpha activity is reported against the radium-226 ACE. See Hoffmann *et al*. (2001, Section 3.1) for further details on the above calculations.

ANSTO's Agreement with Sydney Water (No. 4423) for the Lucas Heights site was reviewed in 2001 and changes were implemented from 1 July. The significant changes were as follows:

- the sampling period for collection of composite effluent samples from all discharges was amended to every four discharge-days (previously fifteen discharge-days);
- hourly pH measurements were to be taken during discharges to sewer;
- the ammonia concentration limit was increased to 100 ppm (previously 40 ppm); and
- the suspended solids concentration limit was increased from 200 to 600 ppm.

The National Medical Cyclotron Site

The airborne emissions from the NMC are regulated by ARPANSA under the ANSTO Airborne Radioactivity Discharge Authorisation (see Section 7.1). The site's liquid waste discharges to the Sydney Water sewer are covered by a Trade Waste Agreement (No.13966, 1994) that incorporates limits set by the NSW EPA for specific radionuclides in the discharges. These emissions are routinely monitored and the results for 2001 are discussed in Section 5.

8 POTENTIAL PUBLIC EXPOSURE FROM ANSTO OPERATIONS

The results of the effluent and environmental monitoring programs and subsequent dose assessments are discussed below.

8.1 AIRBORNE EMISSIONS

As indicated in Section 7.1, the discharge authorisation for airborne emissions from ANSTO sites is based on limiting the radiation doses received by members of the public to levels well below the agreed ALARA objective of 0.02 mSv per year for off-site doses.

The Lucas Heights Site

As indicated in Section 7.2, the PC-CREAM atmospheric transport, dispersion and dosimetry model is used to evaluate potential doses to members of the public at various receptor locations, based on measured stack discharges and local meteorological data. Table 24 shows the estimated effective doses due to airborne discharges from the Lucas Heights site in 2001 at specified locations and distances from the reactor.

The results show that the potential effective doses to critical group members of the public within the 1.6-kilometre-radius buffer zone were calculated to be less than 0.01 mSv per year in 2001. For people residing at the boundary of the 1.6-kilometre buffer zone and beyond, the most exposed individual was also estimated to receive less than 0.01 mSv/year. These results confirm that the ALARA objective of 0.02 mSv/y for off-site doses was met.

Ambient levels of iodine-131 at the Lucas Heights site were continuously monitored at the perimeter fence. Since all of the iodine-131 measurements were below the detectable limit, the average potential dose to the public is calculated to be less than 0.01 mSv per year. This figure is consistent with the results obtained from the PC-CREAM model and represents 1% of the recommended annual public dose limit of 1 mSv (NH&MRC 1995).

Exposure to background radiation varies significantly between individuals and communities, and depends on factors such as local geological conditions and height above sea level, lifestyle, diet and type of dwelling. The global average for adult exposure to radiation from natural sources is estimated to be 2.4 mSv per year (UNSCEAR 2000). The equivalent value for Australia is estimated at around 1.5 to 2 mSv per year (Webb *et al*., 1999).

The estimated potential dose to members of the general public from airborne discharges at the Lucas Heights site is only a very small fraction, less than 0.5%, of the radiation dose received by everyone each year from naturally occurring sources of radiation.

The National Medical Cyclotron Site

Conventional models for atmospheric transport and dispersion such as PC-CREAM cannot be used for the NMC because the complex urban environment, characterised by buildings of

various dimensions, produces unpredictable airflow patterns. Atmospheric dispersion measurements around the NMC were studied (Clark *et al* 1994) using an atmospheric tracer release, sampling and analysis system. Aspects of the meteorology and wind flow patterns at the NMC were also studied (Clark and Bartsch, 1994). The measured dilution factors were applied to a hypothesised accident scenario involving the release of iodine-123 and xenon-123 from the Cyclotron emission stack. The impact on nearby receptors was calculated to be less than 10% of the 1 mSv recommended annual public dose limit (NH&MRC 1995). Releases from the Cyclotron under normal operating conditions are very much lower and are considered to have insignificant impact on health.

8.2 LOW-LEVEL LIQUID EFFLUENT

The studies conducted by ANSTO at the Cronulla Sewage Treatment Plant and the Potter Point ocean outfall area from 1995 through to 2001 determined the dilution effects on radionuclides contained in the treated effluent discharged by ANSTO to the sewer. The predictions of the Unisearch WRL plume transport and dilution model have been confirmed using these measurements. If required, the model may be used to calculate tritium concentrations in the sea near Potter Point at any time since 1995.

The levels of radioactivity found in fish, algae and barnacles collected near the Potter Point outfall, as well as tritium measured in the ocean a short distance from the outfall, are negligible. They do not pose any health risk to members of the public using the ocean in the vicinity of the outfall or ingesting seafood from the area. The potential dose is estimated to be less than 0.2% of the recommended dose limits for members of the public (NH&MRC 1995). Since the upgrade of the Cronulla STP to tertiary treatment, dilution of the effluent has substantially increased, so that the chance of any potential radiological consequences to swimmers (always extremely small) is reduced even further.

Radioactivity in liquid effluent discharges from the NMC to the sewer conforms with the limits in the Trade Waste Agreement with Sydney Water. These discharges are of short-lived, low level effluent.

8.3 EXTERNAL RADIATION AT THE LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE

The levels of external gamma radiation at the Lucas Heights site and private residences in Barden Ridge, Engadine and Woronora were measured by thermoluminescent dosimeters. The local absorbed doses in air were consistent with levels recorded in Australian capital cities (using similar dosimeters) in Australian surveys carried out by the Australian Radiation Laboratory and reported by UNSCEAR (1993).

These results indicate that the external gamma radiation levels at residential locations in the vicinity of the Lucas Heights site are not noticeably affected by ANSTO's operations.

8.4 THE LITTLE FOREST BURIAL GROUND

The 2001 environmental survey results for the Little Forest Burial Ground (LFBG) show a similar range of values to those observed in the past. Tritium was detected in groundwater near the burial trenches and at low levels in several other monitoring bores within the fenced area. Of the fifteen bores sampled, thirteen contained detectable tritium at levels that were below the Australian (NH&MRC 1996) drinking water guideline value.

Gamma spectrometry of the unfiltered LFBG groundwater showed only small concentrations of natural potassium-40 and uranium-238 progeny and, in one bore, low levels of cobalt-60 (at less than 1% of the NH&MRC 1996 guideline value).

The gross alpha and gross beta activities measured in LFBG groundwater were well below levels considered safe for Australian drinking water.

The three groundwater bores that were sampled outside the LFBG fenced area showed low levels of tritium and environmental background levels of naturally occurring radioactivity. Surface water sampled from Mill and Bardens Creeks also contained insignificant levels of radioactivity.

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

Sampling of airborne particulates at LFBG was regularly carried out using a high-volume air sampler. The air filters were analysed for the presence of beryllium and plutonium, but neither was detected in 2001. Based on these and previous surveys, it is concluded that possible radiation exposure to members of the general public via the inhalation pathway is also negligible.

Extra soil, air and dose monitoring was carried out in response to minor vandalism at the LFBG and the results clearly showed that there was no resultant mobilisation of radioactivity.

External radiation readings over the trenches were consistent with normal background levels. Radiation readings around the LFBG site boundary fence were also at background levels, confirming that possible doses to members of the public from external radiation can also be regarded as negligible.

9 CONCLUSIONS

The principal sources of potential radiation exposure to members of the public from routine ANSTO operations at the Lucas Heights site and NMC are from airborne emissions and low-level liquid effluent discharges to the sewer. ANSTO complied with all relevant Commonwealth and New South Wales regulations and international guidelines during 2001. It is concluded that there is no impact on the health of the community as a consequence of operations at the Lucas Heights Science and Technology Centre or the National Medical Cyclotron.

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Dosimeter readings for external gamma radiation at the Lucas Heights site (Tables 18a and 18b), airborne effluent release data (Tables 19a to 19d, and 24) and public dose estimates were supplied by Safety Division.

Details of the environmental monitoring at the National Medical Cyclotron (Tables 23a and 23b) were also supplied by Safety Division.

Liquid effluent release data (Tables 21 and 22) and details of waste treatment were supplied by Waste Operations, Nuclear Technology Division.

11 REFERENCES

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TABLE 1

ENVIRONMENTAL MONITORING SCHEDULE, 2001

SAMPLE	LOCATION [1]	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Stormwater	**MDP+60m**: 60m down-stream of MDP BUND	Weekly, plus monthly composite.	2 x 5 L sampled with polyethylene bottle.	250mL aliquot of the weekly sample distilled for tritium analysis. Weekly samples bulked into two monthly composites: 4 -5L for α,β analysis; 8 - 10L for γ. Remainder acidified & stored.
	Bund C: **MDP**	Weekly, plus monthly composite.	2 x 5 L sampled with polyethylene bottle.	Tritium, α,β & γ analyses as above.
	Bunds A, B & C	Daily samples (working days only) combined into a monthly composite.	1 L sampled with polyethylene bottle into 30 L drum.	Subsampled - 250 mL distilled for tritium analysis. One L acidified & stored.
Estuary water	**Woronora River**: station E5.9 at Jannali Park	Monthly	250 mL, sampled by polyethylene bottle at surface.	Distilled for tritium analysis.
Creekwater	**Bardens Creek Weir**	Weekly	250 mL sampled from weir overflow.	Distilled for tritium analysis.
	SPCC points: Bardens Ck Weir; MDP Ck Weir; Strassman Ck	Monthly	3 L sampled after rain.	Gross α,β analysis on 2L (ISO method). Remaining 1 L acidified & stored.
	Forbes Creek	Monthly	1 L sampled after rain.	250 mL distilled for tritium analysis. Remainder acidified & stored.
	Bardens and Mill Creeks: station T2 near confluence	Yearly	5 L water from each creek (above the junction of the two creeks).	Evaporated and counted for α,β,γ. 250 mL distilled for tritium analysis. Remainder acidified & stored.

Notes:
1. Sampling locations are shown on Figures 1 through 4.

Continued next page...

TABLE 1 Continued...

SAMPLE	LOCATION (1)	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Ground water	**Little Forest Burial Ground**	Twice yearly	Bores are pumped dry & allowed to refill. 7 L sampled from the centre of the bore, avoiding bottom sediments.	Decanted, evaporated and counted for α,β,γ. 250 mL distilled for tritium analysis. 2 L litres acidified & stored.
	Sump near Bld 27	Monthly	1 L ground water seepage collected with clean sponge.	Distilled for tritium analysis. Gamma spectrometry of 500mL in Marinelli beaker. Remainder acidified & stored.
Airborne particulates	**Little Forest Burial Ground**: trench area	Quarterly: particulates are accumulated for ~ 4 hours every 2 weeks over 3 months.	Airborne particulates were collected on 400cm^2 filter paper using *Ecotech* air sampler at 60 m^3 per hour.	Quarterly sample divided into four equal parts: one analysed for beryllium by ICPMS, another put aside for a yearly composite, analysed for $^{239/240}$Pu. Remaining two portions are stored.
Ambient iodine-131 in air	**Stations 1, 2 ,3 & 4**: along the eastern boundary of LHSTC	Continuous samples, changed weekly.	Collected on activated charcoal filters (Maypacks).	Gamma spectrometry of Maypacks using a 20 x 10 cm NaI crystal.
Soil/ sediment	**Stormwater bunds A, B & C**	Yearly, or whenever bunds are emptied.	Bund water is drained. 2 kg sampled randomly from accumulated sediments.	Soils/sediments are dried, ashed and sieved, then counted for α,β,γ activity.
	Little Forest Burial Ground	If indicated by annual dose rate survey.	1 kg, sampled from surface.	As above.
	Effluent discharge pipeline	If indicated by six-monthly dose rate survey.	1 kg, sampled from surface.	As above.
	Bardens and Mill Creeks: Station T2	Yearly	1 kg sampled from each creek bed (upstream of their confluence).	As above.

