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Replacement Research Reactor Project

SAR CHAPTER 3
SITE CHARACTERISTICS

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TABLE OF CONTENTS

3 SITE CHARACTERISTICS

End of Table of Contents

3 SITE CHARACTERISTICS

3.1 INTRODUCTION

The objectives of this chapter are:

1. To provide a comprehensive description of the site characteristics for use in both the justification of the design bases for the Replacement Research Reactor (hereafter Reactor Facility) (e.g. seismic level) and the analysis of the consequences of any accidents (e.g. population distribution).
2. To demonstrate that the assumptions presented in the EIS and earlier licence applications continue to be applicable to the actual Reactor Facility design and associated site layout.

This chapter provides information on the geological, seismological, hydrological, and meteorological characteristics of the site and the vicinity, together with the present and projected population distribution, land use, site activities, monitoring and planning control. It provides site information and related assessments relevant to the Safety Assessment of the Reactor Facility. Information included in this chapter covers the following aspects:

Site characteristics

Site related design bases

Compliance with regulatory assessment requirements

The Reactor Facility has been built on land owned by ANSTO at the western end of the Lucas Heights Science and Technology Centre (LHSTC) adjacent to the High Flux Australian Reactor (HIFAR). The site of the Reactor Facility is within the existing perimeter fence and covers an area of approximately four hectares. ANSTO maintains a buffer zone of 1.6 kilometres, centred on HIFAR, within which land use restrictions apply and all residential development is excluded.

The LHSTC has been the site of HIFAR since 1956. The siting, design, construction, operation and decommissioning of the Reactor Facility requires an updated description and assessment of site characteristics that influence the facility's safety and any potential health and safety impacts.

The design and operation of the Reactor Facility take into account site characteristics which may impact the safety of the facility. These site characteristics include:

a) The site's population distribution and existing population centres, seismology, geology, topography, ecology, hydrology, and meteorology.

b) Nearby facilities and land usage.

c) Offsite and onsite services such as electricity, water, transportation, and communication systems.

d) Other characteristics relevant to the feasibility of emergency response.

The information contained within this chapter is in compliance with the regulatory requirements of the Regulatory Assessment Principles (ARPANSA, 2001), and the siting guideline (ARPANSA, 1999). The structure and contents of the chapter are in accordance with the recommendations of the IAEA (IAEA, 1994) and have made use of the IAEA research reactor codes and guides. These include the Code on the Safety of

Nuclear Research Reactors: Design (IAEA, 1992) and its revision (IAEA, 2001). In addition, the Technical Document on siting of research reactors (IAEA 1987) has been used together with relevant references cited in the aforementioned documents including power reactor siting guides (e.g. IAEA 1981, 1991 and 1996).

End of Section

3.2 SITE CHARACTERISTICS

This Section provides the description of the site characteristics that affect safety considerations in the design of the Reactor Facility.

3.2.1 Geography

The LHSTC is located some 35 km south-west of the Sydney Central Business District, in Sutherland Shire, New South Wales. The LHSTC is on the dissected Woronora Plateau at an elevation of about 150 m Australian Height Datum. The site is approximately 2 km west of the Woronora River and 8 km south of the Georges River and is surrounded by bushland extending for several kilometres with no significant habitation in the north-west, west and south-west quadrants. The laboratories of ANSTO and some divisions of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the operational HIFAR and shut-down Moata research reactors, are located within a 70 hectares fenced area which is surrounded by a 1.6 km radius buffer zone centred on HIFAR. No permanent residential development is permitted within the ANSTO buffer zone. The residential suburbs of Barden Ridge and Engadine are located in the north-east to south-east sectors adjacent to the ANSTO buffer zone boundary while the suburban area of Menai is located some 3 km further to the north-east.

The following maps of the LHSTC site and surrounding areas show the current land use characteristics and survey siting for the Reactor Facility:

Figure 3.2/1	Map of the Lucas Heights Area
Figure 3.2/2	Nearby Land Use Characteristics
Figure 3.2/3	Generalised Zoning Near the LHSTC site
Figure 3.2/4	Land Use Within and Adjoining the Buffer Zone
Figure 3.2/5	Survey Map for the Replacement Research Reactor Site

All the area inside the ANSTO buffer zone, including a small extension around the Little Forest radioactive waste Burial Ground is owned by the Commonwealth or its agencies.

Under the Sutherland Local Environment Plan (SLEP, 2000), land within the ANSTO buffer zone is currently zoned 5(a) - Special Uses (Military) for that portion outside the fenced laboratories area and 5(a) - Special Uses (Research and Technology) for the fenced laboratories area. However, the zoning of that part of the ANSTO buffer zone currently leased out as part of a municipal waste depot is part Special Uses 5(f) and part 6(d) for Future Recreation, reflecting its use as a waste management site and possible future use for recreational purposes. Future development options for the land are outlined in the development control tables under SLEP 2000. Consultation with ANSTO would be required before any final uses of the land could be determined and such final uses must meet ANSTO’s and NSW Emergency Service Organisations’ safety criteria and directions.

Land within the buffer zone is owned and administered by ANSTO with the exception of an area of land within the buffer zone to the east of the Woronora River. Land to the west of Heathcote Road within the Holsworthy Military Area is owned by the Commonwealth and administered by the Department of Defence, while a small portion is controlled and managed by Australian Estate Management on behalf of the Department of Administrative Services. An area immediately to the north of the buffer zone that contains Little Forest Burial Ground is also owned and administered by ANSTO. There are no Native Title claims on land controlled by ANSTO.

ANSTO leases 104 hectares of the western portion to Waste Service NSW, which operates the Lucas Heights Waste Management Centre. Other portions leased by ANSTO include:

a) The site and building used by Vita Medical Ltd in the Business and Technology Park.

b) Eleven hectares of land near the intersection of Little Forest and New Illawarra Roads, to Sutherland Police Community and Youth Club for its mini-bike track.

c) Approximately one hectare immediately east of LHSTC, to the United Pistol Club.

d) The site immediately to the west of the site of the Reactor Facility, leased to the Cooperative Research Centre (CRC) for Waste Management and Pollution Control as a Biowaste Research Facility.

Energy Developments Limited has entered into an agreement with Waste Service NSW to extract landfill gas (a mixture of methane and carbon dioxide) from the fill areas of the Waste Management Centre and convert the gas into electrical energy which will be fed into the local electricity grid via the substation located at LHSTC.

The ANSTO Business and Technology Park, covering an area of about 20 hectares, is located on the northern side of the main laboratories area in Lots 4 and 6 DP 23333. Vita Medical Ltd leases a purpose built building for the manufacture of the Technegas generator used in the diagnosis of lung disorders. Currently two other private companies ATA Scientific and Bilyara lease space in the Park’s central building, the Woods Centre.

ANSTO leases about 11 hectares of land near the intersection of Little Forest and New Illawarra Roads to the Sutherland Police Community and Youth Club for use as an off-road mini-bike-training track. The track is used by the club on Sundays. Another area of about 1 hectare located in bushland to the east of the main laboratories area is leased to the United Pistol club. The two pistol ranges at the club are used by about 30 members on the weekends, although some ANSTO and Australian Protective Service club members also use the facility during weekday lunchtimes.

Land immediately to the north of the ANSTO buffer zone is mainly State, Crown or Defence Department land. Parts of the crown land area (west of Old Illawarra Rd) have been proposed for residential development by the NSW Department of Planning as part of the West Menai urban release and are currently zoned 2(a1) – Residential under the Sutherland Local Environmental Plan (2000).

Very little mixed farming is undertaken in the 5 km vicinity of the LHSTC, but there are a number of poultry farms, mostly of the battery type within 15 km of the site. The nearest dairy farms are located at Glenfield, some 15 km north-west of the LHSTC site. One is privately owned and produces approximately 1.3 x 10^5 litres of milk annually; the other is the Veterinary Research station of the NSW Department of Agriculture with an annual output of 1 x 10^5 litres. Further information on food production and consumption, of relevance to radiological consequence modelling, is given in the EIS Vol. 2, Appendix G, section 4.4 and Annex 2.

The radiological consequences analyses for this document use the very conservative estimate of 25% of the consumed food being locally produced (ANSTO, 1999). In a new study, comprehensive data on food production for the Statistical Local Areas within a 50 km radius of ANSTO were obtained from the Australian Bureau of Statistics and other organisations. These data were interpreted and fully analysed and were used to assess the radiological consequences. A report (Domel, 2003) details the analyses and results obtained, and is summarised below. Agricultural production and consumption analyses for the Sydney basin region clearly highlight that the previous figure of 25% local consumption is an over estimation and highly conservative when considering the whole of the Sydney basin, but especially for the 15 km circumference around ANSTO. The percentage of food produced of the total consumed in the Sydney basin has a range for the fruit and vegetable groups grown in the Sydney region of 0 to 14%. Much of this production occurs in the Gosford, Hawkesbury and Blue Mountains foothills regions – more than 50 km from ANSTO.

The poultry and egg production and consumption figures for the Sydney basin, while higher (25 to 50%), would contribute a negligible dose in a consequence analysis scenario. Most production occurs at distances more than 20 km from ANSTO.

The topography and food production farming within 15 km, 25 km and 50 km around ANSTO was reviewed and analysed. The likely impact to doses from within the food chain pathway of radioactive discharges from the RRR is very low or negligible for all the areas analysed. Almost all food production farming for the Sydney basin is more than 20 km away from the site and constitutes 14% or less of that consumed by the total Sydney population. Even using the EIS and PSAR figure of 25% local consumption, calculations have shown that the contribution to dose from the food pathway for critical groups is very small to negligible.

3.2.2 Demography

The following sections summarise the demographics of the LHSTC site and the surrounding areas.

3.2.2.1 Present and Projected Population Around the LHSTC

The present population data and its geographic distribution beyond 1.6km from HIFAR is presented in Table 3.2/1 and graphically in Figure 3.2/7 for the population to 50 km, and enlarged in Figure 3.2/8 for the population to 4.8 km. These distributions are based on the Australian Bureau of Statistics 2001 Census data, with the analyses and results prepared by consultants (Domel, 2003). The population was grouped into 16 sectors of 22.5 °arc and 6 radial zones out to 50 km. The consultant's methodology was to assign Census Collection Districts to zones on the basis of population centroids. This presents an accurate placement of the current (census) population as it takes account of extensive non-urban areas such as bushland, river escarpments, and water bodies. Small overlaps of zone boundaries tend to balance out. The population projection factors for each sector are also listed in Table 3.2/1. Projection factors were calculated for 2006, 2011, 2016 and 2021.

The population for the 50 km around ANSTO represents close to 90% of the total Sydney Statistical District population. A small portion of the population number (northern part of the Illawarra SD) is additional to the Sydney SD population total. Population distribution estimates for the growing suburbs around ANSTO (Menai, Barden Ridge, Bangor, Illawong and Alfords Point) have been updated and confirmed. The population distribution in these regions constitutes normal suburban inhabitants.

3.2.2.2 LHSTC Site Population

The typical population at the LHSTC site from Mondays to Fridays during normal working hours is presented in Table 3.2/2.

3.2.3 Meteorology

This Section describes the meteorology of the LHSTC site. The meteorological data presented has been recorded at the LHSTC meteorology laboratory (Building 44). Atmospheric mixing, wind patterns, rain fall, inversion layers and associated air movements are addressed in this section.

Such information may be used to model atmospheric transport and dispersion of airborne releases of radioactive materials in the surface layer of the atmosphere.

The 1991 to 2003 wind speed, direction, temperature and rainfall data are recorded digitally every 15 minutes. A description of the meteorological instrumentation, the calibration and digitisation methods are given in Clark (1997, 2003).

3.2.3.1 Winds

Frequencies of surface wind speeds and directions have been summarised by time of day and season in Clark (1997, 2003). During summer, daytime sea breezes occur from the north-east to east and south-east to south-south-east sectors with winds from the south predominant. Autumn and spring represent transition seasons between summer and winter with sea breezes observed later and nocturnal winds indicative of regional drainage of cool air from the west-south-west to south-south-west sectors with an overall predominance of south winds. In winter, winds from the west-south-west to south sectors predominate at night with the distribution extending through west to the north-west sector in the daytime. Table 3.2/3 shows the statistics for all seasons combined as a function of time of day and Table 3.2/4 shows the average statistics for all times combined as a function of season at 10 m height on the Lucas Heights meteorological tower.

Upper wind frequencies.

Median (50% probability) wind speed and direction distribution at 49m on the Lucas Height meteorological tower are presented in Table 3.2/5 and Table 3.2/6 (Clark, 2003). At 49m the wind directions are turned clockwise with respect to those at 10m, and wind speeds are higher, in particular at night when regional drainage winds free of surface influences are observed over the site.

Wind frequencies during precipitation.

Wet deposition or wash out of atmospheric aerosols and gases is dependent, among other things, on the local precipitation rates. In Table 3.2/7 taken from Clark, 2003, the 15 minute precipitation rates are compared with the prevailing wind directions. It is apparent that nearly 45% of rain events occur with winds from the south-east to south sectors with half of these of low intensity (0-1mm per hour).

Wind frequencies during inversions.

Frequencies of initial wind directions and average wind speeds during inversions, obtained from an hour by hour inspection of wind records during inversions, are presented separately for light to moderate inversions and for strong inversions in Table 3.2/8 and Table 3.2/9 (AAEC 1972). Light to moderate inversions correspond to inversions with a temperature gradient smaller than 7.5 ºC per 100 m and strong inversions are those with a temperature gradient exceeding 7.5 ºC per 100 m.

Severe winds.

Data on severe winds at the LHSTC site is given in PLG (1998). An analysis of tornado data in NSW (PLG, 1998) considered 53 tornadoes of which 17 were strong and 36 were weak. Their wind speeds and strike frequency are presented in Table 3.2/10. The overall severe wind mean annual frequencies at designated ranges are presented in Table 3.2/11. These data are graphically presented in Figures 3.2/9 and 3.2/10.

3.2.3.2 Barometric Pressure Variations

Atmospheric pressures vary both during the day and seasonally. Atmospheric pressure data recorded every 15 minutes are summarised into three hour blocks in Table 3.2/12 (Clark, 2003). It is apparent that a shallow pressure minimum occurs between 0300 and 0600 with deeper minimum between 1500 and 1800 EST. Maximum pressures on the diurnal cycle occur between 0600 and 0900 and 2100 to 2400 EST. This cycle is linked to the solar radiation diurnal heating and cooling of the lower atmosphere. During the year maximum atmospheric pressures are observed during April and May with minimum pressures observed in summer. This corresponds to the latitudinal movement of large-scale anti-cyclonic (high) and cyclonic (low), pressure systems. Large pressure changes at the rate of 1-2 hPa h^{-1} and lasting several hours are associated with the passage of cyclones and are therefore almost always accompanied by strong winds from south-westerly to north-westerly directions. Very large transient pressure changes at the rate of 5-10 hPa h^{-1} generally last less than one hour and occur infrequently.

3.2.3.3 Rainfall and Evaporation

Statistical data relating to rainfall and evaporation for the years 1981 to 2002 were taken from Clark (1997, 2003). These are presented in Tables 3.2/13, 3.2/14 and 13.2/15. The annual rainfall across this period may be noted to vary between 576 to 1482 mm, and the total annual evaporation to vary between 1087 to 1462 mm for the same period.

3.2.3.4 Inversions and Atmospheric Mixing Layers

The occurrence of stable temperature inversions and limited atmospheric mixing layers can lead to “worst case” conditions in terms of air pollution impact assessments. For near ground releases of air pollutants the low wind speed, temperature inversion conditions represent a worst case scenario, whereas for an elevated release a low vertical, atmospheric mixing layer might cause maximum impact of air pollutants at ground level. Statistical data (Charash, 1968) relating to inversions are presented in Figure 3.2/11 and Table 3.2/16. The average time of onset and end of inversions throughout the year is recorded, along with the average temperature difference.

All recorded occurrences of stable temperature inversions and limited atmospheric mixing layers are ground based nocturnal inversions. Because the instrumentation extended only to 50m above ground, the top of the ground based inversions and the occurrence of upper level inversions could not be ascertained. From the average time required for the elimination of nocturnal inversions by surface heating after sunrise, the top of inversions is inferred to be, on average, 120m above ground.

An acoustic sounder has been used to study the development of atmospheric mixing layers associated with the dissipation of the nocturnal surface temperature inversion and the onset of sea breezes (Clark, 1981, 1982). The acoustic sounder generally only starts to indicate a rising atmospheric mixing layer when it has reached about 220 m (Table 3.2/17). The final observed height is frequently determined by instrument sensitivity to the acoustic signal strength. Nevertheless, analyses did indicate more rapid rise rates of the mixing layer in summer under the influence of stronger solar heating than in winter when it is observed longer.

On a majority of occasions when sea breezes were observed at Lucas Heights, a limited atmospheric mixing layer was also observed using the acoustic sounder. The average heights of the sea breezes vary from 620m in summer to 730m in spring when they are observed less frequently. Light winds are generally associated with development of the sea breeze and frequently follow low morning atmospheric mixing layers. In these cases, there is an extended period of limited vertical atmospheric mixing which varies on average from 5 hours in winter (approximately 500 to 670 m) to 8.8 hours in summer (approximately 550 to 760 m).

3.2.3.5 Air Movement During Inversions

By integrating wind speeds over the time of duration of an inversion, the theoretical range of air movement during an inversion is obtained. A uniform wind field over many hours and at distances greater than a few kilometres under inversion conditions has been assumed. Hence based on the initial observed wind direction, the results presented in Table 3.2/18 (AAEC, 1972) should be interpreted merely as a broad indication of the general area likely to be affected by emissions during inversions.

3.2.3.6 Turbulence Climatology

ANSTO currently uses the US Environment Protection Authority (USEPA 1987) scheme for classifying atmospheric turbulence. This scheme uses the wind speed and fluctuation wind direction (σ_θ) data to determine the Pasquill atmospheric diffusion stability categories, A=most unstable (most dispersive) to F=most stable (least dispersive).

At night the winds at 49 m are stronger and more laminar than wind lower in the atmosphere. Using data collected from 1991 to 1998, the USEPA scheme has been applied to the 10 and 49 m data from the meteorological tower at the LHSTC as shown in Table 3.2/19. With the USEPA scheme, the stronger wind speeds lead to a lower frequency of occurrence of the most stable Pasquill category F at 49m (2.9% overall) in comparison to the 10 m data (8.0%) where the winds are lighter.

3.2.3.7 Bushfire Weather

The risk of bushfire in the vicinity of the Reactor Facility increases during dry weather and peaks on days of high temperature, low humidity and strong winds. Use of appropriate fuel free and fuel reduced zones and fire fighting equipment minimise any hazard associated with bushfires.

3.2.3.8 Atmospheric Dispersion from the LHSTC and the Woronora Valley

Under highly stable atmospheric conditions, studies by Clark (1990, 1997) indicate that wind flow patterns in the Woronora valley are de-coupled from the flow on the plateau above. Recent studies of atmospheric dispersion from HIFAR (Clark, 1998) using atmospheric tracers confirm this observation. Atmospheric tracer gas was transported across the valley without significant entrainment into the valley flow. Hence, models to predict atmospheric dispersion under highly stable or inversion conditions and for flat terrain, remain satisfactory for approximating the transport of airborne materials from the LHSTC.

3.2.4 Surface Hydrology

The surface hydrology of the LHSTC is relevant to public safety because it forms a possible dispersion pathway of onsite material to drainage channels, creeks and rivers through surface runoff.

3.2.4.1 Dams and Near Surface Bores

There are no known private dams which could be fed by runoff from the area surrounding the LHSTC. The private dams and bores within a 10 km radius of LHSTC known to, and licensed by, the Department of Land and Water Conservation at August 1997 are listed below (Brodrick, 1997):

Dam adjacent to Railway line 1 km north of railway station at Heathcote (just east of line)

Small dam on tributary of Kangaroo Creek 2 km south of Heathcote railway station

Bore 7704, Portion 396, Parish Holsworthy (121.9 m deep)

Bore 7684, Portion 305, Parish Holsworthy (83.2 m deep)

Bore 10563, Portion 261, Parish Holsworthy (45.7 m deep)

Bore 16096, Portion 140, Parish Sutherland (76.5 m deep)

Bore 18433, Portion 99999, Parish Sutherland (198.1 m deep)

Bore 46782, Portion 124, Parish Holsworthy (30 m deep)

Because shallow bores did not have to be registered prior to 1955 there could be others in the area, which are not listed because the Department of Land and Water Conservation do not know them. The nearest major dam owned by a public utility is the Woronora Dam some 7 km south-east of the LHSTC. The public consumes water from the Woronora Dam.

