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AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

ENVIRONMENTAL SURVEY AT THE AAEC RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

RESULTS FOR 1975, 1976 AND 1977

by

E.D. HESPE

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ENVIRONMENTAL SURVEY AT THE AAEC RESEARCH ESTABLISHMENT LUCAS HEIGHTS, RESULTS FOR 1975, 1976 AND 1977

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ABSTRACT

An environmental survey program has been in operation since 1959 at the Australian Atomic Energy Commission's Research Establishment at Lucas Heights, N.S.W. The results for 1975, 1976 and 1977 show that the amounts of radionuclides of AAECRE origin are not greater than the amounts found in earlier years. The possible annual radiation dose to the most highly exposed member of the public, as calculated from the results, represents about one ten-thousandth of that considered acceptable by the NSW Health Commission and the National Health and Medical Research Council of Australia.

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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; TABLES; TRITIUM; UNDERGROUND DISPOSAL; ZINC 65

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1. INTRODUCTION

Since 1959 an environmental survey program has been in operation at the Australian Atomic Energy Commission's Research Establishment (AAECRE) at Lucas Heights, NSW. This is designed to provide information on the amounts of radioisotopes of AAECRE origin present in a variety of environmental materials with which man is likely to have contact. The results are used to calculate the radiation dose to a member of the public which could result from use of, or contact with, the materials. This report gives the results of the program for the years 1975, 1976 and 1977. Results for the years 1959-1974 are given in the reports listed in Appendix A. Appendices B and C summarise the performances, in relation to the approved discharge authorisations for liquid and gaseous emissions respectively, for the period 1 January 1975 to 31 December 1977.

Table 1 summarises the sampling program associated with the Woronora estuary; Table 2 summarises the terrestrial sampling program. Fish samples are now taken by gill net rather than by seine net as in previous years; this change facilitates sample collection. The method of preparation of beach sand samples is unchanged; the entry in Table 1 gives a more complete description of the method than was given in the previous reports. Figures 1 and 1A show the locations of the sampling stations.

The identification code for the estuarine sampling stations used in previous years has been changed. In previous reports the numerals in the code, which represent distance downstream from the discharge point, were quoted in miles. In this report, kilometres have been used. Thus station E0.8 has become E1.3, E3.7 has become E5.9 and so on.

In previous years the integrated dose on the bed of the Woronora at the pipeline outlet, measured by thermoluminescent dosemeter, was reported. For the subject years, because of heavy losses of dosemeters caused by vandalism and floods, no information is available. However, given the small variations observed in the estuarine samples taken in these and previous years, there is no reason to believe that the integrated dose on the river bed in the subject years would have been significantly different from the low doses observed in previous years.

Because of the importance of the radioactivity-in-oysters pathway and the need to be able to differentiate between radioactivity of AAECRE origin and that from other sources (e.g. weapons test fallout) the results obtained for Woronora oysters, which are commercially grown, were compared with those obtained for oysters grown commercially in the Hawkesbury River, about 50 km to the north of AAECRE, which could not be affected by AAECRE operations.

2. PRESENTATION OF RESULTS

In addition to Tables 1 and 2 mentioned above, groups of tables are presented to show the results of radioactivity measurements on samples, and the calculated annual doses to a member of the public for each of the subject years. Comparisons of the results for the subject years with those for previous years are presented in graphical form. The results are grouped thus.

Table	Table number referring to year		
	1975	1976	1977
Radioactivity in Woronora and Hawkesbury Oysters	3	13	23
Radioactivity in Woronora Fish	4	14	24
Radioactivity in Woronora Beach Sands	5	15	25
Tritium in Woronora Water Samples (Station E5.9)	6	16	26
Radioactivity in Woronora Zostera Samples	7	17	27
Radioactivity in Milk Samples	8	18	28
Radioactivity in Vegetation & Soil Samples - Little Forest Burial Ground	9	19	29
Radioactivity in Samples of Groundwater - Little Forest Burial Ground	10	20	30
Radioactivity in Samples Taken at AAECRE Stormwater Outlets	11	21	31
Possible Doses to a Member of the Public Resulting from Exposure to Measured Concentrations	12	22	32
Gamma Survey of Discharge Pipeline	-	-	33
Beta-Gamma Survey of River Bottom at Discharge Pipeline Outlet	-	-	34

The comparisons appear as follows:

Figure Number	Figure Title
2	Tritium in Woronora River (Station E5.9) expressed as fractions of the derived limiting concentration (d.l.c.) 1966-77
3	^{65}Zn in Woronora oysters (Station E7.0) expressed as fractions of the derived limiting concentration (d.l.c.) 1966-77
4	^{60}Co in Woronora fish expressed as fractions of the derived limiting concentration (d.l.c.) 1966-77
5	Gross alpha activity in Woronora beach sands expressed as fractions of the derived limiting concentration (d.l.c.) 1966-77
6	Gross beta activity in Woronora beach sands expressed as fractions of the derived limiting concentration (d.l.c.) 1966-77
7	^{60}Co in Woronora zostera expressed in picocuries per gram, 1966-77 (fresh weight)

3. DISCUSSION OF RESULTS

3.1 Woronora Samples

The results show that the amounts of radioactivity of AAECRE origin found in the Woronora samples in 1975, 1976 and 1977 were, in terms of health significance, either the same as or less than the inconsequential amounts found in previous years. At such low levels of radioactivity it is unwise to be too dogmatic in identifying trends; however, in the period, steady or downward trends can be discerned.

No radioisotopes were found which had not been found previously. The concentrations of zinc-65 in oysters, tritium in estuary water and cobalt-60 in fish for these years represent minute fractions — less than one ten-thousandth — of the appropriate derived limiting concentrations (d.l.c.). The marine plant zostera is a useful indicator of the presence of ^{60}Co in the river water. The amounts detected in zostera were lower than those in previous years. The radioisotopes tritium, ^{65}Zn and ^{60}Co have been detected in AAECRE effluent discharges. The amount of alpha activity on beach sands appears to be larger than, and the amount of beta activity appears to be at the same level as, the amounts found in earlier years. The alpha activity represents about one one-thousandth and the beta activity about one ten-thousandth of the appropriate d.l.c. These ratios are similar to those of previous years. The radioactivity on the beach sands is not attributable to AAECRE operations.

3.2 Samples Related to Airborne Discharges

At least two thirds of the total of 37 milk samples collected in the period had less than the minimum detectable level of caesium-137 and all samples had, as in previous years, less than the minimum detectable level of iodine-131. The ^{137}Cs average annual concentration was, in each of the three years, less than those of previous years, except for that of 1975 which was very slightly higher than that of 1968 but lower than those of the other years. Taken together with the results of the continuous monitoring of ventilation discharges, which indicate insignificant discharges of radioactivity and which are reported regularly to the Radiological Advisory Council of NSW (see Appendix C), these results demonstrate the effectiveness of the measures used to control airborne discharges of radioactivity, and that the radioactivity in the milk is not of AAECRE origin.

3.3 Samples Related to Little Forest Area

(a) Vegetation and soil samples

The results of measurements made on samples of vegetation (grass and acacia) growing at positions very close to ($\leqslant$ 2 m) the buried waste showed that:

- in 1975 all samples contained very small amounts of ^{60}Co and fission products (these can be ascribed to the buried waste);
- in 1976 about 60 per cent of the samples contained no radioactivity which could be attributed to the buried wastes, and the remainder contained very small amounts of ^{60}Co; and
- in 1977 about half the samples contained no radioactivity which could be attributed to the buried wastes, 40 per cent of the samples contained very small amounts of ^{60}Co and about 10 per cent contained very small amounts of fission products.

The results of measurements made on topsoil samples taken from positions very close to (a few metres) the buried wastes showed that the majority of samples contained small amounts of ^{60}Co and/or fission products. The ratios of the concentrations of radioactivity in vegetation to the concentrations of radioactivity in soil indicate that the transfer of radioactivity from soil to vegetation is very small.

(b) Groundwater samples

A small number of samples collected from boreholes outside the burial ground contained very small amounts of radioactivity which could not be identified as originating in the buried waste. Samples of water taken near the junction of Mill and Bardens Creeks, into which the burial area drains, were found also to contain no radioactive species which could be related to buried waste. Thus, the evidence from the environmental survey program indicates that during 1975, 1976 and 1977 no radioactivity associated with the buried waste left the fenced area.

However, during a detailed study of the fate of buried radionuclides, Isaacs & Mears [1977] found very low concentrations of tritium in samples from boreholes outside the northern fence. These concentrations represented about one one-thousandth of that permitted by NSW regulations in drinking water. There was no evidence of other radionuclides in these samples.

Routine tritium measurements are now made on bore water samples from the burial ground area.

3.4 Samples Associated With Stormwater Outlets

Measurements made on samples of soil and vegetation taken near stormwater outlets indicate the presence of both naturally occurring radioisotopes and extremely small amounts of ^{60}Co and fission products. The latter are probably attributable to AAECRE operations; however, the amounts involved are so small that the presence of this radioactivity does not involve a hazard to health.

In 1975 and 1976 samples of water from stormwater drains contained very small amounts of tritium. Late in 1977 a few samples from one drain contained tritium at higher concentrations. The highest was at about the concentration permitted in drinking water by the NSW Radioactive Substances Act. Clearly, since the regulations under this Act apply to water intended for regular, continuous use by a member of the general public, the concentration of tritium found in stormwater drains is of no health significance.

In 1977, surveys made along the effluent pipeline showed that, except at two flanges and a scour valve, the dose rates did not exceed the background dose rate. The dose rate at ground surface over the length of the pipeline did not exceed the background dose rate. The relatively high dose rates at flanges and valve could indicate either small accumulations of radioactive material within the pipe or leaks. The low dose rates at the ground surface and the results of gamma spectroscopy on samples of soil from near the pipeline suggest strongly that no leaks had occurred.

A radiation survey of the river bottom was made in 1977 with a submersible detector. Radiation levels slightly above the natural background level were detected over a small area (< 30 m^2) in the immediate vicinity of the pipeline outlet. These were probably because of AAECRE operations but could not be considered a health hazard.

4. RADIOLOGICAL SIGNIFICANCE OF RESULTS

The methods described in earlier environmental survey reports were used to estimate annual doses for a person who, every day, eats 70 grams each of fish and oysters from the Woronora estuary, swims there for one hour and sunbathes one or two hours and who drinks 0.5 litres of milk produced at Menai. These estimates are listed in Tables 12, 22 and 32. The doses from sunbathing are attributable to natural radioactivity in the beach sand and the doses from ^{137}Cs in milk, to weapons test fallout. The remaining doses are attributable to radioactivity in the liquid effluent discharged from the AAECRE. Whole body doses for the individual using the estuary as described above are estimated for 1975, 1976 and 1977 to be less than 0.04, 0.02 and 0.02 millirem respectively. The radiological significance of these doses can be appreciated by comparing them with

- the recommendation of the International Commission on Radiological Protection (ICRP) and the NSW legal requirement to limit the total body dose to a member of the public to 500 mrem per year;
- the annual dose to any member of the public, caused by natural background radiation, of about 100 mrem per year;
- the dose received from a well designed and conservatively operated machine during a full chest X-ray of not less than 10 mrem; and
- the dose received from natural sources, during a normal trans-Australia flight, of about 2 mrem.

5. SUMMARY

In the years 1975, 1976 and 1977 no radioactivity was detected in the environment which could be attributed to aerial dispersion from AAECRE.

Samples of water, oysters, fish and zostera from the Woronora contained radioisotopes of AAEC origin, tritium, zinc-65 and cobalt-60, that were found previously in these materials. Their concentrations were equal to or lower than the low ones found earlier. In no case did the concentration of a radioisotope of AAECRE origin exceed one ten-thousandth of the appropriate derived limiting concentration.

Samples of soil and vegetation from the former solid waste burial ground at Little Forest contained very small amounts of cobalt-60. Results of measurements on samples of bore and surface water show that only extremely small amounts of tritium have left the immediate vicinity of the burial trenches or the fenced area.

Estimates of possible doses, resulting from AAECRE discharges, to the (probably hypothetical) most highly exposed member of the public, give results which indicate doses very much lower than those due to natural background radiation and about one ten-thousandth of that permitted by the NSW radiation control legislation.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Isaacs, S.R. & Mears, K.F. [1977] - A Study of the Burial Ground Used for Radioactive Waste at the Little Forest Area near Lucas Heights, NSW. AAEC/E427.

Fry, R.M. [1966] - A Reformulation of the Lucas Heights Discharge Authorisation. AAEC/E156.

NOTES

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	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 BS counted for beta gamma emitters. Sample between 60 and 110 mesh BS counted for alpha emitters
Estuary water	E5.8	Weekly	From surface by bucket	Distilled for tritium
Zostera	E1.6, 2.4, E4.6, 7.0, E9.3	Quarterly	Harvested by hand or rake	Ashed

TABLE 2

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

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
Ground water	T1	Six-monthly	Boreholes pumped dry, allowed to refill and sampled from bottom	Sample passed through Amberlite IRC 120 resin which is then ashed
Creek water	T2	Six-monthly	Sampled by bucket or bottle	As for groundwater

TABLE 3

RADIOACTIVITY IN WORONORA AND HAWKESBURY OYSTERS, 1975

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{65}Zn	K ($\mu g\ g^{-1}$)
*E7.0	26 Nov	0.79	0.21	0.04	2300
E9.3	2 May	0.61	0.28	Trace	2600
	7 Aug	0.34	0.16	Trace	3100
	8 Dec	0.32	0.11	0.01	2700
average		0.42	0.18	0.003	
Hawkesbury River	12 May	0.64	< 0.29	n.d.	2500
	11 Sept	0.22	< 0.51	n.d.	3200
	4 Dec	0.31	0.23	n.d.	2400
average		0.39	< 0.35		
Woronora oyster shell (composite)	2 May-8 Dec	0.35	0.95	n.d.	220

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

d.l.c. of ^{65}Zn in oyster flesh = 1000 $pCi\ g^{-1}$

E7.0 Fraction of d.l.c. 4×10^{-5}

E9.3 Fraction of d.l.c. 3×10^{-6}

* Variations in oyster production mean that the oyster farmer cannot always supply samples.

n.d. = not detected.

