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RESEARCH ESTABLISHMENT

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ENVIRONMENTAL SURVEY AT THE LUCAS HEIGHTS RESEARCH LABORATORIES, 1981

by

A.R. WILLIAMS
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March 1983

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ABSTRACT

This survey of environmental conditions in the neighbourhood of the Lucas Heights Research Laboratories during 1981 indicates no significant radiological hazard to the general public. This result is consistent with the fact that controlled airborne and liquid effluent releases throughout the year were maintained within the authorised limits, and also indicates that there were no significant accidental releases. Residual cobalt-60 and zinc-65 activity in the Woronora River has decreased since the cessation of controlled liquid effluent discharges in 1980. No trends are obvious, in any of the data, which could lead to future problems from continued operation on the present scale.

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AAEC; AIR; AUSTRALIA; CESIUM 137; COBALT 60; CONTAMINATION; ENVIRONMENT; EXPERIMENTAL DATA; FISHES; FRESH WATER; GASEOUS WASTES; GROUND WATER; HUMAN POPULATIONS; IODINE 131; LIQUID WASTES; MAN; MILK; OYSTERS; PLANTS; RADIATION DOSES; RADIATION MONITORING; RADIOACTIVITY; RIVERS; SAND; SOILS; TRITIUM

CONTENTS

CONTENTS (cont'd.)

1. INTRODUCTION

Since 1959, a survey has been made by the AAEC of the radioactive content in samples collected in the vicinity of the Lucas Heights Research Laboratories (LHRL)* to ensure that no unacceptable health effects will occur as a result of nuclear research and operation. The results obtained from this survey have been published regularly and details of previous publications are listed in Appendix A.

During the early part of the survey (i.e. throughout the 1960s), readily detectable amounts of weapons test fallout were present in samples collected around Lucas Heights [Giles and Stockdale 1966]. A large program of sampling was therefore required to establish the general levels of radioactivity arising from weapons test fallout, before it became possible to measure additional radioactivity that may have been caused by nuclear operations at Lucas Heights. To establish this general background, samples were collected within a 60 km radius of the site; this expanded program was scaled down in 1970 because the Australian Radiation Laboratory had set up a monitoring system throughout Australia and routinely measured samples from the Sydney region. Results of these surveys were published by various authors in the Australian Journal of Science between 1957 and 1970 [Giles and Dudaitis 1982]. Further reports have been made by the Australian Ionising Radiation Advisory Council [AIRAC 1975] and the United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR 1977]. All of these studies provide a basis for comparison with the results for milk samples reported in the AAEC surveys.

The present monitoring system is designed to detect radioactive contaminants which may have been released from the LHRL, either routinely (under authorisations from the New South Wales Health Commission) or accidentally, and to ensure that such concentrations do not result in intake of radioactivity by, or radiation doses to members of the public in excess of derived limits, in accordance with the recommendations of the International Commission on Radiological Protection (ICRP). These limits are accepted by the Australian advisory body, the National Health & Medical Research Council (NHMRC), which has recently modified its recommendations [NHMRC 1981].

In this report are tabulated the results of measurements taken during 1981.

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* Since 1981, the site formerly called AAEC Research Establishment has been renamed Lucas Heights Research Laboratories.

2. SAMPLE COLLECTION AND PREPARATION

Samples were collected at the sites shown on Figure 1, and the details of collection and sample preparation methods are given in Table 1. [Note: Isotope symbols used in tables are listed in Appendix E.]

3. ANALYTICAL METHODS

Analytical methods have not been modified since the previous survey.

4. RESULTS

4.1 Airborne Releases

The releases of airborne activity during 1981 are given in Appendix B1, and expressed as a fraction of the permissible limit in Appendix B2. In all quarters of the year the authorisation was met.

The site boundary monitoring data for iodine-131 are given in Table 2; at no time was more than a trace detected. The limit of determination of the method is 0.003 Bq m^{-3}, and the derived air concentration for child members of the public [ICRP 1979], i.e. the most sensitive individuals, is ~ 10 Bq m^{-3}, so the peak concentrations were at least 3×10^{-4} below the limit.

The milk monitoring data for caesium-137 and iodine-131 are given in Table 3. At most, a trace of caesium-137 was found, with a limit of determination of 0.003 Bq g^{-1} (fresh weight). This mode of sampling does not distinguish between weapons fallout and local caesium-137, but even if it is all of local origin it is less than 0.006 of the derived limit, based on the assumption that an infant consumes 700 mL of milk per day.

In summary, only negligible traces of airborne activity were found at and beyond the site boundaries.

4.2 Waterborne Releases

The authorised liquid releases to the Metropolitan Water Sewerage and Drainage Board (MWSDB) sewer during 1981 are given in Appendix C. The quantities ranged from 14 to 26 per cent of the quarterly limit.

4.2.1 Drainage waters

Monitoring data for releases via stormwater drainage from the site are given in Table 5, the Little Forest burial ground in Table 6, and the effluent pipeline in Tables 7 and 8. Data for water from the Woronora River are given in Tables 4 and 9. Some data on sources within the Little Forest burial ground are given in Appendices D1 and D2.

A further analysis of soil samples collected from the Little Forest burial ground in earlier years is being undertaken. In one location, for which americium-241 results were recently reported [Hespe 1979b], most of the alpha activity that is over and above naturally occurring levels is attributable to plutonium-241/239. Resuspension of these soils does not constitute a radiological health problem, but the water transport of insoluble oxide particulate is of scientific interest.

Small amounts of tritium (^3H) were detected on several occasions at various locations, however, the average value was 0.6 Bq mL^{-1} and the largest single value was 40 Bq mL^{-1}. The annual limit on intake (ALI) for occupational exposure to ^3H is 3 x 10^9 Bq [ICRP 1979]; if 2 per cent of this is taken as the limit for members of the public [NHMRC 1981] and a daily consumption of 2 L as drinking water [ICRP 1975], then the derived limit is 80 Bq mL^{-1}. Tritium from weapons fallout is insignificant at the limit of determination used here (0.25 Bq mL^{-1}), since it would be of the order of 0.001 Bq mL^{-1} [Calf and Stokes 1979].

