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RESULTS OF 1978 ENVIRONMENTAL SURVEY AT

THE AAEC RESEARCH ESTABLISHMENT, LUCAS HEIGHTS

by

E.D. HESPE

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ABSTRACT

The results of the 1978 environmental survey program at the Australian Atomic Energy Commission Research Establishment (AAECRE) are presented. They show that the amounts of radioisotopes of AAECRE origin found in samples of environmental materials were not significantly different from the very small amounts found in previous years. The possible annual radiation dose to the hypothetical 'most highly exposed' member of the public, as calculated from the results, is less than one ten-thousandth of that considered acceptable by the NSW Health Commission and the National Health and Medical Research Council of Australia. Appendices show that the performances in respect to the State-approved discharge authorisations for liquid and gaseous effluents were very satisfactory.

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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

A program of environmental surveillance has been conducted by the AAEC in the vicinity of its Lucas Heights Research Establishment since 1959. This survey is designed

- to sample materials in the environment which may contain radioactivity of AAECRE origin and with which man may have contact; and

- to measure the amounts of radioactivity present and identify that originating from the AAECRE.

The results are used to calculate the possible radiation dose to a hypothetical 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 year 1978. Results for the years 1959-1977 are given in the reports listed in Appendix A. Appendices B and C summarise the performances, in relation to the discharge authorisations approved by the NSW authorities, for liquid and gaseous emissions for 1978. Table 1 summarises the sampling program associated with the Woronora estuary; Table 2 summarises the terrestrial sampling program. Figures 1 and 1A show the locations of the sampling stations.

2. PRESENTATION OF RESULTS

The results of radioactivity measurements on samples and the calculated dose to a member of the public are presented in tabular form. Comparisons of the results for 1978 with those of previous years are presented in a graphical format.

2.1 Index to Tables

2.2 Index to Figures

2.3 Units

To comply with Australian metrication requirements radioactivity values are reported in becquerels, the International System (SI) unit of radioactivity. In line with the practice adopted by the International Commission for Radiological Protection, dose equivalents are reported in microsieverts. For comparing the results of this with previous reports the following equivalences are useful:

1 picocurie = 3.7×10^{-2} = 0.04 becquerel (Bq) (approx.)
1 Bq = 27.02 = 30 picocuries (approx.)
1 millirem = 10 microsieverts (μSv)
1 μSv = 0.1 millirem

3. DISCUSSION OF RESULTS

3.1 Woronora Samples

In 1978 samples of oysters, fish, water, zostera and sand taken from the Woronora contained amounts of radioactivity that were, in terms of health significance, no different from the inconsequential amounts found in previous years. No radioisotopes were found that had not been previously found. The concentration of ^{3}H in river water remained at the level found in 1975, 1976 and 1977. There were increases in the concentrations of ^{65}Zn in oysters and ^{60}Co in zostera. Although ^{60}Co in fish was not detected in 1976 or 1977, it was found but at a concentration lower than that found in 1975. The concentrations, in 1978, of ^{3}H in river water, ^{65}Zn in oysters and ^{60}Co in fish were all less than one ten-thousandth of the derived limiting concentration (d.l.c.). These radioisotopes are known to occur in AAECRE effluent discharges.

Samples of beach sand contained less alpha activity and more beta activity than in 1977; the amounts present were, respectively, less than one hundredth and less than one thousandth of the appropriate d.l.c. This radioactivity is not attributable to AAECRE operations for two reasons: first, there was no significant decrease in concentration with distance from the discharge point; second, sand samples from Botany Bay contained about the same levels of radioactivity as the Woronora sands, while a sample of sand

from a beach on the far north coast of NSW contained about seven times as much alpha activity and thirteen times as much beta activity as the Woronora samples. The levels of radioactivity in the Woronora beach sands are similar to those which occur elsewhere.

3.2 Samples and Surveys - Effluent Discharge Pipeline

In November 1978, a special set of samples was collected in the vicinity of Double Air Valve No.3. This had been vandalised so that treated effluent had leaked from it. As well as naturally occurring radioactivity these samples contained similar or smaller amounts of ^{137}Cs and ^{60}Co which had probably leaked from the vandalised valve. The highest concentration was found in sand from the floor of the normally inaccessible sump in which the valve is located.

Routine sampling of sand along the pipeline showed the presence only of naturally occurring radioactivity at levels similar to those of 1977.

The final survey of the year showed that the surface dose rates at three points on the pipe were higher than those observed elsewhere on the pipeline. There was no evidence of leaks. The higher dose rates, which would require a dose recipient to sit continuously on the pipe for about 210 days before reaching the annual limit, are thought to have been caused by small depositions of gamma-emitting isotopes within the pipe.

3.3 Samples Related to Stormwater Outlets

All soil samples taken in the vicinity of stormwater outlets contained naturally occurring radioisotopes. A small fraction (approx. 18 per cent) contained isotopes which are known to be of AAECRE and weapons test fallout origin but which were present at concentrations lower than those occurring naturally. In all cases the amounts of radioactivity present were so small that it is considered that no hazard to health was involved.

Samples of vegetation also contained radioactivity of natural origin. A small fraction (about 25 per cent) contained lower, but detectable, concentrations of radioisotopes associated with AAECRE operations.

Samples of water taken from stormwater outlets contained tritium. These tritium concentrations were well below that permitted in drinking water by the NSW Radioactive Substances Act and Regulations. In no sample did the tritium concentration exceed half that value and the average concentration was 7.6 per cent of that value. The presence of tritium at these concentrations in stormwater presents no hazard to health.

3.4 Samples Related to Airborne Discharges

Twelve milk samples were collected in the period. All contained less than the minimum detectable level of ^{131}I and five contained less than the minimum detectable level of ^{137}Cs. All samples contained ^{137}Cs at lower concentrations than the highest found in the 1977 samples. The ^{137}Cs found in the milk is attributable to fallout from nuclear weapons tests. This is supported by the insignificant discharges of fission product activity revealed by the results of continuous stack monitoring (see Appendix C).

3.5 Samples Related to Little Forest Area

(a) Vegetation and Soil Samples

Samples of vegetation (grass and acacia) were taken at positions very close (within 2 m) to the buried waste. All contained naturally occurring radioactivity; one third contained no activity attributable to the buried waste and two thirds contained very small amounts of ^{60}Co. A sample from an acacia growing just outside the Little Forest burial ground fence contained only naturally occurring radioactivity.

The results of measurements made on soil samples taken in the near vicinity (a few metres) of the buried wastes showed that the majority contained very small amounts of ^{60}Co and/or fission products and that samples from one site contained very small amounts of ^{241}Am. These are attributable to the buried wastes. A sample of soil from just outside the fence contained only naturally occurring radioactivity. The amounts of radioactivity in the soil that are attributable to the buried wastes are very much smaller than the amounts of natural radioactivity in the soil. The ratios of the concentrations of ^{60}Co in vegetation to the concentrations of ^{60}Co in soil show that the transfer of ^{60}Co from soil to vegetation is very small.

(b) Groundwater samples

Samples from boreholes inside and outside the burial ground contained no radioactivity which could be associated with the buried wastes, except for small amounts of tritium. The highest concentration found in an external borehole was a very small fraction (0.005) of that permitted in drinking water by the NSW radiation control regulations. Samples of water taken near the junction of Mill and Bardens Creeks (which drain the burial ground area) contained only natural radioactivity.

4. RADIOLOGICAL SIGNIFICANCE OF RESULTS

The methodology of earlier environmental survey reports was used to estimate the annual dose to a hypothetical person who:

- eats, every day, 70 g (1 dozen large) oysters grown in the Woronora;
- eats, every day, 70 g of fish taken from the Woronora;
- swims, every day, for one hour at the effluent pipeline discharge point;
- sunbathes on Woronora beaches for two hours every day; and
- drinks, every day, 0.5 litre of milk produced at Menai.

The results of these calculations are listed in Table 16. The dose contribution from ^{137}Cs is attributable to fallout from nuclear weapons tests. That from sunbathing is attributable to the natural radioactivity of the beach sands. The remainder is attributable to swimming in water, and eating fish and oysters, containing radioisotopes discharged from the AAECRE. The total body dose in 1978 to the individual who used the river in this fashion was 0.25 μSv.

The trivial significance of this dose to the health of this hypothetical member of the public can be appreciated by comparing it with:

- the recommendation of the National Health and Medical Research Council, and the legal requirement in all States, to limit the annual total body dose to a member of the public to 5000 μSv;

- the dose received, during a full chest X-ray, from a well-designed and properly maintained and operated machine, of not less than 100 μSv; and

- the addition, of about 200 μSv, to the annual background dose of the Sydney seaside dweller who makes a return air trip to Europe.

