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RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

ENVIRONMENTAL SURVEY AT THE AAEC RESEARCH ESTABLISHMENT LUCAS HEIGHTS - RESULTS FOR 1979

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ABSTRACT

This report presents the results of the environmental survey at the AAEC Research Establishment, Lucas Heights, during 1979. They show that the only radioactivity detected which could be of AAECRE origin and which could also be ingested by humans was due to tritium. The maximum credible dose which a member of the public could receive from this radioactivity is calculated to be one ten thousandth of the derived working limit consistent with the latest recommendations of the International Commission on Radiological Protection.

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CESIUM 137; COBALT 60; ENVIRONMENT; ESTUARIES; FISHES; GRAMINEAE; GROUND WATER; HUMAN POPULATIONS; MAN; MARINE DISPOSAL; MAXIMUM PERMISSIBLE CONCENTRAT; MILK; OYSTERS; RADIATION DOSES; RADIOACTIVE WASTE DISPOSAL; RADIOACTIVITY; SAMPLING; SAND; TRITIUM; UNDERGROUND DISPOSAL; ZINC 65; AUSTRALIA; AAEC; RADIATION MONITORING

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1. INTRODUCTION

Since 1959 a survey of the content of radioactivity in samples collected from the environs of Lucas Heights has been conducted to ensure that no unacceptable health effects have occurred as a result of operations at the AAEC Research Establishment. The results obtained during the survey have been published regularly and details of prior publications are included as a list 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. A large program of sampling was required to establish the general level of 'background' radioactivity arising from this weapons test fallout in order to measure any additional radioactivity which may have been caused by Lucas Heights operations.

To establish this general background, samples were collected over a 60 km radius but 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, Vol. 19-32. Further reports have appeared in AIRAC No.2 [1975] and UNSCEAR [1977]. All these studies provide a basis for comparison with the results for milk samples reported in the AAEC series of reports.

Present monitoring is designed to detect radioactive contaminants which may have been released from the Lucas Heights research laboratories, either routinely (under authorisations from the NSW health authorities), or accidentally, and to ensure that such concentrations do not result in intake of radioactivity or radiation doses to members of the public in excess of derived working limits consistent with the recommendations of the International Commission on Radiological Protection (ICRP). These are accepted by the Australian authority, the National Health and Medical Research Council (NHMRC).

This report lists the results of measurements taken during 1979 and calculates the maximum credible dose (see Section 6) which a member of the public could have received.

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 Appendix A.

3. ANALYTICAL METHODS

Analytical methods which have been modified and methods which have been introduced since the previous survey are described in Appendix B.

4. RESULTS

The results of measurements taken during 1979 are presented in Tables 3 to 11.

5. DISCUSSION OF RESULTS

5.1 Annual Limits of Intake for Tritium (^3H)

The ICRP has recommended new criteria for limiting uptake of radionuclides and given limits for selected nuclides and occupational exposure in ICRP publication 30 part 1 [ICRP 1979]. In the case of ^3H, the annual limit of intake (ALI) for occupational exposure has been set by the ICRP at 3×10^9 Bq. As annual limits for members of the public in both the ICRP and NHMRC recommendations are one tenth of those for occupational exposure, the ALI for a member of the public is assumed to be 3×10^8 Bq. If one assumes a daily intake of water of 3 L as for Reference Man in ICRP publication 23 [ICRP 1975] and averages the ALI over the year, the derived working limit for drinking water concentration becomes 274 Bq mL^{-1}.

5.2 Woronora Samples (Tables 3-7)

None of the food items collected from the Woronora estuary during 1979 contained detectable levels of radionuclides known to have originated at the Research Establishment. Low levels of potassium-40 and traces of other naturally occurring radioisotopes were found. The ^3H which was present in estuary water can be assumed to have been present in oysters and fish at the

same concentrations as found in the water.

Cobalt-60 was found in zostera samples in slightly higher concentrations than found during the previous four years. As zostera itself is not consumed by people these levels do not constitute a direct source of exposure. However, zostera beds do provide shelter and food for fish. The absence of detectable levels of ^{60}Co in fish nevertheless indicated that indirect exposure via the zostera/fish food chain is not significant.

The natural radioactivity was again found on beach sands at the same levels as in previous years.

5.3 Milk Samples (Table 8)

Concentrations of caesium-137 and iodine-131 in milk taken from cows at Menai were below detectable limits in all samples collected during the year. Some samples were reported as having trace amounts of ^{137}Cs. In these cases small unresolvable peaks were seen in the spectrum, which could indicate its presence. The detectable levels for ^{131}I and ^{137}Cs represent 4.5 per cent and 0.6 per cent of the derived working limit respectively. The derived working limit has been based on the model of an infant consuming 0.7 L of milk per day.

The trend towards lower concentrations of ^{137}Cs seen over the past four years in milk samples reflects the diminishing amounts of weapons test fallout in the atmosphere. No ^{131}I from weapons test fallout is seen because of its relatively short half-life (8 days).

5.4 Samples Related to the Little Forest Burial Ground (Tables 9-11)

5.4.1 Vegetation

Small amounts of ^{60}Co were found in the leaves of an acacia tree growing on top of one of the burial trenches.

5.4.2 Groundwater

In previous surveys, groundwater samples were passed through exchange resins and the radioactivity on the resin then counted. This method, however, did not take into account any losses in some of the dissolved substances

through the resin as a consequence of marked seasonal variability in TDS (total dissolved solids) of groundwater. The method has, therefore, been changed and the total sample is now evaporated to dryness and the total residue examined for traces of radioactivity.

Because of the highly variable amount of suspended solids in groundwater the results have been reported as Bq g^{-1} of sediment. The figures quoted in Table 10 refer to a 10 L sample of groundwater.

Apart from ^{3}H, no radioactivity other than that due to natural radioisotopes was found.

A trace amount of ^{3}H was found in BHC (see Table 10) outside the burial ground fence. The concentration reported is at the limit of detection for the method used. Similar concentrations are reported for water taken at the junction of Mill and Barden's Creeks.