Water monitoring results, including results of strontium-90 analysis, from the freshwater reaches of the Woronora River are given in Table 4. River sand results indicate a slight elevation in strontium-90 over background. There are two above-average tritium levels in water recorded for April and June (2.4 and 10.4 Bq mL^{-1}); the stormwater monitoring data for this period (Table 5) failed to indicate any significant uncontrolled releases. The activity in sand is well below the limit applied to beach sand (Section 4.2.3).

Traces of caesium-137, cobalt-60, strontium-90, the ^{238}U + ^{232}Th series and unresolved gamma emitters at 0.5 MeV were also occasionally found in soils and water; however, in comparison with their similarly derived drinking water limits, none were of more significance than tritium, either individually or in sum, and no pathway for human exposure from soil contamination could be defined.

Tables 7 and 8 give data on possible leakages from the liquid effluent pipeline. The highest direct radiation level would exceed the limit only for a person occupying the site for 24 hours every day of the year.

4.2.2 The aquatic food chain

Analyses of oyster and fish samples from the Woronora River are reported in Tables 10 and 11, and for seagrass (*Zostera* sp.) in Table 12. The gross alpha and beta activities in Woronora oysters are not significantly different from those in Hawkesbury oysters and there is no longer any detectable zinc-65. In fish there are still traces of cobalt-60 but these are less than in previous years; the system is obviously approaching background again following the cessation of controlled discharge to the river in 1980. Cobalt-60 in *Zostera* is down on the previous year by 60 per cent but is still present in measurable amounts and this may be the source for the fish.

The exposure model used in previous years to include the aquatic food chain has shown that the small amounts of detected activity are quite insignificant; as these traces disappear, any hazard is likewise disappearing altogether.

4.2.3 Beach sand

Data for Woronora beach sand are given in Table 13. The alpha activity at station E5.9 is down by 75 per cent on the previous year, and the beta activity is down by 35 per cent. At station E1.3, no further change has occurred. At both sites the activity is well below the limit for swimmers using the beaches [Fry 1966].

5. SUMMARY

The controlled airborne and liquid effluent releases from the Lucas Heights Research Laboratories during 1981 complied with the respective authorisations on all occasions. Boundary and off-site monitoring has demonstrated that, radiologically, the air is safe to breathe, the drainage waters are safe to drink, the locally produced food is safe to eat and leisure-time use of the Woronora River is not endangered by radioactive material arising from operations at Lucas Heights. The survey identified two items for internal attention: one was the appearance of some tritium in the Woronora River, presumably resulting from stormwater runoff; the other was the identification of plutonium in surface soil from the Little Forest burial ground.

6. ACKNOWLEDGEMENTS

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TABLE 1

SAMPLE COLLECTION SCHEDULE AND PREPARATION DETAILS

Sample	Station	Frequency	Collection Details	Special Preparations
Stormwater	No. 1 Others	Weekly Quarterly	Sampled by bucket at the outlet of the drain	10 L sample evaporated to dryness and the residue counted
Estuary water	E5.9	Weekly	From surface by bucket	Distilled for tritium
Radioactive iodine in air	T0	Weekly	Collected on Maypacks (charcoal filters)	Gamma spectrometry of Maypacks
Milk	T3	Monthly	Sampled from milk produced by locally grazed cows	Gamma spectrometry of whole milk
Oysters	E7.0, 9.3 Hawkesbury River (control)	Quarterly	Obtained from commercial leases	Opened by commercial openers. Drained on sieve for 5 min. Ashed
Fish	E1.3, 6.4 (or wherever available)	Quarterly	Taken by gill net	Whole fish ashed
Beach sand	E1.3, 5.9	Quarterly	Taken by scoop from top 50 mm in inter-tidal region	Sample ashed and sieved. Sample passing 10 mesh BSS counted for beta-gamma emitters. Sample between 60 and 110 mesh BSS counted for alpha emitters
Zostera	E1.6, 2.4, E4.6, 7.0, E9.3	Quarterly (when available)	Harvested by hand or rake	Ashed
Vegetation	T1; LHRL stormwater outlets	Six-monthly	Cut by hand clippers	Whole unwashed vegetation ashed
Sand/Soil	T0,T1; LHRL stormwater outlets	Six-monthly	Scooped from surface	As for beach sand
Groundwater	T1	Six-monthly	Boreholes pumped dry, allowed to refill and sampled from bottom	10 L sample evaporated to dryness and the residue counted
Creekwater	T2	Six-monthly	Sampled by bucket or bottle	As for groundwater

TABLE 2

RADIOACTIVE IODINE IN AIR, 1981*

Week Ending	^{131}I (Bq m^{-3})	Week Ending	^{131}I (Bq m^{-3})
6 January 1981	n. d.	7 July	trace
14	trace	14	trace
20	n. d.	21	n. d.
27	trace	28	trace
3 February	n. d.	4 August	trace
10	n. d.	12	trace
17	n. d.	18	n. d.
		26	trace
3 March	n. d.		
10	trace	1 September	n. d.
17	trace	7	n. d.
24	n. d.	15	trace
		22	n. d.
2 April	n. d.	29	n. d.
7	trace		
14	trace	6 October	trace
21	trace	13	n. d.
28	trace	20	n. d.
		28	n. d.
5 May	trace		
12	trace	4 November	trace
26	trace	10	n. d.
		17	trace
2 June	trace	24	n. d.
9	trace		
17	trace	8 December	n. d.
23	n. d.	15	n. d.
30	n. d.	21	n. d.

n. d. = not detected

* Three air samplers are located along the eastern boundary of the site, where suburban residences are closest.