The person who sunbathes for two hours per day on a Woronora River beach receives an annual skin dose from natural radioactivity of 29 μSv. The person who sunbathes for the same period on Kingscliffe Beach receives an annual skin dose of 320 μSv from natural radioactivity. The dose to a member of the public that results from AAECRE discharges is, therefore, not only a very small fraction of the dose inescapably received from naturally occurring radiation and radioactivity, but also very much smaller than the variations in the background dose resulting from the individual's own decisions on place and style of living.

5. SUMMARY

In 1978, no samples taken in the Lucas Heights environmental survey program contained radioactivity attributable to aerial emissions from the AAECRE. Except at one sampling site very close to buried wastes and within the burial ground fence, no radioisotopes were found which had not been found in previous years. Samples of water, oysters, fish and zostera from the Woronora contained tritium, ^{65}Zn and ^{60}Co. These are attributable to discharges from the AAECRE. The radioisotope concentrations found in these samples were similar to the radiologically insignificant ones of previous years and were less than one ten-thousandth of the applicable derived limiting concentration. Tritium in very small amounts which are of no significance to health, was found in boreholes outside the burial ground fence.

The estimated dose to the hypothetical member of the public who is most highly exposed to the effects of discharges was:

- about one ten-thousandth of the annual dose from natural radiation and radioactivity;

- about one thousandth of the addition to the normal background radiation dose that a Sydneysider would receive during a return flight to Europe; and

- less than one ten-thousandth of the dose considered acceptable for a member of the public by the NSW radiation control legislation.

6. ACKNOWLEDGEMENTS

The author gratefully acknowledges the contributions of members of the Chemical Technology Division and of Messrs J. Fogden and J. Sykes to the field and laboratory work which produced the results recorded here and the support and assistance of colleagues in the Safety Department.

7. REFERENCE

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

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 BS counted for beta gamma emitters. Sample between 60 and 110 mesh BS counted for alpha emitters
Estuary water	E0, E5.9	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 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	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 1978

Station	Date Sampled	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{60}Co	^{65}Zn	K ($\mu g\ g^{-1}$)
E7.0	24 Apr.	0.01	0.01	0.0004	0.006	2700
	3 Aug.	0.006	0.006	0.001	0.001	3600
	31 Oct.	0.001	0.04	n.d.	0.002	3700
Average		0.006	0.019	0.005	0.003	
E9.3	16 Mar.	0.02	0.04	n.d.	0.002	2600
	20 Jul.	0.009	0.015	n.d.	n.d.	3800
	31 Oct.	0.001	0.01	n.d.	n.d.	4000
	27 Dec.	0.007	0.02	n.d.	0.002	3300
Average		0.009	0.02	n.d.	0.001	
Hawkesbury River	27 Apr.	0.01	0.02	n.d.	n.d.	2700
	24 Jul.	0.007	0.007	n.d.	n.d.	2100
	18 Sept.	0.001	0.01	n.d.	n.d.	2600
	12 Dec.	0.007	0.02	n.d.	n.d.	2900
Average		0.006	0.014	n.d.	n.d.	
Woronora River oyster shell (composite)	1978	0.03	0.068	n.d.	n.d.	9200

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

d.l.c. of ^{65}Zn in oyster flesh = 37 $Bq\ g^{-1}$

Station E7.0 Fraction of d.l.c. = 8×10^{-5}

Station E9.3 Fraction of d.l.c. = 2×10^{-5}

n.d. = not detected

TABLE 4

RADIOACTIVITY IN WORONORA FISH 1978

Station and Variety	Date Sampled	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	K ($\mu g\ g^{-1}$)
E-0.2 Mullet	13 Jan.	0.005	0.03	^{65}Zn = 0.001	2500
				^{60}Co = 0.001	
Perch	31 Mar.	0.003	0.004	^{160}Tb = 0.009	2700
				^{51}Cr = 0.03	
				^{65}Zn = 0.002	
				^{110}Ag = trace	
				^{137}Cs = trace	
				^{60}Co = trace	
Average		0.004	0.017	^{65}Zn = 0.0015	
				^{60}Co = 0.0005	
E0 Tailor	26 May	0.004	0.007	n.d.	4000
E0.2 Mullet	31 Mar.	0.02	0.007	^{65}Zn = 0.001	3000
				^{60}Co = 0.001	
Mullet	21 Jul.	0.006	0.004	n.d.	2900
Mullet	24 Nov.	0.01	0.006	n.d.	2700
Average		0.012	0.006	^{65}Zn = 0.0003	
				^{60}Co = 0.0003	
E1.3 Mullet	7 Apr.	0.05	0.04	^{65}Zn = 0.001	2300
				^{60}Co = 0.001	
Mullet	13 Oct.	0.02	0.004	^{60}Co = trace	2700
Average		0.035	0.022	^{65}Zn = 0.0005	
				^{60}Co = 0.0005	
E6.4 Mullet	14 Mar.	0.02	<0.004	n.d.	2500
Mullet	4 Jul.	0.02	0.03	n.d.	2300
Mullet	3 Oct.	0.01	0.02	n.d.	2800
Mullet	1 Dec.	0.01	0.0004	n.d.	3300
Average		0.015	0.014		

Derived limiting concentration taken from Fry [1966].

d.l.c. ^{60}Co = 18.5 $Bq\ g^{-1}$

Station E-0.2 Fraction of d.l.c. = 3×10^{-5}

Station E0.2 Fraction of d.l.c. = 2×10^{-5}

Station E1.3 Fraction of d.l.c. = 3×10^{-5}

n.d. = not detected.

TABLE 5

RADIOACTIVITY IN WORONORA BEACH SANDS 1978

Station	Date Sampled	Radioactivity ($Bq\ g^{-1}$ Dry Weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	K ($\mu g\ g^{-1}$)
E0	17 Feb.	0.19	0.11	n.d.	450
E1.3	5 Apr.	0.87	0.05	n.d.	180
	18 Jul.	0.24	0.03	n.d.	220
	15 Sept.	0.085	0.028	n.d.	370
	8 Dec.	0.36	0.03	n.d.	300
E5.9	14 Apr.	0.65	0.43	^{232}Th series = trace	410
	18 Jul.	0.23	0.07	n.d.	670
	15 Sept.	0.19	0.08	n.d.	780
	8 Dec.	0.38	0.026	n.d.	560
Average (all samples)		0.355	0.095		
d.l.c.		111	92.5		
Average fraction of d.l.c.		3×10^{-3}	1×10^{-3}		

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

n.d. = not detected.

TABLE 5A

RADIOACTIVITY IN MISCELLANEOUS BEACH SANDS 1978

Station	Date Sampled	Radioactivity (Bq g^{-1} Dry Weight) Gross Alpha	Gross Beta (less ^{40}K)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Pelican Point Botany Bay	4 Aug.	0.35	0.05	n.d.	810
Sans Souci Botany Bay	4 Aug.	0.13	0.07	n.d.	240
Kingscliffe Northern NSW	13 Sept.	2.67	1.23	^{238}U series = trace ^{232}Th series = trace	60

TABLE 6
TRITIUM IN WORONORA WATER SAMPLES 1978
STATION E0

Date	Tritium (Bq mL^{-1})	Date	Tritium (Bq mL^{-1})
6 Jan.	<0.04	12 Jul.	<0.04
13 Jan.	<0.04	21 Jul.	<0.04
20 Jan.	<0.04	28 Jul.	<0.04
27 Jan.	0.14	4 Aug.	<0.04
10 Feb.	<0.04	11 Aug.	<0.04
17 Feb.	0.07	18 Aug.	<0.04
24 Feb.	0.09	25 Aug.	<0.04
3 Mar.	<0.04	1 Sept.	0.06
10 Mar.	0.17	8 Sept.	0.06
17 Mar.	0.1	15 Sept.	0.2
23 Mar.	<0.04	22 Sept.	0.1
31 Mar.	<0.04	3 Oct.	<0.04
7 Apr.	<0.04	10 Oct.	<0.04
14 Apr.	<0.04	13 Oct.	<0.04
21 Apr.	0.1	20 Oct.	<0.04
28 Apr.	<0.04	27 Oct.	<0.04
5 May	<0.04	6 Nov.	<0.04
12 May	0.1	13 Nov.	<0.04
19 May	<0.04	24 Nov.	<0.04
26 May	<0.04	1 Dec.	<0.04
2 Jun.	<0.04	8 Dec.	<0.04
9 Jun.	<0.04	14 Dec.	<0.04
16 Jun.	0.07	21 Dec.	<0.04
23 Jun.	<0.04	29 Dec.	<0.04
4 Jul.	0.06		
		Average <0.056	

Derived limiting concentration taken from Fry [1966].
d.l.c. = 1110 Bq mL^{-1}
Average fraction of d.l.c. = 5×10^{-5}