TABLE 4

RADIOACTIVITY IN WORONORA FISH, 1975

Station & Variety	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Fresh Weight)			K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	^{60}Co	
E1.3					
Mullet	6 Feb	0.42	0.41	Trace	3100
Mullet	5 May	0.38	0.01	n.d.	3100
Mullet	16 Sept	0.42	0.18	0.18	2900
Mullet	12 Dec	1.32	0.74	n.d.	2200
Bream	6 Feb	0.18	0.32	Trace	3400
Bream	16 Sept	0.35	0.64	n.d.	3900
Bream	12 Dec	0.49	0.10	n.d.	2700
average		0.51	0.34	0.03	
E6.4					
Mullet	12 May	0.28	0.52	n.d.	2900
Mullet	5 Dec	0.95	0.29	n.d.	2700
Blackfish	12 May	0.38	< 0.31	n.d.	3800
Blackfish	5 Dec	1.05	< 0.34	Trace	2400
average		0.66	< 0.36		

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

Average ^{60}Co all d.l.c. of samples = 0.02 $pCi\ g^{-1}$

d.l.c. ^{60}Co in whole fish = 500 $pCi\ g^{-1}$

Fraction of d.l.c. = 4×10^{-5}

n.d. = not detected

TABLE 5

RADIOACTIVITY IN WORONORA BEACH SANDS, 1975

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Dry Weight)			K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	
E1.3	22 Jan	13.20	0.35	n.d.	200
	22 May	7.73	0.71	n.d.	200
	5 Aug	30.00	2.02	n.d.	100
	28 Nov	6.37	0.89	n.d.	200
E5.9	24 Jan	7.01	0.96	n.d.	400
	22 May	8.39	0.14	n.d.	600
	5 Aug	10.55	1.06	n.d.	500
	28 Nov	10.66	4.55	n.d.	700
average (all samples)		11.74	1.36		
d.l.c.		3000	2500		
average fraction of d.l.c.		4×10^{-3}	5×10^{-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, 1975

Date	Tritium (pCi mℓ$^{-1}$)	Date	Tritium (pCi mℓ$^{-1}$)	Date	Tritium (pCi mℓ$^{-1}$)
3 Jan	< 1.0	9 May	3.5	12 Sept	< 1.0
10 Jan	< 1.0	16 May	3.6	19 Sept	1.2
17 Jan	< 1.0	23 May	< 1.0	26 Sept	< 1.0
24 Jan	< 1.0	30 May	< 1.0	2 Oct	1.5
31 Jan	2.9	6 June	< 1.0	13 Oct	< 1.0
7 Feb	< 1.0	13 June	< 1.0	17 Oct	< 1.0
14 Feb	< 1.0	20 June	< 1.0	24 Oct	< 1.0
21 Feb	1.5	27 June	< 1.0	31 Oct	1.6
28 Feb	< 1.0	4 July	< 1.0	6 Nov	< 1.0
6 Mar	< 1.0	11 July	1.6	14 Nov	< 1.0
14 Mar	< 1.0	18 July	4.7	21 Nov	< 1.0
21 Mar	< 1.0	25 July	1.1	28 Nov	< 1.0
27 Mar	< 1.0	1 Aug	4.7	5 Dec	< 1.0
4 Apr	1.6	8 Aug	1.8	12 Dec	< 1.0
11 Apr	3.5	15 Aug	1.6	19 Dec	< 1.0
18 Apr	< 1.0	22 Aug	< 1.0	30 Dec	< 1.0
24 Apr	4.1	29 Aug	< 1.0		
2 May	5.4	4 Sept	1.6	average	< 1.6

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

d.l.c. = 3×10^{4} pCi mℓ$^{-1}$

Fraction of d.l.c. = 5.3×10^{-5} (based on annual average)

TABLE 7

RADIOACTIVITY IN WORONORA ZOSTERA SAMPLES, 1975

Station	Date Sampled	Radioactivity ($pCi\,g^{-1}$ Fresh Weight)							K ($\mu g\,g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
				0.5 MeV	^{54}Mn	^{95}Zr & ^{95}Nb	^{60}Co	^{238}U Series	
E1.3	22 May	0.7	0.7	n.d.	Trace	Trace	0.9	n.d.	6200
	5 Aug	0.7	1.0	n.d.	n.d.	n.d.	2.2	n.d.	6500
	28 Nov	1.2	0.3	n.d.	n.d.	n.d.	1.1	n.d.	3600
E1.6	22 Jan	1.6	1.5	n.d.	Trace	Trace	0.8	Trace	3700
	22 May	0.9	0.8	Trace	Trace	Trace	0.8	n.d.	5800
	5 Aug	0.8	1.3	n.d.	n.d.	n.d.	1.8	n.d.	5100
	28 Nov	2.5	2.7	n.d.	n.d.	n.d.	1.1	n.d.	5100
E2.4	22 Jan	2.2	1.7	n.d.	n.d.	0.2	0.4	Trace	2200
	22 May	0.6	0.5	n.d.	n.d.	n.d.	0.9	n.d.	6900
	5 Aug	0.7	1.0	n.d.	n.d.	n.d.	1.8	n.d.	7200
	28 Nov	1.8	1.9	n.d.	n.d.	n.d.	0.8	n.d.	3900
E4.6	22 Jan	6.2	3.1	n.d.	n.d.	0.4	0.1	Trace	2400
	22 May	1.0	1.0	n.d.	n.d.	n.d.	0.2	n.d.	5200
	5 Aug	0.9	0.7	n.d.	n.d.	n.d.	0.5	n.d.	5600
	28 Nov	3.3	2.0	0.1	n.d.	n.d.	Trace	Trace	3700
E7.0	22 Jan	4.0	2.7	n.d.	n.d.	Trace	n.d.	n.d.	2200
	22 May	0.9	10.2	n.d.	n.d.	n.d.	0.1	n.d.	3900
	5 Aug	1.4	1.1	n.d.	n.d.	n.d.	0.2	n.d.	4500
	28 Nov	5.3	0.1	n.d.	n.d.	n.d.	n.d.	n.d.	7800
E9.3	22 May	1.5	2.1	n.d.	n.d.	n.d.	Trace	n.d.	3100

n.d. = not detected

TABLE 8

RADIOACTIVITY IN MILK SAMPLES, 1975

Station	Date Sampled	Radioactivity (pCi g^{-1} Fresh Weight)	
		^{137}Cs	^{131}I
T3 (Menai)	14 Jan	0.02	n.d.
	17 Feb	n.d.	n.d.
	21 Mar	n.d.	n.d.
	4 Apr	n.d.	n.d.
	17 Apr	0.02	n.d.
	13 May	n.d.	n.d.
	18 June	0.03	n.d.
	15 July	0.02	n.d.
	15 Aug	0.01	n.d.
	19 Sept	n.d.	n.d.
	16 Oct	0.01	n.d.
	18 Nov	n.d.	n.d.
	16 Dec	0.01	n.d.
average		0.009	

The analytical method used for ^{131}I in milk has a minimum detectable level of 30 pCi ℓ^{-1}.

n.d. = not detected

TABLE 9

RADIOACTIVITY IN VEGETATION AND SOIL SAMPLES -

LITTLE FOREST BURIAL GROUND, 1975

Location	Sample	Date	Radioactivity (pCi g^{-1} Fresh Weight)							K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
					^{137}Cs	^{60}Co	^{238}U Series	^{95}Zr & ^{95}Nb	0.5 MeV	
Near trenches 1-5	Grass	1 May	0.1	2.3	n.d.	n.d.	n.d.	0.6	0.3	3900
	Grass	24 Sept	1.0	3.9	n.d.	n.d.	n.d.	0.2	0.4	3400
Near yellow peg	Grass	18 Feb	0.2	3.5	n.d.	0.2	n.d.	0.2	1.0	6800
	Soil	18 Feb	25	21	n.d.	Trace	Trace	n.d.	n.d.	380
Near trench 54	Grass	1 May	0.5	7.1	n.d.	n.d.	n.d.	1.1	0.5	4100
	Grass	23 Sept	2.3	8.9	n.d.	0.2	n.d.	0.3	0.6	3000
Near trench 57	Topsoil	18 Feb	311	40	11	6.2	Trace	n.d.	n.d.	740
		1 May	330	40	12	5.2	Trace	n.d.	n.d.	3800
		23 Sept	243	10	8.6	5.1	Trace	n.d.	n.d.	3800
Near trench 58	Acacia	23 Sept	0.7	3.0	n.d.	n.d.	n.d.	0.1	0.1	2900
Near trench 59	Acacia	18 Feb	0.33	2.8	n.d.	n.d.	n.d.	1.9	0.5	4200
Near trenches 62-65	Grass	1 May	1.4	17.2	n.d.	1.7	n.d.	1.4	0.7	4300
	Grass	23 Sept	4.8	26.0	n.d.	5.0	n.d.	n.d.	0.5	2900

(continued)

TABLE 9 (Continued)

Location	Sample	Date	Radioactivity (pCi g^{-1} Fresh Weight)							K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
					^{137}Cs	^{60}Co	^{238}U Series	^{95}Zr & ^{95}Nb	0.5 MeV	
Near trench 68	Topsoil	23 Sept	25	125	n.d.	82	n.d.	n.d.	n.d.	5500
Near trenches 69,70	Grass	1 May	4.8	5.5	n.d.	2.0	n.d.	1.8	1.0	3700
	Grass	23 Sept	2.4	3.1	n.d.	2.5	n.d.	n.d.	0.4	3600
Near trench 71	Grass	18 Feb	1.5	16	n.d.	0.8	n.d.	3.6	1.3	2800
	Acacia	18 Feb	0.3	43	n.d.	0.5	n.d.	0.9	0.2	2300
Near trenches 74,75	Soil	1 May	23	23	1.5	4.6	Trace	n.d.	n.d.	3300
	Soil	23 Sept	23	43	n.d.	28	n.d.	n.d.	n.d.	3600
	Grass	1 May	1.9	13.6	n.d.	0.3	n.d.	1.1	0.5	3000
	Grass	23 Sept	2.2	13.6	n.d.	1.5	n.d.	0.2	0.5	3100

The gamma-ray peak 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.

n.d. = not detected

TABLE 10

RADIOACTIVITY IN SAMPLES OF GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1975

Borehole Identification No.	Date Sampled	Radioactivity (pCi ℓ^{-1})		
		Gross Alpha	Gross Beta	Gamma Emitters
10	18 Feb	1.7	9.7	n.d.
1	21 Feb	42	24	n.d.
2		4.8	4.9	n.d.
6		19.1	10.4	n.d.
OS1		3.3	7.0	n.d.
OS2		2.7	6.4	n.d.
OS3		30	42	Trace 0.5 MeV
A	30 Apr	0.3	4.2	n.d.
B		8.9	7.7	n.d.
C		3.2	5.7	n.d.
D		14	18	n.d.
E		3.0	4.4	n.d.
3		0.7	4.1	n.d.
4		1.5	1.8	n.d.
1	22 Sept	1.3	2.6	n.d.
2		2.4	1.8	n.d.
3		1.9	2.3	n.d.
4		2.2	1.8	n.d.
5		0.8	1.1	n.d.
6		0.1	1.7	n.d.
10		4.1	9.1	n.d.
OS1		4.3	3.8	Trace ^{238}U series
OS2		2.1	3.9	n.d.
OS3		0.8	56	2.3, 0.5 MeV
A		0.3	3.3	Trace 0.5 MeV
B		11	6.8	Trace ^{238}U series Trace 0.5 MeV
C		12	5.7	Trace ^{238}U series
D		10	14	n.d.
E		2.1	7.4	n.d.

Results for gross beta not corrected for ^{40}K. In column 5 of this table, the unit pCi ℓ^{-1} refers to the number of disintegrations per second per litre of borewater at the energies indicated.

n.d. = not detected

TABLE 11

RADIOACTIVITY IN SAMPLES TAKEN AT STORMWATER OUTLETS, 1975

Station	Date of Sample	Sample	Radioactivity (pCi g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (pCi $m\ell^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
SW outlet near South Gate	20 Jan	Sand	209	7	-	Trace ^{137}Cs	290
		Grass	0.8	9	-	0.6, 0.5 MeV 2.3 ^{95}Zr & ^{95}Nb	20000
		Water	-	-	7	-	-
	13 Aug	Sand	7.2	4	-	0.6 ^{137}Cs 0.9 ^{60}Co	400
		Grass	0.3	1.3	-	0.2 ^{137}Cs 0.3 ^{60}Co	8400
		Water	-	-	59	-	-
20 m from SW outlet near South Gate	20 Jan	Sand	39	14	-	3.7 ^{137}Cs 8.8 ^{60}Co	500
		Grass	0.3	4	-	1.2 ^{137}Cs	9500
	13 Aug	Sand	18	8	-	0.1 ^{137}Cs 0.1 ^{60}Co	300
		Grass	0.3	1.4	-	0.1, 0.5 MeV 0.1 ^{137}Cs 0.3 ^{60}Co	4800
		Water	-	-	47	-	-
Near No.1 scour valve	13 Aug	Sand	7.1	1.4	-	n.d.	200
		Water	-	-	8	-	-
SW outlet opposite Bld.9	18 Feb	Grass	0.1	1.3	-	0.4 ^{95}Zr & ^{95}Nb 0.1, 0.5 MeV	5200
		Water	-	-	< 1.0	-	-
SW outlet opposite Fermi Street	18 Feb	Grass	0.7	2.3	-	0.7 ^{95}Zr & ^{95}Nb 0.2, 0.5 MeV	4700
		Sand	12	10	-	n.d.	190
		Water	-	-	< 1.0	-	-
	21 Aug	Sand	9	13	-	n.d.	880
		Water	-	-	8	-	-
	19 Nov	Soil	11	8	-	Trace ^{137}Cs	970
		Water	-	-	12	-	-
SW outlet opposite Bld.23	18 Feb	Grass	0.5	3		1.4 ^{95}Zr & ^{95}Nb 0.3, 0.5 MeV 0.1 ^{60}Co	5200
		Sand	12	14		6.0 ^{60}Co	490
		Water	-	-	13	-	-
	20 Nov	Grass	2	2	-	0.1 ^{137}Cs 0.1 ^{60}Co	6500
		Sand	16	14	-	0.3 ^{137}Cs 0.3 ^{60}Co	1200
		Water	-	-	7	-	-
SW outlet opposite Strassman Crescent drain No.1	18 Feb	Grass	0.1	1	-	0.3 ^{95}Zr & ^{95}Nb 0.1, 0.5 MeV	4200
		Sand	5	5	-	1.0 ^{95}Zr & ^{95}Nb	200
	21 Aug	Grass	0.1	1	-	0.1 ^{95}Zr & ^{95}Nb 0.1, 0.5 MeV	4800
	20 Nov	Grass	1	1	-	n.d.	3200

(continued)

TABLE 11 (Continued)

Station	Date of Sample	Sample	Radioactivity (pCi g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (pCi $m\ell^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
SW outlet opposite Strassman Crescent, drain No.2	18 Feb	Grass	0.5	3	-	0.6 ^{95}Zr & ^{95}Nb 0.1, 0.5 MeV 0.3 ^{60}Co	3700
		Sand	6	9	-	3.0 ^{95}Zr & ^{95}Nb 0.6, 0.5 MeV	200
	21 Aug	Sand	20	14	-	2.0 ^{60}Co	590
	20 Nov	Sand	16	14	-	0.6 ^{137}Cs 1.4 ^{60}Co	1100
SW outlet opposite Strassman Crescent, drain No.3	18 Feb	Grass	0.2	2	-	0.6 ^{95}Zr & ^{95}Nb 0.2, 0.5 MeV	4700
		Sand	14	5	-	n.d.	200
	21 Aug	Grass	0.8	1	-	0.1, 0.5 MeV	4500
	21 Nov	Grass	0.2	1	-	n.d.	4500
		Sand	3	8	-	n.d.	680
SW outlet west of test compound	18 Feb	Sand	11.5	3	-	n.d.	600
	19 Nov	Sand	1	42	-	n.d.	800
	9 Apr	Water	-	-	4	-	-
Stormwater outlet opposite Bld.59	18 Feb	Sand	12	5	-	n.d.	100
		Water	-	-	2	-	-