TABLE 3

RADIOACTIVITY IN MILK SAMPLES, 1981

Station	Date	Radioactivity ($Bq\ g^{-1}$ fresh weight)	
		^{137}Cs	^{131}I
T3	29 Jan.	trace	n. d.
(Menai)	25 Feb.	trace	n. d.
	31 March	n. d.	n. d.
	1 May	trace	n. d.
	29 May	n. d.	n. d.
	28 June	trace	n. d.
	30 July	n. d.	n. d.
	31 Aug.	trace	n. d.
	28 Sept.	n. d.	n. d.
	3 Nov.	n. d.	n. d.
	27 Nov.	trace	n. d.
	22 Dec.	trace	n. d.

The analytical method used for ^{131}I in milk has a minimum measurable level of 1×10^{-3} $Bq\ g^{-1}$. For ^{137}Cs the minimum measurable level was 3×10^{-4} $Bq\ g^{-1}$.

n. d. = not detectable

TABLE 4

RADIOACTIVITY IN FRESHWATER SECTION OF WORONORA RIVER, 1981

Station	Date	Radioactivity		
		Sand	Water	
		^{90}Sr (Bq g^{-1})	^{90}Sr (Bq L^{-1})	^{3}H (Bq mL^{-1})
Woronora River at Heathcote Road crossing (upstream of Lucas Heights)	28.1	< 0.0001	0.011	< 0.25
	26.2	0.0002	< 0.014	--
	27.3	0.0001	0.011	< 0.25
	28.4	0.0001	< 0.008	< 0.25
	28.5	< 0.0001	0.009	< 0.25
	30.6	< 0.0001	0.018	< 0.25
	31.7	0.0001	0.010	< 0.25
	11.8	0.0002	< 0.002	< 0.25
	3.9	0.0001	0.008	< 0.25
	27.11	0.0001	< 0.004	< 0.25
Woronora River at the point of Lucas Heights' drainage entrance	28.1	0.0001	0.008	< 0.25
	26.2	0.0003	0.011	--
	27.3	0.0004	0.021	< 0.25
	28.4	0.0004	< 0.008	2.4
	28.5	0.0002	0.014	0.5
	30.6	0.0004	0.018	10.4
	31.7	0.0005	0.008	--
	11.8	0.0002	0.006	< 0.25
	2.9	0.0001	0.01	< 0.25
	27.11	0.0002	0.009	--

-- = not measured

TABLE 5

RADIOACTIVITY IN SAMPLES FROM STORMWATER OUTLETS, 1981

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ fresh weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	^{3}H ($Bq\ mL^{-1}$)	K ($\mu g\ g^{-1}$)
Drain behind Building 1	20.3	water	--	--	--	< 0.25	--
	24.7	"	--	--	--	1.52	--
	15.10	"	--	--	--	3.14	--
	21.12	"	--	--	--	0.44	--
Drain rear of Building 9	20.3	soil	0.5	0.3	$^{238}U+^{232}Th$ series = trace	--	1600
	24.7	water	--	--	--	< 0.25	--
	15.10	"	--	--	--	< 0.25	--
	15.10	soil	0.4	0.3	$^{238}U+^{232}Th$ series = trace	--	1300
	21.12	water	--	--	--	< 0.25	--
Drain on road at west fence	24.7	water	--	--	--	< 0.25	--
	24.7	soil	0.2	0.1	$^{238}U+^{232}Th$ series = trace	--	400
	15.10	"	0.2	0.05	" " " "	--	300
	21.12	"	0.1	0.07	" " " "	--	400
Drain opposite substation	20.3	soil	0.2	0.07	$^{238}U+^{232}Th$ series = trace	--	500
	15.10	"	0.6	0.2	" " " "	--	800
Drain at boom gate	20.3	soil	0.2	0.08	$^{238}U+^{232}Th$ series = trace	--	100
	24.7	"	0.1	0.06	" " " "	--	200
	24.7	water	--	--	--	< 0.25	--
	15.10	soil	0.1	0.06	$^{238}U+^{232}Th$ series = trace	--	300
	21.12	"	0.1	0.07	" " " "	--	200
Drain west of test compound	20.3	soil	0.8	0.4	$^{238}U+^{232}Th$ series = trace	--	900
	24.7	"	0.6	0.7	" " " "	--	900
	24.7	water	--	--	--	< 0.25	--
	15.10	soil	0.9	0.9	$^{238}U+^{232}Th$ series = trace	--	1200
	21.12	"	0.4	0.8	" " " "	--	600
Drain near yellowcake store	20.3	soil	0.6	0.2	$^{238}U+^{232}Th$ series = trace	--	900
	24.7	"	0.2	0.2	" " " "	--	400
	15.10	"	0.2	0.2	" " " "	--	400
	15.10	water	--	--	--	< 0.25	--
	21.12	soil	0.2	0.3	$^{238}U+^{232}Th$ series = trace	--	800
Drain at Fermi Street	20.3	soil	0.9	0.2	$^{238}U+^{232}Th$ series = trace	--	700
	20.3	water	--	--	--	< 0.25	--
	24.7	soil	0.3	0.3	$^{238}U+^{232}Th$ series = trace	--	1000
	15.10	"	0.4	0.2	" " " "	--	600
	15.10	water	--	--	--	0.32	--
	21.12	"	--	--	--	< 0.25	--
	21.12	soil	0.3	0.2	$^{238}U+^{232}Th$ series = trace	--	400

TABLE 5 (Cont'd.)