In summary, neither of the two dams nor the groundwater bores listed is within a groundwater catchment that could be directly influenced by runoff from LHSTC and hence form a possible dispersion pathway.

3.2.4.2 General Topographical Environment

The general topographic environment is such that no part of the LHSTC is far removed from a natural drainage channel in the adjacent terrain.

The principal surface stream immediately adjacent to the LHSTC is the Woronora River, which has incised deeply into the sandstone terrain. It flows in a generally north-easterly direction from near the Woronora Dam and passes within about 2 km of the east of the site eventually to meet the Georges River estuary. Even during unusually dry periods, the river flows at the rate of several hundred thousand litres of water per day, fed by groundwater except during exceptionally hot periods when stream flow ceases because of evaporation losses. The river is tidal in its lower reaches and on either bank there are a number of small tributaries that have steep gradients where they join the river.

Recent data on flow rates in the Woronora River are available from Australian Water Technologies Pty. Ltd. (AWT, 1997), a trading arm of Sydney Water Corporation. AWT have had a gauging station on the Woronora River since May 1992 at a locality known as the Needles, (Station No.213211) which is situated East of LHSTC at a distance of about 1 km outside the ANSTO buffer zone boundary and downstream of LHSTC. The

AWT data (AWT, 1997) show a mean monthly discharge in megalitres per day for the period from mid 1992 to August 1997 in the range of 0.822 ML d^{-1} to 458.113 ML d^{-1} with an average discharge rate of 36.8 ML d^{-1}.

The northerly side of the LHSTC, located on a ridge, is drained by Mill and Bardens Creeks, which also empty into the Georges River estuary. The near-surface low-level waste disposal site, known as the Little Forest Burial Ground, which was operated by the then AAEC between 1960 and 1968, is located within the surface water catchment of Bardens Creek.

An examination of both Bardens and Mill Creeks shows that their stream courses have been actively eroded in recent times, exposing moderately unweathered rock in the creek beds, except near the surface water discharge point from the LHSTC, where kaolinitic sands are in evidence. The mean annual runoff draining from the Bardens and Mill Creek catchment into the Georges River estuary (which has en approximate area of 18.6 sq.km) is estimated at 7.7 x 10^8 litres (Mumme, 1972), which amounts to some 37% of the average annual precipitation falling on this catchment area.

Recent stream discharge data (Petrozzi, 1994) for Mill Creek, at the tidal limit point of the Georges River estuary, indicate a median discharge rate of 0.0216 m^3s^{-1} (6.5 x 10^8 L y^{-1}) with a range of 0.0061 - 0.9812 m^3 s^{-1} (1.92 x 10^8 - 3.1 x 10^{10} L y^{-1}).

Due to the topography of the LHSTC and the surrounding area, flooding of the Reactor Facility site due to external areas is virtually impossible. The Reactor Facility is located on the top of a ridge with a far higher elevation than the surrounding regions. Local creek and river systems have not come anywhere near the site even under the highest historically recorded flooding. Arrangements are in place to control local storm water and maintain water quality.

3.2.5 Geology, Soils and Groundwater Hydrology

This section discusses the surface geology and soil characteristics and ground water hydrology of the LHSTC site and its surrounds. It also provides a summary of the geotechnical investigations performed in 1998 and 2000.

The regional and local geology of the site of the Reactor Facility and the region is discussed in detail in geotechnical and geophysical studies undertaken by Coffey Partners International (Coffey, 1998b; 1998c). Information from these studies on the geology and soils of the site is summarised in the EIS Volume 3, Chapter 8. The following sections (from ANSTO, 1997 and 2000) describe the regional and LHSTC site geology.

3.2.5.1 Surface Geology and Soils

The LHSTC is situated on the dissected Woronora Plateau, a physiographic unit effectively drained by numerous creeks and rivers, which extends south from Sydney in a ramp like structure, the dominant rock formation being the Triassic age Hawkesbury Sandstone. The region forms a part of the Sydney Basin whose physiographic development, tectonic history and broad structure are summarised elsewhere (Taylor, 1923; David, 1950; Mumme, 1966; JGSA, 1969). A 1:100,000 scale map of the geology of a southern portion of the Sydney Basin which includes the area around LHSTC can be found in Sherwin and Holmes (Sherwin, 1986).

The predominant rock formation outcropping at Lucas Heights is medium to coarse quartzose sandstone, although significant minor components of dark grey shale, siltstone and fine sandstone/siltstone laminate are also present and make up about 5% of the total thickness of the formation. These shales and silt stones occur mainly as thin units interbedded with the sandstone, however there are some thicker units present such as at the Little Forest area, located at the northern boundary of the ANSTO buffer zone, which have been quarried for brick and tile making. A near-surface low level waste disposal site used by the then AAEC between 1960 and 1968 is located in a 5-10 m thick clay/shale lens at Little Forest.

The sandstone units of the Hawkesbury Sandstone Formation are composed of mainly medium-coarse quartz grains bound by a secondary quartz-siderite cement with a clay matrix of variable proportion which can completely infill the intergranular pore space. Standard (1969) estimated an average clay matrix of 20% and considers that rock fragments made up about 2% of the sandstone based on a thorough study of the petrology of the Hawkesbury Sandstone throughout its outcrop area. Bowman (1974) has noted that much of the clay matrix within the sandstone is altered rock fragments (clay pellets, siltstone and claystone) which he estimated formed 30-40% of the sandstone in the Illawarra area. The degree of clay matrix infilling is such that the intergranular permeability of the sandstone is very low. Standard (1969) reported that the clays are approximately 70% kaolinite and 20% illite and 10% mixed layer clays. Bowman (1974) has considered that the matrix is about 70% illite and 30% kaolinite, the reverse of Standard's figures, for the southern Sydney Basin which he regards is closer to the source area.

Unconfined compression tests show that the compression strength of the sandstone is 1.7×10^7 Pa with an average value around 2×10^7 Pa. Both massive and strongly crossbedded units of individual thickness in the range of 1.5 to 3 m are a common feature of the formation and the low regional dip of the sandstone is believed to be of the order of 19 m per km in northerly direction. Crossbreeding, ripple marks and brecciated zones are all important structures in the sandstone of the area.

In the Lucas Heights region, the Hawkesbury Sandstone is approximately 192 m thick (see graphic log of DM Camden 86 bore in HSD Fig. 2.4-1). The drilling information shows that at the LHSTC the Hawkesbury Sandstone rests on the Gosford formation. Recently, detailed information on the geology, hydrogeology, geophysical parameters and groundwater chemistry of the Hawkesbury Sandstone in the northwest sector of the ANSTO buffer zone has been gathered as a result of a major hydrogeological investigation of land leased from ANSTO by The Waste Recycling and Processing Service for use as part of the Regional Waste Disposal Depot. The investigation included the drilling of 31 seismic refraction surveys, slug, packer and pump tests and geological groundwater analyses (see Douglas, 1992).

Several sets of high angle (near vertical) well developed joints are apparent in the area. These joint sets are parallel and perpendicular to the two main regional fold axes, and are thus probably tensional features resulting from stress release after folding (Sherwin, 1986). Locally these joint sets strike at 030º and 130º, 005º and 110º, true meridian. Joint spacing is variable, ranging up to 10 m, but is commonly 1-3 m. Lateral continuity of joints up to 100 m is common, but vertical continuity rarely exceeds 20 m (Douglas, 1992).

The Hawkesbury Sandstone has been subject to laterisation and the depth of weathering can be highly variable. Weathering effects vary from superficial colour changes due to the presence of siderite oxidation, with no measurable effects on rock strength or other physical properties to complete loss of strength and disaggregation to sand. The degree of weathering experienced at a particular location is controlled by a number of factors, including the degree of silicification of the original sandstone, unit thickness and joint development.

Enhanced water access is provided by zones of closely spaced, well developed jointing, leading to deeper weathering. Weathering can extend to depths of up to 30 m and may take the form of pronounced "weathering troughs" (Douglas, 1992).

A narrow doleritic dyke some 4-5 km in length and with a strike of 20º (T), changing to 28º (T), is shown cropping out in the ANSTO buffer zone on the Wollongong – Port Hacking 1:100,000 scale geological sheet (Sherwin, 1986). The southern end of the dyke is shown located immediately west of the laboratory area while its northern extremity is shown just short of Mill Creek.

An extensive seepage zone adjacent to the surface water discharge point from the northern end of the LHSTC may represent a crush zone in the sandstone subsequently altered to seams and irregular masses of sandy clays by circulating waters and may, in fact, be related to the inferred fault zone located in the DM86 borehole. An alternative interpretation of the seepage zone is that local subsurface conditions are such that the downward percolation of meteoric water is hindered by a local retaining barrier of claystone/shale. Because the water is prevented from joining the main body of ground water, it spreads laterally, to escape at the surface as a spring which flows into Bardens Creek.

3.2.5.2 Groundwater Hydrology

This section on ground water hydrology discusses Reactor Facility, LHSTC and the buffer zone hydrology, as well as detailing the groundwater monitoring regime and some of the chemical and radiological findings.

3.2.5.2.1 RRR Hydrogeology

Geophysical and hydro-geological investigations of the RRR facility site were completed and the findings included in the EIS, Ch 8. The geophysical study was undertaken to provide information on the subsurface conditions and any structures that may influence groundwater in the region of the Reactor Facility site. The hydro-geological study comprised drilling at 5 locations on the site to a maximum depth of 45 metres, lithological logging, installation of deep and shallow piezometers, groundwater sampling, water analysis and single packer hydraulic parameter testing at three locations. The basic findings were that hydrogeological issues would not adversely affect the construction or operation of the Reactor Facility (Coffey, 1998a; 1998b).

In direct compliance with the Ministerial conditions arising from the EIS, ANSTO, through the consultant PPK Environment and Infrastructure, undertook an intensive baseline program of ground water monitoring which included both the Reactor Facility site and the surroundings of the rest of the LHSTC. This study included the drilling of shallow and deep piezometers (monitoring bores), down hole geophysical logs (gamma and conductivity) and resistivity imaging sections totalling 1220 m for 5 lines (PPK, 2000b). An initial ground water monitoring program was developed for the LHSTC site, including the Reactor Facility, based on a perimeter of seven shallow piezometers, six deep piezometers and two deep open boreholes for specialist down hole geophysics, permeability and groundwater flow velocity studies. The first phase of the program resulted in 15 new wells and use of 9 pre-existing wells on the site for the Reactor Facility. During 2001 – 2003 some of the monitoring wells on the RRR site had to be grouted and abandoned to make way for building construction. These RRR monitoring wells were replaced and additional monitoring wells were drilled on the LHSTC site to cover specific facilities. Details of this monitoring program upgrade are contained in the consolidated groundwater monitoring report compiled by Parsons Brinkerhoff (formerly PPK) and ANSTO (PB 2004, Fig 3.2/12).

Measurements made at the Reactor Facility site in June 1998 (Coffey, 1998a) reveal a shallow groundwater zone between 6 m and 10.7 m and a deeper regional zone between 12.4 m and 19.7 m below the surface. The shallow aquifer is transient (perched) and the result of heavy rain prior to water level measurement, with the flow probably toward the west and southwest to Melinga Molong creek. The deeper groundwater is assessed to flow in a north-westerly direction and eventually to the Georges River. The mean horizontal flow velocity is greater than 0.05 md^{-1} in the shallow aquifer and 1.2 l0^{-3} md^{-1} in the deeper aquifer. Figures 5 and 6 in Coffey 1998a give the groundwater contours at the site.

3.2.5.2.2 Lucas Heights Science and Technology Centre Groundwater Flow Regime

The principal water transmitting capability of the Hawkesbury Sandstone is dependent on the presence of secondary features such as joints and bedding planes. Depending upon local hydro-geological conditions, aquifers may be activated in apparently confined, unconfined or intermediate conditions, and water levels measured in boreholes may reflect local conditions and not give a true indication of regional hydraulic gradients.

Generally, the groundwater flow around the LHSTC is characterised by the local topography. LHSTC is situated on top of a gently north-sloping ridge. On the eastern side, several steep gullies drain into the Woronora River, and on the west are the shallow depressions forming the headwaters of Bardens and Mill creeks. A significant proportion of LHSTC has building and road cover, with the remainder covered by grass or sparse native vegetation. After heavy rain, the stormwater system accounts for surface flows from roads, buildings and surface drainage lines. Rain falling on the grassed and sparsely vegetated portion of LHSTC is absorbed into the soil. In the days following heavy rain, water seeps from the soil into the top of the gullies surrounding LHSTC. Discharge via the soil into the top of the gullies ceases after a few days. Discharge via a deeper groundwater path over a much slower time regime lower in the gullies ultimately forms the base-flow of the Woronora River. A rough comparison of the volumetric flow in the Woronora River a few days after rain compared to base-flow shows groundwater discharge to be dominated by discharge from the thin upper moist soil-regolith layer.

A basic three layer hydro-geological structure is suggested from the seismic refraction survey (Coffey, 1998a) consisting of:

a) a near surface soil and regolith layer, typically <2 m;

b) a weathered sandstone layer of variable thickness and degree of weathering, <1 m - <10m; and

c) an unweathered sandstone, >10 m.

The seismic refraction survey shows the degree of variability for these three layers, both in their thickness and also in their degree of definition. In places there is no clear distinction between these layers and a continuum of increasing seismic velocity with depth to a maximum of ~2,500 m/s exists. A similar but even more exaggerated pattern is expected for the hydraulic conductivity, because both the seismic velocity and hydraulic conductivity are correlated with the degree of consolidation (mineral aggregation or cementation by authigenic mineral growth) for these layers.

Deeper standing water levels in the sandstone aquifers are measured near the centre of the ridgeline and plateau, with slightly shallower standing water levels around the perimeter of the LHSTC. Some differentiation between shallow and deep zones is expected.

Hydraulic conductivity has been measured for 3 pairs of shallow – deep piezometers from the initial Coffey study of the Reactor Facility site, and 6 pairs of shallow - deep piezometers from the PPK LHSTC investigation. In both studies the shallow piezometers (screens ~6-9 m) correspond with the upper variably weathered sandstone layer, and the deep piezometers (screens ~20-25 m) correspond to the lower unweathered sandstone. For 8 of the 9 piezometer pairs, the shallow piezometer has a higher hydraulic conductivity than the deeper piezometer, by 1-2 orders of magnitude. No saturated hydraulic conductivity measurements of the soil layer were attempted because of the expected wide range of values for the soils on site, unsaturated flow for most soils and the difficulty in relating laboratory or field measurements of a single point to a wider representative area. However, textbook figures for saturated hydraulic conductivity in sandy soils show a likely range from 10^{-6} to 10^{-9} cm/sec and 10^{1} to 10^{-1} m/day. A comparative ranking of the hydraulic conductivity for the 3 layers is possible with some conversion of units to cm/sec:

Soil layer (10^{-6} - 10^{-9});

Weathered Sandstone (10^{-9} - 10^{-11}); and

Deep Sandstone (10^{-10} - 10^{-12}).

Inferred true groundwater velocities range from 0.02 my^{-1} to 7.36 my^{-1} (PPK, 2000b).

A conceptual model of the LHSTC site hydro-geological structure is one in which a thin highly permeable soil layer absorbs rain. Most of this water then rapidly drains laterally to the topographic lows at the heads of the gullies. Rainwater cannot effectively flow downward into the sandstone groundwater system because of the low hydraulic conductivity. The contrast in hydraulic conductivity between these layers forms an effective barrier to vertical flow. A schematic diagram of the groundwater flow is shown in Figure 3.2/13. A map of groundwater flow gradients and directions is found in Figures 3.2/14 and 3.2/15.

The 3 layer structure of the sandstone <30 m beneath LHSTC is an undifferentiated stratigraphic portion of the Hawkesbury Sandstone, not a separate stratigraphic unit called the Ashfield Shale. No stratigraphic influence is suggested by the use of the word aquifer to designate groundwater flow in these layers. Drilling logs confirm the general absence of shale layers in the top 25 m of the Hawkesbury Sandstone beneath LHSTC (Coffey, 1998, PPK, 2000b). Preferential groundwater flow paths along fractures and joints, also occurs within the upper sandstone layers (PPK, 2000b). Resistivity imaging geophysics (PPK 2000b) has detected some sparse discontinuities in the rock – water conductivity structure, which probably relates to the presence of fresh water along these joints.

There is significant variability in the occurrence and connection between shallow zones and deeper aquifers. The relationship between groundwater flow in fractures and groundwater flow in the porous sections of the Hawkesbury Sandstone is uncertain (PPK, 2000b).

Ultimately all groundwater in the Hawkesbury Sandstone is thought to discharge to either the Woronora River or the Georges River.

3.2.5.2.3 Groundwater Monitoring

The initial Coffey 1998 investigation of the RRR site constructed 5 pairs of shallow and deep monitoring wells, which were designated BH 1-5 for the shallow monitoring wells and BH 1a- 5a for the deeper wells. All of these monitoring wells, as well as the 7 pairs of monitoring wells installed by PPK, were used for the initial groundwater sampling in November 2000 for a total of 22 monitoring wells.

PPK (2000b) has completed a detailed baseline groundwater investigation for ANSTO at LHSTC. The work involved drilling to establish piezometers at seven sites, borehole logging and resistivity imaging surveys to visualise the subsurface, permeability testing, surveying, and data analysis and interpretation. Figure 3.2/12 shows the topography and final piezometer location map. Previous work on the site and adjoining sites was briefly reviewed and referenced.

A groundwater sampling plan and monitoring protocols has been developed for the site and is presented by PPK (2000b). The groundwater monitoring network was designed and constructed to establish baseline groundwater conditions and to determine the nature of groundwater migrating from the site. This network is used for monitoring during the operation of the Reactor Facility and annual reporting requirements for the whole LHSTC site.

The outcomes of this study address the approval conditions set by Environment Australia in the determination of the EIS for the new research reactor. This initial program confirmed the conceptual groundwater flow model for the site and provided a visualisation of the site conditions in the weathered zone and upper Hawkesbury Sandstone sequence.

The following conclusions have been drawn from this study and initial monitoring performed as part of baseline studies:

a) Groundwater occurs within a two aquifer system (an upper perched zone and lower aquifer), although deeper aquifers are also suspected.

b) Connection or definition of the two aquifers is variable across the site.

c) Groundwater flow within the shallow and deep aquifers beneath the LHSTC is a subdued reflection of the surface topography with groundwater flowing to the north, south and east away from the topographically high area. Figures 3.2/14 and 3.2/15 show the water table contours for the shallow perched zone and for the deeper aquifer respectively.

d) At most individual locations (especially those on the southern and eastern boundaries of the LHSTC), the deeper aquifer levels are lower than the perched zone suggesting this lower zone is draining to springs lower in the valley, or deeper aquifers.

e) There is potential for water in the shallow perched zone to percolate into the deeper sandstone profile in some cases (PPK, 2000b) on the northern boundary where the deeper water levels are higher than the perched water table.

f) Permeability testing and groundwater flow analysis suggests that the weathered zone and rock permeabilities are very low and have associated low flows and velocities.

g) The range of hydraulic conductivity values measured within the perched zone and deeper rock aquifer are similar, the mean values being 5.23 x 10-8 and 8.93 x 10-8 ms-1 respectively.

h) Inferred true groundwater velocities range from 0.02 m per year to 7.36 m per year. The groundwater movement rates do not respond significantly to heavy rainfall events.

i) Baseline geological and hydrogeological conditions were confirmed by the downhole geophysics and a resistivity imaging survey (see Figure 3.2/16).

j) High gamma counts recorded in a piezometer at 18 m and at 22-24.5 m were consistent with shale being recorded in the stratigraphic log. Large conductivity inflections measured in two piezometers, at 14.5 m and at 17.0 m (PPK, 2000b) suggest more saline groundwater perched on top of the shale lenses.

k) A number of anomalies were detailed in the resistivity imaging survey that may indicate potential fracture zones.

l) Four Dataflow pressure transducer and data logger assemblies were installed in four piezometers (PPK, 2000b), recording water levels on a two hourly basis to detect long and short term water table fluctuations in the shallow and deep aquifers. Data collected after the first 6 months operation show no change to the standing water levels, even after heavy rainfall periods.

m) Groundwater in the vicinity of the Reactor Facility and other areas of the sandstone plateau is slightly acidic. This lowering of pH is consistent with groundwater in similar geological areas where some clearing of land has been undertaken as part of development or bushfire activity. It is due to natural oxidation of sulphur bearing minerals within the underlying rock strata.

n) A groundwater monitoring plan was established (PPK, 2000b). Based on the findings of 12 months of baseline monitoring, the groundwater program, including monitoring and interpretation of the results, will continue throughout the operational life of the Reactor Facility.