TABLE 6A
TRITIUM IN WORONORA WATER SAMPLES 1978
STATION E5.9

Date	Tritium (Bq mL^{-1})	Date	Tritium (Bq mL^{-1}
6 Jan.	<0.04	12 Jul.	<0.04
13 Jan.	<0.04	21 Jul.	<0.04
20 Jan.	<0.04	28 Jul.	<0.04
27 Jan.	0.07	4 Aug.	<0.04
10 Feb.	<0.04	11 Aug.	<0.04
17 Feb.	<0.04	18 Aug.	<0.04
24 Feb.	<0.04	25 Aug.	<0.04
3 Mar.	<0.04	1 Sept.	<0.04
10 Mar.	<0.04	8 Sept.	0.14
17 Mar.	<0.04	15 Sept.	0.07
23 Mar.	<0.04	22 Sept.	0.07
31 Mar.	<0.04	3 Oct.	<0.04
7 Apr.	<0.04	10 Oct.	0.1
14 Apr.	<0.04	13 Oct.	<0.04
21 Apr.	<0.04	20 Oct.	<0.04
28 Apr.	<0.04	27 Oct.	<0.04
5 May	<0.04	6 Nov.	<0.04
12 May	0.06	13 Nov.	<0.04
19 May	<0.04	24 Nov.	<0.04
26 May	<0.04	1 Dec.	<0.04
2 Jun.	<0.04	8 Dec.	<0.04
9 Jun.	<0.04	14 Dec.	<0.04
16 Jun.	<0.04	21 Dec.	0.07
23 Jun.	<0.04	29 Dec.	<0.04
4 Jul.	<0.04		
	Average <0.046		

Derived limiting concentration (d.l.c.) taken from Fry [1966].
d.l.c. = 1110 Bq mL^{-1}
Average fraction of d.l.c. = 4×10^{-5}

TABLE 7
RADIOACTIVITY IN WORONORA ZOSTERA SAMPLES 1978

Station	Date	Radioactivity ($Bq\ g^{-1}$ Fresh Weight)		Gamma Emitters						K
		Gross Alpha	Gross Beta (less ^{40}K)	0.5 MeV	^{54}Mn	^{95}Zr+ ^{95}Nb	^{60}Co	^{65}Zn	^{238}U series + ^{232}Th series	($\mu g\ g^{-1}$)
E1.3	5 Apr.	0.06	0.06	n.d.	n.d.	n.d.	0.05	n.d.	trace	4300
	18 Jul.	0.04	0.06	n.d.	n.d.	n.d.	0.02	n.d.	trace	4900
	8 Dec.	0.03	0.05	n.d.	n.d.	n.d.	0.04	n.d.	trace	5900
E1.6	5 Apr.	0.07	0.07	n.d.	n.d.	n.d.	0.04	n.d.	trace	3400
E2.4	5 Apr.	0.06	0.04	n.d.	n.d.	n.d.	0.02	n.d.	trace	4000
	18 Jul.	0.06	0.18	n.d.	n.d.	n.d.	0.02	n.d.	trace	4800
	13 Sept.	0.03	0.01	n.d.	n.d.	n.d.	0.02	n.d.	trace	5700
	8 Dec.	0.08	0.06	n.d.	n.d.	n.d.	0.02	n.d.	trace	4300
E4.6	13 Sept.	0.07	0.03	n.d.	n.d.	n.d.	0.005	n.d.	trace	4200
	8 Dec.	0.17	0.09	n.d.	n.d.	n.d.	0.002	n.d.	trace	4100
E5.9	8 Dec.	0.04	0.05	n.d.	n.d.	n.d.	n.d.	n.d.	trace	5800
E7.0	No zostera growing									

Station E2.4 was only area where zostera was available during the full sampling period .

n.d. = not detected.

TABLE 8

RADIOACTIVITY IN MILK SAMPLES 1978

Station	Date	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) ^{137}Cs	^{131}I
T3 (Menai)	31 Jan.	0.0005	n.d.
	28 Feb.	n.d.	n.d.
	30 Mar.	0.0004	n.d.
	27 Apr.	0.0004	n.d.
	31 May	n.d.	n.d.
	28 Jun.	n.d.	n.d.
	28 Jul.	0.0004	n.d.
	23 Aug.	0.0004	n.d.
	28 Sept.	n.d.	n.d.
	31 Oct.	0.0004	n.d.
	29 Nov.	0.0004	n.d.
	29 Dec.	n.d.	n.d.
Average		0.0002	

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

n.d. = not detected.

TABLE 9
RADIOACTIVITY IN SAMPLES OF VEGETATION AND SOIL FROM LITTLE FOREST BURIAL GROUND 1978

Location	Sample	Date	Gross Alpha	Gross Beta (less ^{40}K)	Radioactivity (Bq g^{-1} Fresh Weight) ^{137}Cs	^{60}Co	^{238}U series + ^{232}Th series	^{95}Zr + ^{95}Nb	0.5 MeV	^{241}Am	K ($\mu g\ g^{-1}$)
Near trenches 1-5	Topsoil	13 Jul.	0.68	0.7	0.04	n.d.	trace	n.d.	n.d.	n.d.	4000
	Topsoil	21 Dec.	0.84	0.55	n.d.	0.01	trace	n.d.	n.d.	n.d.	3700
Near trenches 54-57	Grass	13 Jul.	0.28	0.19	n.d.	n.d.	n.d.	n.d.	0.03	n.d.	3000
Near trenches 57-58	Topsoil	13 Jul.	4.7	1.1	0.055	0.032	trace	n.d.	n.d.	1.29	4900
	Topsoil	21 Dec.	1.81	1.29	0.016	0.04	trace	n.d.	n.d.	0.13	3900
Near trench 58	Acacia	13 Jul.	0.02	0.06	n.d.	n.d.	n.d.	n.d.	0.004	n.d.	2300
Near trenches 63-73	Grass	13 Jul.	0.06	0.9	n.d.	0.07	n.d.	n.d.	0.02	n.d.	2900
Near trench 68	Topsoil	13 Jul.	2.72	3.78	n.d.	1.9	trace	n.d.	n.d.	n.d.	5100
	Topsoil	21 Dec.	2.31	0.17	n.d.	0.8	trace	n.d.	n.d.	n.d.	3300
Near trench 70	Acacia	13 Jul.	0.01	3.73	n.d.	0.1	n.d.	n.d.	n.d.	n.d.	3300
	Acacia	14 Dec.	0.01	2.01	n.d.	0.02	n.d.	n.d.	n.d.	n.d.	2800
Near trench 58	Acacia	21 Dec.	0.02	0.06	n.d.	0.0004	n.d.	n.d.	0.001	n.d.	2600
South-east corner outside burial ground fence	Acacia	13 Jul.	0.03	0.024	n.d.	n.d.	n.d.	n.d.	0.004	n.d.	3400
	Soil	13 Jul.	0.65	0.41	n.d.	n.d.	trace	n.d.	n.d.	n.d.	2500

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 1978

Borehole	Date	Radioactivity (Bq L^{-1}) Gross Alpha	Gross Beta	Gamma Emitters	^{3}H (Bq mL^{-1})
1	5 Jul.	0.1	0.14	n.d.	<0.04
2	5 Jul.	0.1	0.08	n.d.	0.07
3	5 Jul.	0.22	0.15	n.d.	<0.04
4	5 Jul.	0.05	0.1	n.d.	<0.04
5	5 Jul.	0.09	0.09	n.d.	<0.04
6	5 Jul.	0.24	0.23	n.d.	0.1
10	5 Jul.	0.16	0.45	n.d.	0.2
OS1	5 Jul.	0.06	0.14	n.d.	<0.04
OS2	5 Jul.	0.09	0.14	n.d.	10.5
OS3	5 Jul.	0.29	1.29	n.d.	8.9
A	5 Jul.	0.15	0.09	n.d.	0.2
C	5 Jul.	0.04	0.2	n.d.	<0.04
D	5 Jul.	0.2	0.3	n.d.	<0.04
E	5 Jul.	0.24	0.09	n.d.	0.1
B	3 Nov.	-	-	-	<0.04
1	13 Dec.	0.04	0.08	n.d.	<0.04
2	13 Dec.	0.26	0.20	n.d.	<0.04
3	13 Dec.	0.16	0.18	n.d.	<0.04
4	13 Dec.	0.11	0.10	n.d.	<0.04
5	13 Dec.	0.15	0.09	n.d.	<0.04
6	13 Dec.	0.17	0.20	n.d.	<0.04
10	13 Dec.	0.12	0.39	n.d.	0.28
OS1	13 Dec.	0.20	0.22	n.d.	<0.04
OS2	13 Dec.	0.02	0.18	n.d.	8.6
OS3	13 Dec.	0.30	2.0	^{238}U series = trace	18.3
A	13 Dec.	0.15	0.25	n.d.	0.1
B	13 Dec.	0.96	0.54	n.d.	<0.04
C	13 Dec.	0.20	0.19	n.d.	<0.04
D	13 Dec	0.31	0.50	^{238}U series = trace	<0.04
E	13 Dec.	0.23	0.42	n.d.	<0.04

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

n.d. = not detected.