Station	Date	Sample	Radioactivity (Bq g^{-1} fresh weight)			^{3}H (Bq mL^{-1})	K (μg g^{-1})
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters		
Drain opposite Building 23	20.3	soil	0.7	0.3	^{60}Co = trace ^{238}U+^{232}Th series = trace	--	900
	24.7	"	0.7	0.3	" " " "	--	700
	24.7	water	--	--	--	0.45	--
	15.10	soil	0.6	0.4	^{60}Co = trace ^{238}U+^{232}Th series = trace	--	1000
	15.10	water	--	--	--	0.26	--
	21.12	soil	0.4	0.3	^{60}Co = trace ^{238}U+^{232}Th series = trace	--	900
Drain No. 1 opposite Strassman Crescent	20.3	soil	0.5	0.2	^{238}U+^{232}Th series = trace	--	1100
	20.3	water	--	--	--	< 0.25	--
	24.7	"	--	--	--	0.97	--
	24.7	soil	0.2	0.1	^{238}U+^{232}Th series = trace	--	500
	15.10	"	0.5	0.2	" " " "	--	1000
	15.10	water	--	--	--	< 0.25	--
	21.12	"	--	--	--	< 0.25	--
	21.12	soil	0.2	0.2	^{238}U+^{232}Th series = trace	--	700
Drain No. 2 opposite Strassman Crescent	20.3	soil	0.5	0.3	^{60}Co = trace ^{238}U+^{232}Th series = trace	--	900
	24.7	"	0.4	0.4	^{60}Co = 0.06 ^{238}U+^{232}Th series = trace	--	1100
	24.7	water	--	--	--	5.96	--
	15.10	soil	0.6	0.4	^{137}Cs = 0.04 ^{60}Co = 0.05 ^{238}U+^{232}Th series = trace	--	1400
	21.12	"	0.3	0.3	^{60}Co = trace ^{238}U+^{232}Th series = trace	--	900
Drain rear of Building 20	20.3	soil	0.4	0.06	^{238}U+^{232}Th series = trace	--	400
	24.7	"	0.2	0.05	" " " "	--	400
	24.7	water	--	--	--	< 0.25	--
	15.10	soil	0.2	0.07	^{238}U+^{232}Th series = trace	--	500
	21.12	"	0.1	0.1	" " " "	--	700

TABLE 5 (Cont'd.)

Station	Date	Sample	Radioactivity (Bq L^{-1}) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	^{3}H (Bq mL^{-1})	K (µg g^{-1})
LHRL stormwater outlet No. 1 near south gate	6.1	water	0.08	0.2	n. d.	0.3	--
	12.1	"	--	--	--	0.9	--
	20.1	"	0.05	0.06	n. d.	< 0.25	--
	27.1	"	0.07	0.1	n. d.	0.6	--
	3.2	"	0.6	1.6	^{137}Cs = 0.2 ^{60}Co = 0.1 ^{238}U+^{232}Th series = trace	39.8	--
	10.2	"	0.07	0.1	n. d.	0.4	--
	16.2	"	0.06	0.2	n. d.	0.5	--
	24.2	"	0.1	0.2	n. d.	0.6	--
	2.3	"	0.2	0.1	n. d.	2.1	--
	9.3	"	0.1	0.2	n. d.	2.1	--
	16.3	"	0.2	0.2	n. d.	1.3	--
	23.3	"	0.09	0.1	n. d.	0.9	--
	2.4	"	0.2	0.2	n. d.	1.6	--
	6.4	"	0.1	0.2	n. d.	1.0	--
	14.4	"	0.2	0.2	n. d.	0.8	--
	21.4	"	0.06	0.2	n. d.	1.9	--
	28.4	"	0.5	0.5	n. d.	7.2	--
	4.5	"	0.2	0.1	n. d.	< 0.25	--
	19.5	"	0.2	0.1	n. d.	0.5	--
	22.5	"	0.2	0.2	n. d.	< 0.25	--
	2.6	"	0.2	0.2	n. d.	0.5	
	9.6	"	0.1	0.4	n. d.	1.1	--
	15.6	"	0.1	0.2	n. d.	0.6	--
	24.6	"	0.3	0.2	n. d.	0.9	--
	29.6	"	0.2	0.2	n. d.	1.0	--
	7.7	"	0.2	0.2	n. d.	0.9	--
	14.7	"	0.2	0.2	n. d.	0.9	--
	20.7	"	0.9	0.3	n. d.	1.6	--
	28.7	"	0.3	0.1	n. d.	< 0.25	--
	3.8	"	0.2	0.1	n. d.	0.5	--
	11.8	"	0.1	0.2	n. d.	0.7	--
	17.8	"	0.03	0.2	n. d.	1.1	--
	25.8	"	0.2	0.09	n. d.	0.4	--
	31.8	"	0.2	0.07	n. d.	< 0.25	--

TABLE 5 (Cont'd.)

Station	Date	Sample	Radioactivity (Bq L^{-1}) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	^{3}H (Bq mL^{-1})	K (µg g^{-1})
LHRL stormwater outlet No. 1 near south gate (cont'd.)	8.9	water	--	--	--	4.0	--
	14.9	"	--	--	--	3.5	--
	22.9	"	0.08	0.4	n. d.	2.4	--
	28.9	"	0.1	0.2	n. d.	0.6	--
	7.10	"	0.03	0.05	n. d.	< 0.25	--
	14.10	"	0.08	0.2	n. d.	0.8	--
	21.10	"	0.2	0.2	n. d.	0.3	--
	26.10	"	0.2	0.2	n. d.	0.5	--
	4.11	"	0.2	0.2	n. d.	0.3	--
	10.11	"	0.1	0.2	n. d.	0.6	--
	17.11	"	0.06	0.2	n. d.	1.1	--
	23.11	"	0.1	0.2	n. d.	0.5	--
	7.12	"	0.3	0.2	n. d.	0.9	--
	15.12	"	0.1	0.2	n. d.	0.5	--
	21.12	"	0.1	0.2	n. d.	0.8	--
			Radioactivity (Bq g^{-1} fresh weight)				
LHRL stormwater outlet No. 2 near south gate	20.3	soil	0.4	0.5	^{137}Cs = 0.05 ^{60}Co = 0.09 ^{238}U+^{232}Th series = trace	--	500
	15.10	"	1.7	1.8	^{137}Cs = 0.5 ^{60}Co = 0.7 ^{238}U+^{232}Th series = trace	--	1300
	15.10	water	--	--	--	0.26	--
	21.12	"	--	--	--	< 0.25	--
	21.12	soil	0.6	0.7	^{137}Cs = 0.2 ^{60}Co = 0.1 ^{238}U+^{232}Th series = trace	--	1000
20 m from LHRL stormwater outlet No. 1	8.9	soil	1.1	0.7	^{137}Cs = 0.1 ^{60}Co = 0.2 ^{238}U+^{232}Th series = trace	--	800

TABLE 5 (Cont'd.)