Notes:
1. Sampling locations are shown on Figures 1 through 4.

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TABLE 1 Continued...

SAMPLE	LOCATION [1]	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Marine Biological Samples	**Potter Point Ocean Outfall**	Twice yearly	Barnacles, algae & fish, collected near the outfall.	Gamma spectrometry of dried and ground samples.
	The Royal National Park	Twice yearly	Barnacles, algae & fish.	As above
Gamma Dose Rate Survey	**Effluent discharge pipeline**	Twice yearly	Pipe joints and ground surveyed using an Eberline PRM-7 doserate meter. Soil is sampled if >3 times the background dose.	If collected, soils are sieved and ashed, then counted for α,β,γ activity.
	Little Forest Burial Ground	Yearly	Burial trenches were surveyed at ground level with Eberline PRM-7 doserate meter. Soil sampled if >3 times the background dose.	As above
External Gamma Radiation	**LHSTC perimeter**: 15 sites; plus **Local suburbs**: 3 sites	Quarterly	Two types of Thermoluminescent Dosimeter (TLD) badges, exposed to ambient gamma radiation.	Personal-type TLDs sent to ARL for analysis. Environmental TLDs analysed at ANSTO. Results reported as effective dose in mSv/year.

Notes
1. Sampling locations are shown on Figures 1 through 4.

TABLE 2

TRITIUM IN WORONORA ESTUARY WATER [1]
STATION E5.9, 2001

Date	Tritium [2] (Bq/L)
9-1-01	< 10 [3]
23-2-01	< 10
21-3-01	< 10
10-4-01	< 10
16-5-01	< 10
5-6-01	< 10
3-7-01	< 10
28-8-01	< 10
11-9-01	< 10
30-10-01	< 10
20-11-01	< 10
4-12-01	< 10

Notes:
1. Refer to Figure 1 for the Woronora Estuary sampling point.
2. The Australian guideline value for tritium in drinking water is 7600 Bq/L (NH&MRC, 1996).
3. Values quoted as "less than" figures were below the stated minimum detectable activity, calculated with 95 % confidence.

TABLE 3

TRITIUM IN FORBES CREEK [1]
WATER SAMPLES, 2001

Date	Tritium [2] (Bq/L)
9-1-01	< 10
23-2-01	< 10
21-3-01	< 10
10-4-01	< 10
16-5-01	< 10
5-6-01	< 10
3-7-01	< 10
28-8-01	< 10
11-9-01	< 10
30-10-01	< 10
20-11-01	< 10
4-12-01	< 10

Notes:
1. Figure 1 shows the sampling location.
2. A "less than" value indicates that the result was below the minimum detectable activity (stated at the 95 % confidence level).

TABLE 4

RADIOACTIVITY IN FISH FROM POTTER POINT
AND THE ROYAL NATIONAL PARK, 2001

Sampling Location	Date Sampled[1]	Gamma-emitters in FISH [2] Bq/kg FW [3]				
		U&Th Series [4]	**^{40}K**	^{60}Co	^{137}Cs [5]	^{131}I
POTTER POINT Ocean Outfall	26-3-01	-	145 ± 15	< 0.9	< 0.5	< 0.9
	26-3-01	-	150 ± 15	< 1.0	< 0.8	< 0.9
	4-01-02	-	200 ± 20	< 1.0	< 0.7	< 0.5
The Royal National Park Reference Site	8-01-02	-	155 ± 15	< 1.0	< 0.4	< 0.6
	8-01-02	-	135 ± 15	< 1.0	< 0.4	< 0.6

Notes:
1. Samples were split to form duplicates, where possible. See Figure 4 for sampling locations.
2. Flesh fillets of Luderick (*Girella sp*.) were analysed.
3. Radioactivity is in units of becquerels per kilogram of fresh (wet) sample.
4. ✓ in the U&Th Series column indicates the unquantified presence of decay products from the natural uranium-238 or thorium-232 series. **U&Th Series** and **^{40}K** are of natural origin.
5. Caesium-137 is widely dispersed in the environment from atmospheric weapons testing and is found at similar levels in other species of fish from Australian regional waters.
6. A "less than" value indicates that the result was below the minimum detectable activity, which is stated with 95 % confidence. The minimum detectable activity is calculated from the gamma spectrum for each sample.

TABLE 5

RADIOACTIVITY IN ALGAE FROM POTTER POINT
AND THE ROYAL NATIONAL PARK, 2001

Location	Date Sampled [3]	Gamma Emitters in ALGAE [1] Bq/kg FW [2]					
		U&Th Series [4]	**^{7}Be**	**^{40}K**	^{60}Co	^{137}Cs	^{131}I
POTTER POINT Ocean Outfall	26-3-01 [5]	✓	7 ± 1	210 ± 20	< 0.4 [6]	< 0.3	30 ± 3
	26-3-01	✓	4 ± 1	215 ± 20	< 0.6	< 0.3	14 ± 1
	23-10-01	✓	< 2.5	460 ± 45	< 0.9	< 0.4	1.9 ± 0.3
	23-10-01	✓	< 2.8	435 ± 40	< 0.7	< 0.4	1.6 ± 0.5
The Royal National Park Reference Site	8-1-02	✓	< 1.7	145 ± 15	< 0.5	< 0.3	< 0.3
	8-1-02	✓	< 3.1	125 ± 10	< 0.4	< 0.2	< 0.3

TABLE 6

RADIOACTIVITY IN BARNACLES FROM POTTER POINT
AND THE ROYAL NATIONAL PARK, 2001

Location	Date Sampled [3]	Gamma-emitters in BARNACLES [1] Bq/kg FW [2]				
		U&Th Series [4]	**^{40}K**	^{60}Co	^{137}Cs	^{131}I
POTTER POINT Ocean Outfall	26-3-01	✓	25 ± 5	< 1.3 [6]	< 0.9	< 1.5
	26-3-01	✓	25 ± 5	< 1.3	< 0.7	< 2.8
	23-10-01	✓	55 ± 10	< 1.3	< 2.0	< 2.7
	23-10-01	✓	70 ± 10	< 1.2	< 1.0	< 4.4
The Royal National Park Reference Site	8-1-02	✓	45 ± 10	< 2.0	< 1.5	< 3.3
	8-1-02	✓	55 ± 10	< 2.0	< 1.6	< 4.2

Notes for Tables 5 & 6:

1. The whole, unwashed algae and barnacles (mainly *Tesseropera rosea*) were dried and ground before gamma spectrometry analysis.
2. Units of radioactivity are becquerels per kilogram of fresh (wet) sample.
3. Two separate samples were collected, where possible. See Figure 4 for sampling locations.
4. In the U&Th Series column, ✓ indicates the unquantified presence of decay products from the uranium-238 or thorium-232 series. **U&Th Series**, **^{7}Be** and **^{40}K** are all of natural origin.
5. The usual species of green algae was collected from Potter Point in March *(Enteromorpha intestinalis)*. Due to unavailability, a non-filamentous type *(Ulva sp*.) was collected in October.
6. A "less than" value indicates that the result was below the minimum detectable activity, which is stated with 95 % confidence. The minimum detectable activity is calculated from the gamma spectrum for each sample.

TABLE 7a

TRITIUM IN COMPOSITE WATER SAMPLES FROM LHSTC STORMWATER BUNDS, 2001

Month	Total Volume collected (L)	TRITIUM [1] (Bq/L)		
		BUND A [2,3] Behind Building 1	**BUND B** Opposite Meteorology Tower	**BUND C** MDP – Waste Management Area
January	19	60 ± 10	50 ± 10	50 ± 20
February	20	150 ± 10	50 ± 10	70 ± 10
March	22	110 ± 10	60 ± 10	80 ± 10
April	18	110 ± 10	100 ± 10	170 ± 10
May	23	70 ± 10	60 ± 10	100 ± 20
June	19	60 ± 10	100 ± 10	210 ± 10
July	23	340 ± 10	90 ± 30	180 ± 10
August	20	60 ± 20	140 ± 20	190 ± 20
September	19	80 ± 10	80 ± 10	180 ± 10
October	21	100 ± 10	90 ± 10	150 ± 30
November	22	190 ± 10	80 ± 10	120 ± 10
December	16	30 ± 10	30 ± 10	90 ± 20

Notes:
1. The Australian guideline value for tritium in drinking water is 7600 Bq/L (NH&MRC 1996).
2. Refer to Figure 2 for the locations of the bunds.
3. 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.

TABLE 7b

TRITIUM IN WEEKLY WATER SAMPLES FROM MDP BUND C,[1] 2001

Date	**Tritium** [2,3] Bq/L	Date	**Tritium** Bq/L
2-1-01	100 ± 20	3-7-01	370 ± 10
9-1-01	70 ± 10	10-7-01	100 ± 10
16-1-01	60 ± 20	17-7-01	170 ± 20
23-1-01	80 ± 10	24-07-01	210 ±10
30-1-01	40 ± 10	31-7-01	180 ± 10
6-2-01	< 20 [4]	7-8-01	160 ± 10
13-2-01	80 ± 20	16-8-01	230 ± 10
20-2-01	100 ± 10	21-8-01	250 ± 10
27-3-01	80 ± 10	28-8-01	180 ± 10
6-3-01	50 ± 10	4-9-01	170 ± 20
13-3-01	100 ± 10	11-9-01	200 ± 20
20-3-01	100 ± 10	18-9-01	200 ± 20
27-3-01	150 ± 10	25-9-01	220 ± 20
3-4-01	130 ± 10	2-10-01	110 ± 10
10-4-01	100 ± 10	9-10-01	100 ± 20
17-4-01	210 ± 10	16-10-01	230 ± 10
24-4-01	220 ± 10	26-10-01	50 ±10
1-5-01	840 ± 30	30-10-01	180 ± 10
8-5-01	110 ± 10	6-11-01	140 ± 20
15-5-01	120 ± 10	13-11-01	130 ± 10
23-5-01	150 ± 10	20-11-01	50 ± 20
29-5-01	80 ± 10	27-11-01	190 ± 10
5-6-01	100 ± 20	4-12-01	30 ± 10
12-6-01	200 ± 10	11-12-01	100 ± 10
19-6-01	410 ± 30	18-12-01	110 ± 10
25-6-01	390 ± 10	24-12-01	50 ± 10

Notes:

1. Refer to Figure 2 for the location of this sampling point.
2. The average tritium level in MDP Bund C during 2001 was 160 Bq/L, which is 2% of the Australian drinking water guideline value of 7600 Bq/L (NH&MRC 1996).
3. The weekly water samples from MDP Bund C were combined into monthly composite samples and analysed for gross alpha/beta and gamma activity. See Table 7c for these results.
4. A “less-than” value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).