\- = not measured.

TABLE 11

RADIOACTIVITY IN SAMPLES TAKEN FROM CREEKS NORTH OF LITTLE FOREST BURIAL GROUND 1978

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ Dry Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Bardens Creek above junction with Mill Creek	27 Jul.	Sand	0.39	0.04	-	^{232}Th series = trace	300
	27 Jul.	Water	<0.25 ($Bq\ L^{-1}$)	0.1 ($Bq\ L^{-1}$)	<0.04	n.d.	-
Mill Creek below junction with Bardens Creek	27 Jul.	Sand	0.34	0.07	-	n.d.	500
	27 Jul.	Water	<0.25 ($Bq\ L^{-1}$)	0.07 ($Bq\ L^{-1}$)	<0.04	n.d.	-

n.d. = not detected.

\- = not measured.

TABLE 12

RADIOACTIVITY IN SAMPLES TAKEN FROM STORMWATER OUTLETS 1978

Station	Date	Sample	Radioactivity (Bq g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Drain No.1							
opposite Strassman	23 Jan.	Soil	0.19	0.06	-	^{238}U series = trace	200
Crescent	23 Jan.	Vegetation	0.003	0.023	-	0.5 MeV = 0.002	4600
	28 Sept.	Soil	0.03	0.247	-	^{238}U series = trace	300
	29 Sept.	Vegetation	0.005	0.033	-	0.5 MeV = 0.001	4600
	29 Dec.	Vegetation	0.02	0.054	-	0.5 MeV = 0.001 ^{137}Cs = 0.0004	2600
	23 Jan.	Water	-	-	<0.04	-	-
	23 May	Water	-	-	<0.04	-	-
	28 Sept.	Water	-	-	<0.04	-	-
Drain west of test							
compound	23 Jan.	Soil	0.24	0.4	-	^{232}Th series = trace	500
	23 May	Soil	0.37	0.29	-	^{232}Th series = trace	700
	28 Sept.	Soil	0.31	0.46	-	^{60}Co = 0.01	900
	29 Dec.	Soil	0.43	0.42	-	^{137}Cs = 0.01 ^{60}Co = 0.006 ^{232}Th series = trace	700
	29 Dec.	Water	-	-	<0.04	-	-

(Continued)

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity (Bq g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Drain near Yellowcake Store	23 Jan.	Soil	0.31	0.32	-	^{238}U series = trace	700
	23 May	Soil	0.24	0.04	-	^{232}Th series = trace	500
	28 Sept.	Soil	0.13	0.16	-	n.d.	300
	23 Jan.	Water	-	-	<0.04	-	-
	23 May	Water	-	-	0.07	-	-
	28 Sept.	Water	-	-	<0.04	-	-
Drain rear of Building 64	28 Feb.	Soil	0.52	0.27	-	^{238}U series = trace	600
	23 Jan.	Water	-	-	<0.04	-	-
Drain at Fermi Street	23 Jan.	Soil	0.32	0.33	-	n.d.	600
	23 May	Soil	0.22	0.20	-	^{232}Th series = trace	600
	28 Sept.	Soil	0.29	0.14	-	^{232}Th series = trace	500
	29 Dec.	Soil	0.37	0.21	-	^{232}Th series = trace	400
	23 Jan.	Water	-	-	<0.04	-	-
	23 May	Water	-	-	0.14	-	-
	28 Sept.	Water	-	-	0.07	-	-
Drain rear of Building 9	23 Jan.	Soil	0.37	0.28	-	^{238}U series = trace	600

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Drain rear of Building 9	23 May	Soil	0.41	0.30	-	^{137}Cs = 0.01 ^{238}U series = trace	1400
	28 Sept.	Soil	0.37	0.14	-	^{232}Th series = trace ^{238}U series = trace	800
	29 Dec.	Soil	0.66	<0.01	-	^{232}Th series = trace	900
	23 Jan.	Water	-	-	<0.04	-	-
	23 May	Water	-	-	<0.04	-	-
	28 Sept.	Water	-	-	0.21	-	-
	29 Dec.	Water	-	-	<0.04	-	-
Drain at Boom Gates	23 Jan.	Soil	0.17	0.04	-	n.d.	200
	23 May	Soil	0.13	0.13	-	^{232}Th series = trace	300
	28Sept.	Soil	0.25	0.12	-	^{232}Th series = trace	300
	23 Jan.	Water	-	-	0.06	-	-
	23 May	Water	-	-	<0.04	-	-
	28 Sept.	Water	-	-	0.17	-	-
	29 Dec.	Water	-	-	0.07	-	-

(Continued)

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity (Bq g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Drain on road at west fence	23 Jan.	Soil	0.14	0.06	-	n.d.	300
	23 May	Soil	0.65	2.62	-	^{232}Th series = trace	1400
	28 Sept.	Soil	0.19	0.05	-	^{232}Th series = trace	300
	29 Dec.	Soil	0.67	0.19	-	^{232}Th series = trace	800
	23 Jan.	Water	-	-	0.06	-	-
	23 May	Water	-	-	<0.04	-	-
Drain No.2 Strassman Crescent	24 Jan.	Soil	0.42	0.32	-	^{238}U series = trace	400
	23 May	Soil	0.41	0.16	-	^{232}Th series = trace	500
	28 Sept.	Soil	0.29	0.15	-	^{232}Th series = trace	600
	29 Dec.	Soil	0.46	0.30	-	^{232}Th series = trace	500
	29 Dec.	Water	-	-	<0.04	-	-
Drain rear of Building 20	24 Jan.	Soil	0.27	0.10	-	n.d.	500
	23 May	Soil	0.19	0.08	-	^{232}Th series = trace	200
	28 Sept.	Soil	0.20	0.07	-	^{232}Th series = trace ^{238}U series = trace	200
	29 Dec.	Soil	0.34	0.07	-	n.d.	1000
	23 Jan.	Water	-	-	0.06	-	-
	23 May	Water	-	-	0.07	-	-
	28 Sept.	Water	-	-	0.07	-	-
	29 Dec.	Water	-	-	<0.04	-	-

TABLE 12 (Continued)

Station	Date	Sample	Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
			Radioactivity ($Bq\ g^{-1}$ Fresh Weight)				
Drain No.3 Strassman Crescent	23 May	Soil	0.26	0.19	-	^{137}Cs = 0.02 ^{232}Th series = trace	700
	28 Sept.	Soil	0.07	0.08	-	^{232}Th series = trace	600
	23 May	Water	-	-	<0.04	-	-
	29 Dec.	Water	-	-	<0.04	-	-
Drain behind Building 1	23 May	Soil	0.38	0.29	-	^{137}Cs = 0.02 ^{238}U series = trace	1000
	28 Sept.	Soil	0.41	0.15	-	^{232}Th series = trace	
	23 Jan.	Water	-	-	0.04	-	-
	23 May	Water	-	-	0.07	-	-
	28 Sept.	Water	-	-	0.28	-	-
	29 Dec.	Water	-	-	0.11	-	-
Drain opposite Building 23	28 Sept.	Soil	0.29	0.09	-	^{60}Co = trace ^{232}Th series = trace	800
	23 May	Water	-	-	<0.04	-	-
	28 Sept.	Water	-	-	0.07	-	-
	29 Dec.	Water	-	-	0.07	-	-

(Continued)

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Drain opposite sub-station	29 Dec.	Soil	0.35	0.17	-	^{232}Th series = trace	300
	23 Jan.	Water	-	-	0.17	-	-
	23 May	Water	-	-	0.07	-	-
	28 Sept.	Water	-	-	0.25	-	-
	29 Dec.	Water	-	-	0.11	-	-
RE stormwater outlet No.1 near south gate	23 Jan.	Soil	0.9	0.27	-	^{134}Cs = 0.04 ^{137}Cs = 0.01 ^{60}Co = 0.01 ^{232}Th series = trace ^{238}U series = trace	400
	23 Jan.	Vegetation	0.02	0.09	-	0.5 MeV = 0.002	5000
	4 Jan.	Water	-	-	2.5	-	-
	9 Jan.	Water	-	-	1.4	-	-
	17 Jan.	Water	-	-	2.5	-	-
	23 Jan.	Water	-	-	2.3	-	-
	1 Feb.	Water	-	-	7.0	-	-
	6 Feb.	Water	-	-	8.8	-	-
	14 Feb.	Water	-	-	10.5	-	-
	20 Feb.	Water	-	-	1.4	-	-
	28 Feb.	Water	-	-	8.0	-	-
	6 Mar.	Water	-	-	17.1	-	-
	13 Mar.	Water	-	-	17.9	-	-
	22 Mar.	Water	-	-	4.1	-	-