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ fresh weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	^{3}H ($Bq\ mL^{-1}$)	K ($\mu g\ g^{-1}$)	^{90}Sr (*)
Water pool across road from storm-water outlet No. 1.	28.1	water	--	--	--	0.9	--	0.019
	28.1	soil	--	--	--	--	--	0.0013
	26.2	soil	--	--	--	--	--	0.0007
	26.2	water	--	--	--	--	--	0.04
	20.3	water	--	--	--	1.8	--	0.015
	20.3	soil	0.6	0.3	$^{238}U+^{232}Th$ series = trace	--	400	0.001
	20.3	vegetation	0.01	< 0.01	" " " "	--	4400	--
	28.4	water	--	--	--	2.3	--	0.06
	28.4	soil	--	--	--	--	--	0.0007
	28.5	soil	--	--	--	--	--	0.0013
	28.5	water	--	--	--	1.0	--	0.072
	30.6	water	--	--	--	0.6	--	0.009
	30.6	soil	--	--	--	--	--	0.0015
	31.7	soil	--	--	--	--	--	0.0013
	31.7	water	--	--	--	--	--	0.047
	11.8	water	--	--	--	0.6	--	0.034
	11.8	soil	--	--	--	--	--	0.0014
	2.9	soil	--	--	--	--	--	0.0021
	2.9	water	--	--	--	1.2	--	0.033
	15.10	water	--	--	--	0.4	--	--
	15.10	soil	1.0	0.04	$^{238}U+^{232}Th$ series = trace	--	900	--
	15.10	vegetation	0.01	< 0.01	0.5 MeV < 0.01 $^{238}U+^{232}Th$ series = trace	--	5600	--
	27.11	water	--	--	--	0.6	--	0.044
	27.11	soil	--	--	--	--	--	0.0014
	21.12	vegetation	0.03	< 0.01	0.5 MeV = trace $^{238}U+^{232}Th$ series = trace	--	6200	--
	21.12	water	--	--	--	0.5	--	--

The gamma-ray peaks detected at approximately 0.5 MeV could be ^{7}Be (0.48 MeV), ^{103}Ru (0.5 MeV) or ^{106}Ru (0.51 MeV); ^{7}Be is a cosmic-ray produced spallation product; and ^{103}Ru and ^{106}Ru are fission products.

In column 6 of this table, $Bq\ g^{-1}$ refers to the number of disintegrations per second per gram at the energies indicated.

n. d. = not detected
-- = not measured
(*) = $Bq\ g^{-1}$ for sand and $Bq\ L^{-1}$ for water.

TABLE 6

RADIOACTIVITY IN SAMPLES TAKEN FROM CREEKS NORTH OF LITTLE FOREST BURIAL GROUND, 1981

SAND:

Station	Date	Radioactivity ($Bq\ g^{-1}$ dry weight)			K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	
Barden Creek above junction with Mill Creek	22.12	0.4	0.13	Trace ^{238}U + ^{232}Th series	900
Mill Creek above junction with Barden Creek	22.12	0.6	0.07	Trace ^{238}U + ^{232}Th series	300

WATER:

Station	Date	Radioactivity ($Bq\ L^{-1}$)			^{3}H ($Bq\ mL^{-1}$)
		Gross Alpha	Gross Beta (incl. ^{40}K)	Gamma Emitters	
Barden Creek above junction with Mill Creek	22.12	0.02	0.01	n. d.	< 0.25
Mill Creek above junction with Barden Creek	22.12	0.02	0.01	n. d.	< 0.25

n. d. = not detected

TABLE 7

GAMMA SURVEY - EFFLUENT DISCHARGE PIPELINE, 1981

Surveys of exposed portions of pipeline between the LHRL and the sewer connection using an Ericsson type 1368A field ratemeter.

Date	Location	Dose Rate ($\mu Sv\ h^{-1}$)
2.9	Joint No. 9	0.8
2.9	All other pipe sections	< 0.5
2.9	Soil below joints	< 0.3

TABLE 8

RADIOACTIVITY IN SAMPLES TAKEN NEAR EFFLUENT DISCHARGE PIPELINE, 1981

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ dry weight)			^{3}H ($Bq\ mL^{-1}$)	K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters		
Near scour valve No. 1	2.9	sand	0.4	0.03	^{238}U + ^{232}Th series = trace	--	500
	2.9	water	--	--	--	0.67	--
River at point where crossed by effluent discharge pipe	2.9	sand	0.3	0.05	^{238}U + ^{232}Th series = trace	--	300
	2.9	water	--	--	--	< 0.25	--

TABLE 9

TRITIUM IN WORONORA WATER SAMPLES AT STATION E5.9, 1981

Date	Tritium ($Bq\ mL^{-1}$)	Date	Tritium ($Bq\ mL^{-1}$)	Date	Tritium ($Bq\ mL^{-1}$)
2 Jan.	< 0.25	22 May	< 0.25	28 Sept.	< 0.25
12 Jan.	↑	29 May	↑	2 Oct.	↑
16 Jan.		5 June		7 Oct.	
23 Jan.		11 June		14 Oct.	
30 Jan.		18 June		21 Oct.	
6 Feb.		25 June		4 Nov.	
12 Feb.		29 June		10 Nov.	
19 Feb.		3 July		17 Nov.	
27 Feb.		9 July		23 Nov.	
6 March		17 July		27 Nov.	
16 March		28 July		7 Dec.	
20 March		31 July		15 Dec.	↓
27 March		11 Aug.		23 Dec.	< 0.25
3 April		14 Aug.			
10 April		21 Aug.			
16 April		28 Aug.			
24 April		4 Sept.		Average	< 0.25
4 May	↓	11 Sept.	↓		
8 May	< 0.25	18 Sept.	< 0.25		