The gamma-ray peak 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. In column 7 of this table the unit pCi g^{-1} refers to the number of disintegrations per second per gram of material at the energies indicated.

n.d. = not detected
- *= not measured*

TABLE 12

POSSIBLE DOSES TO A MEMBER OF THE PUBLIC

RESULTING FROM EXPOSURE TO MEASURED CONCENTRATIONS, 1975

Material	Isotope	Exposure Route	Critical Organ	Possible Dose (mrem)	ICRP Dose Limit (mrem)	Possible Dose as Fraction of ICRP Limit
Woronora oysters	^{65}Zn	Ingestion	Total body	0.002	500	4×10^{-6}
	^{3}H	Ingestion	Body tissue	0.007	500	1×10^{-5}
Woronora fish	^{60}Co	Ingestion	Total body	0.003	500	6×10^{-6}
	^{60}Co	Ingestion	Large lower intestine	0.019	1500	1×10^{-5}
	^{3}H	Ingestion	Body tissue	0.007	500	1×10^{-5}
Woronora Water	^{3}H	Daily swimming at station E5.9	Body tissue	0.005	500	1×10^{-5}
Woronora beach sand	Natural gross beta activity	Daily sun-bathing at E5.9	Skin	1.6	3000	5×10^{-4}
Menai milk	^{137}Cs	Ingestion	Total body	0.05	500	1×10^{-4}

TABLE 13

RADIOACTIVITY IN WORONORA AND HAWKESBURY OYSTERS, 1976

Station	Date	Radioactivity ($pCi\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{65}Zn	K ($\mu g\ g^{-1}$)
E7.0	12 May	0.45	0.10	n.d.	2900
	23 Aug	0.76	0.40	0.01	2400
	9 Dec	0.20	0.80	0.08	2200
average		0.47	0.43	0.03	
E9.3	28 Apr	0.02	0.14	n.d.	3000
	28 July	0.57	< 0.14	0.01	5700
	28 Oct	0.26	0.01	0.03	2100
average		0.28	0.10	0.01	
Hawkesbury River	5 May	0.35	0.22	n.d.	3000
	3 Aug	0.75	0.40	n.d.	2200
	18 Nov	0.24	0.01	n.d.	2100
average		0.45	0.21		
Woronora oyster shell (Composite)	28 Apr-9 Dec	0.39	0.19	n.d.	

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

d.l.c. of ^{65}Zn in oyster flesh = 1000 $pCi\ g^{-1}$

Station E7.0 fraction of d.l.c. = 3×10^{-5}

Station E9.3 fraction of d.l.c. = 1×10^{-5}

n.d. = not detected

TABLE 14

RADIOACTIVITY IN WORONORA FISH, 1976

Station & Variety	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{60}Co	K ($\mu g\ g^{-1}$)
E1.3					
Mullet	23 Apr	0.24	0.10	n.d.	3100
Mullet	20 Aug	0.67	< 0.20	n.d.	2500
Mullet	16 Dec	0.34	< 0.20	n.d.	2600
Tailor	16 Dec	0.02	< 0.20	n.d.	2700
Bream	16 Dec	0.20	< 0.20	n.d.	3000
average		0.49	< 0.18		
E6.4					
Mullet	4 May	0.32	0.25	n.d.	3200
Blackfish	4 May	0.34	0.30	n.d.	3300
Mullet	23 Nov	0.16	0.20	n.d.	2800
average		0.27	0.25		

Since no ^{60}Co was detected in any sample, the fraction of the d.l.c. cannot be calculated.

n.d. = not detected

TABLE 15

RADIOACTIVITY IN WORONORA BEACH SANDS, 1976

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Dry Weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	K ($\mu g\ g^{-1}$)
E1.3	22 Apr	0.55	0.23	n.d.	200
	23 July	20.36	< 0.43	n.d.	200
	1 Dec	8.07	1.80	n.d.	200
E5.9	23 Apr	11.80	1.00	n.d.	700
	23 July	12.23	3.38	n.d.	600
	3 Dec	16.27	2.67	n.d.	300
average (all samples)		9.2	1.8		
d.l.c.		3000	2500		
average fraction of d.l.c.		3×10^{-3}	7×10^{-4}		

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

n.d. = not detected

TABLE 16

TRITIUM IN WORONORA WATER SAMPLES AT STATION E5.9, 1976

Date Sampled	Tritium (pCi $m\ell^{-1}$)	Date Sampled	Tritium (pCi $m\ell^{-1}$)	Date Sampled	Tritium (pCi $m\ell^{-1}$)
2 Jan	< 1.0	7 May	2.8	9 Sept	2.7
9 Jan	2.4	14 May	< 1.0	17 Sept	< 1.0
16 Jan	< 1.0	24 May	< 1.0	24 Sept	< 1.0
23 Jan	< 1.0	28 May	< 1.0	1 Oct	< 1.0
30 Jan	< 1.0	4 June	< 1.0	8 Oct	< 1.0
6 Feb	< 1.0	11 June	< 1.0	15 Oct	< 1.0
13 Feb	< 1.0	18 June	< 1.0	22 Oct	1.2
20 Feb	< 1.0	25 June	< 1.0	29 Oct	< 1.0
27 Feb	< 1.0	2 July	2.3	8 Nov	< 1.0
8 Mar	< 1.0	9 July	< 1.0	15 Nov	< 1.0
12 Mar	< 1.0	16 July	< 1.0	19 Nov	< 1.0
19 Mar	< 1.0	23 July	< 1.0	26 Nov	2.7
26 Mar	< 1.0	30 July	1.1	3 Dec	< 1.0
2 Apr	< 1.0	6 Aug	< 1.0	10 Dec	< 1.0
9 Apr	< 1.0	13 Aug	< 1.0	17 Dec	< 1.0
15 Apr	< 1.0	20 Aug	< 1.0	24 Dec	< 1.0
24 Apr	< 1.0	27 Aug	< 1.0	31 Dec	< 1.0
30 Apr	< 1.0	3 Sept	1.6		
				average	< 1.1

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

d.l.c. = 3×10^{4} pCi $m\ell^{-1}$

Fraction of d.l.c. = 4×10^{-5} (based on annual average)

TABLE 17

RADIOACTIVITY IN WORONORA ZOSTERA SAMPLES, 1976

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Fresh Weight)							K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
				0.5 MeV	^{54}Mn	^{95}Zr & ^{95}Nb	^{60}Co	^{238}U Series	
E1.3	10 May	2.0	0.6	n.d.	n.d.	n.d.	0.8	n.d.	5300
	27 July	1.5	1.8	n.d.	n.d.	n.d.	1.1	n.d.	3200
	1 Dec	3.4	2.1	n.d.	n.d.	n.d.	0.9	n.d.	5600
E1.0	10 May	0.8	1.1	n.d.	n.d.	n.d.	1.1	n.d.	5600
	27 July	1.7	1.9	n.d.	n.d.	n.d.	1.0	n.d.	3200
	1 Dec	2.5	1.3	n.d.	n.d.	n.d.	0.5	n.d.	6700
E2.4	22 Apr	1.7	1.4	n.d.	n.d.	n.d.	0.4	n.d.	5600
	27 July	2.3	1.9	n.d.	n.d.	n.d.	0.9	n.d.	3400
	1 Dec	2.7	3.6	n.d.	n.d.	n.d.	0.9	n.d.	5100
E4.6	22 Apr	3.5	1.1	n.d.	n.d.	n.d.	0.1	n.d.	5700
	27 July	1.2	0.7	n.d.	n.d.	n.d.	0.3	n.d.	3900
	1 Dec	4.2	2.9	n.d.	n.d.	n.d.	0.2	n.d.	5800
E7.0	22 Apr	5.5	0.4	n.d.	n.d.	n.d.	Trace	n.d.	6100
	27 July	3.9	1.7	n.d.	n.d.	n.d.	Trace	n.d.	2800
	1 Dec	4.1	0.2	n.d.	n.d.	n.d.	n.d.	n.d.	4700

n.d. = not detected

TABLE 18

RADIOACTIVITY IN MILK SAMPLES, 1976

Station	Date Sampled	Radioactivity (pCi g^{-1} Fresh Weight) ^{137}Cs	^{131}I
T3 (Menai)	19 Jan	n.d.	n.d.
	20 Feb	n.d.	n.d.
	12 Mar	n.d.	n.d.
	21 Apr	0.01	n.d.
	21 May	n.d.	n.d.
	21 June	n.d.	n.d.
	27 July	n.d.	n.d.
	27 Aug	0.01	n.d.
	29 Sept	n.d.	n.d.
	29 Oct	0.01	n.d.
	25 Nov	0.02	n.d.
	21 Dec	n.d.	n.d.
average		0.004	

The analytical method used for ^{131}I in milk has a minimum detectable level of 30 pCi ℓ^{-1}.

n.d. = not detected

TABLE 19

RADIOACTIVITY IN VEGETATION AND SOIL SAMPLES

FROM LITTLE FOREST BURIAL GROUND, 1976

Location	Sample	Date	Radioactivity (pCi g^{-1} Fresh Weight)							K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
					^{137}Cs	^{60}Co	^{238}U Series	^{95}Zr & ^{95}Nb	0.5 MeV	
Near trenches 1-5	Grass	29 Oct	3.6	1.3	n.d.	n.d.	n.d.	n.d.	0.5	4400
Near trenches 53,54	Grass	21 Apr	4.2	6.9	n.d.	0.1	n.d.	n.d.	0.1	4700
	Grass	29 Oct	1.4	1.4	n.d.	n.d.	n.d.	n.d.	0.2	5000
Near trenches 56,57	Topsoil	20 Apr	440	56	5.0	3.3	n.d.	n.d.	n.d.	3600
	Topsoil	29 Oct	7.6	34	0.3	1.0	n.d.	n.d.	n.d.	3600
Near trench 58	Acacia	20 Apr	0.8	2.6	n.d.	n.d.	n.d.	n.d.	0.04	5600
	Acacia	29 Oct	1.0	2.2	n.d.	n.d.	n.d.	n.d.	0.1	5600
Near trenches 62-67	Grass	21 Apr	2.6	10	n.d.	1.0	n.d.	n.d.	0.1	3700
	Grass	29 Oct	8.8	3.7	n.d.	3.6	Trace	n.d.	0.2	3600
Near trench 68	Topsoil	20 Apr	84	86	n.d.	43	n.d.	n.d.	n.d.	5400
	Topsoil	29 Oct	15	19	n.d.	20	n.d.	n.d.	n.d.	4700
Near trenches 69-71	Grass	21 Apr	1.2	16	n.d.	1.1	n.d.	n.d.	n.d.	4400

(Continued)

TABLE 19 (Continued)

Location	Sample	Date	Radioactivity (pCi g^{-1} Fresh Weight)							K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
					^{137}Cs	^{60}Co	^{238}U Series	^{95}Zr & ^{95}Nb	0.5 MeV	
Near trench 71	Topsoil	20 Apr	61	244	n.d.	202	n.d.	n.d.	n.d.	4300
	Topsoil	29 Oct	42	39	n.d.	47	n.d.	n.d.	n.d.	4000
	Acacia	21 Apr	4.2	6.9	n.d.	1.0	n.d.	n.d.	n.d.	2900
	Acacia	29 Oct	1.0	107	n.d.	1.5	n.d.	n.d.	n.d.	2900
Near trenches 74,75	Topsoil	20 Apr	53	27	4.4	5.5	n.d.	n.d.	n.d.	3400
	Topsoil	29 Oct	19	22		2.2	n.d.	n.d.	n.d.	4200
Near trenches 72-76	Grass	29 Oct	2.1	11	n.d.	1.8	n.d.	n.d.	0.2	3400

The gamma-ray peak 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.

n.d. = not detected

TABLE 20

RADIOACTIVITY IN SAMPLES OF GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1976

Location	Date	Radioactivity (pCi ℓ^{-1})		
		Gross Alpha	Gross Beta	Gamma Emitters
Borehole 1	15 Apr	0.8	3.1	n.d.
2		0.8	1.9	n.d.
3		1.7	3.7	n.d.
4		5.6	2.1	n.d.
5		1.6	1.2	n.d.
6		1.1	3.3	n.d.
10		6.7	9.8	Trace ^{238}U series
OS1		0.6	2.5	Trace ^{238}U series
OS2		0.1	4.5	n.d.
OS3		3.9	43	n.d.
A		< 2.0	2.5	n.d.
B		11	7	Trace ^{238}U series
C		9	6.7	Trace ^{238}U series
D		2.3	9.1	n.d.
E		1.2	3.5	n.d.
Borehole 1	25 Oct	4.2	2.6	n.d.
2		0.1	1.4	n.d.
3		4.4	3.6	n.d.
4		2.3	1.8	n.d.
5		0.5	1.1	n.d.
6		2.3	1.7	n.d.
10		8.7	9.9	n.d.
OS1		2.0	2.0	n.d.
OS2		4.8	4.4	n.d.
OS3		8.0	5.3	n.d.
A		0.8	1.4	n.d.
B		18	8.1	n.d.
C		8.4	3.9	n.d.
D		11	9.0	n.d.
E		1.1	4.1	n.d.