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity (Bq g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (Bq mL^{-1})	Gamma Emitters	K ($\mu g\ g^{-1}$)
RE stormwater outlet No.1 near south gate	29 Mar.	Water	-	-	3.8	-	-
	3 Apr.	Water	-	-	0.7	-	-
	10 Apr.	Water	-	-	1.5	-	-
	17 Apr.	Water	-	-	3.3	-	-
	26 Apr.	Water	-	-	6.9	-	-
	1 May	Water	-	-	6.0	-	-
	8 May	Water	-	-	6.0	-	-
	15 May	Water	-	-	6.0	-	-
	22 May	Water	-	-	2.5	-	-
	29 May	Water	-	-	0.8	-	-
	6 Jun.	Water	-	-	0.6	-	-
	12 Jun.	Water	-	-	0.6	-	-
	20 Jun.	Water	-	-	0.25	-	-
	26 Jun.	Water	-	-	0.6	-	-
	4 Jul.	Water	-	-	0.74	-	-
	10 Jul.	Water	-	-	1.15	-	-
	17 Jul.	Water	-	-	0.48	-	-
	24 Jul.	Water	-	-	0.7	-	-
	31 Jul.	Water	-	-	0.7	-	-
	7 Aug.	Water	-	-	1.27	-	-
	14 Aug.	Water	-	-	0.2	-	-
	24 Aug.	Water	-	-	0.44	-	-

(Continued)

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
RE stormwater outlet No.1 near south gate	28 Aug.	Water	-	-	0.82	-	-
	4 Sept.	Water	-	-	1.1	-	-
	11 Sept.	Water	-	-	0.62	-	-
	18 Sept.	Water	-	-	1.48	-	-
	25 Sept.	Water	-	-	0.88	-	-
	3 Oct.	Water	-	-	1.18	-	-
	9 Oct.	Water	-	-	5.3	-	-
	16 Oct.	Water	-	-	8.2	-	-
	23 Oct.	Water	-	-	10.0	-	-
	30 Oct.	Water	-	-	1.2	-	-
	7 Nov.	Water	-	-	8.6	-	-
	13 Nov.	Water	-	-	6.0	-	-
	20 Nov.	Water	-	-	0.39	-	-
	28 Nov.	Water	-	-	17.2	-	-
	4 Dec.	Water	-	-	8.8	-	-
	11 Dec.	Water	-	-	0.85	-	-
	19 Dec.	Water	-	-	7.59	-	-
	28 Dec.	Water	-	-	4.11	-	-
RE stormwater outlet No.2 near south gate	23 Jan.	Soil	1.58	0.87	-	^{137}Cs = 0.15 ^{60}Co = 0.2 ^{238}U series = trace	700
	23 Jan.	Water	-	-	0.24	-	-

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
20 m from RE stormwater outlet No.1	21 Feb.	Soil	1.93	0.96	-	^{137}Cs = 0.22 ^{60}Co = 0.17 ^{238}U series = trace	600
	21 Feb.	Vegetation	0.02	0.1	-	0.5 MeV = 0.002 ^{137}Cs = 0.01 ^{54}Mn = 0.003 ^{60}Co = 0.013	3900
	30 May	Soil	2.22	1.75	-	^{137}Cs = 0.6 ^{60}Co = 0.03	900
	30 May	Vegetation	0.12	0.2	-	^{137}Cs = 0.03 ^{60}Co = 0.015	450
	6 Dec.	Vegetation	0.009	0.04	-	0.5 MeV = 0.001 ^{137}Cs = 0.002 ^{60}Co = 0.003	4700
	6 Dec.	Soil	1.42	0.58	-	^{137}Cs = 0.16 ^{60}Co = 0.08	700
	21 Feb.	Water	-	-	0.17	-	-
	30 May	Water	-	-	0.33	-	-
	6 Dec.	Water	-	-	0.57	-	-
Water pool across road from stormwater outlet No.1	4 Jan.	Water	-	-	2.5	-	-
	9 Jan.	Water	-	-	1.4	-	-
	17 Jan.	Water	-	-	2.0	-	-

(Continued)

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity (Bq g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (Bq mL^{-1})	Gamma Emitters	K ($\mu g\ g^{-1}$)
Water pool across road from stormwater outlet No.1	23 Jan.	Water	-	-	6.7	-	-
	1 Feb.	Water	-	-	6.7	-	-
	6 Feb.	Water	-	-	8.1	-	-
	14 Feb.	Water	-	-	10.9	-	-
	20 Feb.	Water	-	-	1.7	-	-
	28 Feb.	Water	-	-	9.3	-	-
	6 Mar.	Water	-	-	17.6	-	-
	13 Mar.	Water	-	-	8.4	-	-
	22 Mar.	Water	-	-	4.4	-	-
	29 Mar.	Water	-	-	3.7	-	-
	3 Apr.	Water	-	-	0.7	-	-
	10 Apr.	Water	-	-	1.5	-	-
	17 Apr.	Water	-	-	3.2	-	-
	26 Apr.	Water	-	-	6.8	-	-
	1 May	Water	-	-	2.2	-	-
	8 May	Water	-	-	6.0	-	-
	15 May	Water	-	-	6.0	-	-
	22 May	Water	-	-	2.3	-	-
	29 May	Water	-	-	0.6	-	-
	6 Jun.	Water	-	-	0.6	-	-
	12 Jun.	Water	-	-	0.7	-	-
	20 Jun.	Water	-	-	0.14	-	-

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity (Bq g^{-1} Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (Bq mL^{-1})	Gamma Emitters	K ($\mu g\ g^{-1}$)
Water pool across road from stormwater outlet No.1	26 Jun.	Water	-	-	0.6	-	-
	4 Jul.	Water	-	-	0.75	-	-
	10 Jul.	Water	-	-	1.14	-	-
	17 Jul.	Water	-	-	0.48	-	-
	24 Jul.	Water	-	-	0.55	-	-
	31 Jul.	Water	-	-	0.73	-	-
	7 Aug.	Water	-	-	1.27	-	-
	14 Aug.	Water	-	-	0.2	-	-
	24 Aug.	Water	-	-	0.4	-	-
	28 Aug.	Water	-	-	0.79	-	-
	4 Sept.	Water	-	-	0.8	-	-
	11 Sept.	Water	-	-	0.59	-	-
	18 Sept.	Water	-	-	1.55	-	-
	25 Sept.	Water	-	-	0.88	-	-
	3 Oct.	Water	-	-	1.18	-	-
	9 Oct.	Water	-	-	6.2	-	-
	16 Oct.	Water	-	-	8.6	-	-
	23 Oct.	Water	-	-	9.6	-	-
	30 Oct.	Water	-	-	1.2	-	-
	7 Nov.	Water	-	-	7.9	-	-
	13 Nov.	Water	-	-	4.7	-	-
	20 Nov.	Water	-	-	0.53	-	-
	28 Nov.	Water	-	-	15.3	-	-

(Continued)

TABLE 12 (Continued)

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ Fresh Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
Water pool across							
road from	4 Dec.	Water	-	-	4	-	-
stormwater outlet	11 Dec.	Water	-	-	0.92	-	-
No.1	19 Dec.	Water	-	-	7.33	-	-
	28 Dec.	Water	-	-	3.96	-	-

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. In column 7 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 PIPELINE - 1978

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

Date	Location	Dose Rate ($\mu Sv\ h^{-1}$)
20 Feb.	All joins	<0.5
20 Feb.	Scour valves	<0.5
20 Feb.	Soil below joins	<0.5
25 May	All joins	<0.5
25 May	Scour valves	<0.5
25 May	Soil below joins	<0.5
5 Dec.	Join No.5	1.0
5 Dec.	Between Joins 7 and 8	1.0
5 Dec.	Between Joins 8 and 9	1.0
5 Dec.	All other pipe section	<0.5
5 Dec.	Soil below joins	<0.5

TABLE 14

RADIOACTIVITY IN SAMPLES TAKEN AT EFFLUENT DISCHARGE PIPELINE 1978

Station	Date	Sample	Radioactivity (Bq g^{-1} Dry Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H (Bq mL^{-1})	Gamma Emitters	K ($\mu g\ g^{-1}$)
Near scour valve No.1	20 Feb.	Sand	0.19	0.05	-	n.d.	300
	20 Feb.	Water	-	-	2.7	-	-
	25 May	Sand	0.42	0.15	-	^{232}Th series = trace	600
	25 May	Water	-	-	0.25	-	-
	5 Dec.	Sand	0.44	0.13	-	n.d.	500
	5 Dec.	Water	-	-	0.5	-	-
River where effluent discharge pipe crosses	20 Feb.	Sand	0.5	0.06	-	n.d.	300
	20 Feb.	Water	-	-	<0.04	-	-
	25 May	Sand	0.32	0.13	-	^{232}Th series = trace	500
	25 May	Water	-	-	<0.04	-	-
	5 Dec.	Sand	0.28	0.07	-	n.d.	500
	5 Dec.	Water	-	-	0.07	-	-
Double air valve No.3 sump floor*	1 Nov.	Soil	0.89	1.3	-	^{137}Cs = 0.8 ^{60}Co = 0.03 ^{232}Th series = trace	1100
1 m from double air valve No.3*	1 Nov.	Soil	0.85	0.5	-	^{137}Cs = 0.29 ^{60}Co = 0.03 ^{232}Th series = trace	1200