Derived limiting concentration (d.l.c.) taken from ICRP [1979]

d.l.c. = 80 $Bq\ mL^{-1}$ (if taken as drinking water)

TABLE 10

RADIOACTIVITY IN WORONORA AND HAWKESBURY OYSTERS, 1981

Station	Date	Radioactivity ($Bq\ g^{-1}$ fresh weight)			K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	^{65}Zn	
E7.0	1 April	0.012	0.006	n.d.	2800
E9.3	23 March	0.006	0.005	n.d.	2800
	14 July	0.010	0.007	n.d.	2800
	28 Sept.	0.003	< 0.006	n.d.	4000
	14 Dec.	0.009	< 0.007	n.d.	4800
Average		0.007	< 0.007		
Hawkesbury River	23 March	0.007	0.009	n.d.	2500
	6 July	0.010	0.009	n.d.	3000
	21 Sept.	0.005	< 0.006	n.d.	4300
Average		0.007	< 0.008		
Oyster shell composite (Woronora)	1981	0.008	0.014	n.d.	200

TABLE 11

RADIOACTIVITY IN WORONORA FISH, 1981

Station & Variety	Date	Radioactivity ($Bq\ g^{-1}$ fresh weight)			K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	
E0					
Mullet	22 April	0.014	0.006	Trace ^{60}Co Trace ^{238}U + ^{232}Th	2900
	31 July	0.021	< 0.004	Trace ^{238}U + ^{232}Th	3100
	17 Sept.	0.015	< 0.005	Trace ^{60}Co Trace ^{238}U + ^{232}Th	3200
Average		0.017	< 0.005		
E6.6					
Mullet	23 April	0.014	< 0.008	Trace ^{238}U + ^{232}Th	3100
	5 Aug.	0.017	< 0.004	Trace ^{238}U + ^{232}Th	3000
	29 Oct.	0.016	< 0.005	Trace ^{238}U + ^{232}Th	3200
Average		0.016	< 0.006		

TABLE 12

RADIOACTIVITY IN WORONORA *ZOSTERA* SAMPLES, 1981

Station	Date	Radioactivity (Bq g^{-1} fresh weight)				K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters		
				^{60}Co	^{238}U + ^{232}Th Series	
E1.3	29 April	0.04	0.03	0.009	trace	3400
	30 July	0.08	0.03	0.007	trace	4500
	23 Sept.	0.04	0.03	0.010	trace	4000
E2.4	29 April	0.04	0.02	0.007	trace	4900
	23 Sept.	0.06	0.21	0.009	trace	5100
E4.6	30 July	0.05	0.05	trace	trace	4300
	23 Sept.	0.09	0.05	n. d.	trace	3700

n. d. = not detected

TABLE 13

RADIOACTIVITY IN WORONORA BEACH SAND, 1981

Station	Date	Radioactivity ($Bq\ g^{-1}$ dry weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	K ($\mu g\ g^{-1}$)
E1.3	29 April	0.39	0.05	trace $^{238}U + ^{232}Th$	200
	30 July	0.54	0.02	trace $^{238}U + ^{232}Th$	300
	23 Sept.	0.64	0.05	n. d.	300
E5.9	29 April	0.07	0.11	trace $^{238}U + ^{232}Th$	300
	30 July	0.08	0.11	n. d.	300
	23 Sept.	0.05	0.11	trace $^{238}U + ^{232}Th$	200
Average (all samples)		0.30	0.08		
d.l.c.		111	92.5		
Average fraction of d.l.c.		3.1×10^{-3}	8.1×10^{-4}		

Derived limiting concentration (d.l.c.) taken from Fry [1966].