Following release of the RRR building design, BH 4, 4a and 4b, and BH 5 and 5a were grouted and removed from the monitoring network, because they were within the building and facilities of the RRR along with BH 7, 8, 9, 10, and 11. The BH 7 – 11 series bores were not developed into monitoring wells for long term groundwater monitoring because of designed redundancy on the RRR building site. The existing geotechnical bores BH 102, 109 and 112 were developed into monitoring wells to maintain complete proximal spatial coverage around the RRR. An additional pair of monitoring wells, designated MW 8S and 8D, were installed on the northern side of B34 to compensate for the loss of MW 4S and 4D close to the swimming pool when the area was used for placement of fill from the RRR site. MW 8S and 8D are set amongst the trees away from large scale clearing and buildings, on a topographic high representing the undisturbed bush in the buffer zone. The total 23 monitoring wells were available for the August 2001 and December 2001 monitoring periods.

Further changes to the RRR building design in October 2001 necessitated abandonment of BH 1, 1a, 2, 2a, and BH 109 in December 2001. PPK has drilled additional bores and established monitoring wells adjacent to BH 102 for a complimentary shallow monitoring well, a new pair very close to the RRR sump MW15S & D, a shallow – deep pair approximately 30 m south of BH 1 and 1a (MW9S & D) as a replacement and a supplementary deep (~50 m) cored, open bore for detailed stratigraphic and geophysical logging (MW12).

In addition to completing the high density of monitoring wells on the RRR site, PPK have added additional monitoring wells immediately adjacent to B23 pond facility on the southern side of the building and close to the HIFAR foundation stone B40. These wells have added to the spatial coverage of existing facilities close to HIFAR. An additional monitoring well was installed on the ridge line in the centre of LHSTC at B21. The total number of monitoring wells available for monitoring at LHSTC was thus increased to 27 with 3 additional open holes for petrophysical and geophysical measurement (MW1, MW6, MW12).

3.2.5.2.4 Initial Groundwater Monitoring Chemical and Radiological Results

The National Water Quality Guidelines 2000 issued in August 2001 do not provide trigger values for receipt of potential contaminants into groundwater.

Groundwater has been sampled and chemically analysed from each of the monitoring piezometers constructed by Coffey Partners International 1998, or PPK 2000b, during 3 separate sampling periods November 2000, August 2001 and December 2001. Full results for each available monitoring piezometer are presented in the annual E – Report to ARPANSA (Environmental and Effluent Monitoring at ANSTO Sites).

3.2.5.2.4.1 Field Parameters

A first pass examination of field parameters shows significant variation in pH and Eh (ORP) with generally moderate to low electrical conductivities typical for dilute groundwaters. Closer examination reveals a pattern of more acid (pH ~3.5-4.0) and oxic water (Eh >250mV) in the deeper of the piezometer pairs. An interpretation is provided in the following section.

3.2.5.2.4.2 Nutrients and Hydrocarbons

No nutrient or hydrocarbon contamination from anthropogenic sources has been detected.

3.2.5.2.4.3 Radiological Analysis

The WHO reference level for tritium activity in drinking water is 7,800 Bq/L. Tritium concentration in LHSTC groundwater samples ranges between less than detection limit (without electrolysis) to a maximum of 251 Bq/L. Tritium concentrations found in the shallow piezometers are similar to or less than the LHSTC surface water background (MDP bund), with many of the deeper piezometers reporting levels less than detection limits without electrolytic concentration.

3.2.5.2.4.3.1 Gross alpha levels

All gross alpha levels are less than the NSW Clean Water Regulations value of 11.1 Bq/L. All but one of the samples (MW3D, 0.70 Bq/L) are below the WHO Drinking Water reference value for the most critical alpha emitter Ra-226 (0.5 Bq/L). The alpha emitting nuclides are derived from the natural uranium and thorium decay chains. Traces of uranium and thorium are found in most rocks, including the Hawkesbury Sandstone.

3.2.5.2.4.3.2 Gross beta emitters

All gross beta levels are less than the NSW Clean Water Regulations value of 11.1 Bq/L, and the WHO Drinking Water reference value for the nuclide Sr-90 (0.5 Bq/L).

The gamma spectrometry results for the filtered groundwater samples indicate statistically insignificant or very low levels of radioactivity at the limits of detection, with no evidence of anthropogenic radionuclides in any sample.

3.2.5.2.4.4 Major Ions and Trace Metals

No major ion or trace metal from an anthropogenic source has been detected.

3.2.5.2.5 Interpretation

A generalised interpretation of the groundwater chemistry needs to explain the unexpected finding of acid - oxic water in many of the deep piezometers, overlain by near neutral pH to more reducing Eh shallower groundwater. A likely scenario is that during construction of the major facilities at LHSTC, vegetation and soil was stripped from a large proportion of the site. This removal of much of the biological activity (plants, decaying humic material and soil bacteria) from the surface allowed oxygen to diffuse into the upper rock layers along with oxygenated rain - water under a changed recharge rate. The oxidising conditions caused trace pyrite in the sandstone to oxidise, resulting in acid sulphate water. Iron hydroxide may have precipitated in the pore spaces. After construction of the major buildings was complete and the reactor commissioned in 1958, a generally open grassed landscape was constructed between the buildings. The new landscape with either building cover or biological activity in the soil changed the groundwater chemistry back to a more reducing condition, with higher pH's. The acid – oxic groundwater now detected in the deeper piezometers has migrated less than 20m vertically in the intervening 45 years. Most of the deeper piezometers will draw water from anywhere beneath the bentonite seal, which is often between 15-18m beneath the surface.

Tritium from local rainwater in the vicinity of LHSTC since reactor commissioning has typically migrated only as far as the shallow piezometers - generally less than 10 m. The background tritium concentration in Sydney rainfall is approximately 3-4 TU (1TU = 0.119 Bq/L). Any LHSTC groundwater value greater than this value is assumed to be due to a local contribution from HIFAR. Values less than 0.3 Bq/L may include a variable mixture with water > 45 yrs old. An approximate maximum vertical flow rate of < 0.35 m/yr is estimated.

Further evidence for this subsurface flow regime dominated by lateral flow in the soil layer is provided by comparison of 2 existing surface water environmental monitoring points, MDP Bund and MDP +60m. The first of these monitoring points samples water collected in the MDP drainage bund close to waste management facilities and MW 6S and 6D groundwater piezometers, representing rainfall or soil water. The second monitoring point MDP +60 m is 60 m down a drainage line from MDP Bund. It samples water in a shallow pool below a rock ledge at the head of a steep gully. There is no apparent surface water flow between the two monitoring points, yet water can often be seen seeping from the rock ledge above the pool, and flowing after rainfall. An interpretation is MDP +60 m samples the water emerging from the rapid drainage of the soil layer into the head of a gully where the less permeable sandstone is exposed. There is no soil at MDP +60 m through which the water can flow. Comparison of monitoring results shows both sample points have virtually identical tritium levels, which vary significantly in synchrony with each other. Therefore, these sampling points are measuring the same parcels of water, with only a minimal time delay, possibly of less than a week. The tritium labelled water confirms the observed flow patterns of seepage into the heads of the gullies surrounding the LHSTC for several days after heavy rain.

Details of this monitoring program upgrade are contained in the consolidated groundwater monitoring report compiled by Parsons Brinkerhoff (formerly PPK) and ANSTO (PB 2004, Fig 3.2/12).

3.2.5.2.6 Buffer Zone Hydrogeology

Historically, standing groundwater levels are known for the area north of the laboratories in the Lucas Heights Waste Depot area and at the Little Forest Burial Ground. Groundwater levels in the 31 boreholes located in the Waste Depot area range from less than 1 m to 26 m below the ground surface (Douglas & Partners and Coffey Partners International, 1992). The overall hydraulic gradient is to the north, although locally the gradient is strongly influenced by structural and topographic features. The values of hydraulic conductivity and section transmissivity measured by packer tests, pumping tests and flow tests show considerable variability although a clear pattern was established. Values at the upper end of the packer test range (about 6 m^2d^{-1}) would appear appropriate to assess overall flow velocities for the fractured zone sandstone. Outside the Mill Creek fracture zone transmissivities are much lower, in the range 0.1 to 3 m^2d^{-1} with most below 1 m^2d^{-1}. Based on tritium isotope concentration testing it has been concluded that deep water in the aquifer, probably originated in rainfall prior to the 1950's i.e. before the testing of thermonuclear weapons in the early 1960's. Taking this residence time and possible flow paths it is calculated that flow velocities within the aquifer must be no greater than 0.035 - 0.14 md^{-1} (Douglas & Partners and Coffey Partners International, 1992).

Standing water levels at the Little Forest Burial Ground vary directly with rainfall and generally range from less than 1 m to about 4 m below the surface, where a perched water-table occurs on top of a grey shale lens. In-situ hydraulic conductivity measurements carried out on the clay/shales have a range of 0.001 to 0.13 md^{-1} (Isaacs & Mears, 1977)

Close to the Woronora River, the ground water level will fluctuate sympathetically with the level of water in the river. This sympathetic variation probably extends some 30 m from the centre of the river into the jointed sandstone. Further away from the river, the ground water level should only show a small response to the effects of rainfall. As scattered claystone and shale bands occur in the Hawkesbury Sandstone formation, there are probably a number of local sub-surface conditions where a portion of the downward percolating ground water is held back by these low permeability barriers.

3.2.5.3 Summary of Geotechnical Investigations Results

This section presents the results of a geotechnical investigation carried out by Coffey Partners International Pty (Coffey) for ANSTO in June, 1998 and some related results of the investigation carried out by PPK in August, 2000. Details are provided in Coffey (1998c) and PPK (2000b).

3.2.5.3.1 Field Work

3.2.5.3.1.1 Drilling and Sampling

Field work comprised the drilling of six boreholes (BH6 to BH11). Boreholes BH1 to BH5 were drilled for a separate hydrogeological study. The materials encountered in the boreholes were logged and the rock core was boxed on site. In addition to the six boreholes, geotechnical logging of boreholes BH1 and BH5 form the hydrogeological study was also carried out. The engineering logs of the cored boreholes, sheets giving the descriptive terms and symbols used in their preparation, and colour photographs of the recovered core are presented in Appendix A of Coffey, 1998c.

Borehole depths and collar elevations are listed in Table 3.2/22. Borehole locations were determined by tape measurements from existing features, as shown in Figure 3.2/17.

3.2.5.3.1.2 Vertical Seismic Shear Wave Testing

In addition to the work done as indicated in the previous section, four boreholes BH6, 8, 10, and 11 were enlarged with a down hole rock hammer to a diameter of about 11 mm for Vertical Seismic Shear Wave Profiling to be carried out.

3.2.5.3.2 Site Conditions

3.2.5.3.2.1 Subsurface Conditions Encountered

The subsurface conditions encountered in the boreholes indicate the site is generally characterised by a layer of residual soil (except BH6), which overlies weathered sandstone bedrock. BH6 had been topped by fill.

3.2.5.3.2.2 Groundwater Levels

Groundwater was not encountered within the depth of auger drilling, and was not observed at greater depths during drilling due to the use of water as a drilling fluid, which masks the presence of any natural inflows.

The water levels measured in the six cored boreholes a day after completion of each borehole were as indicated in Table 3.2/23.

3.2.5.3.3 Discussions and Recommendations

3.2.5.3.3.1 Geotechnical Model

Based on the conditions encountered during the field work, a geotechnical model has been developed, and is presented in Table 3.2/24. Figures 3.2/18, 3.2/19 and 3.2/20 present inferred cross-sections through the site (see Figure 3.2/17) showing the relationship between the units of the geotechnical model (the two first cross sections by Coffey and the third one by PPK).

The subsurface profile across the site can be generalised as follows:

a) Topsoil: All boreholes, except borehole BH6, intercepted a layer of topsoil of 0.15 to 0.30 m thick. The topsoil comprises clayey sand with root fibres, roots with a trace of organic odour.

b) Fill: A 1.0 m thick layer of clayey sand fill was encountered in borehole BH6. The fill comprises ripped sandstone fragments, broken tile pieces, roots and root fibres and leaves. The distribution of this nature of fill suggests some cut to fill operations may have been carried out adjacent to the existing higher concrete slab.

c) Residual Soil: Residual soil represents the weathering product of the underlying sandstone and was encountered in boreholes BH7 to BH11. The thickness of the residual soil varied from 0.50 m in BH6 to 1.05 in BH7, and can be described as Clayey Sand in a medium dense condition.

d) Weathered Bedrock: Underlying the fill in BH6, and residual soil in other boreholes is a weathered sandstone profile. Extremely weathered sandstone, generally medium grained, was encountered at depths ranging from 0.5 m in BH1 to 1.5 m in BH9, and was logged as Clayey Sand/Sandy Clay due to its exhibition of soil properties. The extremely weathered sandstone is underlain by highly weathered to slightly weathered sandstone, medium grained, with rock strength ranging from low to high strength, and characterised with numerous weathered and clay seams. The thickness of this sandstone layer appears to be about 0.0 m to 2.5 m. At depths below about 2 m to 5.5 m the sandstone grades to moderately weathered to slightly weathered, medium to high strength, fractured to slightly fractured, medium to coarse grained. Some minor bands of weaker rock, however, do exist, as well as the presence of high strength ironstone bands.

3.2.5.3.3.2 Rock Classification

Cored boreholes have been classified using the Sydney rock mass classification system described in Pells, 1978. This classification system is based in the following parameters:

Rock strength

Degree of fracturing

Proportion of defects, including low strength seams, crushed zones, or extremely weathered bands

The resulting classification of the sandstone into two discrete units is summarised in Table 3.2/25.

3.2.5.3.3.3 Results and Interpretation of Vertical Seismic Shear Wave Profile Study

A vertical Seismic Shear Wave Study was carried out at the site. The objectives of this study were to provide soil parameters for Compressional (P) and horizontally polarised Shear (S) wave seismic velocities and the location of elastic interfaces to assist the assessment of foundation conditions at the site.

The objective of the vertical seismic shear profiling was to provide dynamic shear modulus values to assist in the assessment of foundation design.

The vertical seismic shear profiling was completed in all 4 holes over the depth interval 3 m to 14 m.

The arrival times of the P and S waves to each downhole detector position were accurately measured from computer displays of individual seismic traces. For the S-waves, the two records used were obtained from impacting both ends of the plant resulting in S-waves of opposite polarisation.

After correction for the source-offset distances, the times measured were used to compute average seismic velocities over various intervals. The vertical seismic (P and S waves) profiles obtained at borehole BH8, which is located at the reactor position, are shown in Figure 3.2/21.

These velocities allowed the dynamic shear modulus, Young's modulus and Poisson's ratio to be computed assuming a material density of 22 to 24 kNm^{-3} which is believed appropriate for the materials present. These results are listed in Table 3.2/26.

Three layers have been identified from the vertical seismic profiling. The upper layers (0 – 3 m depth) was determined using the travel time to the detectors at 3 m depth.

3.2.5.3.3.4 Rock Properties

1. Unconfined Compressive Strength and Point Load Strength

   The strength of the rock encountered has been assessed from the available point load test data, which are summarised on the borehole logs. Figure 3.2/22 shows the borehole log for BH8. It has been found in Pells, 1985 that the unconfined compressive strength of the Hawkesbury Sandstone is typically about 15 to 30 times the point load strength index ($I_{s(50)}$).

   In addition, six direct measurements of unconfined compressive strength were conducted on core samples from BH6 to BH11. The results are compared against axial point load strength in Appendix B of Coffey 1998c, and confirm the approximate correlation of between 15 and 30 times $I_{s(50)}$. In general, the point load strength index and unconfined compressive strength test results indicate the UNIT

4A (Table 3.2/24) sandstone to be of low to medium strength with local very low strength bands, while UNIT 4B (Table 3.2/24) is generally medium to high strength.

Of the six unconfined compressive strength tests carried out, three gave a range of 8.7 to 13.3 MPa and three gave a range of 30.2 to 45.5 MPa.

2. Defect Spacing and Weathering

   UNIT 4A (Table 3.2/24) generally comprises sandstone of highly to moderately weathered. Various clay seams are also present within this unit with the predominant spacing between 0.03 and 0.1 m.

   UNIT 4B (Table 3.2/24) is generally moderately to slightly weathered sandstone, with some fractured zone and/or weathered clay seams. Defect spacing for this unit varies from about 0.1 to 1.0 m.

   It should be pointed out that the weathering of Hawkesbury Sandstone can often produce ironstone bands which have high to very high strength, even though it may be described as highly weathered due to chemical discoloration.

3. Dynamic Shear Modulus.

   The results of Dynamic Shear Modulus derived from the vertical seismic shear profiling testing indicate the profile shown in Table 3.2/27.

   The exception to the Table 3.2/27 generalised profile is borehole BH8, where the rock above and below 5 m was inferred to have a dynamic shear modulus of 320 MPa and greater than 3400 MPa respectively.

   It should also be pointed out that the appropriate design dynamic shear modulus is strain level dependent. The values given in Table 3.2/27 are applicable for very low strain levels (i.e. less than 0.01%). Reduction of the design dynamic shear modulus in an alternative manner may be required depending on the resulting strain level in the dynamic analysis of foundations.

4. Seismic Velocity

   Attempt has been made to compare the interpreted seismic section against some of the borehole information from the current site investigation.

   The comparison shows UNIT 4A generally has a seismic velocity of 1200 to 1800 m/s with the higher strength, greater defect spacing UNIT 4B having a seismic velocity of 1950 to 2550 m/s.

3.2.5.3.3.5 Rock Class Bearing Parameters

The anticipated rock class and allowable bearing pressures for the various stratigraphic units discussed are given in Table 3.2/28 in accordance with Pells, 1978.

3.2.5.3.3.6 Erosion Potential

The Emerson laboratory tests consistently results in Class 3, 5 and 6 classification (Class 1 is highly dispersive, while Class 8 is non-dispersive).

3.2.5.3.3.7 Site Factors Earthquake

The Australian Standard on earthquake loads has been referred to when considering the site factors for earthquake for the different structures associated with the Reactor Facility.

The Reactor Facility is considered as a special structure which requires special consideration and is not covered by the Australian Standard. Those considerations and additional studies are given in the following Section.

3.2.6 Seismology

This Section provides information on the seismological characteristics of the Reactor Facility site. This information is based on earlier work that was undertaken to characterise seismic hazard and on the reassessment of the seismic hazard curve applicable to the LHSTC site commissioned by the Department of Industry, Science and Resources (IGNS, 1999) and by ANSTO (2002).

3.2.6.1 Background

The LHSTC is located on a sandstone plateau in the Sydney Basin. Figure 3.2/23, the current earthquake hazard map of south-eastern Australia (SAA, 1993), shows the Sydney Basin to lie in a low intensity seismic zone. While there are a number of geological features in the Sydney Basin indicative of past earthquake activity, no seismically active geological structures have been identified, and there are no major faults within 35 km of LHSTC. From a global tectonics perspective Australia is regarded as an intraplate setting, thousands of kilometres from an active plate boundary.

The Reactor Facility site is characterised by a thin cover of weak, unconsolidated residual soil and colluvium overlying middle Triassic (c. 220 million years old), Hawkesbury sandstone, a strong, horizontally- or cross-bedded, quartzose sandstone. The seismic velocity of the weathered upper few metres is in the range 350-950 m/sec, and below this the rock has a seismic velocity that has been measured at 1950-2600 m/sec (Coffey Partners, 1998c). Thus, the site can be described as a rock site from an earthquake ground motion hazard perspective.

The Sydney basin contains up to 5 km thickness of Permian and Mesozoic, terrestrial and marine sedimentary rocks. These rocks rest uncomfortably on Paleozoic rocks that are much more deformed. At the western margin of the Sydney basin, which extends northward from Bateman's Bay (Figure 3.2/24), Permian coal measures lap onto the Paleozoic rocks of the Lachlan Fold Belt. The northeast margin of the Sydney basin is defined by the faulted contact of Sydney basin rocks against Paleozoic rocks of the New England fold belt along the Mooki-Hunter thrust fault (Figure 3.2/24). The Hunter Valley Dome belt, expressed in the early stage Permian rocks of the Sydney basin forms a zone along the southwest side of the Mooki-Hunter thrust fault, and it was probably on one of these structures that the Newcastle earthquake of 1989 occurred. Offshore, a Paleozoic basement ridge runs parallel to the coastline (Figure 3.2/25), across which there is a much thinner section of Sydney basin rocks. Landward dipping Triassic rocks along coastal sections may be evidence of some continued uplift of this basement high during and after deposition of the Mesozoic-age Sydney basin rocks.