Results for gross beta not corrected for ^{40}K. In column 5 of this table, the unit pCi ℓ^{-1} refers to the number of disintegrations per second per litre of borewater at the energies indicated.

n.d. = not detected

TABLE 21

RADIOACTIVITY IN SAMPLES TAKEN AT STORMWATER OUTLETS, 1976

Station	Date of Sample	Sample	Radioactivity ($pCi\ g^{-1}$ Fresh Weight)				K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($pCi\ m\ell^{-1}$)	Gamma Emitters	
RE storm-water outlet No.2 near South Gate	24 May	Grass	0.1	1.8	-	0.3 ^{137}Cs 0.1 ^{60}Co	4200
	24 May	Sand	78	59	-	18 ^{137}Cs 23 ^{60}Co	650
	24 May	Water	-	-	7	-	-
	29 June	Water	-	-	7	-	-
	29 July	Water	-	-	19	-	-
	18 Aug	Water	-	-	3	-	-
	18 Aug	Sand	45	43	-	17 ^{137}Cs 13 ^{60}Co	350
	17 Sept	Water	-	-	2	-	-
	22 Oct	Water	-	-	5	-	-
	25 Nov	Water	-	-	4	-	-
RE storm-water outlet No.1 near South Gate	26 May	Grass	1.2	1.5	-	0.1 ^{137}Cs 0.1 ^{60}Co	5600
	25 May	Water	-	-	31	-	-
	29 June	Water	-	-	12	-	-
	29 July	Water	-	-	19	-	-
	18 Aug	Water	-	-	10	-	-
	18 Aug	Sand	33	14	-	Trace ^{232}Th series	450
	18 Aug	Grass	1.1	4.5	-	0.1, 0.5 MeV 0.1 ^{137}Cs 0.5 ^{60}Co	2900
	17 Sept	Water	-	-	21	-	-
	22 Oct	Water	-	-	45	-	-
	25 Nov	Water	-	-	10	-	-
RE storm-water outlet 20 m from South Gate	24 May	Grass	0.3	1.4	-	1.3 ^{137}Cs 0.3 ^{60}Co	4500
	24 May	Sand	12.1	5.4	-	2.34 ^{137}Cs 2.58 ^{60}Co	200
	24 May	Water	-	-	4	-	-
	18 Aug	Water	-	-	4	-	-
	18 Aug	Grass	5.6	42	-	0.1, 0.5 MeV 0.1 ^{137}Cs 0.5 ^{60}Co	6800
Near scour valve No.1	24 May	Water	-	-	20	-	-
	17 Aug	Water	-	-	9	-	-
	17 Aug	Sand	12	2.4	-	n.d.	300
Stormwater outlet opposite Bld.9	29 Apr	Grass	0.2	0.3	-	0.1, 0.5 MeV	5500
	29 Apr	Sand	7.3	5.8		Trace ^{232}Th series	650
	29 Apr	Water	-	-	< 1	-	-
	13 Sept	Water	-	-	< 1	-	-
	13 Sept	Grass	2.7	39	-	Trace 0.5 MeV	4700
Stormwater outlet No.1 opposite Strassman Crescent	29 Apr	Grass	0.3	1.2	-	n.d.	4800
	29 Apr	Water	-	-	·3	-	-
	13 Sept	Water	-	-	< 1	-	-
	13 Sept	Grass	1.1	52	-	n.d.	4800
	13 Sept	Sand	4.7	6.8	-	0.4 ^{137}Cs Trace ^{232}Th series	700

(Continued)

TABLE 21 (Continued)

Station	Date of Sample	Sample	Radioactivity ($pCi\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($pCi\ m\ell^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Stormwater outlet No.3 opposite Strassman Crescent	29 Apr	Grass	0.3	0.3	-	n.d.	4800
	29 Apr	Sand	10		-	0.1, 0.5 MeV Trace ^{232}Th series	650
	13 Sept	Grass	1.2	9.6	-	n.d.	4000
	13 Sept	Sand	17	10	-	Trace ^{232}Th series	1000
Stormwater outlet opposite Fermi St.	29 Apr	Grass	0.8	0.8	-	0.1, 0.5 MeV	2900
	29 Apr	Sand	3.6	0.3	-	n.d.	500
	29 Apr	Water	-	-	< 1	-	-
	13 Sept	Water	-	-	< 1	-	-
	13 Sept	Grass	4.2	8.5	-	Trace ^{238}U series	2500
	13 Sept	Sand				Trace ^{238}U series	
Stormwater outlet No.2 opposite Strassman Crescent	29 Apr	Sand	11	11	-	0.2 ^{137}Cs 0.4 ^{60}Co	600
	13 Sept	Sand	2.2	9.1	-	0.6 ^{60}Co	500
Stormwater outlet opposite Bld.23	29 Apr	Sand	8.6	15	-	0.1 ^{137}Cs 0.8 ^{60}Co	900
	13 Sept	Water	-	-	3	-	-
	13 Sept	Grass	3.2	11	-	Trace ^{238}U series 0.1 ^{60}Co Trace ^{232}Th series	3200
Stormwater outlet near boom gates	29 Apr	Sand	5.8	0.3	-	n.d.	200
	13 Sept	Sand	96	1.5	-	n.d.	200
Stormwater outlet near Bld.59	29 Apr	Sand	8.5	0.6	-	0.1 ^{137}Cs Trace ^{232}Th series	600
	29 Apr	Water	-	-	< 1	-	-
	13 Sept	Water	-	-	< 1	-	-
Stormwater outlet west of test compound	29 Apr	Sand	4.5	1.7	-	Trace ^{232}Th series	350
	29 Apr	Water			< 1		
	13 Sept	Sand	14	3.1	-	0.4 ^{137}Cs 1.0 ^{60}Co	500
	13 Sept	Water	-	-	2	-	-
Creek crossing main road	29 Apr	Water	-	-	3	-	-
	13 Sept	Sand	9.1	2.1	-	n.d.	400
	13 Sept	Water	-	-	6	-	-
Woronora River where effluent pipe crosses	24 May	Sand	81	1.8	-	n.d.	200

The gamma-ray peak 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. In column 7 of this table $pCi\ g^{-1}$ refers to the number of disintegrations per second per gram at the energies indicated.

n.d. = not detected   *- = not measured*

TABLE 22

POSSIBLE DOSES TO A MEMBER OF THE PUBLIC RESULTING FROM EXPOSURE TO MEASURED CONCENTRATIONS, 1976

Material	Isotope	Exposure Route	Critical Organ	Possible Dose (mrem)	ICRP Dose Limit (mrem)	Possible Dose as Fraction of ICRP Limit
Woronora oysters	^{65}Zn ^{3}H	Ingestion Ingestion	Total body Body tissue	0.003 0.005	500 500	6×10^{-6} 1×10^{-5}
Woronora fish	^{3}H	Ingestion	Body tissue	0.005	500	1×10^{-5}
Woronora water	^{3}H	Daily swimming at station E5.9	Body tissue	0.003	500	6×10^{-6}
Woronora beach sand	Natural gross beta activity	Daily sunbathing at E5.9	Skin	2.2	3000	7×10^{-4}
Menai milk	^{137}Cs	Ingestion	Total body	0.02	500	4×10^{-5}

TABLE 23

RADIOACTIVITY IN WORONORA AND HAWKESBURY OYSTERS, 1977

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{65}Zn	K ($\mu g\ g^{-1}$)
E7.0	15 Feb	0.37	0.53	0.03	4000
	22 July	0.32	0.48	n.d.	3100
	10 Oct	0.27	0.62	0.04	3200
	7 Dec	0.19	0.38	0.01	3390
average		0.29	0.50	0.02	
E9.3	9 Feb	0.22	0.48	n.d.	3500
	17 May	0.13	0.30	n.d.	2800
	25 Aug	0.14	0.42	n.d.	3500
	7 Dec	0.19	0.60	0.02	3080
average		0.17	0.45	0.005	
Hawkesbury River	14 Feb	0.20	0.67	n.d.	3300
	26 June	0.24	0.23	n.d.	1500
	29 Aug	0.41	0.41	n.d.	3400
	20 Dec	0.21	0.44	n.d.	3600
average		0.27	0.44		
Woronora oyster shell (Composite)	9 Feb- 7 Dec	0.86	< 0.01	n.d.	261

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

d.l.c. of ^{65}Zn in oyster flesh = 1000 $pCi\ g^{-1}$

E7.0 Fraction of d.l.c. 2×10^{-5}

E9.3 Fraction of d.l.c. 5×10^{-6}

n.d. = not detected

TABLE 24

RADIOACTIVITY IN WORONORA FISH, 1977

Station	Date Sampled	Radioactivity (pCi g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	K ($\mu g\ g^{-1}$)
El.3					
Mullet	13 Apr	0.26	1.13	n.d.	2800
Mullet	25 Aug	0.05	0.58	n.d.	2500
average		0.16	0.86		
El.3 + 200 m north					
Mullet	9 Sept	0.26	0.21	0.09 ^{65}Zn	1700
Mullet	4 Nov	0.32	0.40	n.d.	2800
average		0.29	0.31		
E6.4					
Blackfish	25 Mar	0.84	1.34	n.d.	2600
Mullet	25 Mar	0.73	0.86	n.d.	2900
Mullet	19 Aug	0.44	0.45	n.d.	2600
Mullet	7 Oct	0.37	0.45	n.d.	2800
Mullet	6 Dec	0.30	0.51	n.d.	2600
average		0.54	0.72		

No ^{60}Co was detected. The fraction of the derived limiting concentration cannot, therefore, be calculated.

n.d. = not detected

TABLE 25

RADIOACTIVITY IN WORONORA BEACH SANDS, 1977

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Dry Weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	K ($\mu g\ g^{-1}$)
E1.3	28 Jan	12.29	1.23	n.d.	100
	15 June	12.18	0.92	n.d.	190
	28 Sept	20.36	1.05	n.d.	230
E5.9	28 Jan	19.08	4.34	n.d.	450
	15 June	15.53	1.87	n.d.	370
	23 Sept	22.10	1.23	n.d.	250
average (all samples)		16.9	1.77		
d.l.c.		3000	2500		
average fraction of d.l.c.		5.6×10^{-3}	7.1×10^{-4}		

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

n.d. = not detected

TABLE 26

TRITIUM IN WORONORA WATER SAMPLES STATION E5.9, 1977

Date Sampled	Tritium ($pCi\ m\ell^{-1}$)	Date Sampled	Tritium ($pCi\ m\ell^{-1}$)	Date Sampled	Tritium ($pCi\ m\ell^{-1}$)
7 Jan	< 1.0	9 May	1.5	2 Sept	< 1.0
14 Jan	< 1.0	13 May	2.1	12 Sept	< 1.0
21 Jan	2.0	20 May	< 1.0	16 Sept	< 1.0
28 Jan	< 1.0	27 May	< 1.0	23 Sept	< 1.0
4 Feb	< 1.0	3 June	< 1.0	30 Sept	< 1.0
11 Feb	< 1.0	10 June	< 1.0	7 Oct	< 1.0
18 Feb	< 1.0	17 June	< 1.0	14 Oct	1.56
25 Feb	< 1.0	24 June	1.0	21 Oct	< 1.0
4 Mar	< 1.0	1 July	< 1.0	27 Oct	< 1.0
14 Mar	< 1.0	8 July	< 1.0	4 Nov	< 1.0
18 Mar	< 1.0	15 July	< 1.0	11 Nov	< 1.0
25 Mar	< 1.0	22 July	1.4	18 Nov	< 1.0
1 Apr	< 1.0	29 July	< 1.0	25 Nov	< 1.0
7 Apr	< 1.0	5 Aug	< 1.0	2 Dec	1.6
15 Apr	< 1.0	12 Aug	1.3	9 Dec	3.4
22 Apr	1.25	22 Aug	< 1.0	16 Dec	< 1.0
29 Apr	< 1.0	26 Aug	< 1.0	22 Dec	< 1.0
				30 Dec	< 1.0
				average	< 1.1

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

d.l.c. = 3×10^{4} $pCi\ m\ell^{-1}$

Average fraction d.l.c. = 3.7×10^{-5}

TABLE 27

RADIOACTIVITY IN WORONORA ZOSTERA SAMPLES, 1977

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Fresh Weight)									K ($\mu g\ g^{-1}$)
		Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters							
				0.5 MeV	^{54}Mn	^{95}Zr & ^{95}Nb	^{60}Co	^{65}Zn	^{238}U Series		
E1.3	28 Jan	1.42	1.65	n.d.	n.d.	n.d.	0.9	n.d.	n.d.		2800
	15 June	2.01	1.44	n.d.	n.d.	n.d.	1.05	n.d.	Trace		3200
	23 Sept	1.03	1.07	n.d.	0.09	n.d.	0.45	1.0	n.d.		4400
E1.6	28 Jan	1.95	1.78	n.d.	n.d.	n.d.	0.09	n.d.	n.d.		2200
	15 June	1.72	2.02	n.d.	n.d.	n.d.	1.03	n.d.	n.d.		3000
	23 Sept	1.52	1.86	n.d.	0.16	n.d.	0.03	1.32	n.d.		-
E2.4	28 Jan	1.51	1.1	n.d.	n.d.	n.d.	0.54	n.d.	n.d.		3000
	15 June	2.25	2.21	n.d.	n.d.	n.d.	0.76	n.d.	Trace		2900
	23 Sept	2.54	2.39	n.d.	n.d.	n.d.	0.37	0.06	n.d.		4300
E4.6	28 Jan	3.65	3.14	n.d.	n.d.	n.d.	0.22	n.d.	Trace		3900
	15 June	2.57	1.69	n.d.	n.d.	n.d.	0.87	n.d.	Trace		2700
	23 Sept	2.76	1.15	n.d.	n.d.	n.d.	0.02	0.16	n.d.		6000
E7.0	28 Jan	No sample - no zostera growing									
	15 June	2.45	1.38	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.		2700
	23 Sept	4.34	2.20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.		2900
E5.8	28 Jan 15 June 23 Sept	No sample - insufficient zostera									

n.d. = *not detected*

\- = *not measured*

TABLE 28

RADIOACTIVITY IN MILK SAMPLES, 1977

Station	Date Sampled	Radioactivity ($pCi\ g^{-1}$ Fresh Weight) ^{137}Cs	^{131}I
T3 (Menai)	28 Jan	n.d.	n.d.
	16 Feb	n.d.	n.d.
	31 Mar	n.d.	n.d.
	29 Apr	n.d.	n.d.
	21 May	0.01	n.d.
	30 June	n.d.	n.d.
	28 July	n.d.	n.d.
	29 Aug	0.01	n.d.
	27 Sept	0.01	n.d.
	27 Oct	n.d.	n.d.
	30 Nov	0.03	n.d.
	30 Dec	n.d.	n.d.
average		0.005	

The analytical method used for ^{131}I in milk has a minimum detectable level of 30 pCi ℓ^{-1}.

n.d. = not detected

TABLE 29

RADIOACTIVITY IN SAMPLES OF VEGETATION AND SOIL FROM

LITTLE FOREST BURIAL GROUND, 1977

Location	Sample	Date	Radioactivity (pCi g^{-1} Fresh Weight)							K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
					^{137}Cs	^{60}Co	^{238}U Series	^{95}Zr & ^{95}Nb	0.5 MeV	
Near trenches 1-5	Grass	28 Apr	1.8	2.0	n.d.	n.d.	n.d.	n.d.	0.32	4500
Near trench 2	Topsoil	28 Apr	18.0	15.9	1.19	n.d.	Trace	n.d.	n.d.	3400
	Topsoil	25 Oct	14.8	14.9	6.52	9.08	n.d.	n.d.	n.d.	3100
Near trenches 53-55	Grass	28 Apr	1.1	2.6	n.d.	n.d.	n.d.	n.d.	0.35	4700
	Grass	25 Oct	1.6	4.6	0.03	n.d.	n.d.	n.d.	0.26	2800
Near trench 56	Topsoil	28 Apr	192.4	37.2	4.63	1.21	n.d.	n.d.	n.d.	2600
	Topsoil	25 Oct	405.5	98.9	12.6	1.7	n.d.	n.d.	n.d.	3500
Near trench 58	Acacia	28 Apr	0.6	1.3	n.d.	n.d.	n.d.	n.d.	0.1	2700
	Acacia	25 Oct	0.6	2.0	n.d.	n.d.	n.d.	n.d.	0.04	3100
Near trenches 60-65	Grass	28 Apr	2.5	9.8	n.d.	0.43	n.d.	n.d.	0.5	3700
Near trenches 66-71	Grass	28 Apr	7.7	81.9	n.d.	3.8	n.d.	n.d.	0.5	4100
Near trenches 71-75	Grass	28 Apr	3.4	72.4	n.d.	5.9	n.d.	n.d.	0.65	2800

(Continued)

TABLE 29 (Continued)