These concentrations represent 0.0003 of the derived working limit for members of the public consistent with the latest recommendations of the ICRP (see Section 5.1).

5.5 Stormwater Outlets (Table 12)

Trace amounts of ^{137}Cs and ^{60}Co continue to be found in soil and vegetation near storm water outlets. The levels found during 1979 are less than those previously reported and represent a diminishing trend.

In many of the water samples taken, ^{3}H was present but generally in low concentrations. The highest concentration found was 14.1 Bq mL^{-1} and the average was 3.1 Bq mL^{-1}. The average represents 0.01 of the derived working limit (see Section 5.1).

5.6 Effluent Discharge Pipeline (Tables 13,14)

The survey of radiation being emitted from the discharge pipeline revealed dose rates above background at two points.

Soil collected along the pipeline showed no extraneous radioactivity except for one sample collected near scour valve 5. This area was sampled to check on some contamination which had been detected near a flange that was

repaired after developing a leak in 1967, and which was last monitored in 1971. The levels of radioactivity found were substantially reduced since the previous measurements. No exposure route involving the public could be defined for the small area (0.6 m^2) which is contaminated.

The small amounts of ^3H found in the creek during the survey can be traced to stormwater outlets.

5.7 Airborne Releases (Table 15)

Table 15 details measurements of radioactivity released to the atmosphere from various buildings at Lucas Heights for the four quarters of 1979. These levels are shown as fractions of the limits permitted under the NSW Radiological Advisory Council authorisation as outlined in Cook [1969] in Table 16. A rationale of the authorisation and compliance requirements are given in the previous report [Hespe 1979].

During the year radioactive noble gases were released from Building 2 stack but were not subject to continuous measurement. Estimates of dose from nuclides, including noble gases, discharged to the atmosphere, are in preparation. The results of this work will be issued at a later date separately.

6. RADIOLOGICAL SIGNIFICANCE OF RESULTS

As in previous surveys a hypothetical individual has been considered in order to provide a conservative assessment of the radiological significance of the results of the survey. It is assumed that this individual:

- eats one dozen oysters (70 g) per day from the Woronora River,
- eats 70 g of fish from the Woronora River per day,
- drinks 250 litres of water per year from the fresh water section of the Woronora River at the point of highest concentration, while picnicking/camping,
- swallows 100 mL per day of water while swimming in the estuary.

An individual in this group would receive a dose of 0.4 μSv per year, i.e. 1/10 000 of the dose limit of 5 millisieverts per year, which is recommended by the National Health and Medical Research Council and which is the legal limit in all States.

In previous years sunbathing on Woronora beaches has been included in dose calculations but has been deleted in this report since the radioactivity on the sand arises from naturally occurring isotopes and not from the AAECRE. Since levels of radioactivity on sand have not changed markedly from previous years, doses would be very close to those reported before.

The exposure route involving milk from Menai has also been excluded because no measurable quantities of ^{131}I or ^{137}Cs were detected. Details of the relationship between the minimum detectable levels for these isotopes and the derived working limit are given in Section 5.3.

Doses from ^{3}H due to ingestion of water while swimming or ingestion of water from the freshwater section of the Woronora River have been included as the possibility of small exposures from this pathway exists. For the calculation of the dose from the latter pathway it has been assumed that the hypothetical individual drinks 5 L of water on each of fifty weekends and that the water is taken from the river where the creek draining the Lucas Heights section of the Woronora valley enters a rockpool in the Woronora channel, i.e. where the ^{3}H concentrations are the highest. It should be noted that only two ^{3}H concentration results of 0.07 and 0.08 Bq mL^{-1}, from two randomly collected samples were used to make the above calculations (see Table 14). The freshwater section of the Woronora River is now being sampled routinely.

7. SUMMARY

During 1979, tritium was the only isotope found in the environment which could have had its origin at the AAECRE and which could also be assumed to be in foodstuffs.

Conservative concepts were used to derive a maximum credible dose rate of about 1 μSv for a hypothetical individual as a result of this tritium.

8. ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of members of the Chemical Technology Division in the preparation and analysis of samples and also the technical assistance of Mr J.A. Fogden.

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TABLE 1

COLLECTION AND PREPARATION OF WORONORA SAMPLES

Sample	Station(s)	Frequency	Method of Collection	Special Preparations
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 intertidal 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
Estuary water	E5.9	Weekly	From surface by bucket	Distilled for tritium
Zostera	E1.6, 2.4, E4.6, 7.0, E9.3	Quarterly (when available)	Harvested by hand or rake	Ashed

TABLE 2

COLLECTION AND PREPARATION OF SAMPLES OF MILK, AND GROUND AND CREEK WATER, VEGETATION, SOIL AND SAND

Sample	Station	Frequency	Collection Details	Special Preparations
Milk	T3	Monthly	Sampled from milk produced by locally grazed cows	Gamma spectrometry of whole milk
Vegetation	T1; RE stormwater outlets	Six-monthly	Cut by hand clippers	Whole unwashed vegetation ashed
Sand/Soil	T0,T1, RE stormwater outlets	Six-monthly	Scooped from surface	As for beach sand Table 1
Groundwater	T1	Six-monthly	Boreholes pumped dry, allowed to refill and sampled from bottom	10L sample evaporated to dryness and the residue counted
Creek water	T2	Six-monthly	Sampled by bucket or bottle	As for groundwater