Sydney Basin sedimentary rocks consist of non-marine coal measures grading up into Triassic and possibly early Jurassic terrestrial and estuarine sandstone and siltstone (Herbert, 1980). The absence of younger Mesozoic rocks is attributed by Ollier (1982) to erosion induced by uplift and doming as a precursor to the opening of the Tasman Sea about 83 to 53 million years ago (Sdrolias, 2001). Thin Tertiary-age rocks occur within the Sydney Basin, most notably in the Penrith Basin adjacent to the Lapstone Structural Complex (LSC) (Mauger, 1984) where several tens of metres of conglomerate, sand and clay represent ancient fluvial terrace and overbank flood deposits. Fan deposits are also locally significant along the LSC. In the coastal area, a significant thickness of estuarine and shallow marine deposits accumulated on the continental shelf during fluctuating

Quaternary sea levels during the last c. 1.6 million years. At the coast, the height of Last Interglacial (c.125,000 years ago) marine deposits are about the same elevation above present sea level as at their time of formation, indicating vertical tectonic stability in coastal areas (Murray-Wallace & Belperio, 1991).

Basin rocks thin to the west from a maximum known thickness of 5000 to 6000 m at the edge of the continental shelf (Mayne et al., 1974). In the metropolitan Sydney region basin fill is typically 2200-3000 m thick. Data from a borehole sunk in 1965 near the main gate of the ANSTO facility at Lucas Heights indicates that the RRR site is underlain by 194 m of the Middle Triassic (c. 225 million years in age) Hawkesbury Sandstone formation, which overlies a further 458 m of interbedded sandstones and claystones of the Triassic Narrabeen Group. These Triassic sedimentary strata are in turn underlain by at least 884 m of Permian rocks. Data from the 1:100,000 Wollongong-Port Hacking Geological Sheet (Sherwin & Holmes, 1986) indicate that Permian rocks, which consist of coal, clastic and volcanic units, are approximately 1200-1500 m thick beneath the RRR site.

The main rock unit cropping out in the region of Lucas Heights is the Hawkesbury Sandstone formation (Sherwin & Holmes, 1986). The Hawkesbury Sandstone typically consists of medium to coarse-grained quartzose sandstone, with minor shale and laminated fine sandstone and mudstone beds. Sandstone beds are well indurated and commonly cross-bedded or horizontally bedded. This formation is interpreted to have been deposited in an extensive braided fluvial system (e.g., Herbert, 1980).

3.2.6.2 Igneous Dykes

Igneous intrusive rocks are widespread in the greater Sydney region (Rickwood, 1985). Within the Sydney Basin basic dykes are common and typically strike northwest-southeast. The dykes are commonly steeply dipping, range in thickness from a centimetre to six metres and are usually deeply weathered near the surface. The dykes recognised on the RRR site typically trend to the north-northeast. Dykes were intruded into Sydney Basin strata during two main periods at 207-163 and 58-26 million years before present (e.g., Rickwood, 1985) but some are as young as 18.8 million years.

3.2.6.3 Geological structures

Rocks of the Sydney Basin have been weakly deformed by a series of tectonic events. Typical fault displacements are less than 15 m but occasional displacements of up to 100 m and bed dips of < 5° have been reported. On a regional scale this deformation is manifest as a number of plateaux separated by monoclines (Bembrick et al., 1980).

The Lapstone Structural Complex is a prominent tectonic and physiographic feature of the Sydney Basin. It consists of a number of related folds and faults, tending generally north-south, coincident with the eastern margin of the Blue Mountains. It is located about 60 km west of Sydney and 35 km west of Lucas Heights. The complex is more than 100km long and generally about 2 to 5 km wide. The complex incorporates a number of named structures, including the Nepean, Glenbrook, Kurrajong and Burralow faults. It is apparent that the Lapstone Structural Complex has had a long history with early deformation clearly influencing sedimentation within the Sydney Basin. It forms a boundary between two regions that have been subjected to a much lower level of tectonic activity.

The complex has been examined in some detail both by mapping and by seismic reflection surveys. Deformation has been by both folding and faulting, but different investigations have placed a range of interpretations on the relative contributions of folding and faulting (Herbert, 1988). It is often difficult to determine the throw of faults due to the absence of key horizons in the Hawkesbury Sandstone.

Analysis of seismic survey results over a 55 km long segment of the complex north of Picton by Herbert (1988) indicates a maximum displacement of 100 m in any individual fault plane, with displacements being generally less than 60 metres. Where the complex has been mapped in detail, these faults (and others located in the lower Blue Mountains such as the Oakdale Fault) appear to consist of relatively short parallel and sub-parallel segments. Displacement along each fault decreases rapidly towards each extremity.

There is a general consensus concerning the timing of major structural events in the Sydney Basin, although there is a degree of ongoing debate about the relative importance of these events in determining the current structure and ongoing tectonic activity. The main item of debate is whether the Triassic (250-205 million years) or Late Cretaceous (80-60 million years) periods of tectonic activity had the most impact. The consensus is that the earlier (Triassic) structures were the loci for later, larger deformations, which took place at the end of the Cretaceous with the opening of the Tasman Sea. Since that time, variable periods of extension and compression have been reflected in warping and episodic fault reactivation. Changes in the relative behaviour of the underlying basement and the Sydney Basin rocks to east-west compression have caused episodic fault reactivation. Offset by the Kurrajong fault of an early Miocene basalt dated at 18.8 million years (Wellman & McDougall, 1974) may indicate no more than a few tens of metres of displacement in this time. No Quaternary age fault scarps have been identified along the structure.

There has been a considerable amount of geological and geophysical investigation in the area between the Lapstone Structural Complex and the coast, related to coal and gas exploration. These investigations have found no evidence of similar zones to the Lapstone complex to the east towards Lucas Heights. These investigations indicate that Lucas Heights is located in a zone dominated by low amplitude folding and normal faults. Thus, the LSC is located in a different tectonic domain from the RRR site, which is in a domain in which structures mainly formed during opening of the Tasman Sea.

3.2.6.4 Fault data in the Sydney region

Faults with throws of up to 100 m are observed throughout the Sydney Basin. These faults typically have steep dips (>60°) and typically strike to the northwest (c. 315°) and the north-northeast (c. 010°) (e.g., Bowman, 1974; Shepherd & Huntington, 1981; Norman & Creasey, 1985; Sherwin & Holmes, 1986; Lohe et al., 1992; Memarian & Fergusson, 1994; Creasey & Huntington, 1985). Fault sets that strike northeast (c. 040°), east (c. 090°) and west-northwest (c. 290°) are also present but in numerical terms are of secondary importance on a regional scale.

Detailed analysis of faults from the Southern Coalfield (south of the RRR site) and from tunnels excavated within Hawkesbury Sandstone (north of the RRR site) indicate predominantly net normal fault displacements on two main sets which strike approximately northwest and north to north-northeast. In addition, some northwest striking faults appear to have experienced late-stage strike slip movements. The northwest striking faults are regional structures with typical trace lengths of 5 to >10 km and maximum apparent throws of 25 to 90 m (Lohe et al., 1992). By contrast there is a tendency for faults striking north-northeast to have displacements of less than 15 m. Therefore, in displacement terms northwest striking faults form the dominant set.

The Southern Coalfield encompasses the southern section of the Sydney Basin south of Botany Bay. Fault data in this region were derived from coalmine plans on the top of the Bulli Seam. The Wollongong – Port Hacking 1:100,000 Geological Sheet, which includes the RRR site, shows that there is a tendency for faults striking north-northeast to have displacements of less than 15m, whereas faults striking west-northwest and northwest can locally reach 100 m in displacement (Sherwin, 1986). The northwest striking faults appear to have accommodated the highest displacements and can be regarded to be the dominant structures in the Southern Coalfield.

Some of the most complete fault data in the Sydney region are from tunnels that, on the scale of the basin, produce one-dimensional samples of the fault population. Data were examined from six tunnels located north of the RRR site and trending in east-west (five tunnels) and north-south (one tunnel) directions. A total of 133 faults were recorded in all tunnels with the main fault strikes being approximately north to northeast and northwest. Approximately 128 of the faults have net normal displacement and only 5 faults appear to have reverse displacement. Displacements range up to 9 m with most faults (n=110) having ≤1 m. From our treatment of clustered faults and using the spacing of faults independent of their strike we calculate an average normal fault spacing of c. 140 m. This value increases to 175 m if we consider only faults with a north to northeast strike and increases to 250 m for faults with northwest strike when the obliquity between the tunnel trend and fault strike is accounted for. These results appear to be independent of tunnel trend.

Within the coastal zone some faults appear to have experienced several phases of movement. In some cases fault-slip directions appear to have been reversed resulting in inversion of the net displacement direction. This inversion typically occurs where early normal faults experienced late-stage reverse faulting (Shepherd, 1981, Norman, 1985, Lohe, 1992, Shepherd, 2002). The timing of these episodes of faulting is poorly constrained. Many normal faults and dyke systems are inferred to have formed during extension associated with rifting of the Tasman Sea at 83-53 million years before present (Sdrolias, 2001). If this is the case then shortening and reverse faults, which typically post-date normal faulting, have been active in the past 53 million years. The upper part of the sedimentary section, presumed to be Tertiary in age is not significantly disrupted by faulting (Colwell, 1993) which suggests that the majority of faulting observed in Mesozoic strata predate formation of these Tertiary rocks. Reactivation of N-NE striking normal faults as reverse faults would be consistent with the subsequent east-west contraction (Denham et al., 1981; Denham & Windsor, 1991).

3.2.6.5 Near Field Study

Following a recommendation of the IAEA peer review and a request from ARPANSA, a near field study was undertaken to characterise the area out to 5 km (Nicol et al, 2002). Fault and lineament data, compiled from rock exposures (i.e. road cuttings, natural exposures along tributaries of the Woronora River, and quarry walls) were examined in the area up to 5 km from the RRR site. Existing data were compiled from Sherwin & Holmes (1986) and from available Coffey's reports. Fieldwork was carried out following completion of the desk study that included an aerial photographic interpretation of available colour aerial photographs.

The rock exposure, access to these rocks and topographic relief are variable. Despite sampling problems introduced by this variability, three faults were located. Occupying approximately one half of this area, and located to the west of Heathcote Road and the Woronora River, is the undeveloped natural bushland of the Holsworthy Army Reserve, approximately half of which is designated as a "No Go Area" due to the possible presence of unexploded ordnances. The topography of this area is characterised by deeply incised creeks, located between gently sloping ridge areas that are often accessible by four wheel drive tracks.

The eastern approximate quarter of the study area, generally to the east of the Woronora River and west of the Illawarra Railway on more gently sloping land, has been extensively developed for residential purposes.

The remaining quarter of the study area, bounded by Heathcote Road to the west and New Illawarra Road to the east, consists of a number of former quarries, the extensive Lucas Heights Landfill site, and areas of both partially developed and undeveloped bushland.

Three igneous dykes are shown on the 1:100,000 Wollongong-Port Hacking Geological Sheet to the west and north of the RRR site, striking north-northeast. The dyke closest to the RRR site is approximately 200 m to the west of it and strikes 013° with a trace length of 1.2 km. The location and existence of this dyke was confirmed by trenching up to 200 m west of the site. A second dyke is located 2.3 km to the north, strikes approximately 025° and extends over a length of 2.8 km. The third dyke is 2.5 km to the northwest of the site, strikes at 020° and has a trace length of approximately 1 km.

No faults are recorded on the 1:100,000 Wollongong-Port Hacking Geological Sheet within a 5 km radius of the RRR site. Geological investigations at the RRR site and immediately surrounding region clearly demonstrate, however, that faults with throws of at least 1 m exist but were not recorded on the map. These faults are too small to be routinely detected and mapped at a 1:100 000 scale.

3.2.6.6 Observed Faults

The field investigations of a number of identified areas did not reveal the presence of faults where surficial materials were preserved. Therefore, it was not possible to constrain the timing of the most-recent movement. Three minor faults in weathered rock, with vertical displacements of less than approximately 0.3m were observed at three locations within the study area.

During the fieldwork for this 5 km study, close attention was given to locating possible exposures of a dyke reported some 200 m west and to the north of the RRR site to examine the possibility that dyke emplacement may have occurred in the path of a previous fault. However, no exposures of the dyke were observed at that time. Later investigations found dykes on the reactor site, west of the footprint for the reactor building.

3.2.6.7 Site Study

Following the commencement of Reactor Facility excavations, detailed geological mapping of the RRR site led to the identification, measurement and analysis of two main fault strands in bedrock exposures on the RRR site (Figure 3.2/26). These generally strike to the north-northeast (000-020°), dip steeply (mostly 65-80° east and west) and have dip separations of c. 1-1.3 m (the eastern strand) and c. 0.20-0.32 m (the western strand). Some smaller faults were found clustered around these dominant structures.

In net displacement terms, the eastern fault strand was an apparent normal fault and was the dominant fault trace observed at the RRR site. The fault extended for at least 140 m across the construction site in a north-northeast direction (mean strike 013°) and dipped steeply to the east (mean dip 67°). Within the area comprising the footprint for the Reactor Building, the fault had a constant dip separation of c. 1-1.3 m up through the rock sequence and across the excavation. The western fault strand was the second largest faulting trace observed at the construction site and had apparent displacement in an opposite direction to the normal fault. This fault trace extended for at least 120 m across the site in a north-northeast direction (mean strike 009°) and dipped steeply to the east. The two main fault strands converged in the northern part of the construction site to form a single fault zone.

Following detailed assessment by a number of world experts (ANSTO, 2002), the last movement on the western fault was determined as being at least 5-13 million years ago, consistent with the thermochronology results of 10-35 million years old, and possibly as old as the Tasman Sea opening of 53-83 million years old. Thus the faults are not potential seismic sources and do not pose a surface-fault rupture hazard.

3.2.6.8 Seismic Hazard Analysis

The seismic hazard existing at a particular place can be considered as being composed of two parts: the Peak Horizontal Ground Acceleration (PHGA) and the associated frequency spectrum. The PHGA is the maximum acceleration determined from an accelerogram. The frequency spectrum is the spectrum obtained from a Fourier transform of the accelerogram and describes accelerations as function of either excitation frequency or its inverse, spectral period.

Deterministic or probabilistic methods can be used to assess the seismic hazard. Deterministic methods tend to be used where good data exists regarding local seismogenic structures. Probabilistic methods tend to be used in order to provide an insight into the uncertainties with the prediction.

The assessment of the PHGA depends upon a number of factors including the earthquake magnitude relationship, the maximum earthquake magnitude considered credible, the attenuation characteristics of the ground and the depth of the focus.

3.2.6.8.1 Previous Studies

The seismic hazard at Lucas Heights has been assessed by various authors and organisations including Mumme (1976), the Bureau of Mineral Resources (1989, now the Australian Geological Survey Organisation or AGSO), and the Department of Transport and Construction (1982). In 1995, Corran reviewed and compiled much of this information into a single report and proposed a seismic hazard curve (best estimate and upper bound). The SL-2 or SSE for the HIFAR reactor had been previously determined in consultation with the then Nuclear Safety Bureau (now ARPANSA) as 0.20 g PHGA, although HIFAR Engineering have in recent times worked to a level of 0.23 g. This was consistent with the seismic hazard assessed by Corran as 0.17 g with an uncertainty of ±0.06 g. The response spectrum utilised was based on that for Carbon Canyon.

When PLG (PLG, 1998) undertook the PSA of HIFAR in 1998, they commented that the seismic hazard curve quoted in Corran (1995) had a low uncertainty band. As a result of this they recommended that ANSTO have the seismic hazard, and in particular, its associated uncertainty, reassessed. For the purpose of the HIFAR PSA, PLG broadened the standard deviation. This resulted in an increase in the mean value to about 0.24 g and the 85% value to 0.34 g.

Following this recommendation the Department of Industry, Science and Resources (DISR), contracted the Institute of Geological and Nuclear Sciences (IGNS) to perform a Probabilistic Seismic Hazard Analysis of the Lucas Heights site. The purpose of the Probabilistic Seismic Hazard Analysis was to determine the strength and recurrence of earthquake-induced ground shaking and its associated spectrum. This analysis included a review of the earthquake ground shaking hazard at Lucas Heights using best international practice as determined from a review of current US and international procedures (IGNS, 1999).

The study utilised the most complete computer catalogue of New South Wales earthquakes; that is maintained by the Australian Seismological Centre. That catalogue was modified and extended for this study, particularly for earthquakes before 1900. The seismic source model used in this study was based on regional geology then modified considering distribution and rate of historical seismicity. Source zones corresponding to the Sydney Basin, the Lachlan Fold Belt and the New England Fold Belt were defined. These were then divided into five zones based on seismicity. The outcomes from the study were predicted mean peak ground accelerations and response spectral accelerations for a range of return periods. IGNS considered a response spectrum based on the Loma Prieta earthquake to be the most applicable.

An extension to that seismic hazard analysis was undertaken for ARPANSA by IGNS to address issues raised in local and international reviews of the IGNS (1999). The report on this additional work (Stirling, 2001) provided modified predicted mean peak ground accelerations and response spectral accelerations for a range of return periods. The study recommended a mean peak horizontal ground acceleration of 0.37 g for the 10,000 year return period earthquake with the response spectrum based on the Loma Prieta earthquake.

3.2.6.8.2 Controlling Earthquakes

Controlling earthquakes are determined by dissaggregation of hazard curves. These show that a bimodal distribution of magnitude-distance combinations dominates the hazard at Lucas Heights. For all return times and spectral periods, a modal magnitude and distance group is observed at about M5.5-6.5 (the mode increases with increasing spectral period) and 10 km distance, and a second group is observed at large magnitudes (from M7 to 8.1) and distance of 30 to 50 km. These correspond to the East Sydney Basin source zone and the Lapstone Structural Complex. The latter has less impact at short distances and so the recommended controlling earthquake for design purposes is the M5.5-6.5 event at around 10 km. This is very similar to the Michael-Leiba M5.75-6.25 event at 15 km identified in previous studies.

3.2.6.8.3 Site stability study

A local site characterisation study was undertaken by Coffey, 1999. It involved the review of available published data from earlier investigations, re-interpretation of available aerial photographs and reconnaissance level field mapping along road cuts and creeks located adjacent to the site, Figure 3.2/27. The study did not identify any particular geological features that could affect the integrity of the bedrock at this site. In particular, the study did not identify any small-scale surface faulting of the form identified in some parts of the Sydney area, nor any features that may help explain the nature of the lower velocity layer located near the western boundary.

The most significant geological feature is the inferred presence of an igneous dyke located to the immediate west of the Replacement Research Reactor Site. Outcrops of this dyke were not observed during the study, where close attention was given to areas where the inferred dyke was assumed to pass across New Illawarra Road and Heathcote Road. This may indicate that the dyke, if present at these locations, is narrow, perhaps deeply weathered and obscured by surface soils.

The pattern of joining within the study area consists of orthogonal sets of steeply dipping joints, possessing strikes similar to those encountered over the majority of the Sydney Metropolitan Area. The joints are generally widely spaced, tight and iron stained, although at some locations clay infilled joints were observed. Lineaments observed to the east of the Reactor site along the Woronora River are considered to reflect the orientation of jointing in the underlying Hawkesbury Sandstone.

In addition to the above features, a minor normal fault with a vertical displacement of up to 200 mm was observed in sandstone outcrops at Site E, (Figure 3.2/28) and a possible low angle shear plane was observed in an outcrop at Site B. The presence of these minor features indicated that similar geological structures may be expected to occur throughout the study area and likely within the Reactor Facility site itself. The site studies reported in Section 3.2.6.7 were consistent with this. Neither of the two studies identified issues that would invalidate the results of the work carried out by IGNS and Stirling.

3.2.6.9 Design Basis Earthquakes for the Reactor Facility

The design basis earthquake for the Reactor Facility was originally set at 0.3 g PHGA. Following recommendation by the IAEA (2001) and discussions with ARPANSA, it was agreed that the design basis earthquake be set at 0.37 g.

Based on the experience of other Research Reactors in seismic areas, and documents issued with regard to the seismic input relevant to Reactor Facility buildings, the Response Spectrum adopted was in accordance to US Regulatory Guide 1.60 (USNRC, 1973) scaled to the PHGA of 0.37 g. The resulting design basis spectrum is shown in Table 3.2/29. Figure 3.2/29 provides a comparison between the adopted design basis earthquake spectrum and that recommended by Stirling and Berryman (2001). Note that the PGA, in accordance with international practice, is kept constant over the period from 0.0 to 0.03 s. As can be seen, the design basis earthquake bounds the Stirling and Berryman spectrum at all points.