TABLE 14 (Continued)

Station	Date	Sample	Radioactivity ($Bq\ g^{-1}$ Dry Weight) Gross Alpha	Gross Beta (less ^{40}K)	^{3}H ($Bq\ mL^{-1}$)	Gamma Emitters	K ($\mu g\ g^{-1}$)
12 m from double air valve No.3*	1 Nov.	Soil	0.94	0.65	-	^{137}Cs = 0.27 ^{60}Co = 0.03 ^{232}Th series = trace	700
25 m from double air valve No.3*	1 Nov.	Soil	0.76	0.45	-	^{137}Cs = 0.55 ^{60}Co = 0.04 ^{232}Th series = trace	500
River bank below double air valve No.3*	1 Nov.	Soil	0.21	0.13	-	^{232}Th series = trace	400
			($Bq\ L^{-1}$)	($Bq\ L^{-1}$)		($Bq\ L^{-1}$)	
River water below double air valve No.3*	1 Nov.	Water	0.05	0.09	<0.04	n.d.	-

*Special survey associated with vandalism of double air valve No.3

n.d. = not detected

\- = not measured.

TABLE 15

POSSIBLE DOSE TO A MEMBER OF THE PUBLIC RESULTING FROM EXPOSURE TO MEASURED CONCENTRATIONS 1978

Material	Isotope	Exposure Route	Critical Organ	Possible Dose (μSv)	Dose Limit (μSv)	Possible Dose as Fraction of Limit
Woronora Oysters	^{65}Zn	Ingestion	Total Body	0.09	5 000	2×10^{-5}
	^{3}H	Ingestion	Body Tissue	0.06	5 000	1×10^{-5}
Woronora Fish	^{60}Co	Ingestion	Large Lower Intestine	0.003	15 000	2×10^{-7}
	^{60}Co	Ingestion	Total Body	0.004	5 000	8×10^{-7}
	^{3}H	Ingestion	Body Tissue	0.06	5 000	1×10^{-5}
Woronora Water	^{3}H	Daily Swimming Station EO	Body Tissue	0.04	5 000	8×10^{-6}
Woronora Beach Sand	Natural beta activity	Daily Sunbathing Station EO	Skin	29	30 000	1×10^{-3}
Menai Milk	^{137}Cs	Ingestion	Total Body	0.31	5 000	6×10^{-5}