TABLE 3

RADIOACTIVITY IN WORONORA AND HAWKESBURY

OYSTERS 1979

STATION	DATE	RADIOACTIVITY (Bq g^{-1} FRESH WEIGHT)			K ($\mu g\ g^{-1}$)
		GROSS ALPHA	GROSS BETA (LESS ^{40}K)	^{65}Zn	
E7.0	17th Jan	0.005	0.020	n.d.	3400
	9th March	0.005	0.016	n.d.	3200
	25th June	0.006	0.012	n.d.	2900
	20th Oct	0.01	0.023	n.d.	2900
Average		0.006	0.018		
E9.3	27th Feb	0.003	0.02	n.d.	2900
	25th June	0.006	0.015	n.d.	2700
	12th Sept	0.007	0.023	n.d.	2800
	14th Dec	0.004	0.022	n.d.	2900
Average		0.005	0.02		
Hawkesbury River	26th Feb	0.004	0.018	n.d.	3300
	15th June	0.007	0.017	n.d.	3000
	12th Sept	0.008	0.005	n.d.	3000
	10th Dec	0.004	0.025	n.d.	2900
Average		0.006	0.016		
Oyster Shell Composite 1979	1979	<0.8	<0.02	n.d.	100

n.d. = not detected

TABLE 4

RADIOACTIVITY IN WORONORA FISH 1979

STATION & VARIETY	DATE	RADIOACTIVITY (Bq g^{-1} FRESH WEIGHT)			K ($\mu g\ g^{-1}$)
		GROSS ALPHA	GROSS BETA (LESS ^{40}K)	GAMMA EMITTERS	
E O					
Mullet	14th June	0.012	0.012	Trace ^{238}U + ^{232}Th	2700
Flathead	27th Sept	0.003	0.012	Trace ^{238}U + ^{232}Th	3600
Mullet	21st Dec	0.005	0.026	Trace ^{238}U	2700
Average		0.007	0.017		
E6.6					
Mullet	8th Feb	0.022	0.028	n.d.	2400

n.d. = not detected

TABLE 5

RADIOACTIVITY IN WORONORA BEACH SANDS 1979

STATION	DATE	RADIOACTIVITY (Bq g^{-1} FRESH WEIGHT)			K ($\mu g\ g^{-1}$)
		GROSS ALPHA	GROSS BETA (LESS ^{40}K)	GAMMA EMITTERS	
E1.3	23rd Feb	0.57	0.044	n.d.	200
	20th July	0.57	0.053	Trace ^{238}U + ^{232}Th	200
	17th Sept	0.63	0.048	Trace ^{238}U + ^{232}Th	100
	13th Dec	0.23	0.065	Trace ^{238}U + ^{232}Th	100
E5.9	26th Feb	0.28	0.077	Trace ^{238}U + ^{232}Th	200
	20th July	0.33	0.046	Trace ^{238}U + ^{232}Th	200
	17th Sept	0.48	0.066	Trace ^{238}U + ^{232}Th	300
	13th Dec	0.06	0.136	Trace ^{238}U + ^{232}Th	100
Average (all samples)		0.39	0.07		
d.l.c.		111	92.5		
Average fraction of d.l.c.		3.5×10^{-3}	7×10^{-4}		

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

n.d. = not detected

TABLE 6

TRITIUM IN WORONORA WATER SAMPLES

AT STATION E5.9 1979

DATE	TRITIUM (Bq mL^{-1})	DATE	TRITIUM (Bq mL^{-1})	DATE	TRITIUM (Bq mL^{-1})
5th Jan	0.11	8th June	<0.04	9th Nov	0.04
12th Jan	0.14	15th June	<0.04	16th Nov	<0.04
19th Jan	<0.04	22nd June	<0.04	22nd Nov	0.07
26th Jan	<0.04	29th June	<0.04	29th Nov	0.08
6th Feb	<0.04	6th July	<0.04	8th Dec	0.08
9th Feb	<0.04	13th July	0.07	14th Dec	0.04
16th Feb	0.07	20th July	<0.04	21st Dec	<0.04
23rd Feb	<0.04	27th July	<0.04	28th Dec	<0.04
2nd March	0.07	3rd Aug	<0.04		
9th March	0.07	10th Aug	<0.04		
16th March	0.07	17th Aug	<0.04	Average	<0.05
23rd March	0.07	24th Aug	<0.04		
30th March	<0.04	31st Aug	0.07		
6th April	<0.04	7th Sept	<0.04		
12th April	<0.04	14th Sept	<0.04		
20th April	0.07	21st Sept	<0.04		
27th April	0.07	27th Sept	<0.04		
4th May	<0.04	5th Oct	<0.04		
11th May	<0.04	12th Oct	0.09		
18th May	<0.04	19th Oct	<0.04		
25th May	<0.04	26th Oct	<0.04		
1st June	0.07	1st Nov	<0.04		

Derived limiting concentration taken from ICRP [1979]

d.l.c. = 274 Bq mL^{-1} (if taken as drinking water)

Average fraction of d.l.c. = 2×10^{-4}

TABLE 7

RADIOACTIVITY IN WORONORA ZOSTERA SAMPLES 1979

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	23rd Feb	0.09	0.09	0.08	Trace	4800
	20th July	0.10	0.07	0.03	Trace	3700
	17th Sept	0.05	0.11	0.05	Trace	6500
	13th Dec	0.04	0.09	0.19	Trace	3500
E1.6	23rd Feb	0.08	0.07	0.05	Trace	4500
	20th July	0.15	0.08	0.03	Trace	4400
	17th Sept	0.08	0.09	0.04	Trace	4700
	13th Dec	0.08	0.11	0.12	Trace	3500
E2.4	23rd Feb	0.06	0.06	0.03	Trace	4700
	20th July	0.11	0.09	0.02	Trace	4600
	17th Sept	0.03	0.15	0.03	Trace	5700
	13th Dec	0.16	0.16	0.09	Trace	3900
E4.6	23rd Feb	0.1	0.09	0.01	Trace	6000
	20th July	0.12	0.12	0.02	Trace	5700
	17th Sept	0.08	0.07	0.01	Trace	4600
	13th Dec	0.10	0.1	0.03	Trace	5100

Zostera was not available at Stn. E7.0

n.d. = not detected

TABLE 8

RADIOACTIVITY IN MILK SAMPLES 1979

STATION	DATE	RADIOACTIVITY (Bq g^{-1} FRESH WEIGHT)	
		^{137}Cs	^{131}I
T3	31st Jan	n.d.	n.d.
(Menai)	28th Feb	n.d.	n.d.
	3rd April	Trace	n.d.
	4th July	n.d.	n.d.
	31st July	Trace	n.d.
	29th Aug	n.d.	n.d.
	27th Sept	n.d.	n.d.
	30th Oct	n.d.	n.d.
	29th Nov	Trace	n.d.
	27th Dec	n.d.	n.d.