Location	Sample	Date	Radioactivity (pCi g^{-1} Fresh Weight)							K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters					
					^{137}Cs	^{60}Co	^{238}U Series	^{95}Zr & ^{95}Nb	0.5 MeV	
Near trenches 62-71	Grass	28 Apr	2.2	11.8	n.d.	0.91	n.d.	n.d.	0.21	4900
Near trench 68	Topsoil	28 Apr	49.9	146.8	n.d.	27.7	n.d.	n.d.	n.d.	3100
	Topsoil	25 Oct	58.4	94.9	n.d.	51.8	n.d.	n.d.	n.d.	3400
Near trench 71	Acacia	28 Apr	0.6	85.0	n.d.	0.96	n.d.	n.d.	n.d.	1500
	Acacia	25 Oct	0.6	72.0	n.d.	0.7	n.d.	n.d.	n.d.	2000
	Topsoil	28 Apr	19.8	115.0	n.d.	76.5	n.d.	n.d.	n.d.	4100
	Topsoil	25 Oct	22.9	117.0	n.d.	74.7	n.d.	n.d.	n.d.	4100
Near trenches 74,75	Topsoil	28 Apr	19.8	24.2	1.2	4.9	n.d.	n.d.	n.d	2600
	Topsoil	25 Oct	22.4	19.9	4.8	5.1	n.d.	n.d.	n.d.	2800

The gamma-ray peak 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.

n.d. = not detected

TABLE 30

RADIOACTIVITY IN SAMPLES OF GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1977

Location	Date Sampled	Radioactivity (pCi ℓ^{-1})		
		Gross Alpha	Gross Beta	Gamma Emitters
Borehole E	22 Apr	1.5	6.4	n.d.
5		1.7	1.2	n.d.
4		3.2	1.5	n.d.
3		1.2	1.9	n.d.
2		0.9	2.2	n.d.
1		1.0	1.8	n.d.
10		4.4	9.3	n.d.
OS3		2.5	25.9	n.d.
OS2		2.1	3.8	n.d.
OS1		2.1	2.9	n.d.
6		12.5	7.9	n.d.
A		1.7	2.6	n.d.
B		14.7	6.5	n.d.
C		8.4	5.7	n.d.
D		6.0	10.3	n.d.
Borehole 1	6 Oct	2.1	1.9	n.d.
10		1.9	8.5	n.d.
OS1		1.2	3.1	n.d.
OS3		2.4	30.5	n.d.
OS2		2.1	3.7	n.d.
2		5.3	3.4	n.d.
5		2.3	1.4	n.d.
4		1.0	1.3	n.d.
3		2.3	2.8	n.d.
6		7.4	4.9	n.d.
Borehole A	27 Oct	1.4	4.1	n.d.
B		10.6	7.6	Trace ^{238}U series
C		9.7	6.6	n.d.
D		5.1	11.3	n.d.
E		6.0	12.2	n.d.

Results for gross beta not corrected for ^{40}K.

n.d. = not detected

TABLE 31

RADIOACTIVITY IN SAMPLES TAKEN AT STORMWATER OUTLETS, 1977

Station	Date of Sample	Sample	Radioactivity (pCi g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (pCi $m\ell^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Drain No.3 opposite Strassman Crescent	14 Jan	Soil	17.0	8.5	-	0.2, 0.5 MeV Trace ^{232}Th series	100
	4 May	Soil	18.7	8.2	-	Trace ^{232}Th series	550
Drain opposite Bld. 20	14 Jan	Soil	14.9	0.8	-	n.d.	200
	4 May	Soil	30.7	2.5	-	n.d.	400
	21 Sept	Soil	5.3	2.0	-	n.d.	200
Drain at boom gates	14 Jan	Soil	6.0	2.7	-	n.d.	220
	4 May	Soil	13.6	3.7	-	n.d.	240
	20 Sept	Soil	10.4	57.0	-	Trace ^{238}U series	210
	14 June	Water	-	-	1.3	-	-
Drain opposite Bld.59	14 Jan	Soil	13.4	7.2	-	Trace ^{232}Th series	1000
	20 Sept	Soil	12.0	7.7	-	0.98 ^{137}Cs	390
	14 Jan	Water	-	-	4.9	-	-
	4 May	Water	-	-	< 1.0	-	-
Drain No.1 opposite Strassman Crescent	14 Jan	Soil	14.9	75.8	-	n.d.	1100
	14 Jan	Vegetation	0.2	1.6	-	0.09, 0.5 MeV	3700
	4 May	Vegetation	0.1	0.6	-	0.08, 0.5 MeV	4200
	21 Sept	Soil	14.1	9.0	-	Trace ^{137}Cs Trace ^{60}Co Trace ^{238}U series	460
	21 Sept	Vegetation	0.2	0.8	-	0.03, 0.5 MeV	4400
	14 Jan	Water	-	-	< 1.0	-	-
	4 May	Water	-	-	< 1.0	-	-
Drain opposite Bld.23	14 Jan	Soil	11.7	8.8	-	0.2 ^{137}Cs Trace ^{232}Th series	770
	20 Sept	Soil	8.7	5.8	-	Trace ^{238}U series Trace ^{232}Th series	350
	14 Jan	Water	-	-	4.6	-	-
Drain opposite Fermi Street	14 Jan	Soil	9.2	4.8	-	n.d.	280
	14 Jan	Vegetation	1.1	1.5	-	0.05, 0.5 MeV	2900
	4 May	Soil	8.9	7.9	-	1.19 ^{137}Cs	900
	20 Sept	Soil	11.5	1.1	-	0.82 ^{137}Cs	560
	14 Jan	Water	-	-	19.6	-	-
	4 May	Water	-	-	< 1.0	-	-
Drain on road, west fence	14 Jan	Soil	9.8	2.7	-	Trace ^{232}Th series	270
	4 May	Soil	2.1	2.1	-	n.d.	350
	20 Sept	Soil	19.3	1.7	-	Trace ^{238}U series	620
	14 Jan	Water	-	-	11.2	-	-
Drain west of test compound	14 Jan	Soil	36.6	48.6	-	0.34 ^{137}Cs	480
	4 May	Soil	38.4	37.5	-	n.d.	480
Drain opposite Bld.9	18 Jan	Soil	11.1	5.8	-	n.d.	620
	18 Jan	Vegetation	0.23	1.4	-	0.02, 0.5 MeV	3900
	4 May	Soil	11.5	6.4	-	n.d.	850
	18 Jan	Water	-	-	0.1	-	-
	3 May		-	-	2.6	-	-

(Continued)

TABLE 31 (Continued)

Station	Date of Sample	Sample	Radioactivity (pCi g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (pCi $m\ell^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Drain opposite Bld.1	4 May	Soil	14.6	6.9	-	n.d.	830
	20 Sept	Soil	11.8	1.6	-	n.d.	490
Drain No.2 Strassman Crescent	4 May	Soil	16.4	10.8	-	0.5 ^{137}Cs 0.28 ^{60}Co	500
Drain at west fence	20 Sept	Soil	5.3	17	-	n.d.	560
RE storm-water outlet No.1 near south gate	6 Jan	Water	-	-	9.5	-	-
	25 Jan	Water	-	-	98	-	-
	23 Mar	Water	-	-	38.5	-	-
	29 Apr	Water	-	-	5.2	-	-
	25 May	Water	-	-	16.2	-	-
	29 June	Water	-	-	33	-	-
	22 July	Water	-	-	4	-	-
	10 Aug	Water	-	-	3.7	-	-
	14 Sept	Water	-	-	201	-	-
	19 Oct	Water	-	-	1080	-	-
	23 Nov	Water	-	-	447	-	-
	30 Nov	Water	-	-	733	-	-
	8 Dec	Water	-	-	88	-	-
	12 Dec	Water	-	-	57	-	-
	20 Dec	Water	-	-	55	-	-
	30 Dec	Water	-	-	414	-	-
	25 Jan	Soil	24.9	10.0	-	0.3 ^{137}Cs Trace ^{238}U series	280
	19 Oct	Soil	27.2	13.5	-	0.24 ^{137}Cs Trace ^{238}U series	460
	25 Jan	Vegetation	0.6	1.0	-	0.05, 0.5 MeV 0.04 ^{137}Cs	4700
RE storm-water outlet No.2 near south gate	6 Jan	Water	-	-	9.1	-	-
	25 Jan	Water	-	-	5.9	-	-
	23 Mar	Water	-	-	18	-	-
	29 Apr	Water	-	-	18	-	-
	25 May	Water	-	-	10	-	-
	29 June	Water	-	-	5.9	-	-
	22 July	Water	-	-	11	-	-
	10 Aug	Water	-	-	12	-	-
	14 Sept	Water	-	-	7	-	-
	19 Oct	Water	-	-	10	-	-
	23 Nov	Water	-	-	7	-	-
	20 Dec	Water	-	-	4.7	-	-
	25 Jan	Soil	142	39	-	18.7 ^{137}Cs 8.5 ^{60}Co	430
	29 June	Soil	14.5	19	-	0.9 ^{137}Cs 0.6 ^{95}Zr & ^{95}Nb 1.7 ^{60}Co	390
	19 Oct	Soil	76	87	-	7.3 ^{137}Cs 9.6 ^{60}Co	330
	29 June	Vegetation	3.4	8.3	-	0.3, 0.5 MeV 0.5 ^{137}Cs 1.6 ^{60}Co	540

(Continued)

TABLE 31 (Continued)

Station	Date of Sample	Sample	Radioactivity (pCi g^{-1} Fresh Weight)				K ($\mu g\ g^{-1}$)
			Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (pCi $m\ell^{-1}$)	Gamma Emitters	
20 m from RE storm-water outlet No.1	25 Jan	Water	-	-	3.8	-	-
	29 June	Water	-	-	7	-	-
	19 Oct	Water	-	-	33	-	-
	25 Jan	Soil	53	21	-	5.0 ^{137}Cs 7.0 ^{60}Co	320
	29 June	Soil	65	51	-	7.3 ^{137}Cs 65 ^{60}Co	1000
	19 Oct	Soil	66	13	-	4.1 ^{137}Cs 4.4 ^{60}Co	550
	25 Jan	Vegetation	0.4	1.4	-	0.9 ^{137}Cs 0.2 ^{54}Mn 0.2 ^{60}Co	3900
	29 June	Vegetation	0.4	1.8	-	0.2, 0.5 MeV 0.3 ^{137}Cs 0.04 ^{54}Mn	4000
	19 Oct	Vegetation	0.6	1.8	-	0.02, 0.5 MeV 0.37 ^{137}Cs 0.29 ^{60}Co	5000
RE effluent discharge pipeline near scour valve No.1	24 Jan	Soil	16	2.4	-	Trace ^{232}Th series 0.1 ^{137}Cs	600
	23 June	Soil	12	1.8	-	n.d.	450
	19 Oct	Soil	23	2.7	-	n.d.	310
River where effluent discharge pipe crosses	24 Jan	Sand	10	2.4	-	n.d.	160
	23 June	Sand	11	2.6	-	n.d.	300
	19 Oct	Sand	50	52	-	n.d.	320
Bardens Creek above junction with Mill Creek	16 June	Sand	7.3	1.4	-	n.d.	490
		Water	0.21 (pCi ℓ^{-1})	2.3 (pCi ℓ^{-1})	< 1.0	n.d.	-
Mill Creek below junction with Bardens Creek	16 June	Sand	15	1.3	-	n.d.	330
		Water	1.7 (pCi ℓ^{-1})	1.7 (pCi ℓ^{-1})	< 1.0	n.d.	-

The gamma-ray peak 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. In column 7 of this table pCi g^{-1} refers to the number of disintegrations per second per gram at the energies indicated.

n.d. = not detected

\- *= not measured*

TABLE 32

POSSIBLE DOSES TO A MEMBER OF THE PUBLIC RESULTING FROM EXPOSURE TO MEASURED CONCENTRATIONS, 1977

Material	Isotope	Exposure Route	Critical Organ	Possible Dose (mrem)	ICRP Dose Limit (mrem)	Possible Dose as Fraction of ICRP Limit
Woronora oysters	^{65}Zn	Ingestion	Total body	0.002	500	4×10^{-6}
	^{3}H	Ingestion	Body tissue	0.005	500	1×10^{-5}
Woronora fish	^{3}H	Ingestion	Body tissue	0.005	500	1×10^{-5}
Woronora water	^{3}H	Daily swimming at station E5.9	Body tissue	0.003	500	6×10^{-6}
Woronora beach sand	Natural gross beta activity	Daily sun-bathing at E5.9	Skin	2.4	3000	8×10^{-4}
Menai milk	^{137}Cs	Ingestion	Total body	0.03	500	6×10^{-5}

TABLE 33

GAMMA SURVEY OF DISCHARGE PIPELINE, 1977

Gamma survey of effluent discharge pipeline between the RE and Woronora River discharge point using a 1368A field ratemeter.

Location	Date	Gamma ($mR\ h^{-1}$)
Scour valves	23 June	< 0.15
Pipe joints	23 June	< 0.15
Between joints	23 June	< 0.15
Scour valves	19 Oct	< 0.15
Pipe joints	19 Oct	< 0.15
Between joints	19 Oct	< 0.15

TABLE 34

BETA GAMMA SURVEY OF RIVER BOTTOM

DISCHARGE PIPELINE OUTLET, 1977

Beta gamma survey of river bottom at station EO using a submersible scintillation counter and IME portable ratemeter

Location	Date	Beta Gamma ($counts\ s^{-1}$)
Radius of 30 cm from discharge end of effluent pipe	21 Oct	60
Radius of 3 m from discharge end	21 Oct	15
Radius of 5 m from discharge end	21 Oct	< 5