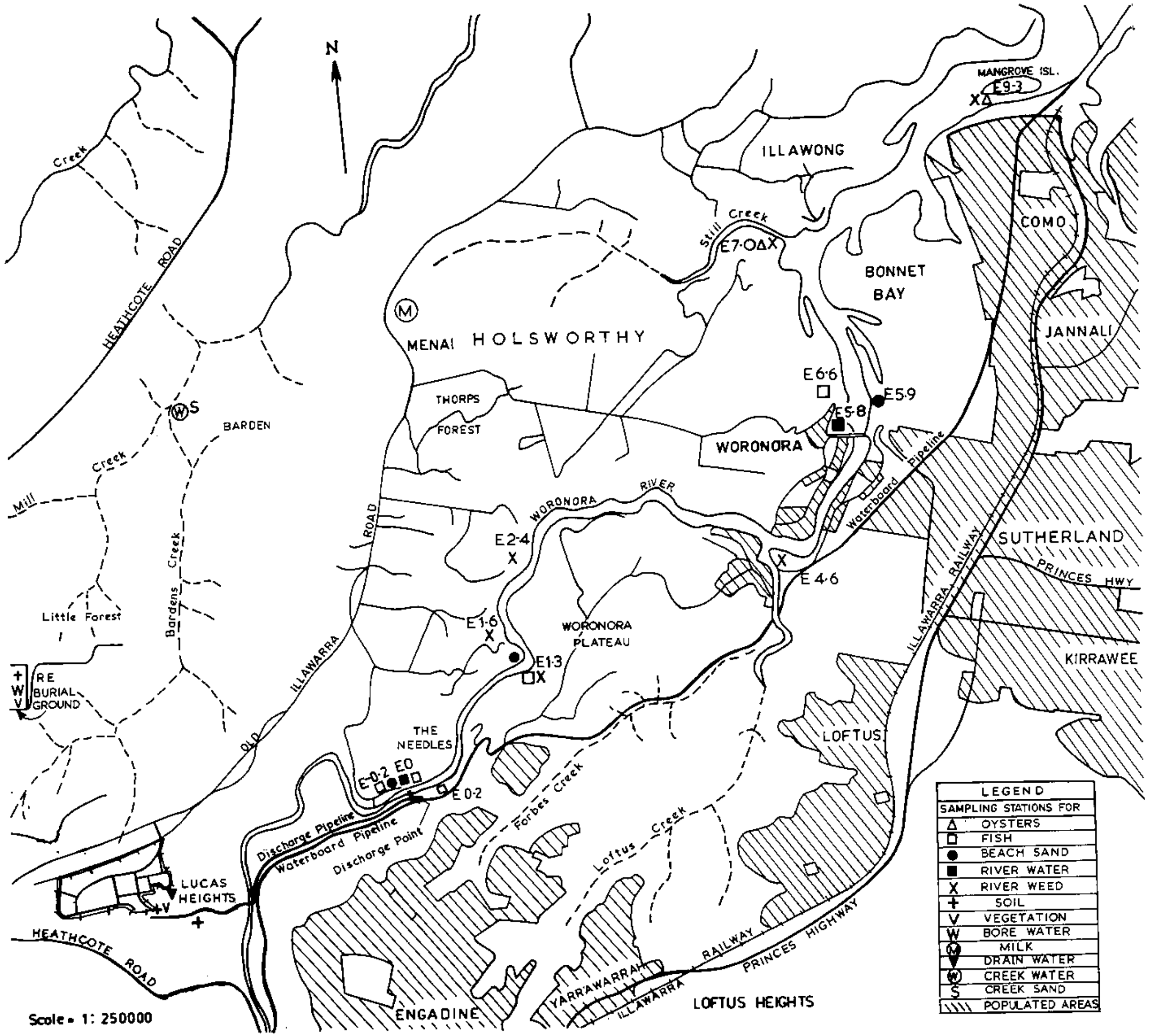

FIGURE 1. LUCAS HEIGHTS DISTRICT - LOCATION OF SAMPLING STATIONS

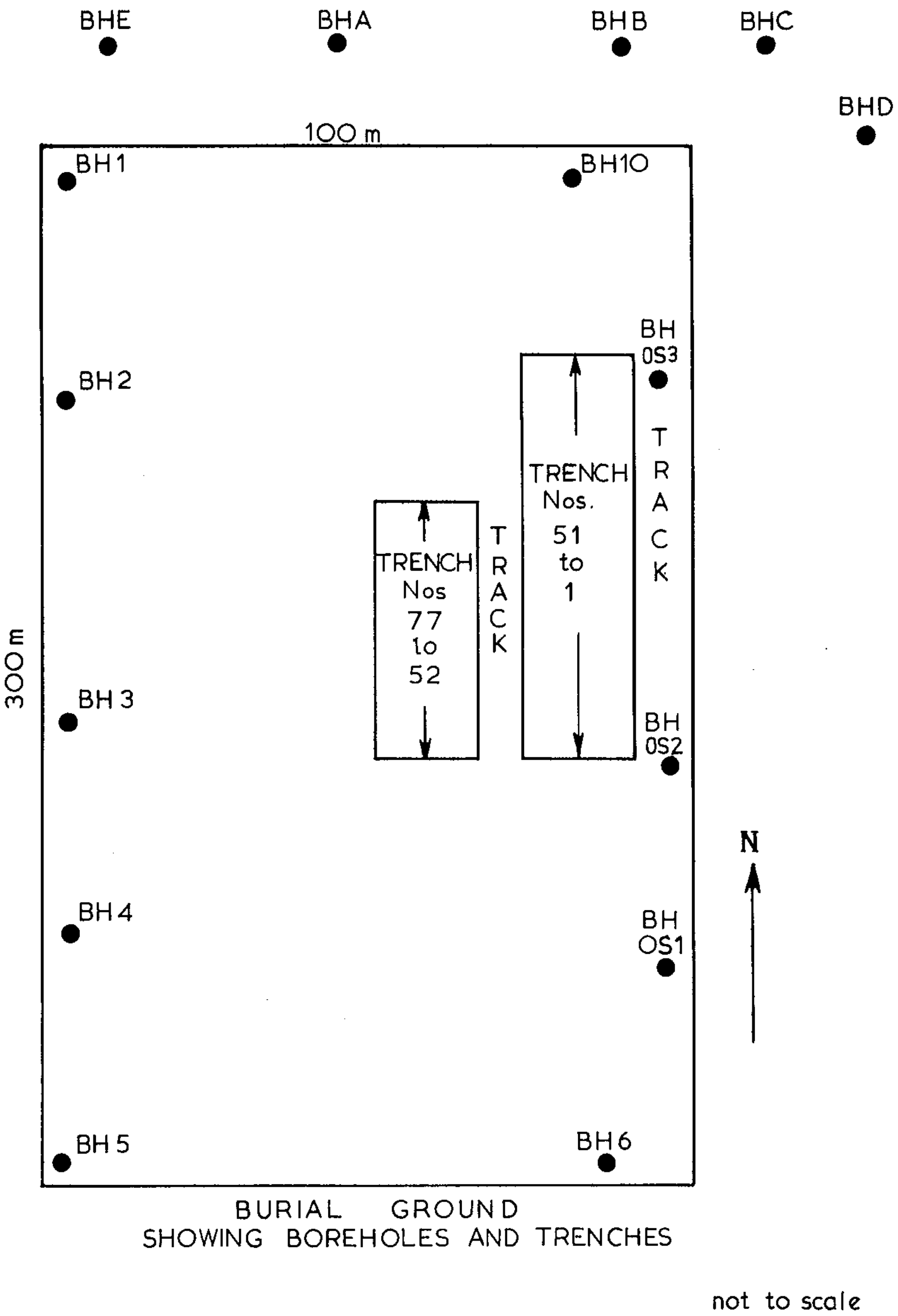

FIGURE 1A. LITTLE FOREST BURIAL GROUND - LOCATION OF SAMPLING STATIONS

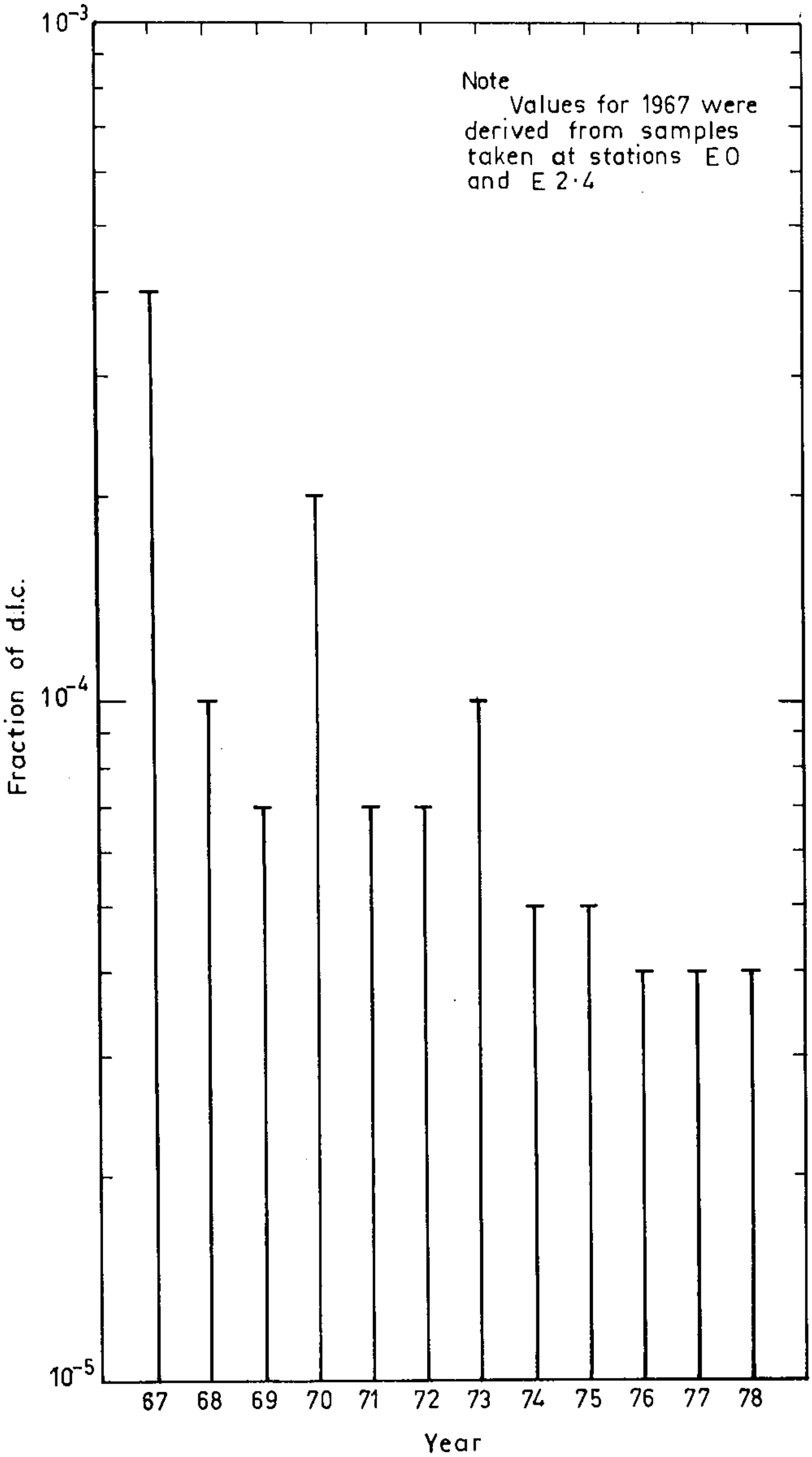

FIGURE 2. TRITIUM IN WORONORA WATER (STATION E5.9) EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1967-1978)

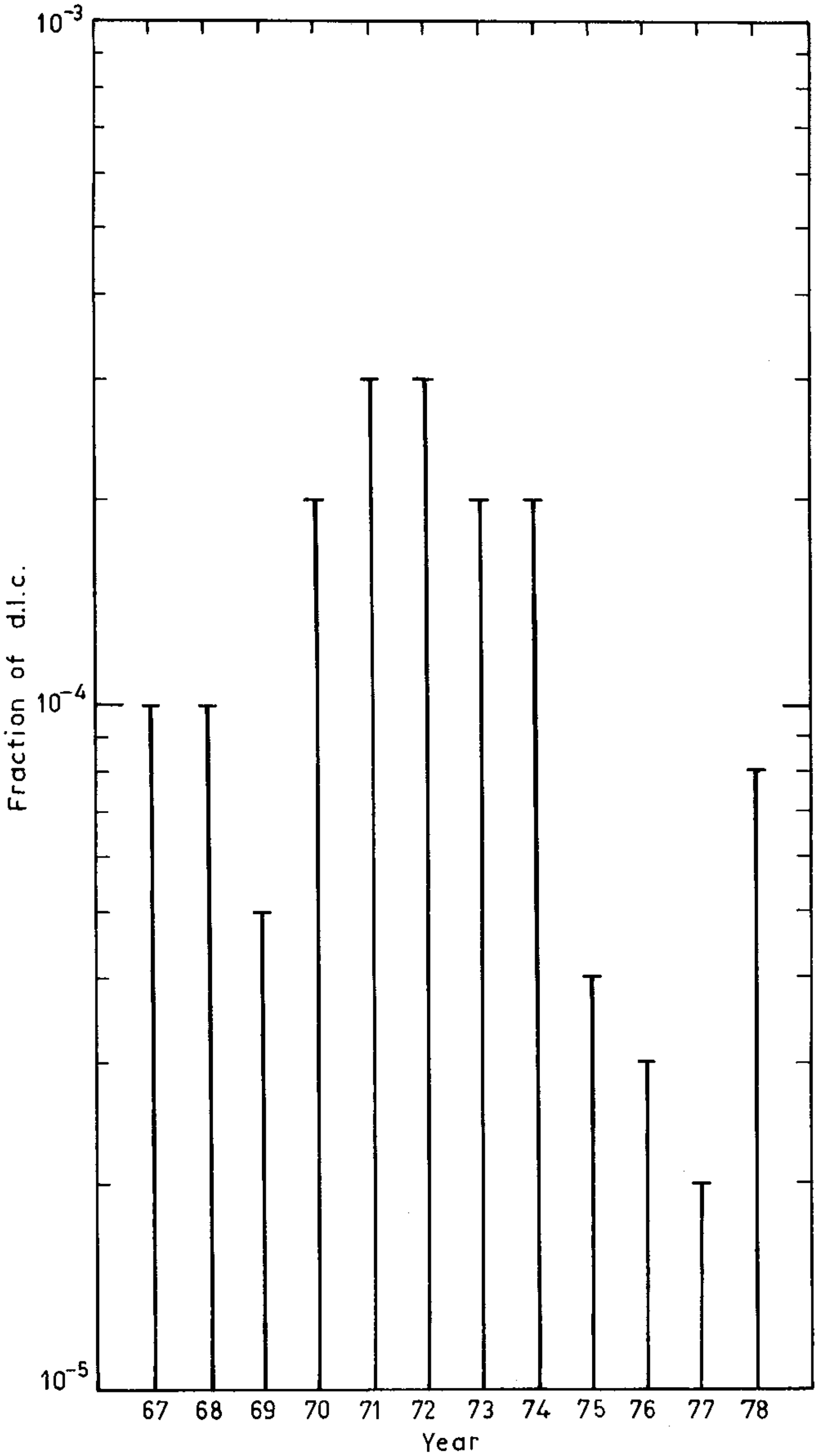

FIGURE 3. ^{65}Zn IN WORONORA OYSTERS (STATION E7.0) EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1967-1978