The analytical method used for ^{131}I in milk has a minimum detectable level of 1×10^{-3} Bq g^{-1}. For ^{137}Cs the minimum detectable level was 0.0003 Bq g^{-1}.

n.d. = not detected

TABLE 9

RADIOACTIVITY IN SAMPLES OF VEGETATION FROM

LITTLE FOREST BURIAL GROUND 1979

LOCATION	SAMPLE	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	0.5 MeV	
Near Trench 58	Acacia	5 July	0.02	0.12	n.d.	Trace	0.01	2600
	Acacia	6 Dec	0.02	0.12	n.d.	Trace	0.01	3700
Near Trench 70-71	Acacia	5 July	0.02	2.93	0.01	n.d.	n.d.	2600
	Acacia	6 Dec	0.01	3.50	0.12	Trace	n.d.	2800

n.d. = not detected

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 activation product; ^{103}Ru and ^{106}Ru are fission products.

TABLE 10

RADIOACTIVITY IN SAMPLES OF GROUNDWATER

FROM LITTLE FOREST BURIAL GROUND 1979

BORE-HOLE NO.	Bq g^{-1} sediment						Bq mL^{-1}	
	GROSS ALPHA		GROSS BETA +		GAMMA EMITTERS		^{3}H	
	Jun	Dec	Jun	Dec	Jun	Dec	Jun	Dec
BH 1	0.25	Dry	0.12	Dry	n.d.	Dry	<0.04	Dry
2	0.28	Dry	0.17	Dry	n.d.	Dry	<0.04	Dry
3	0.23	0.37	0.14	0.15	n.d.	Trace ^{232}Th series	<0.04	0.12
4	0.3	0.12	0.13	0.05	n.d.	Trace ^{238}U, ^{232}Th series	<0.04	<0.04
5	0.39	Dry	0.18	Dry	Trace ^{238}U, ^{232}Th series	Dry	<0.04	Dry
6	0.24	0.15	0.24	0.06	n.d.	Trace ^{238}U, ^{232}Th series	<0.04	<0.04
10	0.01	0.14	0.03	0.05	n.d.	Trace ^{238}U, ^{232}Th series	0.48	-
OS 1	0.001	0.04	0.03	0.03	Trace ^{238}U ^{232}Th series	Trace ^{238}U series	-	<0.04
2	0.2	0.19	0.23	0.06	n.d.	Trace ^{232}Th series	-	7.2
3	0.08	0.12	0.24	0.1	n.d.	Trace ^{232}Th series	-	33.2
BH A	0.02	0.01	0.04	0.01	n.d.	n.d.	-	<0.04
B	0.01	0.01	0.01	0.01	n.d.	n.d.	<0.04	<0.04
C	0.004	0.004	0.01	0.01	n.d.	n.d.	<0.04	0.08
D	0.01	0.02	0.02	0.01	Trace ^{238}U ^{232}Th series	n.d.	-	<0.04
E	0.02	0.05	0.03	0.02	n.d.	Trace ^{238}U ^{232}Th series	<0.04	<0.04

+ includes ^{40}K contribution n.d.= not detected - = not measured

TABLE 11

RADIOACTIVITY IN SAMPLES TAKEN FROM CREEKS

NORTH OF LITTLE FOREST BURIAL GROUND 1979

SAND:

STATION	DATE	RADIOACTIVITY Bq g^{-1} DRY WEIGHT			K $\mu g\ g^{-1}$
		GROSS ALPHA	GROSS BETA (LESS ^{40}K)	GAMMA EMITTERS	
Bardens Creek above junction with Mill Creek	20.12	0.44	0.06	Trace ^{238}U & ^{232}Th series	280
Mill Creek above junction with Bardens Creek	20.12	0.77	0.09	Trace ^{238}U & ^{232}Th series	490

WATER:

STATION	DATE	RADIOACTIVITY Bq L^{-1}			^{3}H (Bq mL^{-1})
		GROSS ALPHA	GROSS BETA (incl ^{40}K)	GAMMA EMITTERS	
Bardens Creek above junction with Mill Creek	20.12	2.30	0.21	n.d.	0.08
Mill Creek above junction with Bardens Creek	20.12	4.02	0.20	n.d.	0.08

n.d. = not detected

TABLE 12

RADIOACTIVITY IN SAMPLES FROM STORMWATER OUTLETS 1979

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 behind Building 1	19.4	Soil	0.36	0.18	^{238}U & ^{232}Th series = trace	-	1200
	19.4	Water	-	-	-	<0.04	-
	8.6	Soil	0.98	1.24	^{238}U & ^{232}Th series = trace	-	700
	5.9	Water	-	-	-	0.07	-
	28.12	Water	-	-	-	0.19	-
Drain rear of Building 9	19.4	Soil	0.40	0.33	^{238}U & ^{232}Th series = trace	-	1100
	8.6	Soil	0.33	0.24	^{238}U & ^{232}Th series = trace	-	900
	5.9	Soil	0.36	0.29	^{238}U & ^{232}Th series = trace	-	1300
	5.9	Water	-	-	-	<0.04	-
	28.12	Soil	0.39	0.29	^{238}U & ^{232}Th series = trace	-	1700
Drain on road at west fence	19.4	Soil	0.44	0.16	^{238}U & ^{232}Th series = trace	-	800
	8.6	Soil	0.54	0.14	^{238}U & ^{232}Th series = trace	-	450
	5.9	Soil	0.29	0.11	^{238}U & ^{232}Th series = trace	-	250
Drain opposite sub-station	19.4	Soil	0.28	0.10	^{238}U & ^{232}Th series = trace	-	400
	8.6	Soil	0.37	0.20	" " " " " "	-	400
	5.9	Soil	0.31	0.13	" " " " " "	-	400
Drain at Boom Gate	19.4	Soil	0.23	0.24	" " " " " "	-	300
	8.6	Soil	0.31	0.13	" " " " " "	-	400
	5.9	Soil	0.26	0.14	" " " " " "	-	250
	28.12	Soil	0.38	0.14	" " " " " "	-	250
Drain west of test compound	19.4	Soil	<0.01	0.64	" " " " " "	-	1100
	8.6	Soil	0.46	0.48	" " " " " "	-	900
	12.9	Soil	0.56	0.70	" " " " " "	-	1100
	28.12	Soil	0.44	0.63	" " " " " "	-	600
Drain near Yellowcake Store	19.4	Soil	0.51	0.30	" " " " " "	-	1150
	19.4	Water	-	-	-	0.07	-
	8.6	Soil	0.48	0.42	^{238}U & ^{232}Th series = trace	-	1200
	5.9	Soil	0.60	0.32	" " " " " "	-	1000