n. d. = not detected

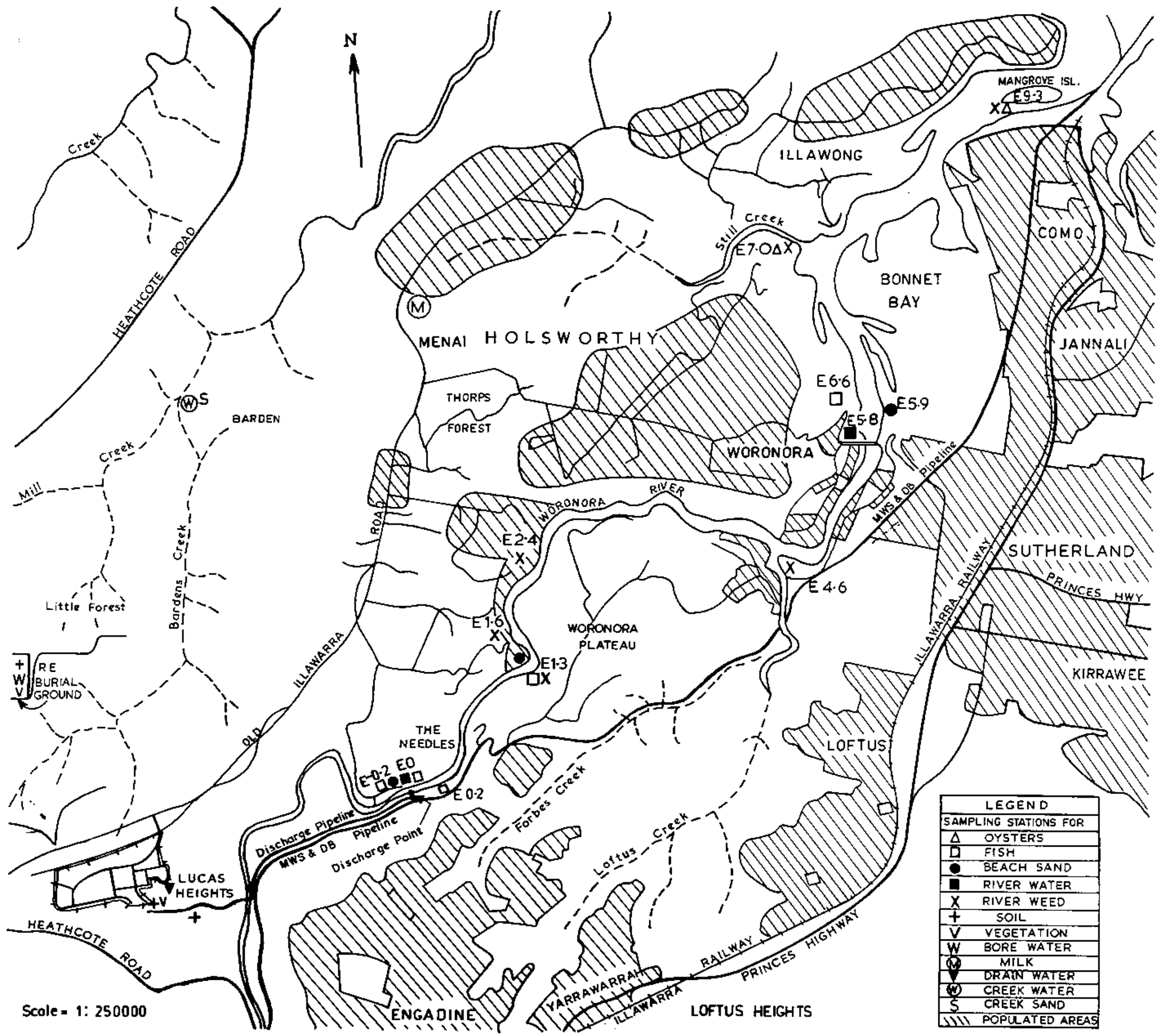

FIGURE 1. LUCAS HEIGHTS DISTRICT - LOCATION OF SAMPLING STATIONS

APPENDIX A

PREVIOUS ENVIRONMENTAL SURVEY REPORTS

Giles, M.S. and Stockdale, J.A. [1966] - Results of the Lucas Heights Biological Survey, December 1959 to December 1964. AAEC/E151.

Cook, J.E., Dudaitis, A. and Giles, M.S. [1969] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1965, 1966 and 1967. AAEC/E151 Supplement No. 1.

Cook, J.E. and Dudaitis, A. [1970] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1968. AAEC/E151 Supplement No. 2.

Cook, J.E. and Dudaitis, A. [1970] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1969. AAEC/E151 Supplement No. 3.

Conway, N.F. and Dudaitis, A. [1972] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for Period January - July 1970. AAEC/E246.

Dudaitis, A. [1973] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for Period August 1970 to December 1971. AAEC/E271.

Dudaitis, A. [1974] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1972. AAEC/E301.

Davy, D.R. and Dudaitis, A. [1974] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1973. AAEC/E335.

Davy, D.R. and Dudaitis, A. [1976] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1974. AAEC/E375.

Hespe, E.C. [1979a] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1975, 1976 and 1977. AAEC/E467.

Hespe, E.C. [1979b] - Results of the 1978 Environmental Survey at the AAEC Research Establishment, Lucas Heights. AAEC/E494.

Giles, M.S. and Dudaitis, A. [1980] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1979. AAEC/E508.

Giles, M.S. and Dudaitis, A. [1982] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1980. AAEC/E542.

APPENDIX B1

AIRBORNE RADIOACTIVITY RELEASES, 1981

	Gross α (kBq)	^{131}I (MBq)	^{3}H (GBq)	^{41}Ar (TBq)	Other β/γ (MBq)	Fission Product Noble Gases (TBq)
Quarter No. 1						
Bld. 2	< 10	1.7×10^3	--	--	< 10	60
15	< 10	< 10	7.9×10^2	16	19	--
19	19	< 10	--	--	< 10	--
23A	< 10	3.8×10^3	--	--	< 10	--
23B	< 10	< 10	--	--	< 10	--
41	< 10	< 10	--	--	< 10	--
Quarter No. 2						
Bld. 2	72	3.4×10^3	--	--	10	60
15	10	< 10	8.6×10^2	17	44	--
19	15	< 10	--	--	16	--
23A	22	1.6×10^3	--	--	< 10	--
23B	< 10	< 10	--	--	< 10	--
41	< 10	< 10	--	--	< 10	--
Quarter No. 3						
Bld. 2	< 10	1.3×10^3	--	--	< 10	20
15	< 10	< 10	4.7×10^2	17	2.0×10^2	--
19	17	< 10	--	--	< 10	--
23A	< 10	2.0×10^3	--	--	< 10	--
23B	< 10	< 10	--	--	< 10	--
41	< 10	< 10	--	--	< 10	--
Quarter No. 4						
Bld. 2	< 10	1.1×10^3	--	--	< 10	15
15	< 10	< 10	5.4×10^2	18	1.2×10^2	--
19	< 10	< 10	--	--	< 10	--
23A	11	1.9×10^3	--	--	< 10	--
23B	< 10	< 10	--	--	< 10	--
41	< 10	< 10	--	--	< 10	--

APPENDIX B2

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS EXPRESSED AS FRACTIONS OF PERMITTED QUARTERLY POINT DISCHARGE FOR 1981