TABLE 7c

RADIOACTIVITY IN COMPOSITE
WATER SAMPLES FROM MDP BUND C, 2001

Monthly Composite[1]	RADIOACTIVITY (Bq/L)					
	Gross α [2]	Gross β [3]	Gamma Emitters			
			^{7}Be [4]	^{40}K	^{137}Cs [5]	^{60}Co
January	0.02 ± 0.01	0.72 ± 0.02	0.26 ± 0.04	0.11 ± 0.03	0.075 ± 0.008	0.031 ± 0.006
February	0.02 ± 0.01	0.52 ± 0.01	0.19 ± 0.03	< 0.15 [6]	0.007 ± 0.003	LLD
March	0.02 ± 0.01	0.43 ± 0.01	0.07 ± 0.03	0.08 ± 0.04	0.007 ± 0.003	LLD
April	0.04 ± 0.01	0.53 ± 0.02	0.13 ± 0.03	0.12 ± 0.05	0.040 ± 0.005	LLD
May	0.04 ± 0.01	1.02 ± 0.02	LLD [7]	< 0.22	0.030 ± 0.004	LLD
June	0.03 ± 0.01	0.47 ± 0.01	LLD	0.11 ± 0.05	0.007 ± 0.003	LLD
July	0.02 ± 0.01	0.40 ± 0.01	LLD	< 0.09	LLD	LLD
August	0.03 ± 0.01	0.40 ± 0.01	LLD	< 0.19	LLD	LLD
September	0.02 ± 0.01	0.47 ± 0.01	LLD	< 0.25	0.012 ± 0.003	LLD
October	0.02 ± 0.01	0.80 ± 0.02	LLD	< 0.20	0.021 ± 0.003	LLD
November	0.02 ± 0.01	0.96 ± 0.02	0.31 ± 0.05	0.11 ± 0.05	0.041 ± 0.005	LLD
December	0.04 ± 0.01	0.74 ± 0.02	0.22 ± 0.05	0.15 ± 0.05	0.185 ± 0.018	LLD

Notes:

1. Refer to Figure 2 for the sampling location. MDP Bund C was sampled weekly for tritium analysis (see Table 7b). The remainder of the weekly samples were combined to make a monthly composite water sample for gross alpha, beta and gamma analysis.
2. The NSW Regulations (Prot. Env. Op. Act, 1997) limits for radioactivity in class C waters as follows:
3. Gross alpha (α) 1.1 Bq/L; Gross beta (β) 11.1 Bq/L.
4. The gross beta results include the contribution from potassium-40 (a natural beta-gamma emitter).
5. **^{7}Be** and **^{40}K** are of natural origin.
6. In 2001, the average concentration of 137Cs in MDP Bund Composites was < 0.035 Bq/L, which is < 0.4 % of the Australian guideline value for ^{137}Cs in drinking water: 10.5 Bq/L (NH&MRC, 1996).
7. A less-than value indicates that a small peak was evident in the sample spectrum but the result was not statistically significant (that is, was not above the background). The minimum detectable activity is therefore known precisely and is quoted at the 95 % confidence level.
8. LLD indicates that no gamma peak was seen in the sample spectrum so that the result is definitely less than the limit of detection but, in this case, the minimum detectable activity is not known precisely and an approximate detection limit is appropriate. Indicative limits of detection are: ^{60}Co < 0.01; ^{7}Be < 0.10 ; ^{137}Cs < 0.01, all in Bq/L.

TABLE 8

RADIOACTIVITY IN SEDIMENT FROM STORMWATER BUNDS, 2001

Location [1]	Date	RADIOACTIVITY in SEDIMENT, Bq/g DW[2]		
		Gross α	**Gross β**	**Gamma Emitters**
BUND A: Behind Building 1	27-4-01	0.32 ± 0.07	0.23 ± 0.02	U & Th series ^{7}Be = 0.14 ± 0.014 ^{137}Cs = 0.0032 ± 0.0006 ^{40}K = 0.22 ± 0.02
BUND B: Opposite Meteorological Tower	27-4-01	0.25 ± 0.07	0.28 ± 0.02	U & Th series ^{7}Be = 0.34 ± 0.03 ^{137}Cs = 0.0029 ± 0.0006 ^{60}Co = 0.018 ± 0.002 ^{40}K = 0.20 ± 0.02
BUND C: MDP (on Stormwater Outlet No.1)	27-4-01	0.31 ± 0.07	0.31 ± 0.02	U & Th series ^{7}Be = 0.069 ± 0.008 ^{137}Cs = 0.036 ± 0.003 ^{60}Co = 0.022 ± 0.002 ^{241}Am = 0.0017 ± 0.0004 ^{40}K = 0.094 ± 0.012

Notes:
1. See Figure 2 for the location of the stormwater bunds.
2. Refers to the radioactivity per gram (dry weight) of sample.

TABLE 9a

TRITIUM IN WEEKLY WATER SAMPLES FROM
MDP + 60m,[1] 2001

Date	**Tritium** [2,3] Bq/L	Date	**Tritium** Bq/L
2-1-01	80 ± 20	3 -7-01	200 ± 10
9-1-01	70 ± 10	10-7-01	470 ± 20
16-1-01	80 ± 10	17-7-01	170 ± 10
23-1-01	70 ± 10	24-07-01	140 ± 10
30-1-01	70 ± 10	31-7-01	160 ± 10
6-2-01	< 20 [4]	7-8-01	170 ± 10
13-2-01	70 ± 10	16-8-01	180 ± 10
20-2-01	70 ± 10	21-8-01	180 ± 10
27-2-01	90 ± 10	28-8-01	160 ± 10
6-3-01	40 ± 10	4-9-01	160 ± 10
13-3-01	90 ± 10	11-9-01	110 ± 10
20-3-01	90 ± 10	18-9-01	120 ± 10
27-3-01	90 ± 10	25-9-01	100 ± 10
3-4-01	100 ± 10	2-10-01	80 ± 10
10-4-01	90 ± 10	9-10-01	100 ± 20
17-4-01	110 ± 10	16-10-01	70 ± 10
24-4-01	210 ± 10	26-10-01	90 ± 10
1-5-01	110 ± 10	30-10-01	100 ± 20
8-5-01	50 ± 10	6-11-01	80 ± 10
15-5-01	100 ± 10	13-11-01	80 ± 10
23-5-01	80 ± 10	20-11-01	50 ± 20
29-5-01	70 ± 10	27-11-01	110 ± 10
5-6-01	90 ± 20	4-12-01	70 ± 10
12-6-01	180 ± 10	11-12-01	50 ± 10
19-6-01	270 ± 10	18-12-01	70 ± 10
25-6-01	140 ± 10	24-12-01	50 ± 10

Notes:

1. Refer to Figure 2 for the location of this sampling point, 60m downstream of Stormwater Outlet No. 1 on MDP Creek.
2. The average tritium level during 2001 was about 110 Bq/L, representing < 2 % of the Australian drinking water guideline value of 7600 Bq/L (NH&MRC 1996).
3. The weekly water samples were combined to make monthly composite samples, then analysed for gross alpha/beta and gamma activity. See Table 9b for these results.
4. A “less-than” value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).

TABLE 9b

RADIOACTIVITY IN COMPOSITE
WATER SAMPLES FROM MDP+60m[1], 2001

Monthly Composite	RADIOACTIVITY (Bq/L)				
	Gross α [2]	**Gross β**	**Gamma-Emitters** [3]		
			^{7}Be	**^{40}K**	^{137}Cs [4]
January	0.02 ± 0.01	0.30 ± 0.01	0.11 ± 0.03	0.10 ± 0.03	0.015 ± 0.003
February	0.03 ± 0.01	0.37 ± 0.01	0.20 ± 0.03	< 0.12	0.015 ± 0.003
March	0.03 ± 0.01	0.39 ± 0.01	0.09 ± 0.03	0.08 ± 0.04	0.018 ± 0.003
April	0.03 ± 0.01	0.36 ± 0.01	0.09 ± 0.02	0.09 ± 0.03	0.008 ± 0.003
May	0.10 ± 0.01	0.32 ± 0.01	0.09 ± 0.02	0.09 ± 0.04	0.008 ± 0.003
June	0.03 ± 0.01	0.29 ± 0.01	LLD [6]	< 0.24	LLD
July	0.03 ± 0.01	0.30 ± 0.01	LLD	< 0.08	LLD
August	0.06 ± 0.01	0.33 ± 0.01	LLD	0.20 ± 0.06	0.010 ± 0.004
September	0.04 ± 0.01	0.28 ± 0.01	LLD	< 0.11	0.012 ± 0.003
October	0.03 ± 0.01	0.35 ± 0.01	LLD	0.08 ± 0.02	0.008 ± 0.002
November	< 0.03 [5]	0.28 ± 0.02	LLD	< 0.21	LLD
December	0.02 ± 0.01	0.38 ± 0.01	LLD	< 0.21	0.029 ± 0.004

Notes:

1. Refer to Figure 2 for the location of this sampling point. This location was sampled weekly for tritium (see Table 9a). The remaining weekly samples were combined into a monthly composite water sample for gross alpha, beta and gamma analyses.
2. The NSW Regulations (Prot. Env. Operations Act, 1997) limits for radioactivity in class C waters are as follows: gross α 1.1 Bq/L ; gross β 11.1 Bq/L. The gross beta results include the contribution from potassium-40 (a natural beta-gamma emitter).
3. **^{7}Be** and **^{40}K** are of natural origin.
4. The average ^{137}Cs concentration measured in 2001 was 0.010 Bq/L, which is less than 0.2 % of the Australian guideline value for ^{137}Cs in drinking water: 10.5 Bq/L (NH&MRC, 1996).
5. A less-than value indicates that a small peak was evident in the sample spectrum but the result was not statistically significant (that is, was not above the background). The minimum detectable activity is therefore known precisely and is quoted at the 95 % confidence level.
6. LLD indicates that no gamma peak was seen in the sample spectrum so that the result is definitely less than the limit of detection but, in this case, the minimum detectable activity is not known precisely and an approximate detection limit is appropriate. Indicative limits of detection are:
   ^{7}Be < 0.10 ; ^{137}Cs < 0.01, all in Bq/L.