TABLE 12 (CONTINUED)

STATION	DATE	SAMPLE	RADIOACTIVITY (Bq g^{-1} FRESH WEIGHT)			^{3}H ($Bq\ mL^{-1}$)	K ($\mu g\ g^{-1}$)
			GROSS ALPHA	GROSS BETA (LESS ^{40}K)	GAMMA EMITTERS		
Drain at Fermi Street	19.4	Soil	0.23	0.10	^{238}U & ^{232}Th series = trace	-	600
	19.4	Water	-	-	-	0.17	-
	8.6	Soil	0.60	1.10	^{238}U & ^{232}Th series = trace	-	1200
	5.9	Soil	0.20	0.16	" " " "	-	300
	28.12	Water	-	-	-	0.04	-
Drain opposite Building 23	8.6	Soil	0.29	0.27	^{238}U & ^{232}Th series = trace	-	700
	5.9	Soil	0.68	0.46	^{60}Co = 0.07 ^{137}Cs = trace ^{238}U & ^{232}Th series = trace	-	700
	28.12	Water	-	-	-	<0.04	-
Drain No. 1 opposite Strassman Crescent	19.4	Soil	0.31	0.20	^{238}U & ^{232}Th series = trace	-	1000
	19.4	Water	-	-	-	<0.4	-
	19.4	Vegetation	0.01	0.02	0.5 MeV = 0.002 ^{137}Cs = trace ^{238}U & ^{232}Th series = trace	-	3200
	8.6	Soil	0.56	0.23	^{60}Co = trace ^{238}U & ^{232}Th series = trace	-	2300
	8.6	Water	-	-	-	0.07	-
	8.6	Vegetation	0.01	0.01	0.5 MeV = 0.004 ^{238}U & ^{232}Th series = trace	-	5800
	5.9	Soil	0.38	0.21	^{60}Co = trace ^{238}U & ^{232}Th series = trace	-	700
	5.9	Water	-	-	-	0.14	-
	5.9	Vegetation	<0.01	0.02	0.5 MeV = 0.001 ^{238}U & ^{232}Th series = trace	-	4600
	28.12	Water	-	-	-	0.04	-
Drain No.2 Opposite Strassman Crescent	5.9	Soil	0.38	0.28	^{238}U & ^{232}Th series = trace	-	700

TABLE 12 (CONTINUED)

STATION	DATE	SAMPLE	RADIOACTIVITY (Bq g^{-1} FRESH WEIGHT)			^{3}H (Bq mL^{-1})	K ($\mu g\ g^{-1}$)
			GROSS ALPHA	GROSS BETA (LESS ^{40}K)	GAMMA EMITTERS		
Drain rear of Building 20	19.4	Soil	0.19	0.09	^{238}U & ^{232}Th series = trace	-	700
	8.6	Soil	0.16	0.08	" " " "	-	500
	5.9	Soil	0.23	0.11	" " " "	-	250
	28.12	Soil	0.27	0.09	" " " "	-	300
RE stormwater outlet No. 1 near south gate	11.6	Vegetation	0.08	0.12	0.5 MeV = 0.003 ^{238}U & ^{232}Th series = trace	-	4600
	5.9	Vegetation	0.01	0.03	0.5 MeV = 0.001 ^{238}U & ^{232}Th series = trace	-	3500
	28.12	Vegetation	<0.01	0.04	^{238}U & ^{232}Th series = trace	-	3700
	3.1	Water	-	-	-	3.96	-
	8.1	Water	-	-	-	6.96	-
	17.1	"	-	-	-	14.10	-
	22.1	"	-	-	-	4.66	-
	30.1	"	-	-	-	6.73	-
	5.2	"	-	-	-	10.40	-
	12.2	"	-	-	-	9.14	-
	19.2	"	-	-	-	0.56	-
	26.2	"	-	-	-	0.88	-
	5.3	"	-	-	-	0.74	-
	15.3	"	-	-	-	0.88	-
	21.3	"	-	-	-	0.64	-
	27.3	"	-	-	-	0.63	-
	2.4	"	-	-	-	3.99	-
	10.4	"	-	-	-	0.49	-
	17.4	"	-	-	-	5.70	-
	7.5	"	-	-	-	0.28	-
	14.5	"	-	-	-	2.78	-
	21.5	"	-	-	-	2.55	-
	28.5	"	-	-	-	4.96	-
	5.6	"	-	-	n.d.	5.66	-
	11.6	"	-	-	-	0.85	-
	20.6	"	-	-	-	0.28	-
	25.6	"	-	-	-	1.26	-

TABLE 12 (CONTINUED)