3.2.7 Site Services

There are a number of physical services at the LHSTC site that are being extended to meet the requirements of the Reactor Facility. These physical services include:

a) Potable water - reliable supplies of potable water to support, for example fire fighting systems and cooling tower operation.

b) Wastewater and stormwater – collection and treatment infrastructure.

c) Electricity - reliable supplies of high voltage power for systems and equipment, including emergency control and management facilities.

d) Communications/data services - reliable telecommunication facilities with links to other on site facilities, including connection of all digital data services via fibre optic links.

3.2.7.1 Water Supply

The existing water reticulation system at the Lucas Heights Science and Technology Centre consists of supply pipelines, storage facilities, pump systems and site distribution systems. Water is supplied from the 230 ML Lucas Heights Reservoir, located approximately 2.1 km north-east of the Lucas Heights Science and Technology Centre, via a 300 millimetre diameter gravity-fed pipeline. On reaching the Lucas Heights Science and Technology Centre, water is received into two balance tanks before being pumped to a water tower near Einstein Avenue. It is then gravity fed throughout the system by ring mains around each sector of the Centre. The multiple pump system is controlled with valves and the water tower can be bypassed by a pump direct from a balance tank into the ring main so as to increase the general site pressure. The total water storage capacity at the Centre is 1.5 ML.

The capacity of the existing water supply system, both to the Lucas Heights Science and Technology Centre and within the Centre, is sufficient to meet the operational requirements of the Reactor Facility. Water supply to the reactor has been achieved by supplementing the existing site distribution system near the site of the Reactor Facility. A new reticulation main has been installed to provide additional capacity and the fire hydrant system has been extended further out from the site to provide additional depth of coverage by hoses.

Water requirements during operation of the Reactor Facility depend on the design of the reactor's cooling system. The water usage by ANSTO is expected to be approximately 47 ML per month.

3.2.7.2 Wastewater

Infrastructure is currently in place at the LHSTC for the treatment and discharge of low level liquid wastes ('B' line wastewater), trade wastes ('C' line waste-waters), and non-radioactive sewage. This infrastructure includes delay tanks for collection from buildings with pipe-work to the low level liquid and trade waste treatment facilities, a sewage treatment plant and a liquid waste disposal pipeline, most of which are located in the south-east corner of the LHSTC. While the existing wastewater infrastructure is adequate to also service the Reactor Facility, ANSTO has nevertheless upgraded the system.

Additional collection pipelines, effluent treatment plant upgrades, recycling proposals for treated effluents and renegotiations of the trade waste agreement have been arranged in conjunction with the Reactor Facility development to complement the existing system.

3.2.7.3 Stormwater

Storm-water runoff from the Lucas Heights Science and Technology Centre drains to three main discharge points and a number of small stormwater drain outlets.

The main discharge points include:

MDP Creek, which flows into the Woronora River.

Strassman Creek, which also flows into the Woronora River.

Bardens Creek, which flows into Georges River via Mill Creek.

Small capacity concrete retention bunds exist at two of the above discharge points. Any, accidental spills or releases of contaminated liquid which enter the LHSTC site storm-water system can be contained and pumped back to the wastewater treatment system. Following inspection of the contents, the bunds are discharged daily in normal weather conditions in order to maintain capacity for potential spills and during rain periods the storm-water overflows are allowed to function. Accumulated sediments are removed from the dams annually. The quality of storm-water discharged from the Lucas Heights Science and Technology Centre is discussed in the EIS, Vol. 3 Chapter 8 and incidents involving unintentional emissions are discussed in EIS Vol. 3 Chapter 10.6.

The site of the Reactor Facility is on a watershed between Bardens Creek and Melinga Molong Gully catchments and consequently surface waters flow either north or south from the Lucas Heights Science and Technology Centre. North-flowing storm-water is conducted through short lengths of storm-water piping underneath Old Illawarra Road and through a culvert under New Illawarra Road. It is then directed into a retention weir

(Bardens Creek weir) on the northern side of the road and then into a tributary of Bardens Creek. South-flowing storm-water flows through a number of outlets, via Strassman Creek, into Melinga Molong Gully and the Woronora River.

3.2.7.3.1 Stormwater Requirements During Operation

A new storm-water system comprising a retention bund has been constructed on the southern side of the site of the Reactor Facility. The bund is located within the proposed bush fire fuel-reduced zone and existing fire trails. Furthermore, additional storm-water control for both existing drainage catchments (with consideration of contouring bunds, detention ponds and rubbish collection) has been constructed. The systems have been designed to current best practice and in accordance with NSW Environment Protection Authority guidelines and monitoring requirements and ANSTO land management constraints.

3.2.7.4 Electricity

The existing electricity supply to the Lucas Heights Science and Technology Centre consists of two independent 33 kV feeders which converge on an Energy Australia main substation, located at the northern boundary. The power is then converted by two transformers to 11 kV, and distributed from ANSTO’s main 11 kV switchboard to other ANSTO substations. The capacity of the main electrical substation has been increased and the distribution system of the LHSTC augmented to allow it to service the Reactor Facility. All aspects of the electrical power supply for the Reactor Facility are discussed in Chapter 9. The effects of a complete loss of off-site electric power is considered in Chapter 16.

3.2.7.5 Other Infrastructure and Services

This section provides a summary of the existing LHSTC infrastructure and services that have been integrated with the Reactor Facility. Reactor Facility infrastructure is described in detail in Chapter 10.

a) Public Address System

The public address system at ANSTO, which is used for major broadcasts to staff, covers the whole of the Lucas Heights Science and Technology Centre, and is divided into zones, which can be selected to control the required range of coverage. Loudspeakers from both systems are located in all occupied buildings as well as throughout the outdoor areas of the Centre. Broadcasts may be made from either of the two Site Control Centres. The existing public address system has been extended to the Reactor Facility.

b) Safety and Plant Alarm System

The alarm system, which consists of a network of alarm sensors, detects events such as changes in the status of safety and plant systems. The network covers the whole of the Lucas Heights Science and Technology Centre. The existing alarm system has been extended into the site of the Reactor Facility.

c) Telephone and Related Communications

The ANSTO telephone system provides general, on site (internal extension to extension) and off site (external, STD and IDD) voice communications for normal ANSTO operations.

d) High Speed Computer Network and Related Data Communications

The ANSTO computer communication system provides general, on site (Intranet) and off site (Internet) data communications for normal ANSTO operations.

e) Security Access Control System

The security access control system provides for the physical access protection of on site facilities in accordance with national and international obligations. The network covers the whole of the Lucas Heights Science and Technology Centre, and is divided into zones each with a level of local intelligence.

f) Security Alarm System

The security alarm system provides for the physical protection of nuclear materials and facilities in accordance with national and international obligations. The network covers specific locations at the Lucas Heights Science and Technology Centre, and is divided into zones each with a level of local intelligence.

g) Miscellaneous Services

The LHSTC also contains other services, such as non-flammable gases, bulk liquid nitrogen, gaseous nitrogen, compressed air reticulation, distributed compressed air system, landscaping, garden sprinklers, cooling water systems, chemical stores and solvent stores. Pneumatic transfer lines in underground shielded ducts have been installed to allow the safe delivery of irradiation target cans from the Reactor Facility building to the radioisotope production facilities.

Gaseous nitrogen is reticulated from the existing site system vessels near Building 23 and linked to a new bulk storage facility at the Reactor Facility. These storage vessels provide a supply of liquid nitrogen for use in the Neutron Guide Hall.

3.2.8 Nearby Facilities

The Reactor Facility is remote from other major industrial plants and is 340 m from the New Illawarra Road, and 600 m from the facilities immediately adjacent to the site in the Business and Technology Park, the nearest privately operated building. Other nearby facilities include the Lucas Heights Waste Management Centre, the Energy Developments Limited landfill gas electricity generating plant and associated pipeline, and the CRC for Waste Management and Pollution Control research building and a proposed bio-waste processing facility. Adjacent to the site boundary at the south-east over Heathcote Road is the Holsworthy Military Training Area operated by the Australian Army.

3.2.8.1 Facilities and Activities at the LHSTC Site

A wide range of activities take place on the LHSTC site typical of a small industrial facility or university campus. Some of these activities are potentially capable of releasing minor quantities of hazardous materials. Such releases could necessitate temporary evacuation of local areas on site and could lead to temporary shut down of the Reactor Facility. The safety of activities at the LHSTC is ensured by the ANSTO Safety Management System. The characterisation and management of LHSTC chemical hazards, including bulk chemical and other hazardous materials storage facilities, is described by Pegler (1998).

Operations involving conventional industrial activity are subject to the Commonwealth Occupational Health and Safety Act and Regulations and, where no specific Commonwealth legislation exists, to the NSW Workcover Occupational Health and

Safety requirements in order to minimise industrial accidents. An industrial accident occurring at the LHSTC site, outside the Reactor Facility, that could significantly damage the reactor or its safety systems is extremely unlikely. No operations on site have sufficient stored energy to penetrate the Containment; none have the energy and proximity to cause an accident at the Reactor Facility.

3.2.8.2 Nearby Industrial Facilities

The following describes the types of facilities and activities undertaken in the vicinity of the LHSTC site.

The ANSTO Business and Technology Park is located on the northern side of the main LHSTC area, some 600 m to the north-east of the Reactor Facility site. The companies that lease the buildings in the Park are the Vita Medical Ltd., ATA Scientific, and Bilyara and Whitesmith Australia Pty. Ltd.

The Lucas Heights Waste Management Centre covers some 185 hectares, of which 115 ha is in the buffer zone. Its nearest boundary to the Reactor Facility site is approximately 300 m to the north. The centre is a general waste disposal site taking in municipal and industrial solid waste from the south of Sydney. In order to utilise the methane gas generated by the Waste Management Centre, Energy Developments Limited operate two electricity generating plants. The nearest plant, currently rated at 12 MWe, is located some 450 m northwest of the Reactor Facility site and a second smaller plant, less than 4 MWe, located 3 km northeast. There is an underground 4 km long and 250 mm diameter gas pipeline between the two plants as part of the energy development for the facility. The effect of these plants and pipeline on the LHSTC was considered and the conclusion was that ‘the total mass of methane is very small and the effects of an explosion or fire would be negligible at the 450 m distance between the plant and the replacement Reactor Facility site. Also, the effects of the burning of released methane gas are bounded by the effects of the aircraft crash (PLG, 1998).

There are no major commercial pipelines transporting gas within 10 km of the Reactor Facility site (PLG, 1998). A review of the list of sites for storage of dangerous goods licensed under the Dangerous Goods Acts 1975 within an 8 km radius of Lucas Heights (referenced in PLG 1998) reveals that there are no oil refineries, chemical plants, plastic manufacturing plants, or any industrial complexes that handle large quantities of hazardous materials. A paint manufacturing plant is located within 8 km of the Reactor Facility site.

3.2.8.3 Military Facilities

The Holsworthy Training Area is run by the Australian Army and includes an artillery range. It lies to the north, west and south of Lucas Heights, the boundary following the Heathcote Road and the Woronora River. The nearest point of the military training area is approximately 300 m from the Reactor Facility site (PLG, 1998). Artillery practices are controlled by the Commander, Liverpool Area, whose standing orders invoke standard instructions for practice artillery training (PLG, 1998).

The Army ensures that all practices using live ammunition at the Holsworthy Military Training Area are carried out safely; whilst there are two known cases of shells falling outside a practice impact area, the procedures were subsequently reviewed and updated (PLG, 1998). Administrative measures include:

a) Prior to a practice the unit submits to Headquarters Eastern Command a “range detail" (a plan for the practice). The plan is scrutinised and if acceptable and safe, it is approved.

b) During practice, the unit is accompanied by a “Safety Officer” (appointed by Headquarters Eastern Command), who carries out an independent check of all aspects of the practice and has authority to stop it at any time. He is assisted by an Assistant Safety Officer attached to each gun crew.

Material measures include the delineation of:

(i) A safe target area (within which all shells should land) to allow for scatter of fall of shot

(ii) An impact area surrounding the safe target area to allow for ricochets, splinter travel etc

(iii) The perimeter of the impact area, which is never less than 1,000 metres from the range boundary

Firing is prohibited when any part of the trajectory is outside the range boundary. Missiles or rockets are not normally fired in the training area but are subjected to the same general rules, which make damage outside the range boundary virtually impossible.

Military aircraft are subject to the restrictions dictated by the Civil Aviation Authority in relation to the restricted zone R521 (PLG, 1998).

3.2.9 Transport Routes

Nearby transport accidents may have the potential to affect the Reactor Facility through overpressure following explosions, fires, generation of missiles, release of toxic material. The following section describes the local and regional transport characteristics involving air, road, rail and water.

3.2.9.1 Air Transportation

There are two airports in the vicinity of the LHSTC site: Sydney (Kingsford Smith) at Mascot, and Bankstown. Sydney Airport is 19 km NE of the site and takes all aircraft types including helicopters. Bankstown Airport is some 13 km N of the site and is used by light aircraft and helicopters only. Military aircraft also occasionally operate in the vicinity of the site owing to its proximity to the Holsworthy Army Training Area. The LHSTC site lies within an air traffic lane in and out of Kingsford Smith Airport.

LHSTC is on the boundary of the Sydney control area where the lower limit of the controlled air space rises from 500 to 2000 feet above sea level. All civil and military aircraft are prohibited from entering the restricted airspace above LHSTC unless a prior air traffic clearance has been obtained by the pilot from the Civil Aviation Authority (CAA, formerly the Department of Civil Aviation, or DCA). CAA regulations prohibit aircraft from flying lower than 2000 feet above sea level within a radius of one nautical mile (1.85 km) from HIFAR unless a CAA Air Traffic Control Clearance has been obtained by the pilot (PLG, 1998). This restricted region is known as R521. ANSTO requires that a formal written request for permission for limited use of the designated airspace be obtained.

The HIFAR restricted area R521 is significantly overlapped by another restricted area over the Holsworthy Army training Area. This second region (called R555, previously R505) prohibits aircraft from flying lower than 3000 feet above sea level (PLG, 1998).

The aircraft crash risk information has been provided in PLG (1998) and Chapter 16 of this document (section 16.17).

3.2.9.2 Road Transportation

The main road near the Reactor Facility along which hazardous chemical may be transported is Heathcote Road. The Heathcote Road and the New Illawarra Road are used by suppliers of certain hazardous materials for local demands, such as those of ANSTO and the Holsworthy military base, as well as a route to other destinations. The hazardous materials for local demands are primarily petrol and diesel. ANSTO receives petrol delivery about once every 3 months, and it also gets modest shipments of bulk carbon dioxide, nitrogen, argon, and LPG. A major supplier of petrol and diesel, AMPOL oil refinery, uses the Heathcote Road about once every 3 weeks for a maxi tanker, which holds 40,000 litres petrol or 36,000 litres diesel. Mobil Oil uses the Heathcote Road at a rate of six petrol trucks (average capacity of 40,000 litres) per day, for 6 days a week for delivery of the fuel from the company site at Silverwater to Wollongong.

Explosives for the Holsworthy military base are delivered from the Orchard Hills Ammo depot approximately 3 to 4 times a year. About 10 tonnes of the explosives are shipped each time in an explosive qualified vehicle or truck. The shipment of the explosives, however, does not pass through the Heathcote road but instead through Liverpool to the north.

3.2.9.3 Rail Transportation

The Illawarra railway line passing through Engadine and Heathcote is approximately 3 km from the HIFAR site. The railway companies that use this line are the City Rail, Freight Rail, and the National Rail. The City Rail is a commuter rail and does not carry hazardous materials. National Rail cargo can include steel, coal, explosives, and sodium cyanide pellets on the Illawarra line through Engadine. Ammonia and chlorine may be transported via this line only if there is a problem in using the normal route, which is the Sydney-to-Melbourne line. Using the Illawarra line to transport chlorine and ammonia by the National Rail is, therefore, an infrequent event.

One hazardous material transported on the Illawarra railway line is sodium cyanide with 0.5-2% of caustic soda added. The cyanide is transported in pellet form stored in containers, each of which is 6.1 m in length and weighs about 15 to 20 tonnes. The cyanide compound when released from the containers in the event of an accident does not react with air but dissolves in water. Sodium cyanide does react with acid to form the hazardous hydrogen cyanide gas. The cyanide compound in pellet form, when transported by rail is kept at least 250 m away from any acid on the train. In addition, when the railway transports the cyanide pellets, it does not transport any fuels or liquids on the same train. This practice will preclude the railway accident scenario in which burning fuel (spilled and then ignited during the accident) comes into contact with the cyanide pellets spilled from their containers.

Explosives carried on the Illawarra line are the types used for mining. About 15 to 40 tonnes of explosives are transported once a week through this railway line.

3.2.9.4 Water Transportation

The Woronora River, approximately 2 km to the east of HIFAR, is not a navigable waterway.

3.2.10 Baseline Environmental Radioactivity

Information from environmental baseline surveys, or pre-operational, radioactivity in soils, water, and biota is identified and summarised in this section. The purpose of this information is to enable comparisons with future environmental radioactivity surveys during the life of the Reactor Facility, and also to establish a baseline level for eventual decommissioning. The categories of information comprise ANSTO environmental surveys, additional material in the EIS, and specific studies of the Reactor Facility site.

Information on measured environmental radiation at the LHSTC site and its vicinity is reported in the ANSTO annual environmental surveys. The first of such surveys covering the period 1960-64 was published in 1966 (Giles, 1966), and the most recent are given in Hoffman, 2001 and Hoffman et al 2003, . These surveys provide results of measured radioactivity and radiation levels for airborne emissions, low-level liquid effluent, and external radiation. All results are within the relevant discharge authorisations which also specify the standard or guideline (eg WHO Guidelines for Drinking Water Quality) against which compliance is assessed. The reports also detail the radioactivity in a range of environmental media including environmental water samples, airborne dust, soil and marine samples including macroalgae, barnacles and fish. ANSTO is committed to an ongoing monitoring programme for radioactivity in the environment and effluent discharges for the life of the Reactor Facility.

3.2.10.1 Current Environmental Monitoring

The environmental monitoring at LHSTC involves measurements of the radioactivity in local environmental samples. The routine environmental surveys of the site and surrounding areas are performed by the Environmental Monitoring group, located in the ANSTO Environmental Radiochemistry Laboratory. The environmental sample collection and preparation schedule is shown in Table 3.2/30. Methods for gross alpha, gross beta and gamma determinations were updated in 1997. The purpose of this change was to bring the procedures into line with the relevant Australian Standard (AS) or International Standards Organisation (ISO) methods and to enable direct comparison between ANSTO and ARPANSA results. More detailed information on the collection, preparation and analysis of environmental samples is available in Appendix D of the Environmental and Effluent Monitoring at Lucas Heights Science and Technology Centre (Hoffman,1998).

3.2.10.1.1 Types of Radioactivity Measured

Samples of sediment, air, surface water and marine biota are collected at the sites shown in Figures 3.2/30, 3.2/31 and 3.2/32 and analysed for radioactivity. Sampling locations included the Woronora River, Mill Creek, Bardens Creek, Forbes Creek, Potter Point ocean outfall, LHSTC stormwater outlets, creeks draining LHSTC and the Little Forest Burial Ground. The on-site meteorological station collects data all year round and external gamma radiation levels at the perimeter of LHSTC have been measured since 1994. The following radioactivity and radionuclides are routinely analysed by ANSTO: gross alpha activity, gross beta activity, gamma activity which includes cobalt-60, caesium-137, iodine-131, as well as tritium, uranium and thorium series and potassium-40.

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

Tritium (as tritiated water) is chemically indistinguishable from normal water and may be taken up as such by living organisms. The effective or biological half-life is relatively short, typically of the order of days. When present, tritium is found more or less uniformly distributed throughout living species, not accumulated in any particular organ. Thus 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 during transport through geologic media.

The gross alpha and gross beta activities are interpreted in terms of the most restrictive isotope. If daughters 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 daughters range from 0.001 to 0.520 Bqg^{-1} in different soil types (UNSCEAR, 1993).

Potassium-40 (half-life 1.28 x 10^9 years) is a primordial radioisotope of potassium, found in essentially all rocks, natural waters and material of plant and animal origin. Potassium-40 occurs naturally in a fixed ratio to stable potassium, and decays by beta/gamma emission with a specific activity of 27.6 Bqg^{-1} of potassium (NHMRC, 1987). Potassium-40 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 gkg^{-1} of body weight, and includes about 60 Bq of potassium-40 per kg of body weight.

3.2.10.1.2 Air, Water and Biological Sampling Locations

The air, water and biological sampling is described below:

1. Woronora River

Routine water samples are collected monthly from the Woronora River at the boat ramp in Jannali Reserve and analysed for tritium.