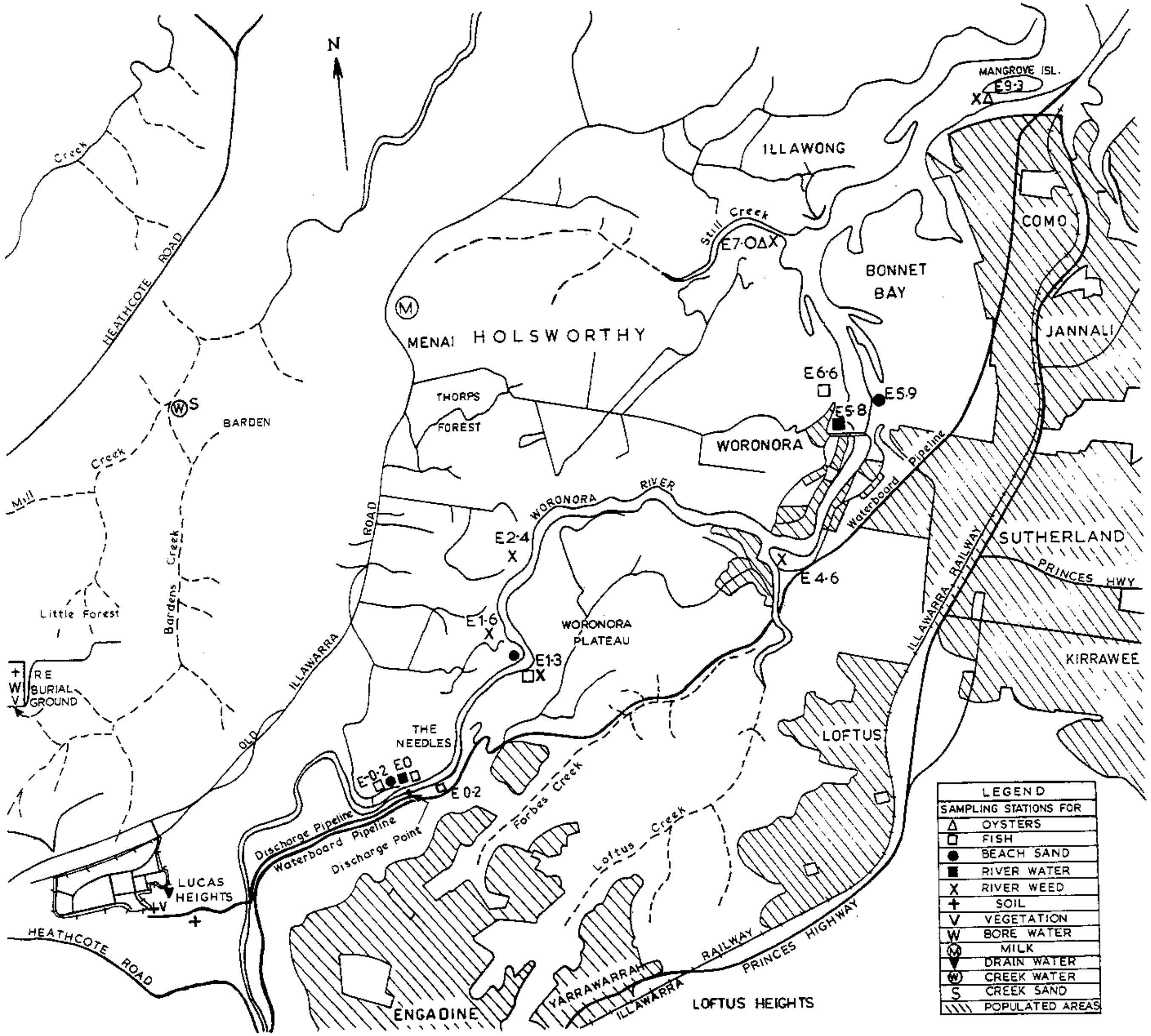

FIGURE 1. LUCAS HEIGHTS DISTRICT - LOCATION OF SAMPLING STATIONS

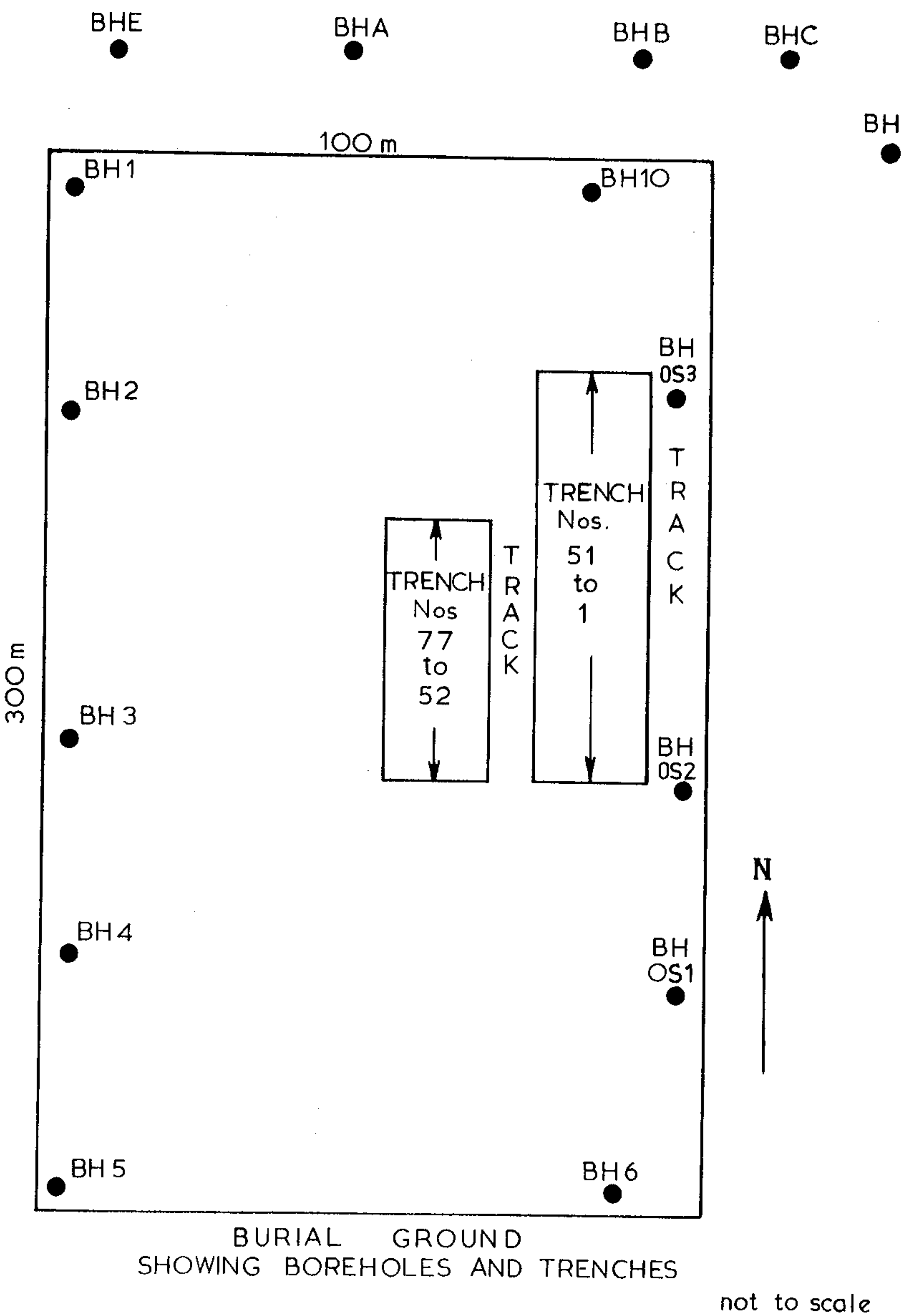

FIGURE 1A. LITTLE FOREST BURIAL GROUND - LOCATION OF SAMPLING STATIONS

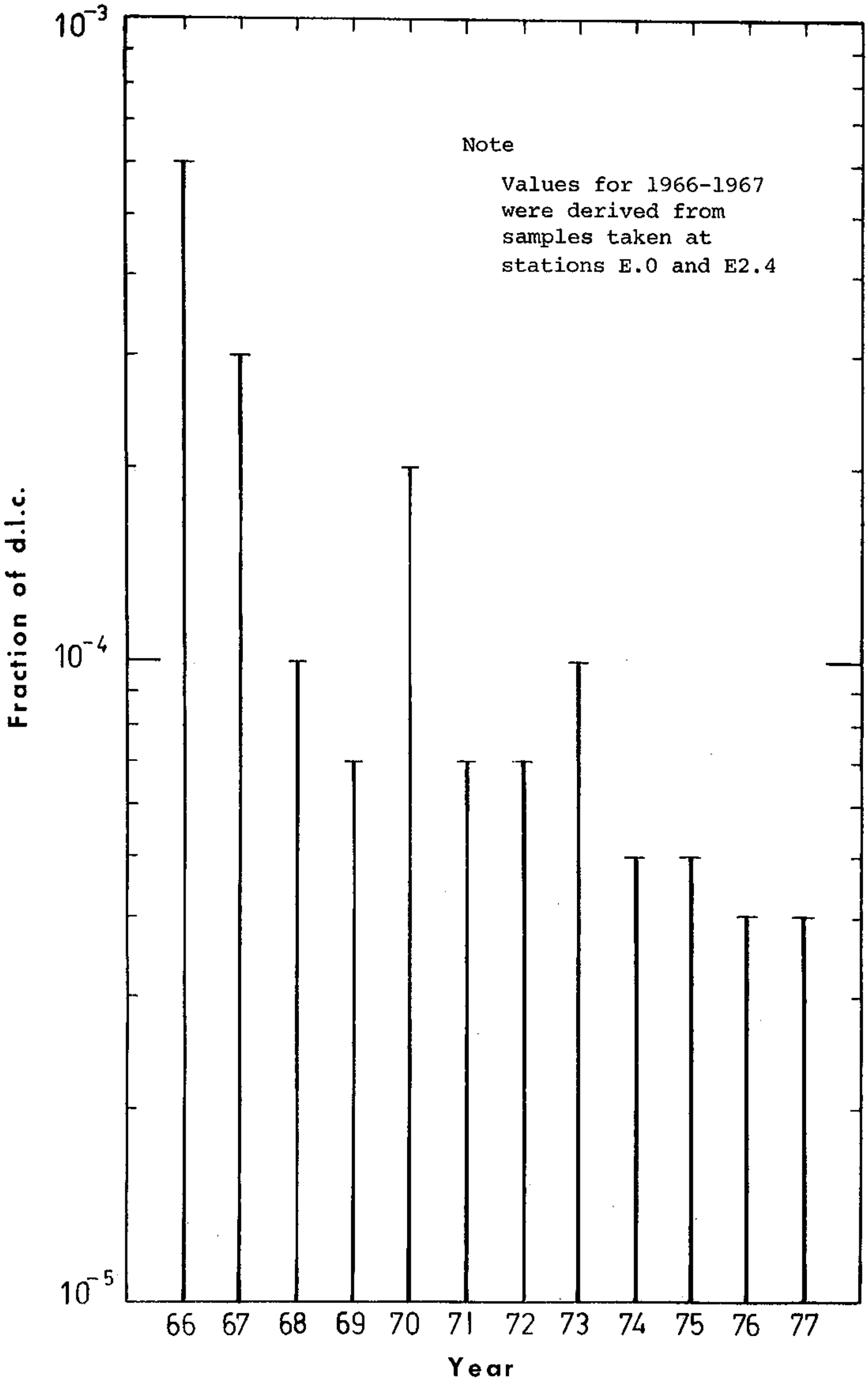

FIGURE 2. TRITIUM IN WORONORA WATER (STATION E5.9) EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1966-1977

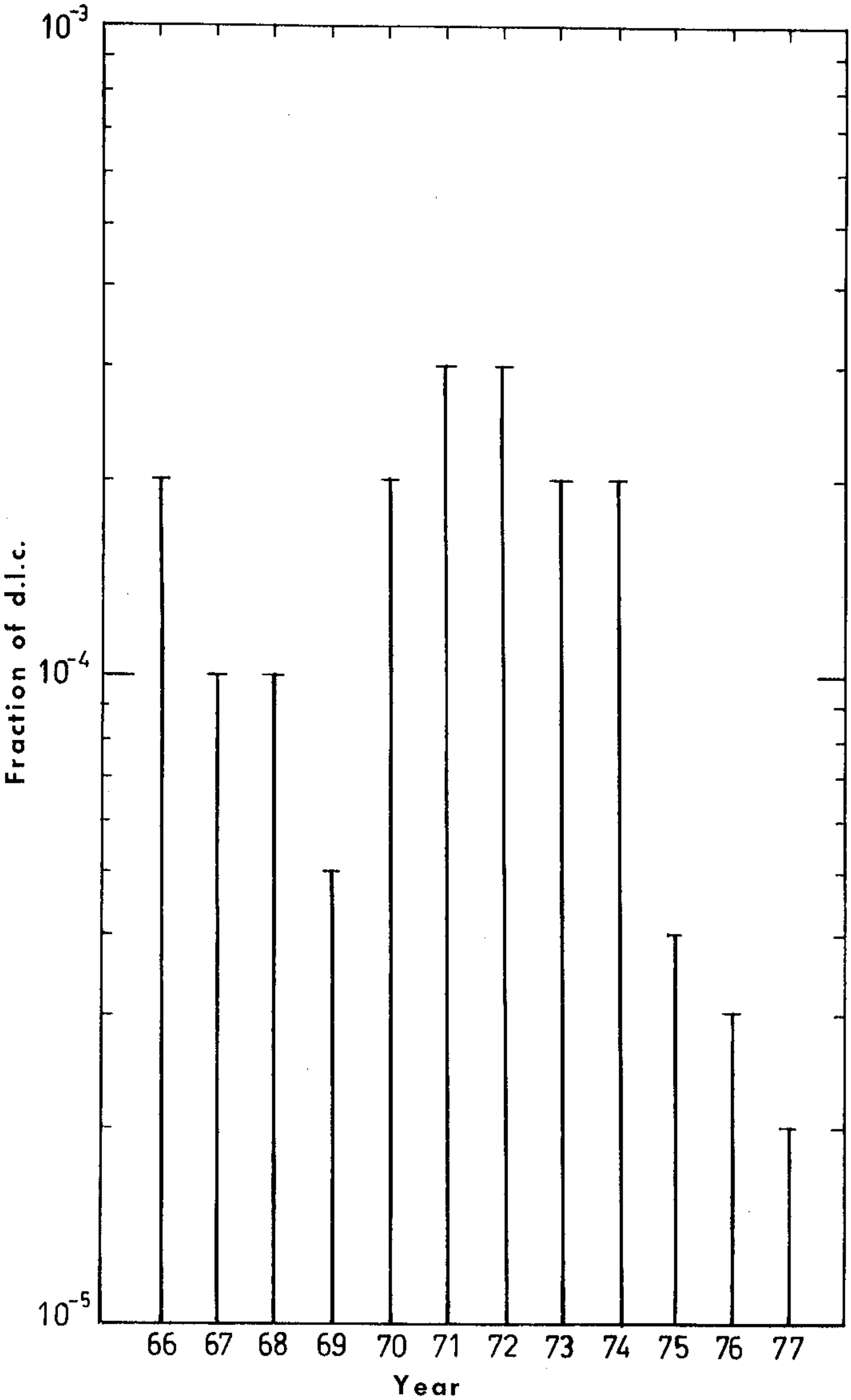

FIGURE 3. ^{65}Zn IN WORONORA OYSTERS (STATION E7.0) EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1966-1977