STATION	DATE	SAMPLE	RADIOACTIVITY (Bq L^{-1})		GAMMA EMITTERS	^{3}H (Bq mL^{-1})	K (µg g^{-1})
			GROSS ALPHA	GROSS BETA (incl ^{40}K)			
RE stormwater outlet No. 1 near south gate (continued)	3.7	Water	-	-	-	0.91	-
	10.7	"	-	-	-	1.75	-
	17.7	"	-	-	n.d.	1.22	-
	23.7	"	-	-	-	2.04	-
	31.7	"	-	-	n.d.	1.85	-
	6.8	"	-	-	-	2.52	-
	14.8	"	-	-	-	0.93	-
	20.8	"	-	-	-	1.46	-
	28.8	"	0.55	0.57	n.d.	2.11	-
	3.9	"	0.16	0.20	n.d.	2.08	-
	11.9	"	0.23	0.20	n.d.	0.10	-
	18.9	"	0.05	0.23	n.d.	2.04	-
	25.9	"	0.37	0.65	0.5 MeV = 0.03 ^{238}U = trace	0.92	-
	3.10	"	0.04	1.60	0.5 MeV = 0.17 ^{238}U = trace	0.27	-
	9.10	"	0.06	0.42	0.5 MeV = 0.76 ^{60}Co = trace ^{238}U = trace	9.01	-
	15.10	"	0.08	0.30	0.5 MeV = 0.20 ^{238}U = trace	0.38	-
	23.10	"	0.05	2.28	0.5 MeV = 0.20	5.03	-
	29.10	"	-	-	-	0.56	-
	5.11	"	0.08	1.98	0.5 MeV = 0.15 ^{238}U = trace	5.67	-
	12.11	"	0.09	3.11	0.5 MeV = 0.24 ^{60}Co = trace ^{238}U & ^{232}Th = = trace 0.5 MeV = 0.11	11.33	-
	20.11	"	0.50	0.63	^{238}U & ^{232}Th = trace	0.31	-
	26.11	"	0.14	1.48	0.5 MeV = 0.11 ^{238}U & ^{232}Th = trace	7.87	-
	3.12	"	0.08	0.35	n.d.	0.16	-
	10.12	"	0.04	0.11	n.d.	0.38	-
	18.12	"	0.05	0.13	n.d.	0.26	-
	24.12	"	-	-	-	5.53	-

TABLE 12 (CONTINUED)

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		
RE stormwater outlet No.2 near south gate	28.12	Soil	0.53	0.18	^{238}U & ^{232}Th = trace	-	500
	23.4	Water	-	-	-	0.35	-
	15.6	Water	-	-	-	0.35	-
	5.9	Water	-	-	-	0.14	-
	28.12	Water	-	-	-	0.16	-
20m from RE stormwater outlet No. 1	25.6	Soil	1.37	0.68	^{60}Co = 0.11 ^{238}U & ^{232}Th = trace	-	800
	25.6	Vegetation	0.03	0.05	0.5 MeV = 0.008 ^{238}U & ^{232}Th = trace	-	4000
	28.12	Vegetation	0.01	0.05	^{238}U & ^{232}Th = trace	-	4300
	25.6	Water	-	-	-	0.24	-
	28.12	Water	-	-	-	0.16	-
Water pool across road from stormwater outlet No. 1	23.4	Vegetation	0.01	0.04	0.5 MeV = 0.003 ^{238}U & ^{232}Th = trace	-	3100
	3.1	Water	-	-	-	4.00	-
	8.1	"	-	-	-	6.44	-
	17.1	"	-	-	-	10.77	-
	22.1	"	-	-	-	5.07	-
	30.1	"	-	-	-	7.03	-
	5.2	"	-	-	-	7.96	-
	12.2	"	-	-	-	2.92	-
	19.2	"	-	-	-	0.60	-
	26.2	"	-	-	-	0.81	-
	5.3	"	-	-	-	0.74	-
	15.3	"	-	-	-	0.88	-
	21.3	"	-	-	-	0.74	-
	27.3	"	-	-	-	0.62	-
	2.4	"	-	-	-	3.96	-
	10.4	"	-	-	-	0.48	-
	23.4	"	-	-	-	1.30	-
	30.4	"	-	-	-	1.92	-
	28.12	"	-	-	-	0.19	-
						Av = 3.1	

NB. Footnotes appear overleaf

TABLE 12

(CONTINUED)

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; ^{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

TABLE 13

GAMMA SURVEY - EFFLUENT DISCHARGE PIPE - 1979

Surveys of Pipeline between the RE and Woronora River Discharge Point using a 1368A Field Ratemeter

Date	Location	Dose Rate ($\mu Sv\ h^{-1}$)
14.6	Join No. 9	0.8
14.6	All other pipe sections	<0.5
14.6	Soil below joins	<0.5
12.12	Join No. 16	0.6
12.12	All other pipe sections	<0.5
12.12	Soil below joins	<0.5

TABLE 14

RADIOACTIVITY IN SAMPLES TAKEN AT EFFLUENT DISCHARGE

PIPELINE 1979

STATION	DATE	SAMPLE	RADIOACTIVITY (Bq g^{-1} Dry Weight)			^{3}H (Bq mL^{-1})	K (µg g^{-1})
			GROSS ALPHA	GROSS BETA (LESS ^{40}K)	GAMMA EMITTERS		
Near scour valve No. 1	13.6	Sand	0.24	0.06	^{238}U & ^{232}Th series = trace	-	800
	13.6	Water	-	-	-	0.44	-
	12.12	Sand	0.43	0.08	^{238}U & ^{232}Th series = trace	-	150
	12.12	Water	-	-		0.61	-
River where effluent discharge pipe crosses	13.6	Sand	0.37	0.06	^{238}U & ^{232}Th series = trace	-	300
	13.6	Water	-	-	-	0.07	-
	12.12	Sand	0.31	0.09	^{238}U & ^{232}Th series = trace	-	500
	12.12	Water	-	-	^{238}U & ^{232}Th series = trace	0.08	-
Join above scour valve No.5	13.6	Soil	2.83	4.27	^{137}Cs = 2.94 ^{60}Co = 1.73 ^{238}U & ^{232}Th series = trace	-	1500