2. Forbes Creek

Water from Forbes Creek, a tributary of the Woronora River, is sampled monthly (after rain, if possible) and analysed for tritium. The sample is taken at the point where the Sydney Water supply pipeline crosses the creek, shown on Figure 3.2/30.

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

3. Potter Point Biological Monitoring

The biological monitoring program at Potter Point commenced in 1995. Specimens of fish, algae and barnacles are collected very close to the outfall. This is to maximise the chance of detecting radionuclides in the marine environment across a range of trophic levels in the food chain. A similar background coastal sampling site was selected for comparison purposes at The Royal National Park, approximately 6½ km south of Potter Point. The sampling locations at Potter Point and the Royal National Park are shown on Figure 3.2/31.

The species collected at Potter Point and The Royal National Park are listed below:

Common Name	Scientific Name
Blackfish	*Girella sp.*
Green algae (seaweed)	*Enteromorpha sp.* and *Cladophora sp.*
Surf barnacles	*Tesseropera rosea*

Blackfish are caught using a fishing line baited with seaweed, while the green algae and barnacles are scraped off the rocks. Fish are filleted, the algae and barnacle samples are left whole. Samples are dried, ground and analysed for gamma-emitting radioisotopes.

4. NSW Environment Protection Authority Sampling Points

Stormwater from the LHSTC flows into three small local streams, which are classified as class ‘C’, waters under the NSW Clean Waters Regulations (NSWCWA, 1972). In 1975, the State Pollution Control Commission (now the NSW Environmental Protection Authority) required that the stormwater be sampled periodically at selected locations, in order to demonstrate compliance with the activity limits specified in the NSW Clean Waters Regulations (NSWCWA, 1972). Sampling points on Strassman Creek, Bardens Creek and MDP Creek (Figure 3.2/32) were sampled and analysed for gross alpha and gross beta activity.

Gross alpha and gross beta analyses are performed using ISO methods 9696 & 9697 (ISO, 1992a, 1992b). The gross beta results include the contribution of natural potassium-40 activity. Samples of water are also collected from the sampling weir on Bardens Creek at weekly intervals for tritium analysis. Water from Bardens Creek is not part of any known drinking water supply.

5. MDP+60 m

Stormwater and groundwater from the south-east corner of the site drain into MDP creek (Figure 3.2/32). Historically, the water from this area has been sampled weekly from a small pool about 60 m below the actual stormwater outlet itself, known as MDP+60 m. Some of the weekly MDP+60 m sample was combined each month to make a composite sample for gross alpha, gross beta and gamma spectrometry analyses. Each weekly sample was analysed for tritium.

6. Effluent Discharge Pipeline

The ANSTO liquid effluent disposal pipeline, runs above ground for much of its length, from the LHSTC to the sewer main, as shown on Figure 3.2/32. Surveys of the dose rates along this pipeline are carried out annually. These surveys are performed as part of the regular program of inspection and maintenance of the pipeline in order to detect past or present leaks.

7. Ambient Iodine-131 in Air

Four (4) continuous air sampling stations are situated along the eastern fence boundary of the site (where suburban residences are closest) to monitor concentrations of ambient iodine-131 and other volatile radionuclides in air. The locations of these samplers are shown on Figure 3.2/32. Iodine-131 is measured since it could potentially be incorporated into the food chain. Noble gases emissions cannot be detected by this method as they are inert and very short-lived.

At each station the air is sampled by means of a vacuum pump drawing 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 m^3 per day. Filters are replaced and analysed weekly, with air flow 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. Analysis is via gamma spectrometry of the Maypacks in the low background whole body counter.

3.2.10.2 Recent Changes in Environmental Monitoring

The current radiological baseline information, reported in the annual environment reports and the EIS, covers forty years of radiological monitoring. As part of the approval conditions arising from the EIS, ANSTO undertook a range of new initiatives to characterise the radiological “footprint” at the site of the Reactor Facility. A high sensitivity environmental gamma monitoring system was used, capable of measuring the background radiation characteristics of the site and isolating the comparatively very small component arising from ANSTO’s operations. A mobile high sensitivity gamma detector combined with a global positioning system was used to map the variation in radioactivity over the Reactor Facility site to define the pre-existing radiological baseline (Clark, 2003).

A ground water monitoring program was developed and became operational in 2000. Similarly, a series of new surface water monitoring points were developed specifically to monitor run-off from areas influenced by the Reactor Facility. These programs provide not only baseline radiological information but also allowed examination of the non-radiological impacts associated with the construction of the Reactor Facility.

One of the specific tasks undertaken was the radiological characterisation of the LHSTC. This determined the radiological “footprint” of all past activities. The characterisation included the development of a detailed gamma radiation “map” of the areas of the site with the potential to have been influenced by ANSTO’s (and its predecessors’) activities. The gamma map utilised sensitive instruments capable of extracting any comparatively small indicators of ANSTO’s activities from the far larger natural background radiation. The system was linked to a global positioning system. The characterisation of the radiological “footprint” of the Reactor Facility site and surrounding areas was based on the forty years of environmental monitoring combined with new monitoring initiatives using state of the art monitoring techniques. This work has been reported in detail in Clark (2003).

End of Section

Table 3.2/1 **2001 Census Population from 1.6km to 50km around ANSTO, divided into 16 equiangular sectors with due North in the middle of sector 1 (Domel, 2003)**

Zone:	A	B	C	D	E	F	G	H	I	J	K	
distance from ANSTO, km	1.6 – 3.2	3.2 - 4.8	4.8 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	Totals
1	0	0	4100	23830	71128	102181	130945	125615	86257	14252	9075	567383
2	0	1699	12807	60596	108685	110434	101886	137689	107851	57822	14816	714285
3	0	5442	23001	71783	135629	155971	228556	204818	72205	76888	30264	1004557
4	0	3283	29709	38464	33184	17204	115239	26268	0	1278	0	264629
5	2707	5511	17259	46175	17632	815	0	0	0	0	0	90099
6	2347	3408	0	519	2091	0	0	0	0	0	0	8365
7	1236	2223	1407	39	0	0	0	0	0	0	0	4905
8	913	1868	849	0	279	0	0	0	0	0	0	3909
9	0	0	426	2316	5144	540	6326	8173	12341	9374	8994	53634
10	15	0	0	0	0	0	1748	9878	20733	34163	30567	97104
11	0	0	0	319	0	1781	0	1231	506	1913	2554	8304
12	0	0	0	6290	31875	867	1622	1371	4400	7338	1978	55741
13	0	0	433	28335	27516	20231	11213	926	2363	2033	0	93050
14	0	0	1056	28802	10040	2516	2217	1463	6369	0	0	52463
15	0	0	4260	22456	32313	7035	2804	6668	19427	68197	22786	185946
16	0	0	326	39957	105947	81308	9697	98014	120759	23056	18903	497967
Total	7218	23434	95633	369881	581463	500883	612253	622114	453211	296314	139937	3702341
Projection factors from 2001 for each of the above sectors												
2006	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.01	1.01	1.01	1.01	1.06
2011	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.05	1.05	1.05	1.05	1.11
2016	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.08	1.08	1.08	1.08	1.16
2021	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.12	1.12	1.12	1.12	1.20

Table 3.2/2 LHSTC Site Population on a Typical Day

Organisation	Number of People
ANSTO	780
Commonwealth Scientific and Industrial Research Organisation	95
The Australian Institute of Nuclear Science and Engineering	6
Catering	6
AINSE grant recipients accessing ANSTO facilities ANSTO facilities (maximum at any one time)	200
Students (Nov-Feb each year)	30
ANSTO Business and Technology Park	65
ANSTO Training courses of 1 day to 3 weeks duration; maximum number	50
Site visitors, contractors, sales service personnel (nominal figure)	20

Table 3.2/3 Summary of diurnal wind variations in (10 m) meteorological data at Lucas Heights – all seasons combined

TIME (EST)	STATS	DIRECTION															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0000-0300	PROB (%)	2.0	2.9	3.4	1.8	1.5	1.5	2.8	6.8	20.1	13.1	11.8	10.3	6.8	4.5	6.2	4.7
	U50%	0.9	0.6	1.0	0.9	0.8	1.0	1.4	1.3	1.4	1.2	1.6	1.9	1.7	1.3	1.2	0.9
	USEPA50%	E	E	D	D	D	D	D	D	D	D	D	D	D	D	D	D
0300-0600	PROB (%)	1.9	2.3	2.4	1.3	1.1	1.3	2.2	6.2	20.5	13.2	13.5	11.6	7.1	4.9	6.3	4.2
	U50%	0.9	0.6	0.9	0.9	0.9	1.0	1.3	1.3	1.4	1.2	1.5	1.9	1.6	1.4	1.2	0.9
	USEPA50%	E	E	D	D	D	D	D	D	D	D	D	D	D	D	D	D
0600-0900	PROB (%)	2.9	3.1	3.0	2.0	1.4	1.4	2.8	6.5	16.2	9.6	10.2	10.8	8.4	5.6	10.1	6.0
	U50%	1.1	1.2	1.4	1.3	1.2	1.5	2.0	2.0	1.9	1.4	1.7	2.1	1.8	1.7	1.6	1.2
	USEPA50%	A	B	B	C	C	C	C	C	C	C	D	D	C	C	C	B
0900-1200	PROB (%)	4.2	4.7	6.0	4.6	2.7	2.8	5.5	9.7	11.0	4.4	3.4	6.6	8.4	6.9	12.4	6.7
	U50%	1.7	1.8	2.0	2.2	2.0	2.1	2.6	2.9	3.3	3.2	2.5	3.0	2.6	2.1	2.0	1.8
	USEPA50%	A	A	B	C	C	B	C	C	C	C	C	C	C	B	B	A
1200-1500	PROB (%)	3.1	3.4	6.5	13.8	4.9	4.7	8.8	11.2	9.9	3.0	1.9	4.6	6.8	5.1	7.9	4.5
	U50%	1.6	1.7	2.4	3.1	2.5	2.7	3.1	3.3	3.8	3.7	2.6	3.3	3.6	2.7	2.2	1.7
	USEPA50%	A	A	C	C	C	C	C	C	C	C	C	C	C	B	B	A
1500-1800	PROB (%)	1.7	1.9	9.2	16.8	6.4	5.7	10.6	12.1	10.6	3.3	2.3	4.1	5.8	3.0	3.9	2.6
	U50%	1.0	1.0	2.6	2.7	2.2	2.4	2.7	2.9	3.2	2.9	2.2	3.1	3.4	3.4	2.2	1.1
	USEPA50%	C	C	D	D	C	C	C	C	D	D	D	D	D	C	C	C
1800-2100	PROB (%)	1.0	3.2	14.0	7.5	4.2	3.7	7.3	11.6	16.7	6.7	4.9	5.3	5.4	3.1	3.4	2.0
	U50%	0.8	1.0	1.7	1.3	1.1	1.2	1.6	1.6	1.8	1.7	2.0	2.2	2.2	2.0	1.7	1.1
	USEPA50%	E	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
2100-2400	PROB (%)	2.7	4.9	6.5	3.1	2.1	1.8	3.9	8.2	18.5	10.9	9.3	8.5	6.2	3.8	5.0	4.5
	U50%	1.0	0.7	1.1	1.0	0.9	1.0	1.4	1.4	1.4	1.3	1.5	1.9	1.8	1.5	1.3	0.9
	USEPA50%	E	E	D	D	D	D	D	D	D	D	D	D	D	D	D	E

Notes Beginning date: 05 April 1991; End date: 30 June 2003

PROB (%) is the frequency of occurrence of a wind direction in the time period.

U50% is the median wind speed in m s^{-1} (Clark 2003)

USEPA50% is the median value of the Pasquil stability category (USEPA, 1987) [Pasquill stability categories A through F : Category A = most unstable/diffusive through D = neutral to F = most stable/least diffusive]

Table 3.2/4 Summary of seasonal wind variations in (10 m) meteorological data at Lucas Heights – all times combined.

TIME (EST)	STATS	DIRECTION															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
SUMMER	PROB(%)	2.5	4.5	10.4	11.8	5.1	4.4	8.2	12.8	17	5.3	3	2.7	2.6	2.1	4	3.5
	U50%	1.1	1.1	2	2.7	2	2.1	2.6	2.5	2.5	1.4	1.3	1.8	2	1.8	1.6	1.2
	USEPA50%	B	C	D	C	C	C	C	C	D	D	D	D	D	C	C	C
AUTUMN	PROB(%)	2.4	2.8	5	4.9	2.6	2.8	5.8	9.6	19.6	10.6	7.7	7.4	5.8	3.6	5.5	4.1
	U50%	1	1	1.5	1.8	1.4	1.8	2.2	2.1	1.9	1.5	1.5	1.9	1.8	1.5	1.4	1.1
	USEPA50%	B	C	D	D	C	C	C	D	D	D	D	D	D	C	C	C
WINTER	PROB(%)	2.2	2.1	2.3	1.9	1.2	1.2	2.1	4.8	12.6	10	11.9	13.31	1.6	7	10.2	5.5
	U50%	1	1	1.2	1.3	1.1	1.3	1.6	1.5	1.5	1.6	2	2.4	2.3	1.9	1.8	1.2
	USEPA50%	C	D	D	D	D	D	D	D	D	D	D	D	D	D	C	C
SPRING	PROB(%)	2.7	3.7	7.8	6.9	3.2	3	5.8	9	12.5	6.2	6	7.6	7.4	5.7	8	4.5
	U50%	1.1	1.2	1.9	2.4	1.9	2.1	2.4	2.5	2	1.4	1.7	2.3	2.4	2.1	1.8	1.2
	USEPA50%	B	C	D	D	C	C	C	C	D	D	D	D	D	C	C	C
COMBINED	PROB(%)	2.4	3.3	6.3	6.3	3	2.8	5.5	9	15.5	8.1	7.2	7.8	6.9	4.6	6.9	4.4
	U50%	1.1	1.1	1.8	2.3	1.7	1.9	2.3	2.2	2	1.5	1.7	2.2	2.2	1.9	1.7	1.2
	USEPA50%	B	C	D	D	C	C	C	C	D	D	D	D	D	C	C	C

Notes Beginning date: 05 April 1991; End date: 30 June 2003

PROB (%) is the frequency of occurrence of a wind direction in the time period.

U50% is the median wind speed in m s^{-1} (Clark 2003)

USEPA50% is the median value of the Pasquil stability category (USEPA, 1987) [Pasquill stability categories A through F : Category A = most unstable/diffusive through D = neutral to F = most stable/least diffusive]

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Table 3.2/5 Summary of diurnal wind variations in (49 m) meteorological data at Lucas Heights – all seasons combined

TIME (EST)	STATS	DIRECTION															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0000-0300	PROB (%)	3.5	4.2	3.6	2.6	2.1	2.7	3.6	7.6	11.8	9.4	9.2	10.7	8.1	6.8	7	6.9
	U50%	2.6	2.7	2.6	2.3	2.1	2.6	3.2	3.6	4.1	3.8	4.2	5.2	4	3.2	3.1	3.2
	USEPA50%	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
0300-0600	PROB (%)	3.0	3.3	2.4	1.8	1.7	2.3	3.0	7.2	12.5	9.6	10.7	12.7	8.9	7.7	7.3	6.1
	U50%	2.4	2.6	2.4	2.3	2.1	2.8	3.1	3.6	4.0	3.8	4.2	5.0	3.8	3.1	3.1	3.0
	USEPA50%	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
0600-0900	PROB (%)	3.1	3.5	2.1	2.0	1.6	1.8	3.3	8.1	11.8	7.9	8.5	11.9	9.5	8.0	9.6	7.2
	U50%	2.6	2.7	2.2	2.2	2.2	3.0	3.3	3.7	4.1	3.6	3.9	4.6	3.8	3.0	2.8	2.9
	USEPA50%	B	B	C	C	C	C	C	C	C	D	D	D	D	C	C	C
0900-1200	PROB (%)	4.6	5.1	3.8	4.5	3.0	3.2	5.8	10.4	9.7	4.0	3.1	6.6	8.9	8.5	10.6	8.3
	U50%	3.1	3.1	3.0	3.4	3.1	3.4	4.0	4.8	5.3	5.1	4.2	5.0	4.5	3.1	3.0	3.1
	USEPA50%	B	B	B	C	C	C	C	C	C	C	C	C	C	C	C	B
1200-1500	PROB (%)	3.5	3.7	4.1	13.8	5.5	5.5	9.1	11.9	8.4	2.6	1.6	4.3	7.2	6.0	7.0	5.5
	U50%	3.0	2.9	3.6	4.9	4.1	4.1	4.8	5.5	6.2	6.1	4.5	5.9	6.3	4.2	3.5	3.2
	USEPA50%	B	B	C	C	C	C	C	C	C	C	C	C	C	C	C	B
1500-1800	PROB (%)	2.1	2.3	6.6	17.7	7.2	7.1	10.7	12.8	8.2	3.1	1.7	4.2	5.9	3.6	3.5	3.2
	U50%	2.8	3.0	4.5	4.6	3.9	4.1	4.7	5.3	5.6	5.3	4.7	6.1	6.8	6.5	5.0	3.3
	USEPA50%	C	C	D	D	C	C	D	D	D	D	D	D	D	C	C	C
1800-2100	PROB (%)	1.6	5.4	12.8	9.2	5.3	6.0	8.0	12.2	10.3	5.2	3.6	5.2	5.8	3.8	3.0	2.6
	U50%	3.3	3.4	3.7	3.2	2.7	3.0	3.5	4.0	4.4	4.3	4.8	5.5	5.5	5.1	4.8	4.5
	USEPA50%	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
2100-2400	PROB (%)	4.3	7.6	6.2	4.2	3.1	3.7	4.9	8.9	11.1	7.9	7.0	8.4	6.6	5.0	5.3	6.0
	U50%	2.8	3.0	2.8	2.4	2.2	2.5	3.0	3.7	4.1	3.9	4.2	5.2	4.8	3.8	3.5	3.4
	USEPA50%	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

Notes Beginning date: 05 April 1991; End date: 30 June 2003

PROB (%) is the frequency of occurrence of a wind direction in the time period.

U50% is the median wind speed in m s^{-1} (Clark 2003)

USEPA50% is the median value of the Pasquil stability category (USEPA, 1987) [Pasquill stability categories A through F : Category A = most unstable/diffusive through D = neutral to F = most stable/least diffusive]

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Table 3.2/6 Summary of seasonal wind variations in (49 m) meteorological data at Lucas Heights – all times combined.

SEASON	STATS	DIRECTION															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
SUMMER	PROB(%)	3.0	5.8	8.6	12.9	6.1	6.0	8.8	14.4	11.6	3.8	2.2	2.5	2.8	3.1	4.1	4.4
	U50%	2.6	3.0	3.4	4.5	3.5	3.6	4.4	4.9	5.0	3.4	3.2	4.0	4.3	3.2	2.8	2.9
	USEPA50%	C	D	D	D	C	D	D	D	D	D	D	D	D	D	C	C
AUTUMN	PROB(%)	3.2	3.8	4.2	5.4	3.4	4.4	7.0	11.0	13.0	7.9	6.0	7.9	6.8	5.2	5.8	4.9
	U50%	2.6	2.8	3.2	3.4	2.7	3.2	3.8	4.1	4.4	4.1	4.1	4.7	3.8	2.7	2.7	2.8
	USEPA50%	C	D	D	D	D	D	D	D	D	D	D	D	D	D	D	C
WINTER	PROB(%)	3.1	2.8	1.9	2.0	1.4	1.8	2.6	5.2	8.7	8.5	9.9	14.0 1	2.6	9.4	9.0	7.1
	U50%	3.1	2.8	2.9	2.9	2.4	2.8	3.0	3.5	4.2	4.3	4.7	5.5	5.0	3.9	3.7	3.6
	USEPA50%	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
SPRING	PROB(%)	3.6	5.1	6.1	7.7	3.9	3.9	5.9	9.0	8.5	4.7	4.7	7.5	8.2	7.0	7.6	6.4
	U50%	3.0	3.1	3.6	4.1	3.2	3.5	4.1	4.6	4.6	3.8	4.0	5.2	5.1	4.0	3.5	3.3
	USEPA50%	C	D	D	D	D	D	D	D	D	D	D	D	D	D	C	C
COMBINED	PROB(%)	3.2	4.4	5.2	7.0	3.7	4.0	6.0	9.9	10.5	6.3	5.7	8.0	7.6	6.2	6.7	5.7
	U50%	2.8	2.9	3.4	3.9	3.1	3.3	3.9	4.3	4.5	4.0	4.2	5.1	4.7	3.5	3.2	3.2
	USEPA50%	C	D	D	D	D	D	D	D	D	D	D	D	D	D	C	C

Notes Beginning date: 05 April 1991; End date: 30 June 2003

PROB (%) is the frequency of occurrence of a wind direction in the time period.