TABLE 10

RADIOACTIVITY IN WATER FROM SPCC [1] SAMPLING POINTS, 2001

Date	RADIOACTIVITY [2] (Bq/L)					
	Strassman Creek		**Bardens Creek Weir**		**MDP Creek Weir**	
	Gross α	Gross β	Gross α	Gross β	Gross α	Gross β
1-2-01	< 0.02 [3]	0.07 ± 0.01	< 0.02	0.09 ± 0.01	0.03 ± 0.01	0.29 ± 0.01
27-2-01	< 0.02	0.05 ± 0.01	< 0.02	0.07 ± 0.01	< 0.02	0.28 ± 0.01
22-3-01	< 0.02	0.05 ± 0.01	< 0.03	0.06 ± 0.01	< 0.03	0.28 ± 0.01
27-4-01	< 0.02	0.04 ± 0.01	< 0.02	0.05 ± 0.01	< 0.03	0.27 ± 0.01
18-5-01	< 0.02	0.06 ± 0.01	< 0.02	0.06 ± 0.01	< 0.01	0.25 ± 0.01
22-6-01	< 0.02	0.05 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	< 0.02	0.26 ± 0.01
30-7-01	< 0.02	0.05 ± 0.01	< 0.02	0.04 ± 0.01	< 0.01	0.22 ± 0.01
28-8-01	0.02 ± 0.01	0.04 ± 0.01	< 0.02	0.05 ± 0.01	< 0.02	0.20 ± 0.01
25-9-01	< 0.02	0.04 ± 0.01	< 0.02	0.06 ± 0.01	0.02 ± 0.01	0.23 ± 0.01
22-10-01	< 0.02	0.04 ± 0.01	< 0.02	0.04 ± 0.01	< 0.02	0.22 ± 0.01
30-11-01	< 0.02	0.05 ± 0.01	< 0.02	0.05 ± 0.01	< 0.01	0.24 ± 0.01
19-12-01	0.02 ± 0.01	0.08 ± 0.01	< 0.02	0.06 ± 0.01	< 0.02	0.27 ± 0.01

Notes:
1. See Figure 2 for the location of the former SPCC (now NSW EPA) sampling points.
2. The NSW Regulations (Prot. Env. Operations Act 1997) specify limits for radioactivity in class C waters as follows: gross alpha < 1.1 Bq/L ; gross beta < 11.1 Bq/L. All gross beta results include the contribution from the naturally-occurring beta-gamma emitter, potassium-40.
3. Values which are quoted as "less than" figures were below the stated minimum detectable activity (calculated with 95 % confidence).

TABLE 11

TRITIUM IN WATER FROM BARDENS CREEK WEIR [1]
(at SPCC sampling point), 2001

Date	**Tritium** [2] Bq/L	Date	**Tritium** Bq/L
2-1-01	50 ± 10	3-7-01	30 ± 10
9-1-01	50 ± 10	10-7-01	170 ± 10
16-1-01	40 ± 10	17-7-01	80 ± 10
23-1-01	60 ± 10	24-07-01	30 ± 10
30-1-01	40 ± 10	31-7-01	170 ± 20
6-2-01	< 30 [3]	7-8-01	40 ± 10
13-2-01	60 ± 10	16-8-01	60 ± 20
20-2-01	50 ± 10	21-8-01	50 ± 10
27-2-01	100 ± 10	28-8-01	70 ± 10
6-3-01	30 ± 10	4-9-01	30 ± 10
13-3-01	40 ± 10	11-9-01	40 ± 10
20-3-01	30 ± 10	18-9-01	30 ± 10
27-3-01	50 ± 10	25-9-01	40 ± 10
3-4-01	60 ± 10	2-10-01	30 ± 10
10-4-01	50 ± 10	9-10-01	50 ± 10
17-4-01	40 ± 10	16-10-01	40 ± 10
24-4-01	50 ± 20	26-10-01	40 ± 10
1-5-01	80 ± 10	30-10-01	30 ± 10
8-5-01	30 ± 10	6-11-01	30 ± 10
15-5-01	30 ± 10	13-11-01	70 ± 10
23-5-01	40 ± 10	20-11-01	140 ± 20
29-5-01	50 ± 10	27-11-01	90 ± 10
5-6-01	40 ± 10	4-12-01	40 ± 10
12-6-01	70 ± 10	11-12-01	40 ± 10
19-6-01	30 ± 10	18-12-01	30 ± 10
25-6-01	40 ± 10	24-12-01	60 ± 10

Notes:
1. See Figure 2 for the location of this sampling point.
2. The average weekly tritium concentration at Bardens Creek weir during 2001 was 50 Bq/L, which less than 1% of the Australian drinking water guidelines value of7600 Bq/L (NH&MRC, 1996).
3. Values which are quoted as "less than" figures were below the stated minimum detectable activity (calculated with 95 % confidence).

TABLE 12a

GAMMA DOSE-RATE SURVEY OF EFFLUENT DISCHARGE PIPELINE, 2001

Date	Location [1,2]	Dose-rate (μSv/hour)		Background Dose-rate (μSv/hour)
		Ground Below Joint	Pipe Joint	
28-5-01	Joints #1-22	0.06 – 0.11	0.06 – 0.12	0.06 – 0.12
16-10-01	Joints #1-22	0.06 – 0.13	0.06 – 0.12	0.06 – 0.12

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 12b

RADIOACTIVITY IN SOIL NEAR THE ANSTO EFFLUENT PIPELINE, 2001

Location [1]	Date	RADIOACTIVITY, Bq/g DW [2]						
		Gross α	**Gross β**	**Gamma Emitters**				
				Am-241	**Tc-99m**	**Cs-137**	**Co-60**	**K-40**
Soil under pipe joint # 6	1-8-01	0.57 ± 0.07	0.53 ± 0.02	0.017 ± 0.002	0.27 ± 0.081	0.26 ± 0.026	0.12 ± 0.012	0.074 ± 0.010
1m downhill of joint #6	1-8-01	0.57 ± 0.07	0.30 ± 0.02	0.004 ± 0.001	< 0.001	0.095 ± 0.010	0.010 ± 0.001	0.082 ± 0.012
Comparison: 7m upslope of joint #6	3-8-01	0.43 ± 0.07	0.26 ± 0.02	< 0.002	< 0.001	0.008 ± 0.001	< 0.002	0.069 ± 0.008

Notes:
1. See Figure 2 for the approximate location of the effluent pipeline. These soil samples were collected in response to a small leak from the liquid effluent disposal pipeline. See Section 3.6 for discussion.
2. Soils were ashed prior to gamma spectrometry. Results are reported in terms of radioactivity per gram of dry sample.

TABLE 13

GAMMA DOSE-RATE SURVEY OF BURIAL TRENCHES AT LITTLE FOREST BURIAL GROUND, 2001

Date	Location [1,2]	Dose-rate (μSv/hour)
7 August 2001	Soil samples [3]	0.10 – 0.15
9 & 13 November 2001	Background reading (at LFBG gate)	0.10 – 0.15
	Trenches 1-51	0.10 – 0.15
	Trenches 52-77	0.10 – 0.15

Notes:
1. See Figure 3 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.
3. Two soil samples from the trench area were collected in response to a vandalism incident, see Table 14a for the analysis results.

TABLE 14a

RADIOACTIVITY IN SOIL FROM THE LITTLE FOREST BURIAL GROUND, 2001

Sampling Location [1]	Date	RADIOACTIVITY in SOIL (Bq/g DW) [2]		
		Gross α	**Gross β**	**Gamma Emitters**
#1: southern end of burial trench area numbered 1-51.	7-8-01	0.46 ± 0.08	0.36 ± 0.02	U & Th series, ^{40}K = 0.14 ± 0.02
#2: southern end of burial trench area numbered 52-77.	7-8-01	0.40 ± 0.07	0.47 ± 0.02	U & Th series, ^{40}K = 0.18 ± 0.02
Reference site: outside LFBG fenced area [3], near bore MB 22.	12-10-00	0.44 ± 0.06	0.40 ± 0.02	U & Th series, ^{40}K = 0.07 ± 0.01

Notes:
1. These soil samples were collected in response to minor vandalism of the LFBG fenced area. See Section 3.7 for discussion.
2. Refers to the radioactivity per gram (dry weight) of sample.
3. The soil from this location was sandy whereas the trench covering consists of clay/shale.

TABLE 14b

RADIOACTIVITY IN GROUNDWATER FROM THE LITTLE FOREST BURIAL GROUND, 2001

Bore [1]	Date Sampled	RADIOACTIVITY [2,3] Bq /L				
		^{3}H	**Gross α**	**Gross β**	**Gamma Emitters**	
					^{40}K	Others
BHF	8-6-01	340 ± 10	0.03 ± 0.01	0.15 ± 0.01	0.25 ± 0.10	Trace U-238 series
BH10	"	150 ± 20	< 0.03	0.06 ± 0.01	0.22 ± 0.11	Trace U-238 series
OS2	"	800 ± 20	0.03 ± 0.01	0.11 ± 0.01	< 0.30	Trace U-238 series
OS3	"	660 ± 30	0.03 ± 0.01	0.25 ± 0.01	< 0.30	Trace U-238 series
MB11	"	< 10	0.04 ± 0.01	0.04 ± 0.01	< 0.56	Trace U-238 series
MB12	"	< 20	< 0.02	0.04 ± 0.01	< 0.30	Trace U-238 series
MB13	"	1080 ± 30	< 0.02	0.07 ± 0.01	< 0.30	Trace U-238 series
MB14	"	< 10	0.03 ± 0.01	0.13 ± 0.01	< 0.28	Trace U-238 series
MB15	"	< 10	0.06 ± 0.01	0.12 ± 0.01	< 0.30	Trace U-238 series
MB16 [4]	"	2280 ± 30	0.06 ± 0.01	0.34 ± 0.01	< 0.30	^{60}Co 0.10 ± 0.02
MB17	"	600 ± 20	< 0.02	0.06 ± 0.01	< 0.30	Trace U-238 series
MB18	"	< 10	0.04 ± 0.01	0.09 ± 0.01	< 0.52	Trace U-238 series
MB19 [5]	"	< 30	< 0.03	0.20 ± 0.01	0.26 ± 0.11	N.D.
MB20	"	< 10	0.03 ± 0.01	0.21 ± 0.01	< 0.30	N.D.
MB21	"	< 10	0.04 ± 0.01	0.14 ± 0.01	< 0.59	Trace U-238 series
BHF	9-11-01	290 ± 20	0.04 ± 0.01	0.16 ± 0.01	< 0.56	N.D
BH10	"	5690 ± 50	0.09 ± 0.04	0.15 ± 0.04	< 0.49	Trace U-238 series
OS2	13-11-01	900 ± 30	0.03 ± 0.01	0.12 ± 0.01	< 0.57	N.D
OS3	9-11-01	1520 ± 30	0.07 ± 0.01	0.54 ± 0.02	< 0.31	N.D
MB11	"	30 ± 10	0.04 ± 0.01	0.11 ± 0.01	< 0.31	N.D
MB12	13-11-01	< 30	0.03 ± 0.01	0.10 ± 0.01	< 0.63	N.D
MB13	9-11-01	1750 ± 30	0.03 ± 0.01	0.12 ± 0.01	< 0.31	N.D
MB14	"	30 ± 10	0.06 ± 0.01	0.18 ± 0.02	< 0.31	N.D
MB15	"	30 ± 10	0.03 ± 0.01	0.08 ± 0.01	< 0.34	N.D
MB16	"	3570 ± 60	0.10 ± 0.01	0.49 ± 0.01	< 0.29	^{60}Co 0.18 ± 0.03
MB17	"	570 ± 10	0.02 ± 0.01	0.05 ± 0.01	< 0.30	N.D
MB18	"	60 ± 10	< 0.02	0.07 ± 0.01	< 0.47	N.D
MB19	23-11-01	100 ± 20	0.16 ± 0.05	0.53 ± 0.06	< 0.31	N.D
MB20	23-11-01	< 20	0.03 ± 0.01	0.30 ± 0.02	< 0.49	N.D
MB21	"	40 ± 10	0.04 ± 0.01	0.19 ± 0.02	< 0.35	N.D

Notes:

1. See Figure 3 for the location of the groundwater monitoring bores at the Little Forest Burial Ground.
2. The Australian Drinking Water Guidelines (NH&MRC, 1996) recommend screening levels for gross alpha and gross beta activity of < 0.5 Bq/L (excluding potassium-40 beta activity). The gross beta results above include the contribution from natural potassium-40. The Australian guideline value for tritium in drinking water is 7600 Bq/L (NH&MRC 1996).
3. A "less than" value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level). "N.D." indicates that no other statistically significant radioactivity was detected.
4. The maximum ^{60}Co level in MB16 was < 1 % of the Australian drinking water guideline value of 20 Bq/L (NH&MRC 1996).
5. Shading indicated those bores that are outside the fenced area of the LFBG.