	Gross α	^{131}I	^{3}H	^{41}Ar	Other β/γ	Fission Product Noble Gases
Quarter No. 1						
Bld. 2	$<1.5\times10^{-5}$	2.6×10^{-2}			$<6.3\times10^{-6}$	0.4
15	$<3.0\times10^{-4}$	$<6.3\times10^{-4}$	6.1×10^{-3}	0.59	2.9×10^{-4}	
19	5.8×10^{-5}	$<3.0\times10^{-4}$			$<1.5\times10^{-5}$	
23A	$<6.3\times10^{-4}$	0.24			$<3.0\times10^{-4}$	
23B	$<1.5\times10^{-3}$	$<6.3\times10^{-4}$			$<6.3\times10^{-4}$	
41	$<3.0\times10^{-5}$	$<6.3\times10^{-4}$			$<1.5\times10^{-5}$	
Quarter No. 2						
Bld. 2	1.1×10^{-4}	5.2×10^{-2}			6.3×10^{-6}	0.4
15	3.0×10^{-4}	$<6.3\times10^{-4}$	6.6×10^{-3}	0.63	6.7×10^{-4}	
19	4.5×10^{-4}	$<3.0\times10^{-4}$			2.4×10^{-5}	
23A	1.4×10^{-3}	0.1			$<3.0\times10^{-4}$	
23B	$<1.5\times10^{-3}$	$<6.3\times10^{-4}$			$<6.3\times10^{-4}$	
41	$<3.0\times10^{-5}$	$<6.3\times10^{-4}$			$<1.5\times10^{-5}$	
Quarter No. 3						
Bld. 2	$<1.5\times10^{-5}$	2×10^{-2}			$<6.3\times10^{-6}$	0.1
15	$<3.0\times10^{-4}$	$<6.3\times10^{-4}$	3.6×10^{-3}	0.63	3.0×10^{-3}	
19	5.2×10^{-5}	$<3.0\times10^{-4}$			$<1.5\times10^{-5}$	
23A	$<6.3\times10^{-4}$	0.13			$<3.0\times10^{-4}$	
23B	$<1.5\times10^{-3}$	$<6.3\times10^{-4}$			$<6.3\times10^{-4}$	
41	$<3.0\times10^{-5}$	$<6.3\times10^{-4}$			$<1.5\times10^{-5}$	
Quarter No. 4						
Bld. 2	$<1.5\times10^{-5}$	1.6×10^{-2}			$<6.3\times10^{-6}$	0.09
15	$<3.0\times10^{-4}$	$<6.3\times10^{-4}$	4.2×10^{-3}	0.67	1.8×10^{-3}	
19	$<3.0\times10^{-5}$	$<3.0\times10^{-4}$			$<1.5\times10^{-5}$	
23A	6.9×10^{-4}	0.12			$<3.0\times10^{-4}$	
23B	$<1.5\times10^{-3}$	$<6.3\times10^{-4}$			$<6.3\times10^{-4}$	
41	$<3.0\times10^{-5}$	$<6.3\times10^{-4}$			$<1.5\times10^{-5}$	

APPENDIX C

RADIOACTIVITY DISCHARGED TO THE MWSDB SEWER DURING 1981

	Radioisotope Measured (MBq)			Percentage of Authorised Limit**
	* α_μ	^3H	† β_μ	
Quarter No. 1	12.2	2.48×10^5	3.3×10^2	20
Quarter No. 2	30	1.83×10^5	3.5×10^2	26
Quarter No. 3	18	7.2×10^4	1.3×10^2	14
Quarter No. 4	28	9.3×10^4	2.4×10^2	21

* α_μ = a mixture of unidentified α-emitting nuclides taken as being all ^{226}Ra (i.e. the worst possible case) in calculating percentage of authorised limit.

† β_μ = a mixture of unidentified β-emitting nuclides taken as being all ^{90}Sr (i.e. the worst possible case) when calculating the percentage of authorised limit.

** = In the case of sewer discharge, the authorised limit is outlined in the regulations to the NSW Radioactive Substances Act published in Government Gazette No. 136, 19 September 1980.

APPENDIX D1

RADIOACTIVITY IN SAMPLES OF SOIL AND VEGETATION FROM LITTLE FOREST BURIAL GROUND, 1981

Location	Sample	Date	Radioactivity (Bq g^{-1} fresh weight)					K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters			
					0.5 MeV	^{60}Co	$^{238}U + ^{232}Th$	
Near trench 1-5	soil	1 July	0.68	0.63	n. d.	trace	trace	2900
Near trench 56-57	soil	1 July	3.15	0.71	n. d.	trace	trace	3900
Near trench 59-60	acacia	1 July	0.02	0.02	n. d.	trace	trace	2400
Near trench 68-69	soil	1 July	1.01	0.85	n. d.	n. d.	trace	4400
Near trench 70-71	acacia	1 July	0.03	0.10	0.02	0.01	trace	2300
Near trench 72-73	soil	1 July	0.96	0.81	n. d.	trace	trace	2600

n. d. = not detected

APPENDIX D2

RADIOACTIVITY IN SAMPLES OF GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1981

Bore Hole No.	Date	Sediment ($Bq\ g^{-1}$)			^{3}H ($Bq\ mL^{-1}$)
		Gross Alpha	Gross Beta*	Gamma Emitters	
BH 1	1 July	2.1	0.6	n. d.	< 0.25
2	"	2.6	0.9	n. d.	< 0.25
3	"	4.1	1.1	n. d.	< 0.25
4	"	3.0	0.8	n. d.	< 0.25
5	dry				
6	1 July	2.8	0.8	n. d.	< 0.25
10	"	0.4	0.6	n. d.	0.8
OS 1	"	0.1	0.2	n. d.	< 0.25
2	"	0.4	0.6	n. d.	4.0
3	"	3.1	4.3	n. d.	10.1
BH A	"	0.2	0.2	n. d.	< 0.25
B	"	1.0	1.4	n. d.	< 0.25
C	"	0.06	0.2	n. d.	< 0.25
D	"	0.1	0.2	Trace ^{238}U + ^{232}Th series	< 0.25
E	"	0.1	0.2	n. d.	< 0.25

* includes ^{40}K contribution

n. d. = not detected

APPENDIX E

LIST OF ISOTOPE SYMBOLS USED IN TABLES OF SURVEY RESULTS

Symbol	Name
^{41}Ar	argon-41
^{7}Be	beryllium-7
^{60}Co	cobalt-60
^{137}Cs	caesium-137
^{3}H	tritium
^{131}I	iodine-131
K	potassium (stable)
^{40}K	potassium-40
^{226}Ra	radium-226
^{103}Ru	ruthenium-103
^{106}Ru	ruthenium-106
^{90}Sr	strontium-90
^{232}Th	thorium-232
^{238}U	uranium-238
^{65}Zn	zinc-65