U50% is the median wind speed in m s^{-1} (Clark 2003)

USEPA50% is the median value of the Pasquil stability category (USEPA, 1987) [Pasquill stability categories A through F : Category A = most unstable/diffusive through D = neutral to F = most stable/least diffusive]

Table 3.2/7 Precipitation Rates v. Wind Directions for Lucas Heights Precipitation Rates

	Rainfall Rates (mm/hr)											
Direction	0.-1.	1.- 2.	2.-3.	3.- 4.	4.- 5.	5.- 6.	6.- 7.	7.- 8.	8.- 9.	9.-10.	>10.	Total
N	1.64	0.13	0.38	0.21	0.09	0.11	0.02	0.04	0.00	0.00	0.09	2.67
NNE	1.80	0.17	0.57	0.23	0.11	0.05	0.14	0.01	0.03	0.03	0.07	3.19
NE	2.95	0.46	0.94	0.48	0.34	0.20	0.09	0.12	0.10	0.06	0.24	5.91
ENE	2.51	0.28	0.63	0.32	0.21	0.12	0.08	0.11	0.05	0.05	0.17	4.50
E	1.75	0.10	0.57	0.24	0.20	0.12	0.05	0.03	0.05	0.03	0.20	3.29
ESE	2.33	0.30	0.71	0.52	0.25	0.22	0.11	0.13	0.07	0.09	0.35	5.01
SE	3.76	0.52	1.30	0.74	0.46	0.39	0.23	0.24	0.13	0.15	0.46	8.29
SSE	6.74	0.64	2.08	1.05	0.75	0.52	0.30	0.27	0.25	0.13	0.71	13.27
S	12.24	1.00	3.42	1.78	1.09	0.72	0.59	0.37	0.15	0.24	0.85	22.32
SSW	6.86	0.55	1.65	0.77	0.38	0.32	0.21	0.14	0.16	0.06	0.33	11.37
SW	3.08	0.20	0.79	0.33	0.23	0.21	0.10	0.05	0.07	0.03	0.16	5.20
WSW	2.02	0.19	0.66	0.32	0.27	0.12	0.11	0.11	0.03	0.05	0.11	3.97
W	1.48	0.17	0.32	0.24	0.16	0.09	0.10	0.04	0.06	0.03	0.16	2.78
WNW	0.96	0.09	0.38	0.22	0.08	0.03	0.02	0.03	0.02	0.00	0.07	1.87
NW	1.61	0.23	0.49	0.24	0.16	0.13	0.06	0.02	0.02	0.03	0.06	3.03
NNW	1.90	0.17	0.58	0.22	0.12	0.10	0.10	0.06	0.04	0.01	0.05	3.33
Total	53.60	5.20	15.50	7.90	4.90	3.40	2.30	1.80	1.20	1.00	3.30	

Notes: Beginning date: 05 April 1991 End date: 30 June 2003.

Table frequencies are in %. (Clark 2003)

Table 3.2/8 Wind Direction and Average Wind Speed during Inversions

Direction	Light to Moderate Inversion				Strong Inversion			
	10m		49m		10m		49m	
	Frequency	Wind Speed	Frequency	Wind Speed	Frequency	Wind Speed	Frequency	Wind Speed
	(%)	(m/s)	(%)	(m/s)	(%)	(m/s)	(%)	(m/s)
N	1.85	1.0	3.88	3.4	0.28	1.0	1.84	1.9
NNE	4.04	1.2	6.47	3.4	0.64	1.2	1.80	2.2
N E	3.81	1.3	3.93	3.2	0.88	1.3	1.10	1.8
ENE	1.85	1.2	2.59	2.8	0.58	1.3	1.16	2.2
E	1.38	1.1	2.05	2.6	0.28	1.4	1.66	2.0
ESE	1.26	1.2	2.79	3.2	0.41	1.3	2.03	2.4
SE	2.00	1.3	2.91	3.3	0.43	1.2	2.90	2.4
SSE	5.41	1.6	5.23	3.8	5.21	1.4	4.82	2.7
S	14.86	1.7	7.09	4.1	48.85	1.7	8.32	3.5
SSW	10.06	1.6	6.39	3.9	27.07	1.6	11.73	3.6
SW	11.66	2.0	9.25	4.8	11.14	1.7	16.62	3.4
WSW	11.62	2.2	11.03	5.2	1.78	1.7	17.57	3.2
W	8.71	2.1	9.6	4.5	0.90	1.8	12.89	2.7
WNW	6.25	2.0	8.94	4.1	0.51	1.7	7.06	2.3
NW	9.87	2.0	9.62	4.2	0.60	1.7	5.01	2.0
NNW	5.36	1.4	8.23	4.1	0.43	1.3	3.48	2.1
Overall	100.00	1.8	100.00	4.1	100.00	1.6	100.00	2.9

Table 3.2/9 Frequencies (%) of Wind Speeds during Inversions

Height	10 m				49 m			
Wind Speed Ranges (m/s)	0 - 2	2 - 4	>4	Total	0 - 2	2 - 4	>4	Total
Light to Moderate Inversion	66.24	31.48	2.28	100	9.68	42.19	48.13	100
Strong Inversion	86.21	12.19	1.60	100	2.85	51.69	24.46	100

Table 3.2/10 Tornado Strike Annual Frequency with Wind Speed (Miles Per Hour)

Tornado Category	**Wind Speed (mph)**				
	50	**100**	**150**	**200**	**250**
Strong	2.6E-04	4.4E-05	5.3E-06	5.0E-07	3.6E-08
Weak	1.1E-04	2.8E-06	4.2E-08	4.4E-10	< 1.0E-10
Total	3.7E-04	4.7E-05	5.4E-06	5.0E-07	3.6E-08

Table 3.2/11 Mean Annual Frequencies at Designated Ranges in Wind Velocity

Wind Velocity Range (mph)					
70 to 80	80 to 90	90 to 120	120 to 150	150 to 180	180 to 200
Designated Wind Velocity (mph)					
WIND1	**WIND2**	**WIND3**	**WIND4**	**WIND5**	**WIND6**
75	85	105	135	165	190
Annual Exceedence Frequency					
1.82E-02	3.80E-03	9.70E-04	2.47E-05	4.05E-06	9.21E-07

Table 3.2/12 Barometric Pressure (hPa) Variations as a Function of Time of Day and Month

	Time (EST)									
	0000	0300	0600	0900	1200	1500	1800	2100	Extreme	
									Minimum	Maximum
January	995.6	995.8	996.8	996.3	994.8	994.2	995.9	996.8	975.8	1006.5
	5.8	5.9	5.7	5.9	6.1	6.2	6.0	5.8	Standard deviations	
	744	744	744	744	744	744	744	744	Number of observations	
February	996.4	996.2	997.3	997.0	995.7	995.1	996.3	996.9	977.3	1008.3
	5.2	5.5	5.3	5.5	5.7	5.7	5.7	5.6	Standard deviations	
	672	672	672	672	672	672	672	672	Number of observations	
March	998.0	997.7	998.9	998.9	997.3	996.9	998.4	999.1	979.4	1008.7
	4.9	4.7	4.8	4.8	4.9	4.8	4.5	4.4	Standard deviations	
	744	744	744	744	744	744	744	744	Number of observations	
April	1001.8	1001.6	1002.6	1002.5	1000.9	1000.7	1002.0	1002.4	988.0	1013.6
	5.5	5.6	5.6	5.8	5.5	5.6	5.7	5.5	Standard deviations	
	720	720	720	720	720	720	720	720	Number of observations	
May	1001.4	1001.2	1002.1	1002.0	1000.4	1000.5	1001.7	1001.9	980.5	1016.5
	7.5	7.5	7.8	8.0	7.7	7.5	7.3	7.3	Standard deviations	
	744	744	744	744	744	744	744	744	Number of observations	
June	999.6	999.3	1000.1	999.9	998.1	998.1	999.4	999.9	980.8	1014.8
	7.4	7.8	7.8	8.0	7.8	7.7	7.5	7.5	Standard deviations	
	720	720	720	720	720	720	720	720	Number of observations	
July	1000.6	1000.3	1001.3	1001.2	999.4	999.5	1000.6	1000.9	984.9	1014.2
	5.6	5.7	5.8	5.8	5.8	5.6	5.7	5.7	Standard deviations	
	708	708	708	708	708	708	708	708	Number of observations	
August	999.6	999.2	1000.2	1000.0	998.1	998.1	999.6	999.9	974.7	1013.2
	7.8	7.8	8.2	8.2	8.0	7.8	7.5	7.5	Standard deviations	
	744	744	744	744	744	744	744	744	Number of observations	
September	998.7	998.6	999.7	999.2	997.2	997.1	998.9	999.5	981.7	1012.4
	6.7	6.8	7.1	6.9	6.9	6.5	6.5	6.6	Standard deviations	
	720	720	720	720	720	720	720	720	Number of observations	
October	995.2	995.1	996.1	995.2	993.4	993.1	995.0	995.7	971.0	1011.1
	6.7	6.5	6.5	6.6	6.3	6.2	6.2	6.3	Standard deviations	
	744	744	744	744	744	744	744	744	Number of observations	
November	997.8	997.8	998.7	998.1	996.5	996.2	997.9	998.6	977.6	1011.0
	5.6	5.3	5.5	5.7	5.9	5.8	5.8	5.7	Standard deviations	
	720	720	720	720	720	720	720	720	Number of observations	
December	994.2	994.3	995.1	994.2	992.7	992.3	994.0	994.9	977.6	1007.2
	5.6	5.6	6.0	6.3	6.3	6.4	6.1	5.9	Standard deviations	
	744	744	744	744	744	744	744	744	Number of observations	

Table 3.2/13 Monthly and Annual Statistics on Rainfall and Evaporation (mm) at Lucas Heights, 1981 to 1989

		1981	1982	1983	1984	1985	1986	1987	1988	1989
Jan	R. Total	52.0	39.2	24.1	148.7	7.1	179.6	44.4	83.7	104.5
	R Days	13	9	5	13	4.	14	7	10	18
	E Total	170.2	190.6	207.8	164.4	206.8	183.0	154.8	160.4	140.2
	E Max	9.5	12.0	14.1	8.8	11.6	10.4	8.8	8.1	8.8
Feb.	R Total	163.8	20.9	20.4	133.2	29.4	51.6	19.2	83.3	44.3
	R Days	14	6	11	14	9	11	7	11	10
	E Total	122.8	145.3	164.3	140.5	144.1	121.6	134.2	147.4	125.9
	E Max	8.0	9.9	10.4	8.8	10.1	8.7	7.9	7.4	6.5
Mar.	R Total	14.3	138.7	274.9	157.7	70.8	20.9	134.0	47.4	108.9
	R Days	3	18	8	10	13	5	10	15	18
	E Total	156.2	99.8	159.7	138.2	147.0	118.4	182.2	120.3	90.7
	E Max	8.2	8.0	12.5	7.4	9.5	6.2	11.1	8.4	5.6
April	R Total	190.8	11.4	61.4	93.2	209.0	56.5	8.4	399.6	365.5
	R Days	8	3	12	10	16	8	7	22	21
	E Total	103.1	97.7	92.8	83.9	95.9	105.7	86.1	73.1	70.5
	E Max	6.0	5.0	6.8	6.4	5.7	8.0	4.6	4.9	6.3
May	R Total	91.6	4.1	127.6	75.2	153.9	22.2	78.8	114.2	96.1
	R Days	8	3	15	14	17	9	12	12	20
	E Total	67.2	88.5	64.6	54.5	71.9	57.1	61.4	56.6	42.1
	E Max	4.4	4.9	4.8	3.1	8.3	3.4	5.0	6.3	3.0
June	R Total	55.6	71.4	98.3	72.9	163.5	5.4	53.1	44.6	187.7
	R Days	6	12	10	4	8	2	11	9	20
	E Total	64.7	65.1	53.6	48.7	54.1	55.5	47.2	57.3	55.9
	E Max	3.4	3.2	2.9	3.1	3.5	2.9	3.0	3.7	6.6
July	R Total	39.8	69.8	21.2	141.1	111.4	24.0	93.6	135.8	17.9
	Days	7	12	8	14	10	9	11	8	9
	E Total	68.7	66.7	50.5	49.2	71.4	60.4	59.7	51.0	53.2
	E Max	4.0	3.5	2.6	3.6	5.9	3.9	4.0	4.0	2.8
Aug.	R Total	6.4	1.3	25.8	13.1	25.2	403.8	360.2	27.3	36.8
	R Days	7	3	10	7	8	10	16	11	6
	E Total	97.1	88.8	66.7	85.8	74.0	63.4	65.7	12.5	72.3
	E Max	5.6	4.7	4.5	4.6	5.8	4.1	6.6	5.3	4.4
Sept	R Total	7.2	174.5	41.4	31.4	62.6	50.4	10.3	121.6	0.6

		1981	1982	1983	1984	1985	1986	1987	1988	1989
	R Days	4	10	9		11	8	5	10	1
	E Total	117.4	122.3	115.6	96.9	88.6	100.8	109.8	101.9	109.0
	E Max	8.0	8.7	7.2	5.1	5.4	6.2	6.3	6.6	6.0
Oct	R Total	137.2	43.6	154.0	26.3	213.6	56.2	191.4	0	12.3
	R Days	11	9	14	9	17	8	14	0	4
	E Total	151.3	135.9	107.0	142.2	133.1	137.7	110.0	178.4	159.1
	E Max	13.2	7.3	5.4	8.0	8.0	8.3	6.6	9.1	9.1
Nov.	R Total	152.6	9.8	57.8	312.3	104.4	127.6	98.4	146.5	54.5
	R Days	13	2	7	16	14	15	8	15	12
	E Total	128.9	182.8	154.0	151.6	148.2	131.6	153.8	131.9	140.4
	E Max	8.9	10.8	8.7	9.9	7.1	7.7	8.6	10.1	7.2
Dec	R Total	93.3	14.3	80.4	76.1	103.6	28.7	65.7	112.9	72.5
	R Days	10	9	14	9	13	5	14	17	10
	E Total	169.5	172.5	171.4	214.1	179.4	166.3	154.9	142.3	150.8
	E Max	10.1	8.6	10.2	11.2	9.5	11.2	8.0	8.9	9.2
Annual	R Total	1004.6	599.0	987.4	1281.2	1255.0	1027.8	1157.5	1316.9	1101.6
	R Days	104	96	1123	129	140	104	122	140	149
	E Total	1417.1	1426.0	1408.0	1370.0	1412.5	1297.5	1319.8	1293.1	1210.1

R Total: Monthly total rainfall (mm)

R Days: Number of rain days in the month

E Total: Total Evaporation per month (mm)

E Max: Maximum 24 hour evaporation (mm)

Table 3.2/14 Monthly and Annual Statistics on Rainfall and Evaporation at Lucas Heights, 1990 to 1998, and Monthly Averages for 1990 to 1998

		1990	1991	1992	1993	1994	1995	1996	1997	1998	Average
Jan	R. Total	64.1	53.6	123.2	50.2	11.2	122.1	136.0	113.2	75.0	84.2
	R Days	12	15	12	10	7	12	13	1.1	1.1	
	E Total	139.8	175.5	137.5	149.0	205.2	135.8	125.2	151.8	163.9	
	E Max	8.0	9.8	7.1	9.1	12.6	7.9	7.6	7.8	10.1	
Feb.	R Total	443.0	24.4	300.4	88.5	47.3	47.6	64.1	127.7	56.0	103.8
	R Days	19	9	12	1.1	8	12	15	10	8	
	E Total	104.3	152.8	104.4?	133.4	147.6	122.9	137.5	118.5	154.7	
	E Max	6.0	10.4	7.9	8.0	10.2	7.6	7.8	11.3	10.0	
Mar.	R Total	90.3	27.8	80.2	144.6	151.7	205.4	33.7	61.2	15.5	104.6
	R Days	17	4	9	17	17	16	9	10	8	
	E Total	114.9	148.3	99.0	117.0?	118.3?	123.7	101.7	124.0	127.8	
	E Max	7.1	8.6	6.1	10.4?	8.2?	8.4	6.1	6.2	7.7	
April	R Total	287.6	28.3	93.6	30.3	95.5	14.2	33.2	0.5	161.3	125.9
	R Days	20	7	13	7	8	2	6	1	10	
	E Total	70.1	100.2	77.0	83.0	85.9	91.0	99.2	91.9	94.9	
	E Max	4.0	5.6	4.7	4.5	5.8	5.5	6.4	7.0	8.1	
May	R Total	146.2	48.0	37.8	15.8	25.5	199.9	143.5	96.5	203.7	98.9
	R Days	12	13	9	4	5	16	14	16	13	
	E Total	65.2	58.3	47.2	55.3	82.0	67.7	60.1	64.7	61.8	
	E Max	6.6	3.8	2.7	4.9	6.6	6.0.	3.9	4.7	4.9	
June	R Total	21.4	409.5	70.5	34.3	39.5	40.4	51.8	51.0	45.5	89.2
	R Days	11	11	8	6	7	8	9	1,0	4.1	
	E Total	50.9	46.9?	48.7	53.3	51.1	44.1	58.9	54.7	86.8	
	E Max	2.6	2.6	3.2	3.4	3.5	3.3	3.8	6.4	12.0	
July	R Total	45.1	91.6	11.2	64.8	7.4	1.0	78.4	48.2	50.1	61.9
	Days	8	13	5	10	8	4	6	6	3.8	
	E Total	55.9	64.6	59.0	42.1	56.7	52.7	60.0	52.7	316.3	
	E Max	2.9	3.5	3.5	2.6	3.1	3.5	3.2	2.6	15.0	
Aug.	R Total	218.4	9.8	19.2	69.0	8.4	0.0	129.9	18.7	51.0	83.8
	R Days	10	5	8	9	2	0	6	5	3.3	
	E Total	69.8	105.5	76.3	76.6	85.5	86.1	76.0	82.4	37.7	
	E Max	5.3	6.4	5.7	6.6	6.0	5.2	5.0	6.9	9.0	
Sept	R Total	57.8	15.7	17.8	81.8	10.4	249.3	74.8	105.6	37.7	67.7

		1990	1991	1992	1993	1994	1995	1996	1997	1998	Average
	R Days	11	6	9	10	2	13	7	15	9	
	E Total	88.6	119.7	96.9	89.4	130.8	85.8	120.0	78.7	82.5	
	E Max	7.0	8.9	5.2	5.0	6.6	7.0	7.5	6.0	5.5	
Oct	R Total	34.9	10.0	33.4	54.6	35.1	34.4	31.2	60.2	26.7	67.9
	R Days	14	4	12	7	9	1.0	10	8	8	
	E Total	130.2	150.9	106.3	138.2	139.0	121.9	118.1	136.9	121.1	
	E Max	7.8	9.8	7.4	9.9	7.2	6.6	6.8	7.6	6.8	
Nov.	R Total	17.6	34.4	143.4	57.3	94.2	135.4	70.8	21.7	110.3	102.9
	R Days	3	7	18	9	14	15	12	9	15	
	E Total	165.9?	156.6	127.3	142.4?	164.6	126.4	146.5	150.2	113.6	
	E Max	13.8	8.1	7.9	13.6?	10.5	7.2	7.3	7.5	7.2	
Dec	R Total	56.4	259.4	186.0	46.7	50.7	93.9	68.8	27.3	37.8	86.4
	R Days	9	9	18	12	9	13	6	7	9	
	E Total	182.0	180.7	125.8	167.3	163.7	155.0	160.6	162.9	148.9	
	E Max	10.6	9.0	7.6	8.8	11.6	8.5	8.2	11.2	9.6	
Annual	R Total	1482.8	1012.5	1116.7	731.9	576.2	1143.6	916.2	731.8	1207.3	1097.1
	R Days	146	103	133	112	87	121	113	108	129	
	E Total	1237.6?	1462.0?7	1105.4	1247.0?	1430.4?	1220.4	1260.5	1269.4	1215.8	

R Total: Monthly total rainfall (mm)
R Days: Number of rain days in the month
E Total: Total Evaporation per month (mm)
E Max: Maximum 24 hour evaporation (mm)
? = uncertainty due to a missing value.