TABLE 15

RADIOACTIVITY IN CREEKS NORTH OF
THE LITTLE FOREST BURIAL GROUND, 2001

Sample Location	Date	RADIOACTIVITY in **SEDIMENT** (Bq/g DW)		
		Gross α	Gross β	γ-emitters
Mill Creek	11-12-01	0.57 ± 0.08	0.19 ± 0.02	^{40}K 0.048 ± 0.011 U + Th series
Bardens Creek	11-12-01	0.52 ± 0.08	0.19 ± 0.02	^{40}K 0.048± 0.01 U + Th series

Sample Location	Date	RADIOACTIVITY in **WATER** (Bq/L)			
		Gross α	Gross β	γ-emitters	Tritium
Mill Creek	11-12-01	0.021 ± 0.005	0.11 ± 0.01	^{40}K < 1.5	< 10
Bardens Creek	11-12-01	0.011 ± 0.005	0.12 ± 0.01	^{40}K < 1.5	< 10

Notes:
1. See Figure 1 for the location of these sampling points.
2. The creeks were each sampled approximately 20m upstream from their confluence.

TABLE 16

PARTICULATES IN AIR AT THE LITTLE FOREST BURIAL GROUND, 2001

Sampling Period (1)	Average (2) Windspeed m.s^{-1}	Equivalent Volume (3) m^3	**Beryllium** (4)		**$^{239/240}$ Plutonium** (5)	
			μg (total)	μg/m^3	Bq (total)	Bq/m^3
Jan – Mar	3.4	458.1	< 0.050	< 1.1 x 10^{-4}	< 0.001	< 2.2 x 10^{-6}
Apr – Jun	2.3	346.4	< 0.050	< 1.6 x 10^{-4}	< 0.001	< 2.9x 10^{-6}
July – Sept	3.9	475.1	< 0.004	< 1.5 x 10^{-5}	< 0.001	< 2.1x 10^{-6}
Oct – Dec	3.9	433.1	< 0.005	< 1.4 x 10^{-5}	< 0.001	< 2.3x 10^{-6}

Notes:
1. Samples were collected using a mobile Ecotech high-volume air sampler (US-EPA-approved).Airborne particulate samples at LFBG 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 average windspeed during each sampling period was calculated from the data recorded at the 10m point on the LHSTC meteorological tower.
3. The Equivalent Volume is 25% of the total volume of air sampled during the period, since one-quarter of the filter is analysed.
4. The Worksafe Australia Exposure Standard for atmospheric contaminants such as beryllium in air is 2 μg/m^3 (applicable to workers exposed 8 hours per day, 50 weeks per year).
5. 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.

TABLE 17

AMBIENT IODINE-131 IN AIR AT LHSTC, 2001

Sampled during the week ending:	**Iodine-131**[1,2] Air Concentration Bq / m^3	Sampled during the week ending:	**Iodine-131** Air Concentration Bq / m^3
2-1-01	< 0.0025	3-7-01	< 0.0025
10-1-01	< 0.0025	12-7-01	< 0.0025
16-1-01	< 0.0025	17-7-01	< 0.0025
23-1-01	< 0.0025	24-7-01	< 0.0025
30-1-01	< 0.0025	31-7-01	< 0.0025
6-2-01	< 0.0025	7-8-01	< 0.0025
13-2-01	< 0.0025	16-8-01	< 0.0025
20-2-01	< 0.0025	21-8-01	< 0.0025
27-2-01	< 0.0025	28-8-01	< 0.0025
6-3-01	< 0.0025	4-9-01	< 0.0025
13-3-01	< 0.0025	11-9-01	< 0.0025
20-3-01	< 0.0025	18-9-01	< 0.0025
27-3-01	< 0.0025	25-9-01	< 0.0025
3-4-01	< 0.0025	2-10-01	< 0.0025
10-4-01	< 0.0025	9-10-01	< 0.0025
17-4-01	< 0.0025	16-10-01	< 0.0025
24-4-01	< 0.0025	26-10-01	< 0.0025
1-5-01	< 0.0025	30-10-01	< 0.0025
8-5-01	< 0.0025	6-11-01	< 0.0025
15-5-01	< 0.0025	13-11-01	< 0.0025
23-5-01	< 0.0025	20-11-01	< 0.0025
29-5-01	< 0.0025	27-11-01	< 0.0025
5-6-01	< 0.0025	4-12-01	< 0.0025
12-6-01	< 0.0025	13-12-01	< 0.0025
19-6-01	< 0.0025	18-12-01	< 0.0025
26-6-01	< 0.0025	24-12-01	< 0.0025

Notes:

1. Four air samplers are located along the eastern boundary of the LHSTC site, where suburban residences are closest (see Figure 2). Results are calculated making the conservative assumptions that:
   (a) all iodine-131 activity was released during the first day of the 7 day sampling period;
   (b) all the activity was concentrated at one sampling point.
2. A person with continuous exposure to iodine-131 at a concentration of 0.0025 Bq/m^3 would receive an effective dose of less than 0.01 mSv per year (IAEA, 1994).

TABLE 18a

EXTERNAL GAMMA RADIATION AT LHSTC
(ARPANSA Dosimeter Results), 1997 to 2001

	Dosimeter Location: **on-site** [1]	**Effective Dose** [2] ARPANSA Dosimeters [3] (mSv / year)				
		1997	**1998**	**1999**	**2000**	**2001**
1	Hifar fence - south east	0.9 ± 0.4	1.0 ± 0.4	1.0 ± 0.5	0.9 ± 0.3	0.77 ± 0.03
2	Hifar fence - south	3.3 ± 0.5	3.3 ± 0.5	3.2 ± 0.5	3.3 ± 0.4	2.86 ± 0.11
3	Perimeter fence - west	1.2 ± 0.5	1.3 ± 0.5	1.0 ± 0.5	1.0 ± 0.3	0.94 ± 0.04
4	Hifar fence - west	1.5 ± 0.6	1.2 ± 0.5	1.5 ± 0.2	1.3 ± 0.2	1.21 ± 0.05
5	Hifar fence - north west	1.2 ± 0.5	0.9 ± 0.4	1.1 ± 0.5	1.1 ± 0.4	0.98 ± 0.04
6	Perimeter fence - north A	0.9 ± 0.4	0.8 ± 0.4	0.8 ± 0.4	0.8 ± 0.3	0.71 ± 0.03
7	Internal fence - north	1.1 ± 0.4	0.8 ± 0.4	0.8 ± 0.4	0.9 ± 0.3	0.80 ± 0.03
8	Perimeter fence - north B	1.0 ± 0.4	0.8 ± 0.4	1.0 ± 0.4	0.9 ± 0.3	0.87 ± 0.03
9	Perimeter fence - north east	0.8 ± 0.3	0.8 ± 0.3	0.7 ± 0.3	0.7 ± 0.2	0.66 ± 0.03
10	Perimeter fence - east	0.9 ± 0.4	0.8 ± 0.4	0.8 ± 0.4	0.8 ± 0.3	0.75 ± 0.03
11	Perimeter fence - south east	0.9 ± 0.3	0.9 ± 0.4	0.6 ± 0.3	0.7 ± 0.2	0.72 ± 0.03
12	Corner of Curie and Roentgen Streets	1.2 ± 0.5	0.8 ± 0.4	1.1 ± 0.5	1.0 ± 0.3	0.91 ± 0.03
13	Perimeter fence - south	0.7 ± 0.3	0.8 ± 0.4	0.7 ± 0.3	0.6 ± 0.2	0.56 ± 0.02
14	Hifar fence - east	1.0 ± 0.4	1.1 ± 0.5	1.0 ± 0.4	1.0 ± 0.3	0.87 ± 0.03
15	Hifar fence - north east	1.1 ± 0.5	1.0 ± 0.4	1.1 ± 0.5	1.0 ± 0.3	0.91 ± 0.03
	Dosimeter Location: **off-site**	**1997**	**1998**	**1999**	**2000**	**2001**
16	Private house - Barden Ridge	0.8 ± 0.3	0.9 ± 0.4	0.7 ± 0.3	0.7 ± 0.2	0.65 ± 0.02
17	Private house - Engadine	1.1 ± 0.4	0.9 ± 0.4	1.0 ± 0.4	0.9 ± 0.3	0.85 ± 0.03
18	Private house - Woronora	0.9 ± 0.4	0.9 ± 0.4	0.8 ± 0.3	0.8 ± 0.2	0.74 ± 0.03
19	Cronulla Sewage Treatment Plant	-	-	0.5 ± 0.2[4]	0.6 ± 0.2	0.45 ± 0.02

Notes:
1. Refer to Figure 2 for the locations of dosimeters 1 to 15.
2. 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.
3. The ARPANSA dosimeters are the same as those usually used for personal monitoring, consisting of calcium sulphate thermoluminescent material with three filtered areas and an open window. The uncertainties (at the 95% confidence level) have been estimated from the standard deviation of the results for several dosimeters placed at the same location.
4. New sampling point introduced in 1999 with an estimated value based on two measurements.

TABLE 18b

EXTERNAL GAMMA RADIATION AT LHSTC
COMPARISON OF ARPANSA AND ANSTO DOSIMETER RESULTS, 2001

	Dosimeter Location: **on-site** [1]	**Thermoluminescent Dosimeter Results 2001** Effective Dose [2] (mSv / year)	
		ARPANSA [3]	**ANSTO** [4]
1	Hifar fence - south east	0.77 ± 0.03	0.85 ± 0.03
2	Hifar fence - south	2.86 ± 0.11	3.16 ± 0.10
3	Perimeter fence - west	0.94 ± 0.04	1.13 ± 0.04
4	Hifar fence - west	1.21 ± 0.05	1.39 ± 0.04
5	Hifar fence - north west	0.98 ± 0.04	1.19 ± 0.04
6	Perimeter fence - north A	0.71 ± 0.03	0.84 ± 0.03
7	Internal fence - north	0.80 ± 0.03	0.92 ± 0.03
8	Perimeter fence - north B	0.87 ± 0.03	0.95 ± 0.03
9	Perimeter fence - north east	0.66 ± 0.03	0.82 ± 0.03
10	Perimeter fence - east	0.75 ± 0.03	0.91 ± 0.03
11	Perimeter fence - south east	0.72 ± 0.03	0.87 ± 0.03
12	Corner of Curie and Roentgen St	0.91 ± 0.03	1.06 ± 0.03
13	Perimeter fence - south	0.56 ± 0.02	0.77 ± 0.02
14	Hifar fence - east	0.87 ± 0.03	1.05 ± 0.03
15	Hifar fence - north east	0.91 ± 0.03	1.12 ± 0.04
	Dosimeter Location: **off-site**	**ARPANSA**	**ANSTO**
16	Private house - Barden Ridge	0.65 ± 0.02	0.89 ± 0.03
17	Private house - Engadine	0.85 ± 0.03	1.17 ± 0.04
18	Private house - Woronora	0.74 ± 0.03	0.90 ± 0.03
19	Cronulla Sewage Treatment Plant	0.45 ± 0.02	0.55 ± 0.02

Notes:
1. Refer to Figure 2 for the locations of thermoluminsecent dosimeters (TLD's) 1 to 15.
2. 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.
3. The ARPANSA dosimeters are the same as those usually used for personal monitoring, consisting of calcium sulphate thermoluminescent material with three filtered areas and an open window.
4. 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.