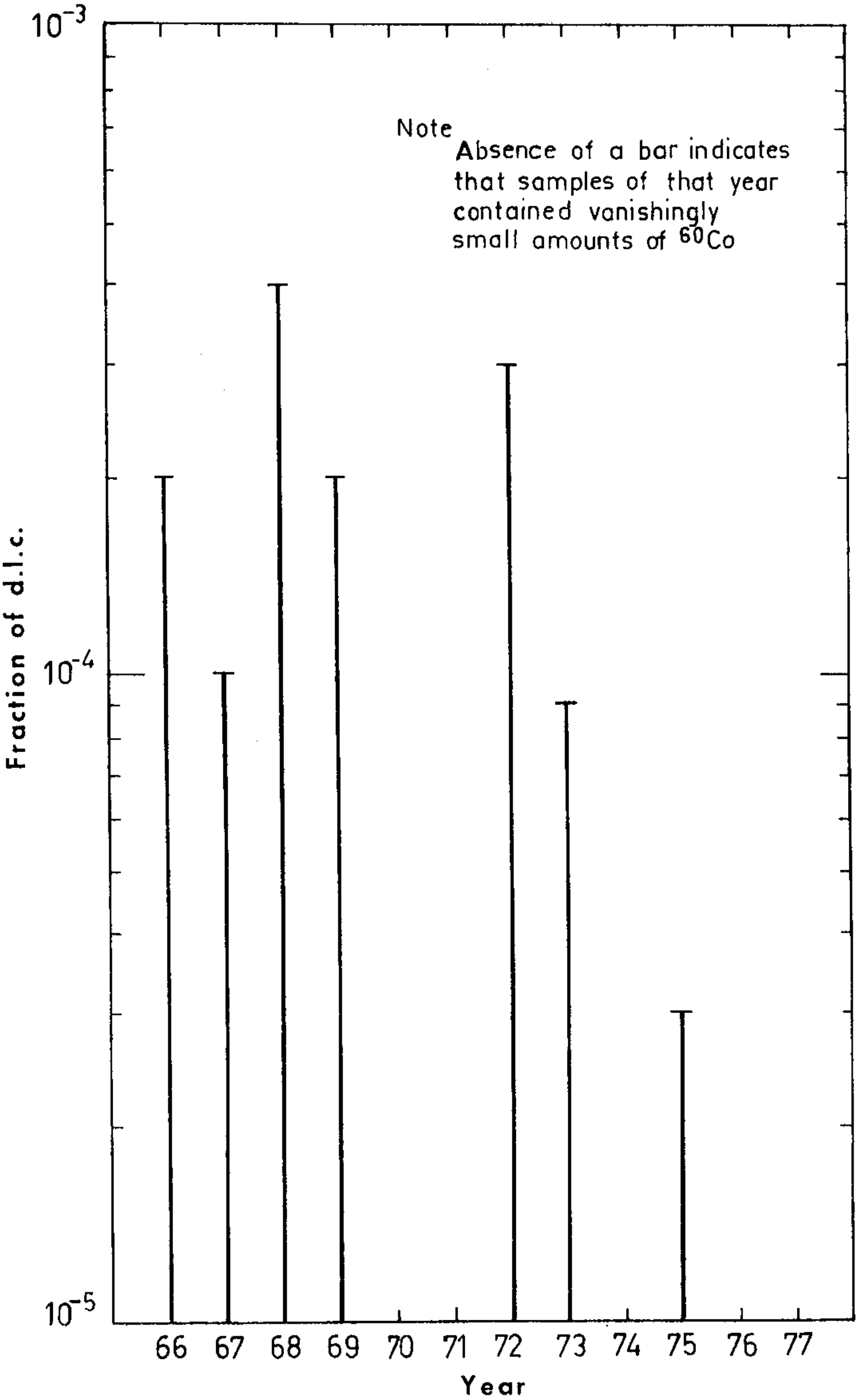

FIGURE 4. ^{60}Co IN WORONORA FISH EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1966-1977

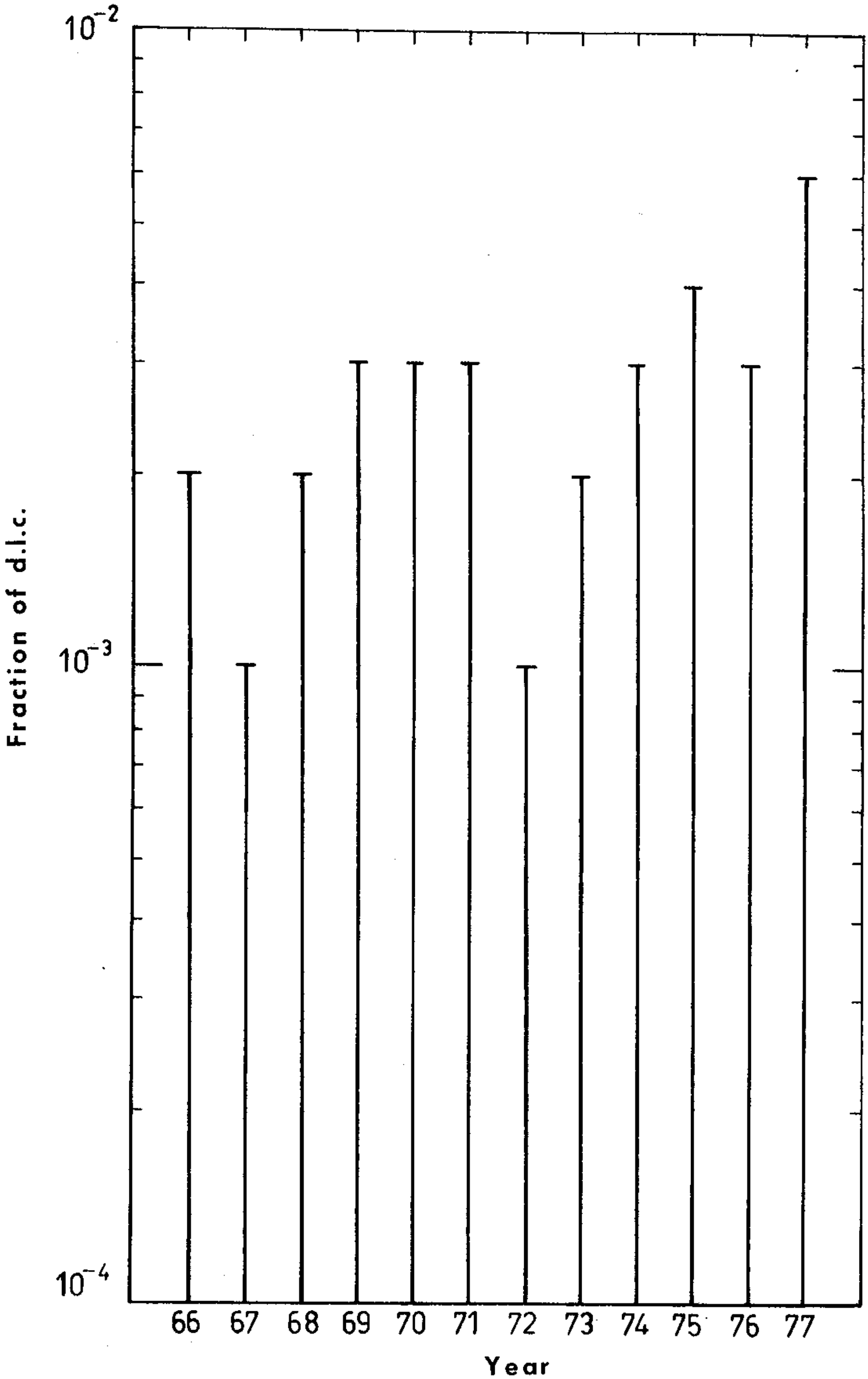

FIGURE 5. GROSS α-ACTIVITY IN WORONORA BEACH SANDS EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1966-1977

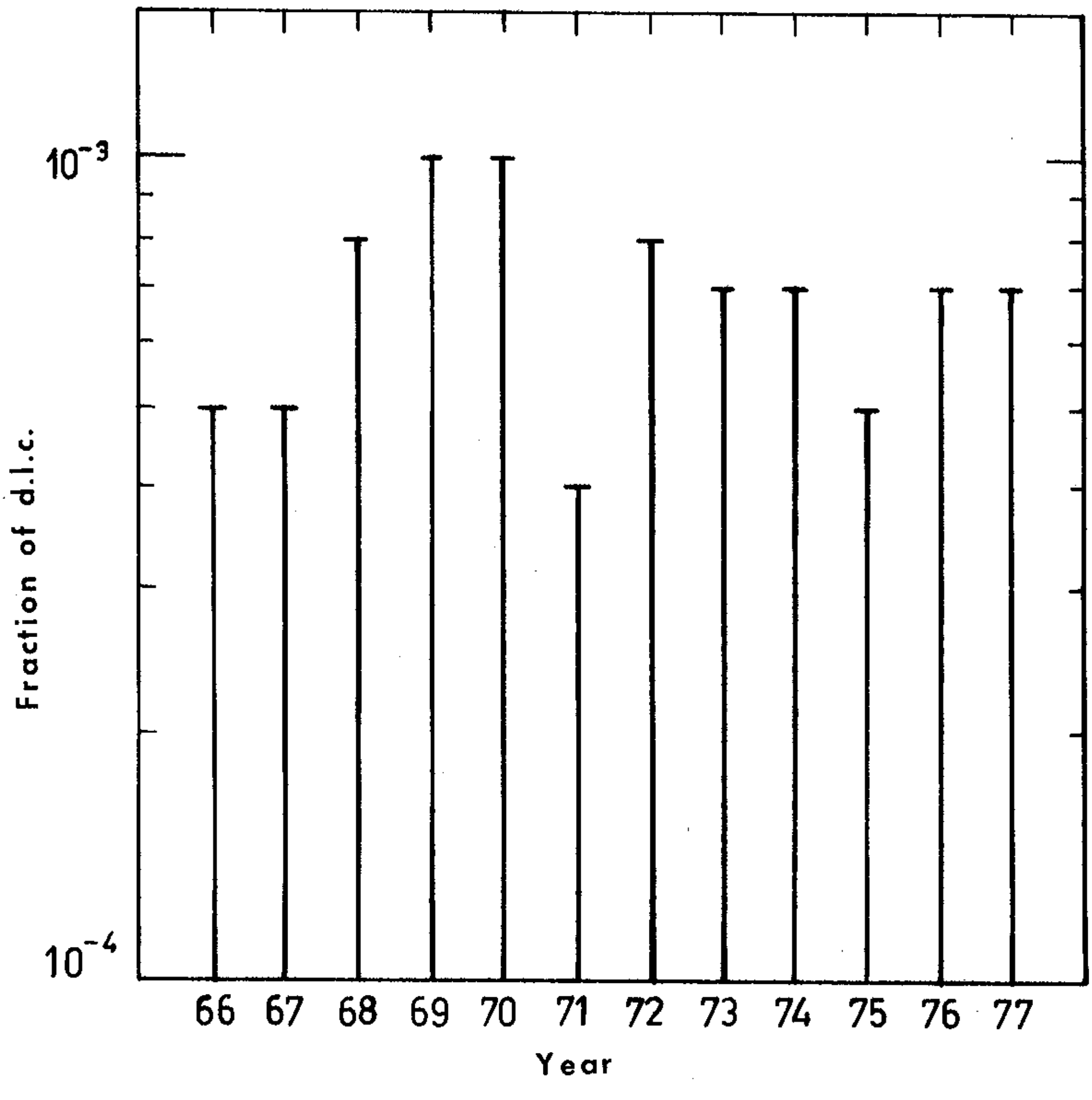

FIGURE 6. GROSS β-ACTIVITY IN WORONORA BEACH SANDS EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1966-1977

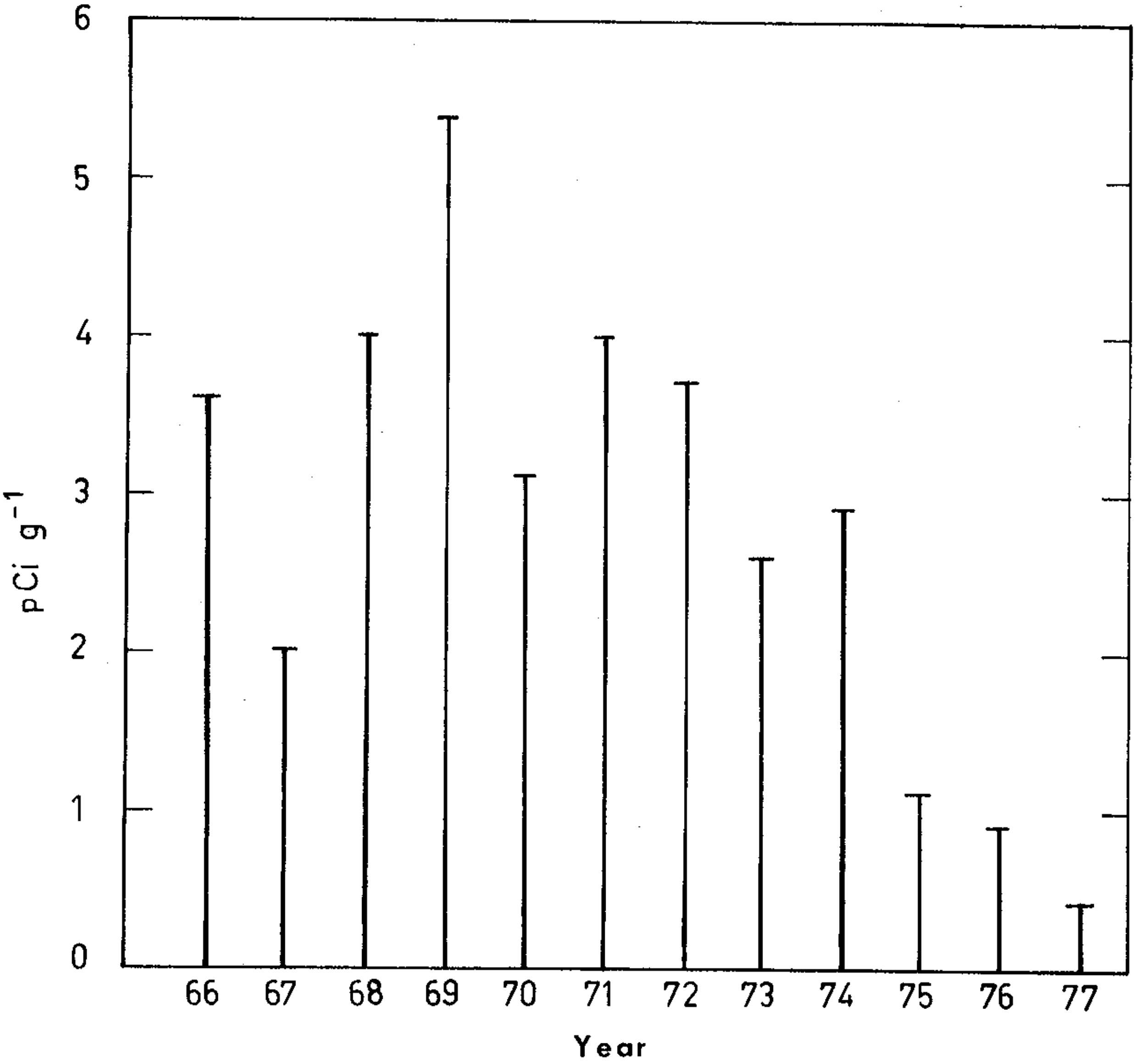

FIGURE 7. ^{60}Co IN WORONORA ZOSTERA EXPRESSED IN PICOCURIES PER GRAM (FRESH WEIGHT), 1966–1977

APPENDIX A

PREVIOUS ENVIRONMENTAL SURVEY REPORTS

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

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

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

Conway, N.F. & 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. & Dudaitis, A. [1974] - Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1973. AAEC/E335.

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

APPENDIX B

LIQUID EFFLUENT DISCHARGES FROM AAECRE 1975-1977

Compliance with Authorisation

The authorisation for AAECRE effluent discharges to the Woronora, which is approved by the NSW authorities, has the form

$$\Sigma_i \; \frac{X_{iq}}{3\,(\text{mpmd})_i} < \frac{V}{9 \times 10^6}$$

where X_{iq} = the number of curies of the i^{th} nuclide discharged in a calendar quarter,

$(\text{mpmd})_i$ = the permissible monthly discharge, in curies, of the i^{th} nuclide,

V = the volume, in gallons, of effluent discharged in a quarter, or 9×10^6, whichever is the smaller.