Table 3.2/15 **Monthly and Annual Statistics on Rainfall and Evaporation at Lucas Heights, 1999 to 2002, and Monthly Averages for 1999 to 2002**

		1999	2000	2001	2002	Average
Jan	R. Total	111.9	29.6	191.0	55.2	82.7
	R Days	14	12	9	10	
	E Total	165.4	138.0	151.3	176.6	163.3
	E Max	10.0	8.0	10.1	13.4	
Feb.	R Total	196.5	11.0	110.6	295.1	108.1
	R Days	14	9	11	18	
	E Total	113.1	149.6	108.4	103.4	133.0
	E Max	6.6	9.3	6.4	8.7	
Mar.	R Total	40.2	217.6	122.0	143.3	104.6
	R Days	10	14	20	15	
	E Total	94.3	94.6	110.1	90.2	122.1
	E Max	5.1	5.1	7.9	5.5	
April	R Total	94.3	31.9	70.2	15.4	106.9
	R Days	17	12	7	6	
	E Total	72.0	65.3	78.0	68.8	85.7
	E Max	4.0	4.0	5.0	3.5	
May	R Total	48.7	34.5	105.3	50.6	87.3
	R Days	10	9	10	11	
	E Total	44.7	54.9	58.1	61.6	61.2
	E Max	3.4	3.4	4.5	3.7	
June	R Total	66.6	34.2	9.3	18.1	76.3
	R Days	14	9	6	5	
	E Total	45.9	45.7	44.4	49.1	52.1
	E Max	2.8	4.5	2.4	3.1	
July	R Total	163.3	31.4	109.2	26.4	64.5
	Days	12	9	14	2	
	E Total	47.4	52.1	44.3	57.0	55.7
	E Max	4.1	3.8	2.3	3.3	
Aug.	R Total	31.2	19.2	49.4	14.3	82.0
	R Days	8	11	6	7	
	E Total	65.6	59.6	75.4	73.0	75.9
	E Max	3.2	4.3	5.5	5.9	
Sept	R Total	20.7	37.2	18.2	7.0	56.1

		1999	2000	2001	2002	Average
	R Days	5	6	10	4	
	E Total	82.5	120.6	82.9	118.4	102.7
	E Max	4.4	7.5	5.0	8.5	
Oct	R Total	211.0	55.1	39.8	1.4	66.5
	R Days	13	9	8	4	
	E Total	104.1	117.2	128.9	149.8	132.3
	E Max	6.3	6.8	7.6	8.5	
Nov.	R Total	32.7	150.3	57.1	14.5	91.1
	R Days	9	17	11	6	
	E Total	112.1	100.5	129.6	157.1	140.4
	E Max	5.4	6.0	9.4	10.3	
Dec	R Total	112.8	46.4	15.9	59.8	77.4
	R Days	13	11	8	9	
	E Total	140.4	170.5	150.5	177.2	163.9
	E Max	6.8	10.1	10.8	12.7	
Annual	R Total	1129.9	698.4	898.0	701.1	980.3
	R Days	139	128	120	97	
	E Total	1087.5	1168.6	1161.9	1282.2	1283.6

R Total:	Monthly total rainfall (mm)
R Days:	Number of rain days in the month
E Total:	Total Evaporation per month (mm)
E Max:	Maximum 24 hour evaporation (mm)

Table 3.2/16 Average Annual Data for Inversions

Number of Occurrences	291
Time of Start	Sunset plus 134 minutes
Time of Termination	Sunrise plus 25 minutes
Duration (average)	8 – 9 hours
Intensity	< 5°C per 100 m

Table 3.2/17 Atmospheric Mixing Layer Development Analyses Using Acoustic Sounder Statistics

		Summer	Autumn	Winter	Spring
Beginning Time (hours)	Average (EST.)	0657	0816	0850	0719
	S.D.	0.9	1.0	1.0	1.1
	No.	194	172	234	211
End Time (hours)	Average (EST.)	1054	1130	1216	1031
	S.D.	2.5	2.0	2.3	2.2
	No.	194	172	234	211
Duration (hours)	Average	3.9	3.2	3.4	3.2
	S.D.	2.5	2.0	2.3	2.2
	No.	194	172	234	211
Beginning Height (m)	Average	234.3	227.7	218.6	234.9
	S.D.	94.3	86.4	64.7	73.3
	No.	194	172	234	211
Final Height (m)	Average	728.5	697.7	630.2	674.6
	S.D.	225.4	256.5	228.5	220.6
	NO.	194	172	234	211
Rise Rate (m h^{-1})	Average	161.9	177.2	159.6	176.4
	S.D.	100.8	97.3	99.3	102.9
	No.	194	172	234	211
Wind Speed (m s^{-1})	Average	2.0	2.1	2.6	2.5
	S.D.	0.9	0.9	1.1	1.0
	No.	194	172	234	211
Net Radiation (mW cm^{-2})	Average	30.0	22.9	15.2	23.3
	S.D.	15.8	9.9	5.8	12.7
	No.	194	172	234	211

S.D = Standard Deviation; No. = number of days in each season that mixing layers were detected

Table 3.2/18 Range and Direction of Air Movements during Inversions

Distance (Miles)	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total
Direction of Movement	%	%	%	%	%	%	%	%	%	%	%
South Winds	64	24	12								
South West Winds	67	33									
West Winds	68	28	4								
North West Winds	44	43	10	4	1						
North Winds	21	48	12	8	5	1	2	1	2		
North East Winds	19	34	15	12	9	5	2	2	1	1	
East Winds	20	30	17	12	13	6	2				
South East Winds	20	32	17	8	7	8	4	4			
All Directions	27	38	13	8	6	3	2	1	1	1	
Distance (Miles)	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-11
(km)	1.6-16	17.6-32	33.6-48	49.6-64	65.6-80	81.6-96	97.6-112	113.6-128	129.6-144	145.6-160	161.6-176

Note: the direction of movement indicated above is the wind direction at the commencement of the inversion.

Table 3.2/19 Turbulence Categorisation Using EPA Methods

Data for dates 05 April 1991 to 21 October 1998

Stability categorisation scheme: Using: USEPA 10m

	A	B	C	D	E	F	Bad data	Total
Frequency	6.48	4.33	9.68	48.30	23.15	8.07	15112	414008

Stability categorisation scheme: Using: USEPA 49m

	A	B	C	D	E	F	Bad data	Total
Frequency	2.71	4.02	7.64	60.21	22.50	2.92	15404	413716

USEPA 10m vs. USEPA 49m (%)

USEPA 49m	A	B	C	D	E	F	Total
A	2.33	0.20	0.10	0.06	0.00	0.00	2.70
B	2.39	0.95	0.52	0.16	0.00	0.00	4.02
C	1.24	2.24	3.25	0.91	0.00	0.00	7.64
D	0.52	0.94	5.82	38.83	11.08	3.06	60.25
E	0.00	0.00	0.00	7.86	11.03	3.59	22.49
F	0.00	0.00	0.00	0.54	1.02	1.34	2.90
Total	6.49	4.33	9.69	48.36	23.13	8.00	100.00

Table 3.2/20 Lucas Heights Meteorological Tower at 2m dates: 5 April 1991 to 14 June 2004 Dry Bulb Temperature (deg.c); Time (EST)

Month	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400	Average		Extreme	
									Min	Max	Min	Max
January	18.7	18.1	20.8	23.9	24.9	23.2	20.9	19.6	17.3	26.3	10.0	43.2
Standard Dev.	2.3	2.3	2.7	4.0	4.6	4.0	2.9	2.3				
Observations.	4716.	4715.	4709.	4749.	4744.	4748.	4742.	4739.				
February	19.0	18.4	20.4	23.7	24.9	23.4	21.1	19.8	17.5	26.2	10.3	39.9
Standard Dev.	2.4	2.5	2.8	3.6	4.2	3.6	2.7	2.4				
Observations.	4408.	4416.	4412.	4409.	4403.	4401.	4402.	4404.				
March	17.5	16.8	18.5	21.9	23.2	21.9	19.5	18.3	15.9	24.3	7.6	38.7
Standard Dev.	2.3	2.4	2.6	2.8	3.5	3.3	2.4	2.3				
Observations.	4683.	4670.	4699.	4685.	4674.	4700.	4701.	4684.				
April	14.7	14.1	15.4	19.5	21.1	19.5	17.0	15.6	13.1	22.1	6.3	32.6
Standard Dev.	2.4	2.4	2.6	2.5	3.1	3.0	2.3	2.4				
Observations.	4789.	4793.	4799.	4811.	4817.	4834.	4828.	4809.				
May	12.4	11.9	12.6	16.6	18.2	16.7	14.3	13.1	10.6	19.1	0.6	27.9
Standard Dev.	2.6	2.6	2.7	2.5	2.6	2.7	2.4	2.5				
Observations.	4978	4987	4999	4991	4981	4994	4988	4983				
June	10.1	9.5	10.0	14.0	16.0	14.5	12.0	10.8	8.1	16.8	2.2	24.3
Standard Dev.	2.5	2.6	2.6	2.3	2.4	2.4	2.2	2.4				
Observations.	4760.	4761.	4752.	4752.	4751.	4771.	4774.	4775.				
July	9.0	8.5	8.9	13.1	15.2	13.8	11.1	9.8	7.0	16.0	1.5	21.8
Standard Dev.	2.3	2.3	2.4	2.1	2.0	2.2	2.0	2.2				
Observations.	4414.	4416.	4417.	4413.	4405.	4409.	4396.	4393.				
August	9.4	8.6	9.7	14.5	16.7	15.3	12.3	10.6	7.3	17.6	1.6	29.1
Standard Dev.	2.7	2.7	2.9	2.7	3.1	3.3	2.7	2.7				
Observations.	4668.	4668.	4681.	4710.	4711.	4715.	4716.	4709.				
September	11.6	10.7	12.8	17.1	19.0	17.4	14.4	12.7	9.4	20.2	2.8	33.9
Standard Dev.	3.1	3.1	3.3	3.3	4.0	4.0	3.2	3.2				
Observations.	4676.	4679.	4673.	4671.	4672.	4677.	4679.	4673.				
October	13.5	12.6	15.6	19.4	20.8	19.0	16.2	14.6	11.5	22.0	2.8	33.9
Standard Dev.	3.0	2.9	3.1	3.9	4.6	4.3	3.4	2.9				
Observations.	45852.	4567.	4563.	4533.	4525.	4569.	4551.	4575				
November	15.0	14.4	17.5	20.7	21.6	19.9	17.4	16.1	13.3	23.1	6.3	40.2
Standard Dev.	3.0	3.0	3.2	4.3	4.8	4.4	3.5	3.1				
Observations.	4652.	4645.	4624.	4652.	4643.	4638.	4643.	4645.				
December	17.3	16.8	19.8	22.9	23.8	22.3	19.8	18.4	15.8	25.1	8.9	42.8
Standard Dev.	2.7	2.6	3.0	4.2	4.7	4.3	3.3	2.7				
Observations.	4464.	4464.	4443.	4414.	4430.	4446.	4451.	4463.				

Table 3.2/21 Lucas Heights Meteorological Tower at 2m dates: 4 July 2001 to 14 June 2004
Wet Bulb Temperature (deg.c); Time (EST)

Month	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400	Average		Extreme	
									Min	Max	Min	Max
January	16.6	16.2	17.5	18.4	18.6	18.0	17.4	17.1	15.1	19.6	7.7	24.9
Standard Dev.	2.5	2.6	2.5	2.6	2.6	2.4	2.3	2.4				
Observations.	1116.	1116.	1109.	1110.	1102.	1108.	1115.	1116.				
February	17.4	17.1	18.1	19.0	19.4	18.8	18.1	17.8	16.2	20.3	9.9	25.2
Standard Dev.	2.3	2.5	2.4	2.3	2.2	2.2	2.1	2.2				
Observations.	1020.	1020.	1019.	1020.	1017.	1020.	1020.	1020.				
March	15.5	15.1	16.0	17.4	17.8	17.3	16.5	16.0	14.0	18.7	6.7	23.9
Standard Dev.	2.3	2.3	2.2	2.0	2.0	2.0	2.0	2.1				
Observations.	1114.	1105.	1104.	1093.	1079.	1101.	1104.	1103.				
April	13.9	13.5	14.4	16.1	16.4	15.7	14.8	14.2	12.4	17.2	7.0	20.3
Standard Dev.	2.3	2.3	2.4	2.1	2.1	2.2	2.3	2.4				
Observations.	1068.	1068.	1068.	1056.	1055.	1078.	1080.	1080.				
May	10.2	9.8	10.4	12.5	13.0	12.4	11.3	10.7	8.8	13.7	4.1	18.2
Standard Dev.	2.6	2.6	2.8	2.5	2.3	2.4	2.5	2.5				
Observations.	1080.	1080.	1081.	1087.	1091.	1092.	1088.	1084.				
June	8.2	7.6	8.2	10.8	11.6	10.7	9.5	8.8	6.3	12.4	2.9	17.7
Standard Dev.	2.7	2.7	2.6	2.4	2.3	2.4	2.5	2.7				
Observations.	888.	888.	888.	888.	888.	888.	888.	888.				
July	7.0	6.6	6.9	9.4	10.3	9.6	8.2	7.5	5.4	10.9	0.1	14.6
Standard Dev.	2.5	2.5	2.5	2.3	1.9	2.0	2.2	2.3				
Observations.	1079.	1080.	1079.	1079.	1080.	1080.	1080.	1079.				
August	7.0	6.4	7.2	9.8	10.5	9.9	8.6	7.7	5.3	11.3	1.0	17.1
Standard Dev.	2.3	2.2	2.3	2.0	2.0	2.1	2.2	2.3				
Observations.	1116.	1113.	1116.	1113.	1111.	1115.	1116.	1116.				
September	9.3	8.6	10.1	12.0	12.5	12.1	10.9	10.1	7.5	13.4	2.4	20.5
Standard Dev.	2.7	2.7	2.9	2.5	2.5	2.5	2.5	2.6				
Observations.	1080.	1080.	1079.	1072.	1073.	1079.	1080.	1080.				
October	10.5	9.8	11.7	12.9	13.4	12.8	11.9	11.3	8.8	14.3	2.7	20.1
Standard Dev.	2.7	2.7	2.6	2.4	2.4	2.4	2.5	2.6				
Observations.	1092.	1092.	1101.	1087.	1092.	1091.	1092.	1092.				
November	13.1	12.8	14.5	15.4	15.6	15.1	14.2	13.7	11.6	16.7	5.3	22.1
Standard Dev.	2.9	2.9	2.7	2.8	2.7	2.7	2.6	2.7				
Observations.	1064.	1057.	1072.	1077.	1076.	1066.	1068.	1070.				
December	15.3	15.0	16.5	17.2	17.4	16.9	16.3	15.9	14.0	18.5	6.1	24.0
Standard Dev.	2.6	2.6	2.8	2.8	2.7	2.6	2.5	2.5				
Observations.	1116.	1116.	1115.	1114.	1113.	1115.	1116.					

Table 3.2/22 Schedule of Boreholes for Geotechnical Investigation

Borehole No.	Borehole Depth (m)	Collar RL* (m) AHD**
BH1	25.00	157.30
BH5	26.60	156.30
BH6	15.07	155.80
BH7	15.13	156.53
BH8 (+)	15.06	157.29
BH9	15.06	157.08
BH10	15.08	154.38
BH11	15.00	155.12

(+) Borehole practised at the reactor position

*RL = Reduced Level

**AHD = Australian Height Datum

Table 3.2/23 Groundwater Level Measurement

Borehole No. and (date)	Water Level Depth (m) BGL*	Water Level (m) AHD**
BH6 (9/6/98)	9.35	146.45
BH7 (9/6/98)	10.09	146.41
BH8 (11/6/98) (+)	8.25	149.34
BH9 (12/6/98)	10.64	146.46
BH10 (11/6/98)	4.32	150.08
BH11 (12/6/98)	8.17	146.93

(+) Borehole practised at the reactor position.

*BGL = Below Ground Level

** AHD = Australian Height Datum

Table 3.2/24 Summary of Geotechnical Model

Unit	Material / Origin	Description	Consistency/ Strength	Range of Depths to Top of Unit (m)
1	Fill	Sand/ Ripped Sandstone	-	0
2	Topsoil	Clayey Sand	-	0
3	Residual Clay/ Extremely Weathered Sandstone	Clayey Sand/ Sandy Clay	Verify stiff to hard or medium Dense/ Dense	0.15 to 1.00 m
4A	Sandstone	Highly to Slightly Weathered	Low to Medium Rock Strength	1.00 to 2.25 m
4B	Sandstone	Moderately to Slightly Weathered	Medium to High Rock Strength	2.20 to 5.50 m

Table 3.2/25 Summary of Rock Classification

Unit	Sandstone Rock Class
4A	IV
4B	III / II

Table 3.2/26 Seismic Velocities and Dynamic Moduli

Depth Interval (m)	S-Wave Velocity (m/s)	P-Wave Velocity (m/s)	Shear Modulus (MPa)	Young's Modulus (MPa)	Poisson's Ratio (-)	Assumed Density (kN/m^3)
BH6						
0 – 3	300	600	200	100	0.33	22
3 – 8	800	1350	1400	4500	0.23	22
6 – 12	1400	2350	4700	1400	0.22	24
BH8 (+)						
0 – 5	380	850	320	1150	0.58	22
5 – 9	1450	2400	4600	14800	0.21	22
9 – 12	1200	2150	3500	10600	0.27	24
12 – 14	1200	2500	3400	11300	0.35	24
BH10						
0 – 3	250	540	140	500	0.36	22
3 – 6	800	1650	1400	5000	0.35	22
6 – 14	1320	2600	4180	13400	0.33	24
BH11						
0 – 3 m	280	480	170	560	0.24	22
3 – 6 m	800	1500	1400	4850	0.30	22
6 – 14 m	1350	2350	4350	13250	0.25	24

(+) Borehole practised at the reactor position

Table 3.2/27 Dynamic Shear Modulus

Depth	Dynamic Shear Modulus of Rock
Above 3 m	140 MPa to 200 MPa
3 to 8 m	About 1400 MPa
8 to 14 m	3500 MPa to 4700 MPa

Table 3.2/28 Guideline Design Parameters of Rock Units for Shallow Footings and Bored Pile Design

Unit	Description	Allowable End Bearing Pressure (MPa)	Allowable Adhesion for Bored Piles (kPa)	Soil or Rock Mass Modulus (MPa)
3	Residual Soil	200	25	30
4A	Class IV Sandstone	1000 to 3500	100 to 350	100 to 700
4B	Class III / II Sandstone	3500 to 6000	350 to 600	350 to 1200

Table 3.2/29 Design Basis Earthquake for the Reactor Facility

Period (sec)	Acceleration (g)	Amplification A
0.00	0.37	PGA
0.03	0.37	1.00
0.11	0.78	2.60
0.20	0.86	2.87
0.40	0.94	3.13
1.00	0.46	1.53
3.85	0.14	0.47

Table 3.2/30 Environmental Monitoring Schedule, 1999

SAMPLE	LOCATION [(1)]	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Stormwater	MDP+60m: 60 m 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 –5 L 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.	As above.
	Bunds A & B	Monthly.	1 L sampled with polyethylene bottle.	250 mL distilled for tritium analysis. Remainder 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.
Creek water	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.	3L sampled after rain.	Gross α,β analysis on 2L (ISO method). Remaining 1L 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:
Sampling locations are shown on Figures 3.2/30, 3.2/31 and 3.2/32.

Continued next page...

TABLE 30 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. Seven litres sampled from the centre of the bore, avoiding the bottom sediments.	Decanted, evaporated and counted for α,β,γ. 250 mL distilled for tritium analysis. Two litres acidified & stored.
	Sump near Bld 27.	Monthly.	1 L ground water seepage collected with clean sponge.	Distilled for tritium analysis. Immediate 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 three months.	Airborne particulates were collected on 40 cm^2 filter paper using *Ecotech* air sampler at 60 m^3 per hour.	Each quarterly sample divided into four equal parts: one analysed for beryllium by ICPMS, another put aside for a yearly composite, analysed for $^{239/240}Pu$. The 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, from surface.	As above.
	Effluent discharge pipeline.	If indicated by six-monthly dose rate survey.	1 kg, from surface.	As above.
	Bardens and Mill Creeks: Station T2.	Yearly.	1 kg from each creek bed (upstream of their confluence).	As above.

Notes:

1. Sampling locations are shown on **Figures 3.2/30, 3.2/31 and 3.2/32.**

Continued next page...

TABLE 30 Continued...

SAMPLE	**LOCATION** [1]	**FREQUENCY**	**COLLECTION DETAILS**	**SAMPLE PREPARATION & ANALYSIS**
Marine Biological Samples	Potter Point Ocean Outfall	Twice yearly.	Barnacles, algae & fish, near the outfall.	Gamma spectrometry of dried and ground samples prepared in duplicate.
	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 Eberline PRM-7 dose-rate meter. Soil 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 are surveyed using a field dose-rate monitor. Soil is sampled if >3 times background.	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 3.2/30, 3.2/31 and 3.2/32**

End of Tables