TABLE 19a

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS AT LHSTC

January – March 2001

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)
3	N.D. [4]	N.D.	0.59[5]			
15A	N.D.	270	2.0	540	37	Hg-197 12 Hg-203 3.1 As-76 81 Br-82 1.8
15M	N.D.	N.D.	0.59	29	3.5	
19S	N.D.	N.D.	2.4			
19D	N.D.	N.D.	0.12			
20	N.D.	N.D.	0.42 [5]	2.3		
21A	N.D.	N.D.	0.091[5]			
21B	N.D.	N.D.	N.D.[5]			
23A	N.D.	270	490			
23B	N.D.	N.D.	0.082			
41A	N.D.	N.D.	15[5]			
41B	N.D.	N.D.	0.44[5]			
54	N.D.	N.D.	5300		40	I-132 49000 I-133 1700
56	N.D.	N.D.	2.2[5]			
57	N.D.	N.D.	0.73[5]	140		

Notes:

1. See Figure 2 for the location of the discharge stacks and Appendix B for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 54 stack are short-lived radioactive isotopes of Xenon and Krypton from Tc-99 production. HIFAR emits mainly Argon-41 produced by the neutron activation of air inside the reactor irradiation facilities.
4. "N.D." indicates that the radioactivity was not detected.
5. Indicates emissions where I-131 is included with non-specific emissions for that stack, ie there is no specific Notification Level for I-131 for that stack.

TABLE 19b

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS AT LHSTC,
April – June 2001

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)			
3	N.D. [4]	N.D.	0.49[5]						
15A	N.D.	180	1.2	420	35	Hg-197 12	Hg-203 1.4	As-76 39	Br-82 3.3
15M	N.D.	N.D.	0.16	61	3.4				
19S	N.D.	N.D.	1.8						
19D	N.D.	N.D.	N.D.						
20	N.D.	N.D.	1.9[5]	3.3					
21A	N.D.	N.D.	0.067[5]						
21B	N.D.	N.D.	0.0092[5]						
23A	N.D.	1200	400						
23B	N.D.	N.D.	0.28						
41A	N.D.	N.D.	3.3[5]						
41B	N.D.	N.D.	0.5[5]						
54	N.D.	N.D.	2900		53	I-132 42000	I-133 550		
56	N.D.	N.D.	1.7[5]						
57	N.D.	N.D.	0.73[5]	16					

Notes:
1. See Figure 2 for the location of the discharge stacks and Appendix B for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 54 stack are short-lived radioactive isotopes of Xenon and Krypton from Tc-99 production. HIFAR emits mainly Argon-41 produced by the neutron activation of air inside the reactor irradiation facilities.
4. "N.D." indicates that the radioactivity was not detected.
5. Indicates emissions where I-131 is included with non-specific emissions for that stack, ie there is no specific Notification Level for I-131 for that stack.

TABLE 19c

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS at LHSTC,

July – September 2001

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)			
3	N.D. [4]	N.D.	0.64 [5]						
15A	N.D.	220	1.0	490	35	Hg-197 12	Hg-203 0.9	As-76 47	Br-82 2.1
15M	N.D.	N.D.	0.28	92	4.1				
19S	N.D.	N.D.	0.59						
19D	N.D.	N.D.	0.08						
20	N.D.	N.D.	0.31 [5]	6.5					
21A	N.D.	N.D.	0.03 [5]						
21B	N.D.	N.D.	N.D.[5]						
23A	N.D.	1200	760						
23B	N.D.	N.D.	0.35						
41A	N.D.	N.D.	12[5]						
41B	N.D.	N.D.	1.90 [5]						
54	N.D.	N.D.	3000		54	I-132 15500	I-133 580		
56	N.D.	N.D.	1.1[5]						
57	N.D.	N.D.	N.D.[5]	34					

Notes:

1. See Figure 2 for the location of the discharge stacks and Appendix B for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 54 stack are short-lived radioactive isotopes of Xenon and Krypton from Tc-99 production. HIFAR emits mainly Argon-41 produced by the neutron activation of air inside the reactor irradiation facilities.
4. "N.D." indicates that the radioactivity was not detected.
5. Indicates emissions where I-131 is included with non-specific emissions for that stack, ie there is no specific Notification Level for I-131 for that stack.

TABLE 19d

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS AT LHSTC,
October – December 2001

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)
3	N.D. [4]	N.D.	0.29 [5]			
15A	N.D.	180	1.1	300	33	Hg-197 12 Hg-203 0.84 As-76 64 Br-82 1.2
15M	N.D.	N.D.	0.31	29	3.5	
19S	N.D.	N.D.	3.0			
19D	N.D.	N.D.	0.03			
20	N.D.	N.D.	0.57 [5]	11		
21A	N.D.	N.D.	0.06 [5]			
21B	N.D.	N.D.	N.D. [5]			
23A	N.D.	940	580			
23B	N.D.	N.D.	0.24			
41A	N.D.	N.D.	3.7 [5]			
41B	N.D.	N.D.	5.4 [5]			
54	N.D.	N.D.	3600		77.55	I-132 20000 I-133 700
56	N.D.	N.D.	0.54 [5]			
57	N.D.	N.D.	0.45 [5]	12		

Notes:
1. See Figure 2 for the location of the discharge stacks and Appendix B for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 54 stack are short-lived radioactive isotopes of Xenon and Krypton from Tc-99 production. HIFAR emits mainly Argon-41 produced by the neutron activation of air inside the reactor irradiation facilities.
4. "N.D." indicates that the radioactivity was not detected.
5. Indicates emissions where I-131 is included with non-specific emissions for that stack, ie there is no specific Notification Level for I-131 for that stack.

TABLE 20

RADIOACTIVITY IN GROUNDWATER
FROM THE VICINITY OF BUILDING 27 [1], 2001

Date Sampled	RADIOACTIVITY (Bq/L)	
	Gamma-emitters [2,3]	Tritium [4]
29-1-01	N.D.	350 ± 20
19-2-01	N.D.	360 ± 20
21-3-01	N.D.	340 ± 10
18-4-01	N.D.	390 ± 20
18-5-01	N.D.	360 ± 30
21-6-01	N.D.	380 ± 10
30-7-01	N.D.	310 ± 10
31-8-01	N.D.	310 ± 20
28-9-01	N.D.	350 ± 10
26-10-01	N.D.	370 ± 10
22-11-01	N.D.	240 ± 20
20-12-01	N.D.	360 ± 20

Notes:

1. See Figure 2 for the location of the groundwater sump near building 27. Building 27 houses the intermediate waste and spent fuel storage facility.
2. Gamma spectrometry was performed on a 500mL acidified sample in a Marinelli beaker.
3. N.D:- no statistically significant gamma peaks were detected.
4. The average tritium level recorded in the groundwater for 2001 was 340 Bq/L. This is < 5% of the Australian guideline value for tritium in drinking water: 7600 Bq/L (NH&MRC, 1996).

TABLE 21

RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED FROM LHSTC
TO THE SYDNEY WATER SEWER, 2001

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	6729	$< 7.0 \times 10^2$	9.77×10^3	3.75×10^6	< 0.15
February	9671	$< 7.5 \times 10^2$	7.55×10^3	2.25×10^6	< 0.13
March	8203	$< 9.2 \times 10^2$	9.18×10^3	2.82×10^7	< 0.29
April	5100	$< 8.0 \times 10^2$	4.92×10^3	1.39×10^7	< 0.18
May	11613	$< 9.1 \times 10^2$	7.18×10^3	1.60×10^6	< 0.14
June	6677	$< 1.0 \times 10^3$	5.25×10^3	3.06×10^7	< 0.30
July	6771	$< 9.3 \times 10^3$	1.60×10^4	9.90×10^7	< 0.24
August	8504	$< 1.1 \times 10^3$	1.04×10^4	1.23×10^6	< 0.18
September	5986	$< 1.1 \times 10^3$	3.32×10^3	1.99×10^6	< 0.12
October	7689	$< 1.3 \times 10^3$	3.38×10^3	4.90×10^6	< 0.16
November	7902	$< 1.2 \times 10^3$	1.83×10^3	3.99×10^6	< 0.13
December	5971	$< 9.5 \times 10^2$	4.04×10^3	3.16×10^6	< 0.12
Average	7568	$< 1.7 \times 10^3$	6.90×10^3	1.62×10^7	< 0.18
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 for 2001 were below the Activity Concentration Equivalents at ANSTO (which are based on the WHO Guidelines for Drinking-Water Quality, 1993).

TABLE 22

NON-RADIOACTIVE COMPONENT OF LIQUID EFFLUENT
DISCHARGED FROM LHSTC TO THE SYDNEY WATER SEWER,
1997 – 2001

Component mg/L	Yearly Average and Range of Values [1]					Standard for Acceptance mg/L [2]
	1997	**1998**	**1999**	**2000**	**2001**	
Suspended Solids	22 (5 to 62)	22 (7 to 51)	19 (1 to 35)	19 (2 to 76)	23 (9 to 133)	**200 (600 from 1st July 2001)**
pH	7.3 (7.0 to 8.3)	7.6 (7.0 to 8.3)	7.3 (6.9 to 8.0)	7.3 (6.3 to 8.0)	7.7 (6.1 to 8.6)	**7 – 10**
Ammonia	16.0 (2.4 to 60)	10.7 (1.0 to 46)	10 (1.0 to 40)	6.7 (0 to 30)	13.5 (2.1 to 32.6)	**50 (100 from 1st July 2001)**
B.O.D.	23	12	14	7	12 (2 to 54)	**85** [3]
Grease	13	12	7	5	6 (5 to 46)	**50**
Chromium [4]	1.4	1.2	0.8	0.01	-	**3**
Zinc	-	-	-	0.39	0.16 (0.02 to 0.32)	**5**

Notes:

1. Yearly averages are slightly overestimated since "less-than" values were included. The minimum and maximum values for the year are given in brackets.
2. Under the Sydney Water Trade Waste Agreement, the sampling regime was every 15 days until 1 July 2001, when a new Agreement came into effect that stipulated sampling every 4 days. At the same time the allowable concentrations for suspended solids and ammonia were also increased. 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.
4. Chromium was removed from the effluent analysis schedule in May 2000 and replaced by zinc.