TABLE 15

AIRBORNE RADIOACTIVITY RELEASES 1979

	Gross γ (kBq)	^{131}I (MBq)	^{3}H (GBq)	^{41}Ar (GBq)	Other β (MBq)
Quarter No 1					
Building 2	11	1.4×10^3	-	-	<10
" 15	<10	<10	1×10^3	1.4×10^4 (1)	166 (3)
" 19	<10	<10	-	-	<10
" 23A	<10	0.8×10^3	-	-	29
" 23B	<10	1.5×10^3	-	-	<10
" 41	<10	<10	-	-	<10
Quarter No 2					
Building 2	<10	3.0×10^3	-	-	<10
" 15		<10	1×10^3	1.7×10^4 (1)	35.4 (4)
" 19	16	<10	-	-	<10
" 23A		0.64×10^3	-	-	<10
" 23B		0.72×10^3	-	-	<10
" 41		0.98×10^3	-	-	<10
Quarter No 3					
Building 2	1.2×10^2	1.2×10^3	-	-	<10
" 15	<10	<10	2×10^3	2.0×10^4 (2)	<10 (5)
" 19	36	<10	-	-	<10
" 23A	<10	4.5×10^2	-	-	<10
" 23B	<10	1.3×10^3	-	-	<10
" 41	<10	3.1×10^2	-	-	<10
Quarter No 4					
Building 2	1.0×10^2	1.4×10^2	-	-	1
15	6	<10	2.8×10^3	Nil	3.3 (6)
19	25	<10	-	-	9
23A	6.7	95	-	-	1
23B	5	19	-	-	1
41	15	5.3	-	-	1

(1) Based on 9 spot samples

(2) Based on 8 spot samples

(3) Includes 27 MBq ^{197}Hg + ^{203}Hg

(4) Includes 33 MBq ^{197}Hg + ^{203}Hg

(5) Incldues 33 MBq ^{197}Hg + ^{203}Hg

(6) Includes 1 MBq ^{197}Hg + ^{203}Hg

TABLE 16

RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS EXPRESSED AS FRACTIONS OF THE PERMITTED QUARTERLY DISCHARGE THROUGHOUT 1979

	Gross γ	^{131}I	^{3}H	^{41}Ar	Other β
Quarter No 1					
Building 2	2×10^{-5}	0.02			$<6 \times 10^{-6}$
" 15	$<3 \times 10^{-4}$	$<6 \times 10^{-4}$	0.008	0.5	2.5×10^{-3}
" 19	$<3 \times 10^{-4}$	$<3 \times 10^{-4}$			$<2 \times 10^{-5}$
" 23A	$<6 \times 10^{-4}$	$<6 \times 10^{-4}$			9×10^{-4}
" 23B	$<2 \times 10^{-4}$	$<6 \times 10^{-4}$			$<6 \times 10^{-4}$
" 41	$<3 \times 10^{-4}$	$<6 \times 10^{-4}$			$<2 \times 10^{-5}$
Quarter No 2					
Building 2	$<2 \times 10^{-5}$	0.05			$<6 \times 10^{-6}$
" 15	$<3 \times 10^{-4}$	$<6 \times 10^{-4}$	0.008	0.6	5×10^{-4}
" 19	5×10^{-5}	$<3 \times 10^{-4}$			$<2 \times 10^{-5}$
" 23A	$<6 \times 10^{-4}$	0.04			$<3 \times 10^{-4}$
" 23B	$<2 \times 10^{-4}$	0.05			$<6 \times 10^{-4}$
" 41	7×10^{-4}	0.06			$<2 \times 10^{-5}$
Quarter No 3					
Building 2	2×10^{-4}	0.02			$<6 \times 10^{-6}$
" 15	$<3 \times 10^{-4}$	$<6 \times 10^{-4}$	0.02	0.7	$<2 \times 10^{-4}$
" 19	1×10^{-4}	$<3 \times 10^{-4}$			$<2 \times 10^{-5}$
" 23A	$<6 \times 10^{-4}$	0.03			$<3 \times 10^{-4}$
" 23B	$<2 \times 10^{-4}$	0.1			$<6 \times 10^{-4}$
" 41	$<3 \times 10^{-5}$	0.02			$<2 \times 10^{-5}$
Quarter No 4					
Building 2	2×10^{-4}	0.002			6×10^{-7}
" 15	2×10^{-4}	$<6 \times 10^{-4}$	0.02	Nil	5×10^{-5}
" 19	8×10^{-5}	$<3 \times 10^{-4}$			1×10^{-5}
" 23A	4×10^{-4}	6×10^{-3}			3×10^{-5}
" 23B	1×10^{-4}	1×10^{-3}			6×10^{-5}
" 41	5×10^{-5}	3×10^{-4}			6×10^{-6}

TABLE 17

POSSIBLE DOSE TO A MEMBER OF THE PUBLIC RESULTING FROM EXPOSURE TO MEASURED CONCENTRATIONS IN 1979

Sample	Isotope	Exposure Route	Critical Organ	Possible Dose (μSv)	Dose limit (μSv)	Possible Dose as fraction of Limit*
Woronora Oysters	^{3}H	Ingestion	Body tissue	0.02	5000	4×10^{-6} (1)
Woronora Fish	^{3}H	Ingestion	Body tissue	0.02	5000	4×10^{-6} (1)
Woronora Water (Fresh)	^{3}H	Ingestion	Body tissue	0.33	5000	0.7×10^{-5} (2)
Woronora Water (Estuary)	^{3}H	Ingestion	Body tissue	0.03	5000	6×10^{-6} (3)