X_{iq} is determined from the results of radioactivity measurements on samples of all the discharges of a quarter. These are collected by an automatic sampling device which ensures that they are representative of the discharges. $(\text{mpmd})_i$ is a value approved by the NSW authorities. The $(\text{mpmd})_i$ value for each nuclide is listed in AAEC/E156 'A Reformulation of the Lucas Heights Discharge Authorisation' by R.M. Fry [1966]. This document is, effectively, part of the discharge authorisation.

V is measured by an integrating flowmeter installed in the discharge pipeline.

In this formula the measured number of curies of a specific nuclide discharged during a quarter is expressed as a fraction of the permitted quarterly discharge for that nuclide. The procedure is repeated for each nuclide to be considered.

If the sum of these fractions is not greater than the value of the term $V/9 \times 10^6$ then the amount of radioactivity discharged in the quarter has been less than the authorised amount. In the case in which the volume of the quarterly discharge is greater than 9×10^6 gallons, the discharge has been below the authorised amount if the sum of the fractions is not greater than unity. If the quarterly discharge of any nuclide were to exceed three times the permissible monthly discharge for that nuclide then the authorisation for that quarter would have been exceeded.

The formula takes account of the facts that the discharges will contain a mixture of nuclides and that, since each has a different potential for delivering a radiation dose, their individual dose contributions must be limited to ensure that the total dose to a member of the public does not exceed the permitted limits.

Although the authorisation appears complex it is not difficult to work with. To demonstrate compliance it is not, in principle, necessary to identify and measure every nuclide. Initially, the total amount of radioactivity measured can be assumed to be due to that nuclide with the lowest permissible monthly discharge. If the calculation made on that basis shows that the authorisation appears to have been exceeded, then a specific analysis is made for that nuclide. If, when the resulting value is taken into the calculation, the authorisation still appears to have been exceeded, an analysis is made for the next most restrictive nuclide and so on. That is, at each stage, the radioactivity of the mixture of nuclides which have not been specifically identified and measured is assumed to be due to the next most restrictive nuclide.

The use of this procedure gives a double advantage. Since it is assumed that the radioactivity is due to the more restrictive nuclides, the number reported, which represents the amount of radioactivity discharged, effectively overstates, in terms of potential radiation dose, the effect of the discharge. Any error introduced by the use of the procedure is therefore in the direction of safety. As well it reduces to a minimum the total effort investment required to demonstrate compliance.

The measured annual radioactivity discharges to the Woronora, for the period 1 January 1975 to 31 December 1977, are given in Table B1. The performance in respect of compliance with the authorisation, for each of the quarters of the same period, is summarised in Figure B1. The information used in both the table and the figure is taken from the quarterly effluent discharge reports which are reviewed by the NSW Radiological Advisory Council.

In Figure B1 the number

$$\Sigma_i \frac{X_{iq}}{3(\text{mpmd})_i} ,$$

which represents the radioactivity discharge for a quarter, has been expressed as a percentage of the number $V/9 \times 10^6$, which represents the permitted radioactivity discharge for that quarter. It can be seen that, in all but three of the twelve quarters, the discharge was less than 20 per cent of that permitted and that, in the other three quarters, the discharge was less than 22 per cent of that permitted. Note that these results were obtained by performing only the minimum number of radioactivity analyses necessary to demonstrate compliance with the authorisation. Had detailed analyses been made and the results included in the calculation, the reported performance in respect of compliance with the discharge authorisation would have been even better.

TABLE B1

RADIOACTIVITY DISCHARGES TO THE WORONORA ESTUARY

Radioisotope Measured	Discharge (Ci)		
	1975	1976	1977
^{210}Po	3.8×10^{-6}	7.5×10^{-6}	7.9×10^{-6}
αu	1.3×10^{-3}	1.6×10^{-3}	1.3×10^{-3}
^{3}H	38.1	37.5	21.4
βu	4.5×10^{-2}	6.6×10^{-2}	7.6×10^{-2}
$^{114m-114}In$	1.1×10^{-5}	1.3×10^{-5}	1.1×10^{-5}
^{51}Cr	n.d.	9.8×10^{-3}	n.d.
^{65}Zn	n.d.	n.d.	1.8×10^{-3}

αu = a mixture of unidentified α-emitting nuclides

βu = a mixture of unidentified β-emitting nuclides.

n.d. = not detected

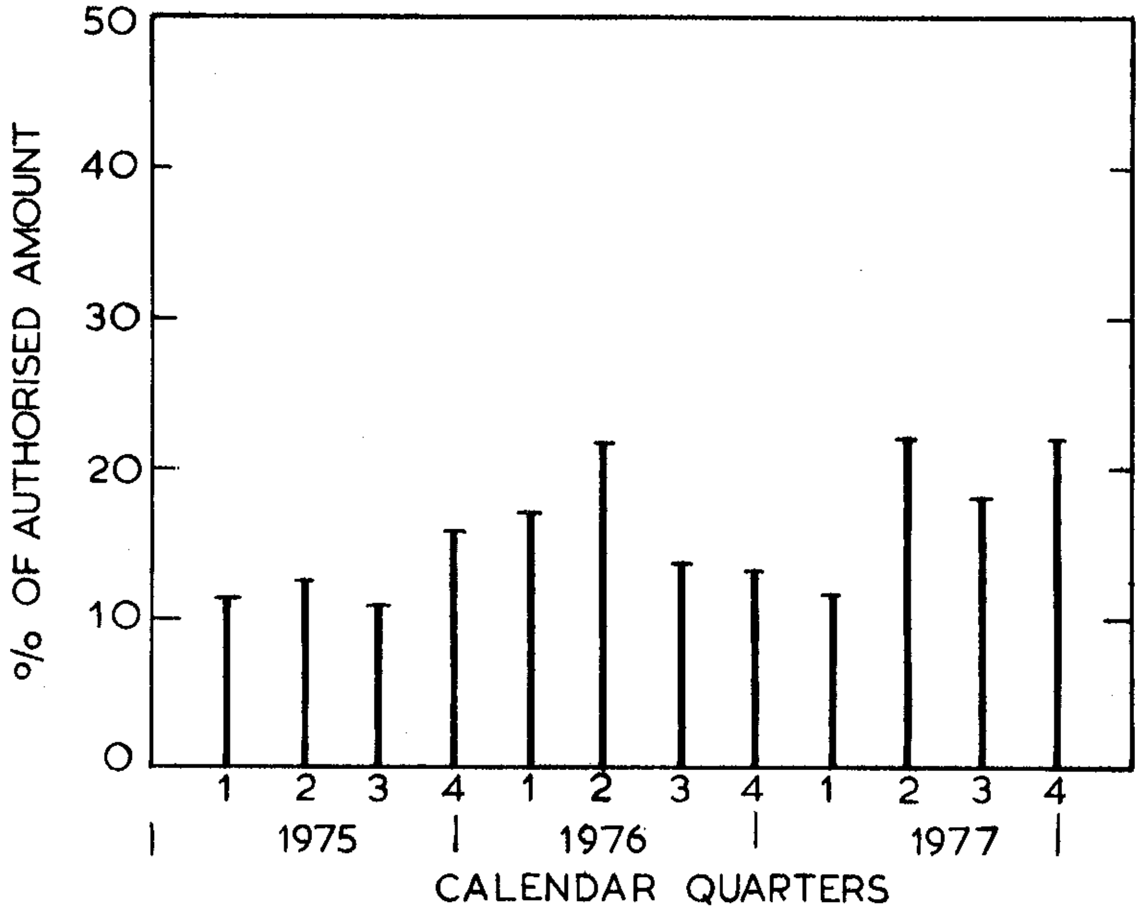

FIGURE B1. DISCHARGES TO THE WORONORA 1975-1977
DISCHARGED RADIOACTIVITY EXPRESSED AS A PERCENTAGE OF THE AUTHORISED AMOUNT

APPENDIX C

AIRBORNE RADIOACTIVITY DISCHARGES FROM AAECRE 1975-1977

Compliance with Authorisation

The ICRP recommendations on dose limitation express the view that, at the low dose levels recommended for the protection of the general public and radiation workers, the rate at which the dose is accumulated is less important than the fact that the recommended annual limits should not be exceeded.

The authorisation limiting the rates of discharge of airborne radioactivity from the AAECRE has been approved by the NSW Radiological Advisory Council (NSWRAC). Adopting the ICRP view it is based on the requirement that the yearly average airborne concentration of discharged radioactivity should not exceed, at any place normally occupied or accessible to a non-radiation worker, that level which is recommended by the ICRP as implying an acceptably low level of risk of radiation damage to the continuously exposed member of the general public. The authorisation also takes into account the fact that discharges of the radioisotopes of strontium, caesium and iodine could concentrate in cows' milk after being deposited on grazing land.

The long-term concentrations of radioactivity in air near the discharge points for airborne emissions depend on a number of factors. These include the range and frequency of changes in atmospheric stability, wind speed and wind direction, the effective height of the discharge (a function of the height of the discharge point, efflux velocity and local topography), and the possibility of downdraft conditions which could give high, ground-level concentrations in close proximity to the discharge point.

The discharge points at the AAECRE have different characteristics. Each of the radioisotopes which may appear in the discharges has a unique capability of delivering a radiation dose. Hence, each discharge point has a unique limit for radioactivity discharge.

The limits are expressed in terms of amounts of radioactivity per day. The permitted annual discharge from a specific point is thus the product of the daily limit and the number of days in a year. If the annual discharge does not exceed that amount then the basic objective of the authorisation - the limitation of exposure of the general public to airborne radioactive materials to less than the levels recommended by ICRP - has been achieved.

The authorisation also permits the daily discharge limit to be exceeded, provided that the weekly discharge does not exceed seven times the daily limit. The objective of this condition is to minimise the possibility of the development, under adverse meteorological conditions, of high, local, ground-level concentrations of airborne radioactivity. It is aimed primarily at limiting the exposure to airborne radioactive materials of people in the close vicinity - a few hundreds of metres - of the discharge points, i.e. essentially the AAECRE work-force.

If the weekly limit is exceeded then, in the strictest interpretation, the authorisation can be said to have been exceeded. However, from the viewpoint of protection of the general public, an occasional weekly discharge in excess of the limits will be of no concern unless the excesses are so large and/or frequent that the annual limit will be exceeded.

Table C1 gives the measured annual discharges, from each discharge point, of airborne radioactivity for the period 1 January 1975 to 31 December 1977. Table C2 summarises the performance in respect of compliance with the authorisation for discharge of airborne radioactivity for the same period. The information used in both tables is taken from the quarterly airborne effluent discharge reports which are reviewed by the NSWRAC.

In Table C2 the measured discharges have been expressed as fractions of the permitted annual discharges. The table shows that, in each of the years reviewed, in no case did the total annual discharge from any discharge point exceed the permitted annual discharge; and that, with the exception of argon-41 from Building 15 in 1977, the discharges represented, in fact, only small fractions of the permissible discharges.

Regular measurements of the amounts of ^{41}Ar in the discharge from Building 15 (HIFAR) commenced late in 1976; hence 1977 is the first full year for which results are available. The discharge limit for ^{41}Ar used in this table was that approved by the NSWRAC on 21 July 1978. Before that date no limit specific to ^{41}Ar existed.

In a one-week period in March/April 1975 the iodine-131 discharge from Building 2 was about twice the weekly limit. In May and October 1977 discharges exceeding the limits occurred at Building 41; in one case the discharge of ^{131}I was about twice, and in the other about three times, the weekly limit. However, as Table C2 shows, in the cases of both discharge points the total discharge for the year was well below the permitted amount. These escapes were associated with the production of technetium-99m for use in radiopharmaceuticals.

In the case of Building 2 an iodine-sorption unit, which was under construction at the time of the incident, was put into operation late in 1975 and has since performed very well. The operation in Building 41 which caused the releases was transferred to Building 2.

The permitted annual discharges of airborne radioactivity from the AAECRE are those which, in the opinions of responsible public health authorities, will not lead to any significant risk of radiation damage to any member of the public. The actual discharges in 1975, 1976 and 1977 were all below those permitted. Hence the probability that a member of the public or the staff could suffer radiation damage as a result of the discharges is very small.

TABLE C1

MEASURED AIRBORNE RADIOACTIVITY DISCHARGES 1975-1977

Year Bld.	Gross α (μCi)	^{131}I (mCi)	^{3}H (Ci)	Other βγ (mCi)	Gross βγ (mCi)	^{41}Ar (Ci)
1975						
2	4	994	-	1096	-	-
15	4	4	292	4	-	-
19	4	-	-	-	4	-
23A	4	124	-	13	4	-
23B	4	60	-	4	-	-
41	4	67	-	4	-	-
1976						
2	5	22	-	4	-	-
15	4	4	99	4	-	-
19	4	-	-	-	4	-
23A	4	53	-	10	-	-
23B	4	38	-	4	-	-
41	4	19	-	4	-	-
1977						
2	4	77	-	4	-	-
15	4	4	73	4	-	2063
19	4	4	-	-	4	-
23A	4	84	-	4	-	-
23B	4	9	-	4	-	-
41	4	231	-	819	-	-

Gross α = a mixture of unidentified α-emitting nuclides

Gross βγ = a mixture of unidentified βγ-emitting nuclides

Other βγ = identified βγ-emitting nuclides not otherwise listed

TABLE C2

ANNUAL RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS

Expressed as Fractions of the Permitted Annual Discharge

Year Bld.	Gross α-emitters	^{131}I	^{3}H	Other βγ Activity	Gross βγ Activity	^{41}Ar
1975						
2	5×10^{-5}	1×10^{-1}	-	6×10^{-3}	-	-
15	3×10^{-4}	2×10^{-3}	2×10^{-5}	5×10^{-4}	-	-
19	1×10^{-4}	-	-	-	5×10^{-5}	-
23A	2×10^{-3}	7×10^{-2}	-	4×10^{-3}	-	-
23B	5×10^{-3}	3×10^{-2}	-	2×10^{-3}	-	-
41	1×10^{-4}	4×10^{-2}	-	5×10^{-5}	-	-
1976						
2	7×10^{-5}	3×10^{-3}	-	2×10^{-5}	-	-
15	3×10^{-4}	2×10^{-3}	7×10^{-6}	5×10^{-4}	-	-
19	1×10^{-4}	-	-	-	5×10^{-5}	-
23A	2×10^{-3}	3×10^{-2}	-	3×10^{-3}	-	-
23B	5×10^{-3}	2×10^{-2}	-	2×10^{-3}	-	-
41	1×10^{-4}	1×10^{-2}	-	5×10^{-5}	-	-
1977						
2	5×10^{-5}	1×10^{-2}	-	2×10^{-5}	-	-
15	3×10^{-4}	2×10^{-3}	5×10^{-6}	5×10^{-4}	-	7×10^{-1}
19	1×10^{-4}	1×10^{-3}	-	-	5×10^{-5}	-
23A	2×10^{-3}	5×10^{-2}	-	1×10^{-3}	-	-
23B	5×10^{-3}	5×10^{-3}	-	2×10^{-3}	-	-
41	1×10^{-4}	1×10^{-1}	-	1×10^{-2}	-	-

Gross α = a mixture of unidentified α-emitting nuclides

Gross βγ = a mixture of unidentified βγ-emitting nuclides

Other βγ = identified βγ-emitting nuclides not otherwise listed