TABLE 23a

AIRBORNE EMISSIONS OF IODINE-123 FROM THE NATIONAL MEDICAL CYCLOTRON, 2001

Month	^{123}I Total Activity (GBq)	^{18}F Total Activity (GBq)	^{67}Ga Total Activity (GBq)	^{201}Tl Total Activity (GBq)
January	0.86	1.59	ND	ND
February	2.76	1.01	0.015	ND
March	1.94	0.29	0.029	ND
April	2.71	0.67	0.032	ND
May	1.83	1.54	0.042	ND
June	1.72	0.54	0.002	ND
July	1.60	0.92	ND	ND
August	1.57	0.36	0.062	ND
September	2.17	1.09	0.0098	ND
October	6.65	0.67	ND	ND
November	3.78	0.90	ND	0.0015
December	4.20	0.61	ND	0.0074
TOTAL	31.8	10.2	0.19	0.0089
Annual Notification Level	100 GBq	250 GBq	500 GBq (total for all other nuclides)	

TABLE 23b

AVERAGE CONCENTRATION OF RADIONUCLIDES IN LIQUID EFFLUENT FROM THE NATIONAL MEDICAL CYCLOTRON, 2001

Month	Monthly Average Concentration in Liquid Effluent (MBq/m^3)					
	^{201}Tl	^{202}Tl	^{67}Ga	^{57}Co	^{65}Zn	^{123}I (1)
January	0.84	3.85	0.07	0.64	0.25	ND
February	0.42	0.12	8.15	0.55	0.08	ND
March	1.77	0.09	0.46	2.42	0.38	ND
April	9.12	1.24	0.33	0.90	0.10	ND
May	0.54	0.13	0.09	0.13	0.39	ND
June	3.76	0.69	0.38	0.94	0.20	ND
July	0.60	0.25	0.19	0.55	0.08	ND
August	0.55	0.34	0.41	0.52	0.17	ND
September	1.28	0.68	0.18	1.79	0.24	ND
October	0.47	0.13	0.04	0.14	0.04	ND
November	0.96	0.28	0.12	0.04	0.11	ND
December	16.46	1.31	0.28	0.33	0.25	0.01
NSW EPA Monthly Limits	**200**	**100**	**600**	**400**	**1008**	**6.00**
Half-life (days)	3.0	12.2	3.3	270.9	244.4	0.54

Notes for Tables 23a and 23b:

1. ND indicates that no statistically significant radioactivity was detected.

TABLE 24

ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, 2001

Receptor Location	2001 Estimated Effective Dose [1] mSv/yr	Estimated Dose as Percentage of site dose constraint [2]	Estimated Dose as Percentage of annual public dose limit [3]
Nearest resident	0.0024	0.78	0.24
LHSTC Library	0.0033	1.10	0.33
LHSTC Building 9	0.0051	1.70	0.51
LHSTC Main gate	0.0022	0.73	0.22
Stevens Hall Motel	0.0062	2.07	0.62
LH Waste Service Centre (tip)	0.0011	0.37	0.11
BMX track	0.0006	0.20	0.06
Woronora Valley	0.0006	0.21	0.06
At 1.6 kilometre radius from HIFAR			
NORTH	0.0046	1.53	0.46
NNE	0.0034	1.13	0.34
NE	0.0034	1.13	0.34
ENE	0.0033	1.10	0.33
EAST	0.0025	0.83	0.25
ESE	0.0013	0.43	0.13
SE	0.0014	0.47	0.14
SSE	0.0014	0.47	0.14
SOUTH	0.0011	0.37	0.11
SSW	0.0011	0.37	0.11
SW	0.0020	0.68	0.20
WSW	0.0017	0.58	0.17
WEST	0.0007	0.24	0.07
WNW	0.0007	0.24	0.07
NW	0.0013	0.43	0.13
NNW	0.0024	0.81	0.24
At 4.8 kilometre radius from HIFAR			
NORTH	0.0011	0.38	0.11
NNE	0.0007	0.23	0.07
NE	0.0008	0.27	0.08
ENE	0.0008	0.25	0.08
EAST	0.0006	0.18	0.06
ESE	0.0003	0.09	0.03
SE	0.0003	0.10	0.03
SSE	0.0003	0.10	0.03
SOUTH	0.0002	0.07	0.02
SSW	0.0002	0.07	0.02
SW	0.0005	0.16	0.05
WSW	0.0004	0.13	0.04
WEST	0.0002	0.05	0.02
WNW	0.0002	0.05	0.02
NW	0.0003	0.10	0.03
NNW	0.0006	0.19	0.06

Notes:

1. The annual effective dose is estimated using actual stack discharge data as input to the computer model, PC-Cream.
2. The site dose constraint is 0.3 mSv/year.
3. The annual dose limit for members of the public is 1 mSv/year (NH&MRC, 1995).

APPENDIX 1. MEASUREMENT OF RADIOACTIVITY

This section presents a brief description of the types of radioactivity analyses performed on environmental samples and the radionuclides commonly found, together with information on natural radioactivity. The statistical analysis of data is also discussed. Definitions of terms used throughout this report may be found in the Glossary. The radioisotope symbols used in this report are listed in Appendix 3.

The unit of radioactivity is the becquerel (Bq), which is equivalent to one nuclear disintegration per second. This unit is usually prefixed by multiples (for discharge data) and submultiples (for environmental concentrations) of 1000. These prefixes, which are applicable to the International System of Units (SI), are tabulated inside the back cover of this report.

NATURAL RADIOACTIVITY IN ENVIRONMENTAL SAMPLES

The uranium-238 and thorium-232 series are two of the primordial radioactive decay chains found in nature. The extremely long half-lives of the parent nuclides (4500 million and 14000 million years respectively) mean that their various decay products are ubiquitous in nature, occurring to varying degrees in soils, biota, water, and air. When present in environmental samples, the decay products of the uranium and thorium series can contribute significantly to the levels of gross alpha, gross beta and gamma radioactivity of such samples. Because of their natural origin, levels of the uranium-238 and thorium-232 series in LHSTC environmental survey samples have not been quantified. If progeny of the uranium-238 and thorium-232 decay series are detected during gamma spectroscopy of samples, their presence is reported in the relevant tables simply as "U & Th series". Typical activities of uranium and thorium and each of their 24 radioactive products range from 0.001 to 0.520 Bq/g in different soil types (UNSCEAR 1993, Table 5, p 65).

Potassium-40 has a half-life of 1280 million years and is found in rocks, natural waters and all material of plant and animal origin. It decays by beta/gamma emission with a specific activity of 30.7 Bq per gram of stable potassium (NH&MRC 1996). Potassium-40 is not considered to be of significance to health because it is present naturally with the stable potassium isotope and does not accumulate in the body but is maintained at a constant level. The average concentration of potassium in an adult male is about 2 g per kg of body weight, or about 60 Bq of potassium-40 per kg of body weight. The average contribution of this nuclide to the annual effective dose from background radiation is estimated to be 0.18 mSv (UNSCEAR 2000).

When evaluating the net gross beta activity of an environmental sample the beta contribution from potassium-40 (at 27.6 Bq per gram of stable potassium) may be calculated and subtracted.

Beryllium-7 is a naturally produced radioisotope that is formed by cosmic ray bombardment of atmospheric gases, mainly nitrogen and oxygen. For this reason beryllium-7 is considered a tracer of air masses coming from the stratosphere or upper troposphere. Beryllium-7 has a half-life of 53 days and is a highly reactive element that rapidly becomes associated with aerosol particles. These particles are efficiently removed from the atmosphere to earth through precipitation. Hence beryllium-7 is often found in stormwater samples collected at the Lucas Heights site.

RADIOACTIVITY MEASUREMENTS

Gross alpha and gross beta activity refers to the measurement of the total alpha or beta radioactivity of a sample from unspecified radionuclides. The measurement of gross radioactivity is a semi-quantitative screening technique, which is used to determine whether

more detailed analyses for specific radionuclides are warranted. Tritium (a weak beta emitter) cannot be detected using gross beta counting techniques.

Gamma activity refers to the electromagnetic radiation (gamma rays or photons) emitted from nuclides undergoing radioactive decay. Gamma photons are counted using a high purity germanium solid-state detector. A gamma spectrum for each sample is accumulated, with an energy range of 20 keV to 2000 keV. The peaks in the spectrum are then identified and compared with background spectra to determine significant nuclides and the specific activity calculated. Nuclides that may be detected by this method include caesium-137, cobalt-60 and iodine-131.

Caesium-137 is a fission-product that was widely dispersed around the world by fallout from nuclear tests performed in the atmosphere. It has a half-life of 30.14 years. The isotope is deposited on land in precipitation or as 'dry' fallout, and adsorbs strongly onto fine sediments (like clays). A typical value for soils in the Sydney region is 1350 Bq/m2 (Cole-Clark, 1993). Caesium-137 is widespread in foods, since its chemical behaviour is similar to that of potassium (an element essential to all living things). This isotope is also present in the marine environment and hence can be found in marine biota such as fish and shellfish. Caesium-137 is also formed as a by-product of the manufacture of technetium-99m generators for medical purposes.

Cobalt-60 is an activation product formed in reactors by the neutron activation of stable cobalt-59 (often present in steel components). It has a half-life of 5.26 years and is a beta-gamma emitter. This isotope is readily concentrated by both aquatic and terrestrial organisms.

Iodine-131 is a beta/gamma-emitting radionuclide with a relatively short half-life of 8.02 days. Iodine-131 is used in hospitals to diagnose and treat various diseases associated with the thyroid. It is biologically important because atmospheric releases of iodine-131 can deposit onto pasture and be incorporated into milk. Human consumption of this milk can then lead to iodine-131 uptake by thyroid tissue. Further, inhalation of gaseous iodine-131 can also result in doses to the lung and thyroid. If present in water, iodine is more readily concentrated by marine biota than by freshwater organisms.

Tritium (3H) is a radioisotope of hydrogen and has a half-life of 12.26 years. It decays with the emission of a weak beta particle, with a maximum energy of 18.6 keV and an average energy of 5.69 keV (there is no gamma emission). Tritium activity in water samples is measured by distillation and liquid scintillation counting.

Tritium is widespread in the environment. It is a cosmogenic radionuclide and was also produced as a result of atmospheric nuclear weapons testing (by far the largest contribution). It is also produced in nuclear reactors (particularly in reactors such as HIFAR that have heavy water moderators) by neutron activation of deuterium.

The penetration of the tritium beta is low (the stopping distance is about 7 mm in air, 0.01 mm thickness of paper, or the outer dead layer of human skin). Exposure through internal uptake is therefore the main consideration when assessing radiation dose due to tritium. The Australian drinking water guideline value for tritium is 7600 Bq/L (NH&MRC 1996) and this reflects the fact that tritium is not as biologically hazardous as other radionuclides having more energetic radiations.

Tritium (as tritiated water) is chemically indistinguishable from normal water and may be taken up as such by living organisms. The biological half-life of tritium is relatively short, with one half of the absorbed tritium being excreted from the body typically within days. When present, tritium is found more or less uniformly distributed throughout living species, not accumulated in any particular organ. The concentration factor is ordinarily assumed to be equal to one. Tritium is therefore not considered to accumulate in aquatic organisms above the concentration found in the surrounding water.

Tritiated water does not undergo geochemical processes such as ion exchange, adsorption or precipitation and can therefore be used as a tracer for groundwater movement.