* Based on new ICRP criteria as outlined in Section 5.1

(1) Allows for 70g ingestion per day

(2) Allows for 250 L ingestion per year

(3) Allows for 100 mL ingestion each day while swimming

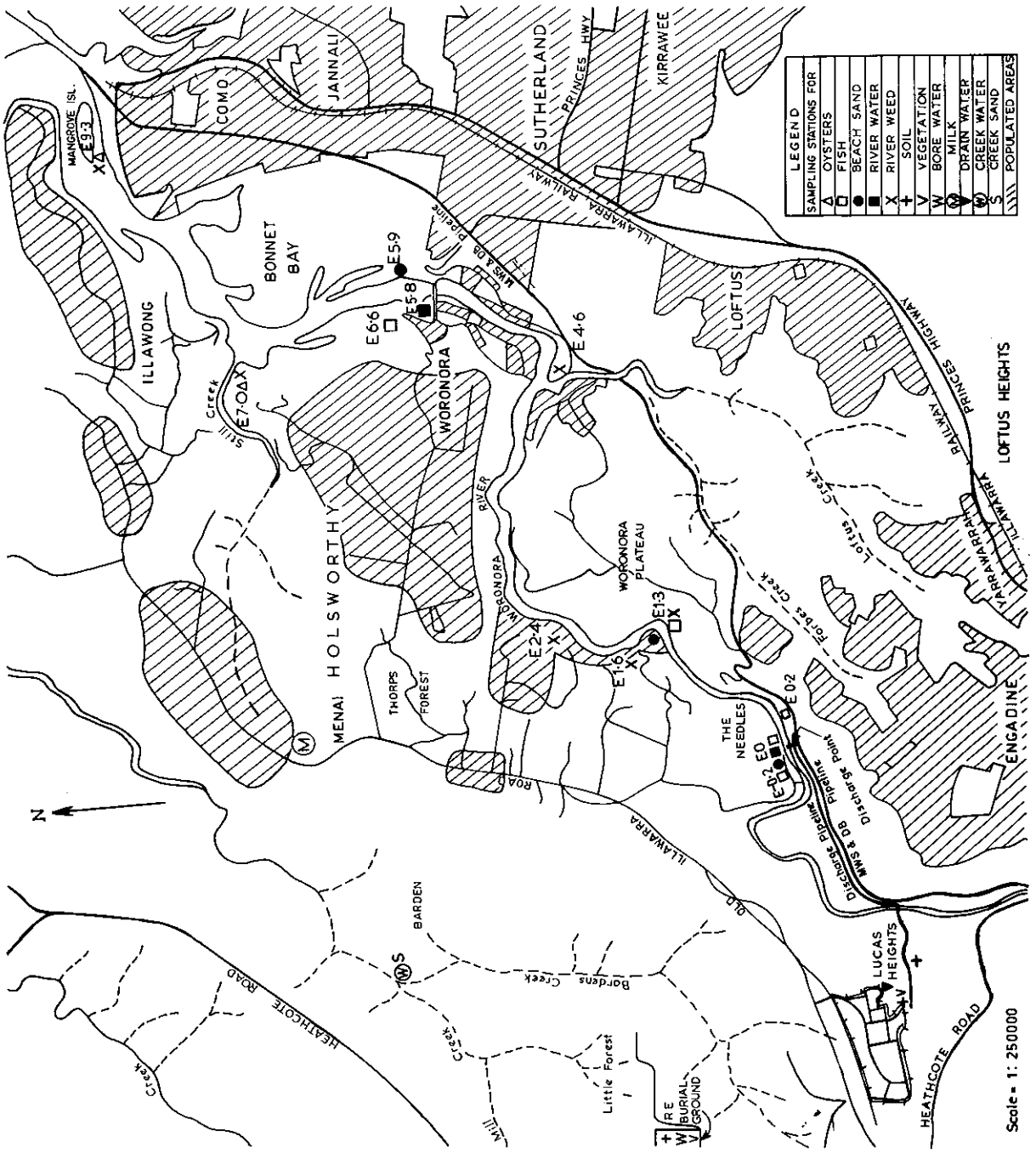

FIGURE 1. LUCAS HEIGHTS DISTRICT - LOCATION OF SAMPLING STATIONS

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

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

APPENDIX B
ANALYTICAL PROCEDURES

1. β and α Activity

All procedures in counting this radioactivity have remained the same except that a Nuclear Chicago Spectro-Shield low background counting system is now used.

2. Tritium in Water

For ^{3}H determinations, a 3 cm^3 aliquot is taken from a distilled portion of each of the samples and placed in 15 cm^3 of a liquid scintillant which consists of 4 g of 2,5-diphenyloxazole, 100 g napthalene dissolved in 1 L of Dioxan. The radioactivity of the sample is measured in a Beckman model LS1 liquid scintillation spectrometer.

3. Gamma Spectrometry

Detectors used for gamma spectrometry now include 7.5 x 7.5 cm NaI(Tl), 20 x 10 cm NaI(Tl) and Ge(Li) crystals. Samples are usually screened using the first two crystals and are measured on the Ge(Li) crystal only when higher resolution is required. Stripping and analysis of the spectra are done using the central computer facility.

APPENDIX C
LIQUID EFFLUENT DISCHARGES FROM AAECRE (1979) COMPLIANCE WITH AUTHORISATION

A detailed account of the authorisation, approved by the NSW State Authorities, under which discharges to the Woronora estuary are made has been given in previous reports [Hespe 1979a, 1979b]. Table C1 details radioactivity discharged to the Woronora estuary during 1979 and indicates the percentage of the authorised limit which was reached. Because the contribution due to unknown β and α activity was assumed to be ^{32}P and ^{226}Ra respectively (i.e. the worst possible cases for contamination), the percentage of authorised limit calculation is, if anything, overestimated.

TABLE C1
RADIOACTIVITY DISCHARGED TO THE WORONORA ESTUARY (1979)

	Radioisotope measured (MBq)					
	^{210}Po	α_{μ}(1)	^{3}H	β_{μ}(2)	^{114m}In	% of Authorised Limit
Quarter No.1	4.7×10^{-2}	10.4	1.9×10^{5}	4.8×10^{2}	9.6×10^{-2}	8.1
Quarter No.2	2.7×10^{-1}	9.3	1.3×10^{5}	5.9×10^{2}	8.9×10^{-2}	10.0
Quarter No.3	4.8×10^{-2}	9.3	1.9×10^{5}	8.9×10^{2}	8.9×10^{-2}	14.6
Quarter No.4	2.6×10^{-2}	11.1	2.6×10^{5}	8.1×10^{2}	1.0×10^{-1}	13.4

(1) α_{μ} = a mixture of unidentified α-emitting nuclides taken as being all ^{226}Ra (i.e. the worst possible case) in calculating per cent of the authorised limit.

(2) β_{μ} = a mixture of unidentified β-emitting nuclides taken as being all ^{32}P (i.e. worst possible case) in calculating per cent of the authorised limit.