QUALITY MANAGEMENT

ANSTO's Quality Policy requires activities to be undertaken in a manner that promotes a quality culture for planning and undertaking research and development, the provision of services and reporting of these activities. Consistent with this policy, a formal commitment to quality systems is fundamental to obligations accepted by ANSTO within the framework of the environmental assessment process for the replacement reactor. ANSTO is in the process of introducing an ISO 9001/2000 regime across the site (including the monitoring laboratories) and has made a commitment to implement the ISO 14001 standard for Environmental Management Systems.

The Environment Division achieved accreditation to the ISO 9001:2000 standard for Quality Management Systems in December 2000 (certificate No. QEC12839). In October 2000 the Safety Division external dosimetry, health physics instrument calibration and stack sampling operations gained certification to the AS/NZS ISO 9002:1994 standard.

Radiological Analysis Methods

Detailed information on sample collection and analysis methods were published in Hoffmann et al, 2001. International Standard methods for radiological analyses are used for tritium analysis via distillation and liquid scintillation counting (ISO 9698:1989), gross alpha activity (ISO 9696:1992) and gross beta activity (ISO 9697:1992). Laboratory instructions for performing gamma spectrometry, gross alpha, gross beta and tritium analyses of waters are documented and incorporate techniques based on those used by the ARPANSA Environmental Radioactivity Branch.

Instruments and detectors are regularly maintained and calibrated against certified standard materials. Blanks and standards are counted regularly.

Counting Statistics

After a sample has been "counted" or measured for radioactivity, it is important to determine whether or not the level of activity is statistically significant. The results from the environmental monitoring program are reported using the principles of counting decision levels endorsed by Gilmore & Hemingway in Practical Gamma-ray Spectrometry (1995), Chapter 5, Section 5.6, pages 119-124. These decision levels are used to determine the statistical significance of a sample count based upon the uncertainty of the background count.

APPENDIX 2. RADIONUCLIDE SYMBOLS AND HALF-LIVES

Symbol	Name	Half-life
α	alpha	
β	beta	
γ	gamma	
^{241}Am	americium-241	432.2 years
^{7}Be	beryllium-7	53 days
^{144}Ce	cerium-144	284.9 days
^{134}Cs	caesium-134	2.06 years
^{137}Cs	caesium-137	30.14 years
^{51}Cr	chromium-51	27.7 days
^{57}Co	cobalt-57	271.8 days
^{60}Co	cobalt-60	5.3 years
^{18}F	fluorine-18	110 minutes
^{67}Ga	gallium-67	3.3 days
^{3}H	tritium	12.3 years
^{123}I	iodine-123	13.2 hours
^{131}I	iodine-131	8.02 days
^{132}I	iodine-132	2.3 hours
^{133}I	iodine-133	20.8 hours
K	stable potassium	
^{40}K	potassium-40	1.3×10^{9} years
^{240}Pu	plutonium-240	6.56×10^{3} years
^{90}Sr	strontium-90	28.6 years
^{201}Tl	thallium-201	3.04 days
^{202}Tl	thallium-202	12.23 days
^{232}Th	thorium-232	1.4×10^{10} years
^{238}U	uranium-238	4.5×10^{9} years
^{65}Zn	zinc-65	244.1 days

GLOSSARY OF TERMS

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

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

ALARA: As low as reasonably achievable. Used in reference to radiation levels.

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

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

A member of the public: A real or hypothetical person outside the effective control of ANSTO who is identified in a critical group pathway analysis.

Ambient: the amount of radioactivity that is considered to fall within measured levels arising from naturally occurring sources.

ARI: Australian Radiopharmaceuticals and Industrials. A commercial unit operated by ANSTO to market and distribute radioisotopes produced by ANSTO.

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

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

1 curie = 3.7×10^{10} becquerels.

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

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

Biota: Fauna and flora of a given region.

Biological half-life of an isotope: The time required for one-half of an absorbed radioisotope to be excreted from the body. Also called biological turnover.

Buffer zone: A 1.6 km boundary around ANSTO (measured radially from the HIFAR reactor) within which no residential development is allowed to occur.

Class C water: Water that is controlled with regard to what can be discharged into it. For a full definition, see the NSW *Protection of the Environment Operations Act*, 1997.

Concentration factor (biological): the ratio of an element in an organism, to that of its environment or what is consumed, i.e.

Concentration in consumer organism ÷ Concentration in environment or food.

Critical group: A group of members of the public that is reasonably homogeneous with respect to its exposure to a given radiation source and given exposure pathway and is typical of individuals receiving the highest radiation dose by the given exposure pathway from the given source.

Critical orifice: A device that restricts air-flow through a sampling assembly to a constant rate, provided the required vacuum is applied.

Decay, radioactive: The disintegration of an atomic nucleus resulting in the release of alpha or beta particles, and/or gamma radiation.

Dilution ratio: The ratio of effluent concentration at release, to the maximum concentration at the destination.

Dose constraint: For public exposure, the dose constraint is the maximum annual dose that members of the public may be allowed to receive from the planned operation of any specific source of radioactivity. The exposure to which the dose constraint applies is the annual dose to any critical group summed over all exposure pathways arising from the predicted operation of the controlled source. The dose constraint for each source is intended to ensure that the sum of doses to the critical group from all controlled sources remains within the public dose limit.

Dose limits: The maximum radiation dose that a person may receive over a stated period of time. Internationally recommended limits adopted by Australia are that radiation workers should not accumulate more than 20 mSv per year. Members of the public should not receive more than 1 mSv per year (NH&MRC 1995).

Effective dose: A physical quantity used in the measurement of ionising radiation dose to humans, taking into account the harmfulness of different types of radiation and the susceptibility to harm of different organs of the body. The effective dose is the sum of weighted equivalent doses to all organs and tissues of the body, where the equivalent dose to each organ and tissue is multiplied by the weighting factor for that organ or tissue. The unit of effective dose is joules per kilogram, termed the sievert (Sv), or more commonly the millisievert (mSv) - one-thousandth of one sievert.

Electromagnetic radiation: Waves of energy that are caused by the acceleration of charged particles. Includes radio waves, infra-red, visible light and ultraviolet radiation (all non-ionising radiation), and x-rays and gamma rays (ionising radiation).

Equivalent dose: A weighted radiation dose to an organ or tissue, which is the product of absorbed dose in the organ or tissue and the radiation weighting factor (determined by the type and energy of the radiation to which the organ or tissue is exposed). This measurement allows the dose received by exposed persons to be expressed on a scale common to all ionising radiation. The unit of equivalent dose is joules per kilogram, termed the sievert (Sv). Dose is most commonly expressed as millisieverts (mSv).

Fission: Usually, the division of a heavy nucleus into two similar but generally unequal masses, with the emission of neutrons, gamma radiation and a great deal of energy.

Fission product decay: The process by which radioactive atoms from fission become stable through the emission of radioactive particles.

Fission products: The atoms formed as a result of fission. Most fission products are very unstable, have short half-lives and are highly radioactive, emitting copious quantities of beta rays and gamma rays over a range of energies. A small number emit delayed neutrons.

Gamma radiation: Gamma radiation is short wavelength electromagnetic radiation of the same physical nature as light, x-rays, radio waves, etc. However, gamma radiation is highly penetrating (more so than x-rays) and, depending on its energy, can require a considerable thickness of lead or concrete to absorb it. Because gamma radiation causes ionisation, it constitutes a biological hazard.

Gamma radioactivity: Electromagnetic radiation of high quantum energy emitted after nuclear reactions or by radioactive atoms when the nucleus is left in an excited state after emission of alpha or beta particles.

Half-life, radioactive: For a single radioactive decay process, the time required for the activity to decrease to half its original value by that process. Half-lives vary, according to the radioisotope, from less than one-millionth of a second to more than one billion years.

Heavy water: Deuterium oxide (D_2O) or water containing significantly more than the natural proportion of heavy hydrogen atoms. Heavy water is used as a moderator in the HIFAR reactor because it slows down neutrons effectively.

HIFAR (high flux Australian reactor): Nuclear reactor of the DIDO class operated by ANSTO and located at Lucas Heights.

Hot cell: A heavily shielded enclosure for highly radioactive materials. It can be used for their handling or processing by remote means, or for their storage.

Ionisation: Any process by which an atom, molecule or ion gains or loses electrons.

Ionising radiation: Radiation capable of causing ionisation of the matter through which it passes. Ionising radiation may damage living tissue.

Isotope: Atoms of an element having the same number of protons but different numbers of neutrons in the nuclei. Different isotopes of the same element have the same chemical properties, but somewhat different physical properties.

Low level waste: Any waste material that contains measurable quantities of radioactivity requiring minimum standards of protection for personnel when the waste is handled, transported or stored.

Noble gases: Also known as inert gases, the noble gases (helium, argon, krypton, xenon and radon) have filled electron shells and normally do not react chemically with other elements. There are some radioactive isotopes of noble gases.

Nuclear reactor: A structure in which a fission chain reaction can be maintained and controlled. It usually contains fuel, coolant, moderator, control absorbers and safety devices and is most often surrounded by a concrete biological shield to absorb neutron and gamma ray emissions.

Planchette: A lipped, flat dish, commonly around 50 mm in diameter, used for holding samples to be counted under a detector. Water samples may be evaporated directly onto the planchette. Usually made of stainless steel or aluminium.

Progeny: A nuclide formed from the radioactive decay of another nuclide, called the parent.

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

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

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

Radioactivity: The property of certain nuclides of spontaneously emitting particles or gamma radiation, or of emitting x-radiation following orbital electron capture, or of undergoing spontaneous fission. The SI (International System) unit of radioactivity is the becquerel (Bq).

One becquerel is equal to one nuclear disintegration per second. This is a direct measure of the amount of radioactivity in a sample.

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

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

Transit time for the passage of effluent: The time interval from the midpoint of an effluent release to the time at which the maximum concentration of the effluent is detected at the destination.

Tritium: The "heavy" hydrogen isotope of mass 3. It is naturally occurring but can also be made in a number of ways, including neutron absorption in lithium, deuterium or heavy water. It is radioactive (a very weak beta-emitter) with a half-life of 12.3 years.

LIST OF ACRONYMS AND ABBREVIATIONS

AAEC	The former Australian Atomic Energy Commission
ARL	The former Australian Radiation Laboratories, now ARPANSA
ANSTO	Australian Nuclear Science and Technology Centre
ANTARES	Australian National Tandem Accelerator for Applied Research
ARI	Australian Radioisotopes and Industrials
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
CSTP	Cronulla Sewage Treatment Plant
EPA	Environment Protection Authority
EMAP	Environmental Management Action Plan
HIFAR	High Flux Australian Reactor
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
INIS	International Nuclear Information System
ISO	International Organisation for Standardisation
LHSTC	Lucas Heights Science and Technology Centre
LFBG	Little Forest Burial Ground
MDP	Main Disposal Pipeline
NH&MRC	National Health and Medical Research Council
NMC	The National Medical Cyclotron
NSB	The former Nuclear Safety Bureau, now ARPANSA
NSW	New South Wales
RAC	The former Radiological Advisory Council, now ARPANSA
SPCC	The former State Pollution Control Commission, now the NSW Environment Protection Agency
STP	Sewage Treatment Plant
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organisation
WMAP	Waste Management Action Plan