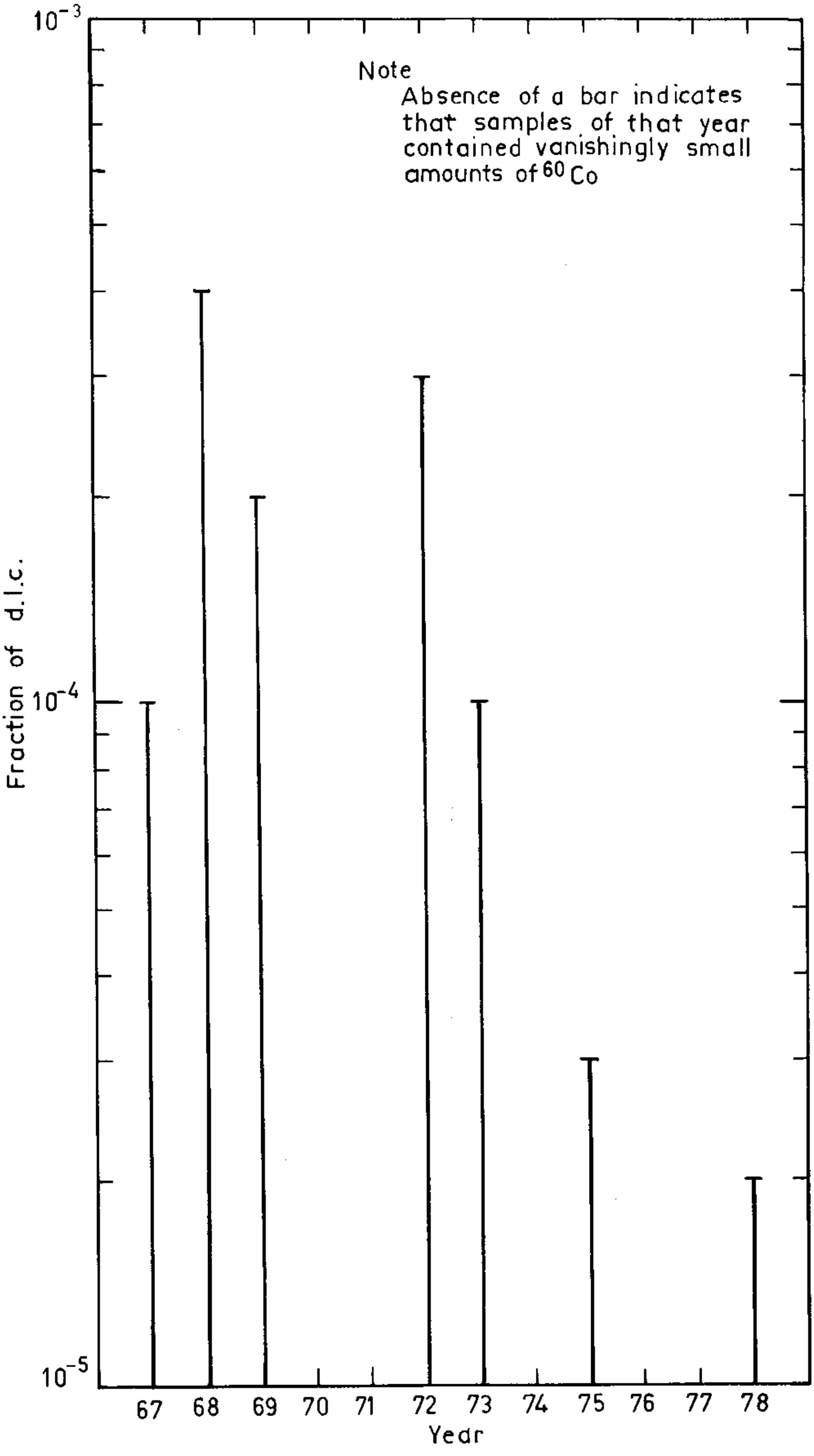

FIGURE 4. ^{60}Co IN WORONORA FISH EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1967-1978

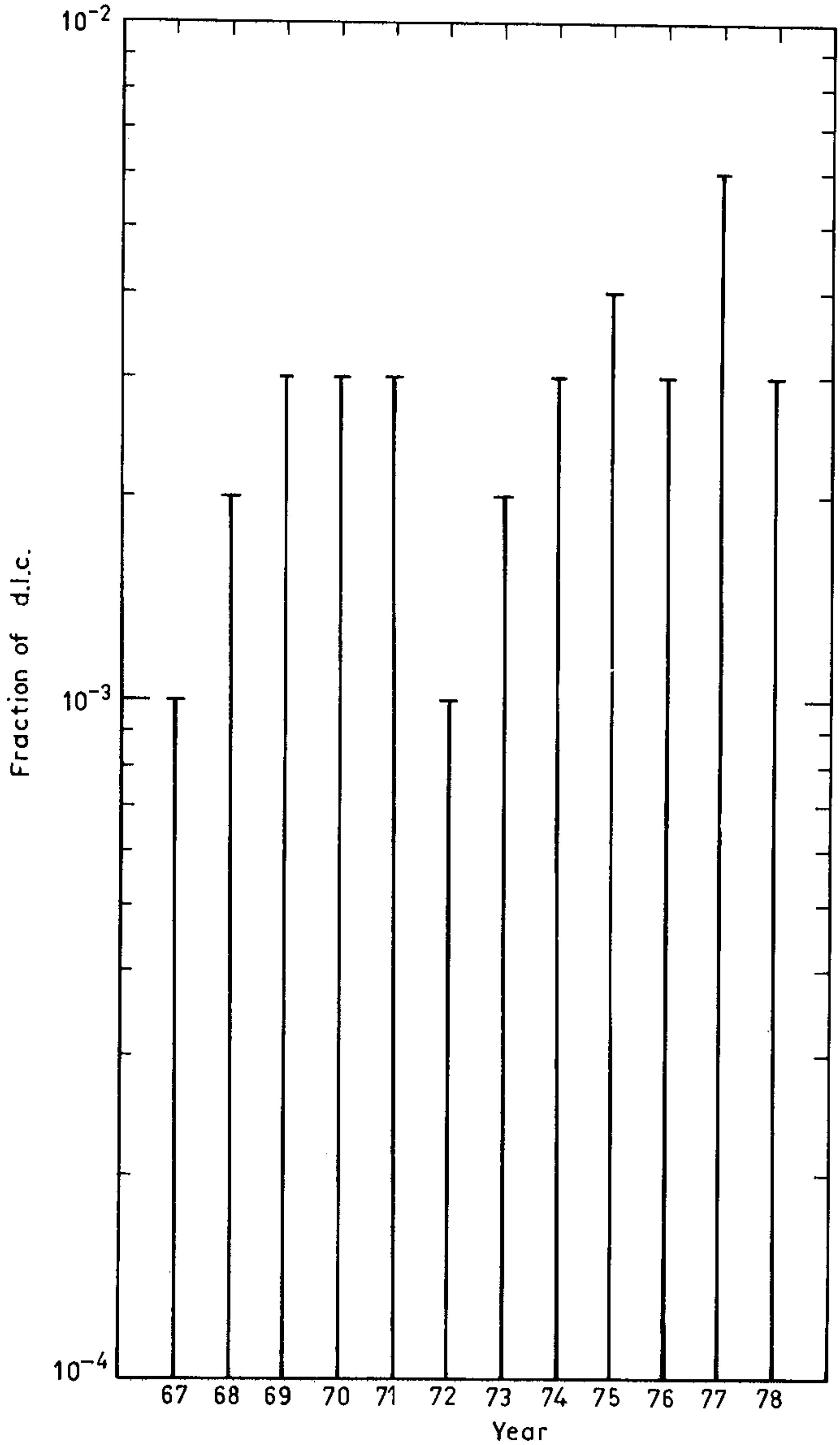

FIGURE 5. GROSS α-ACTIVITY IN WORONORA BEACH SANDS EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1967-1978

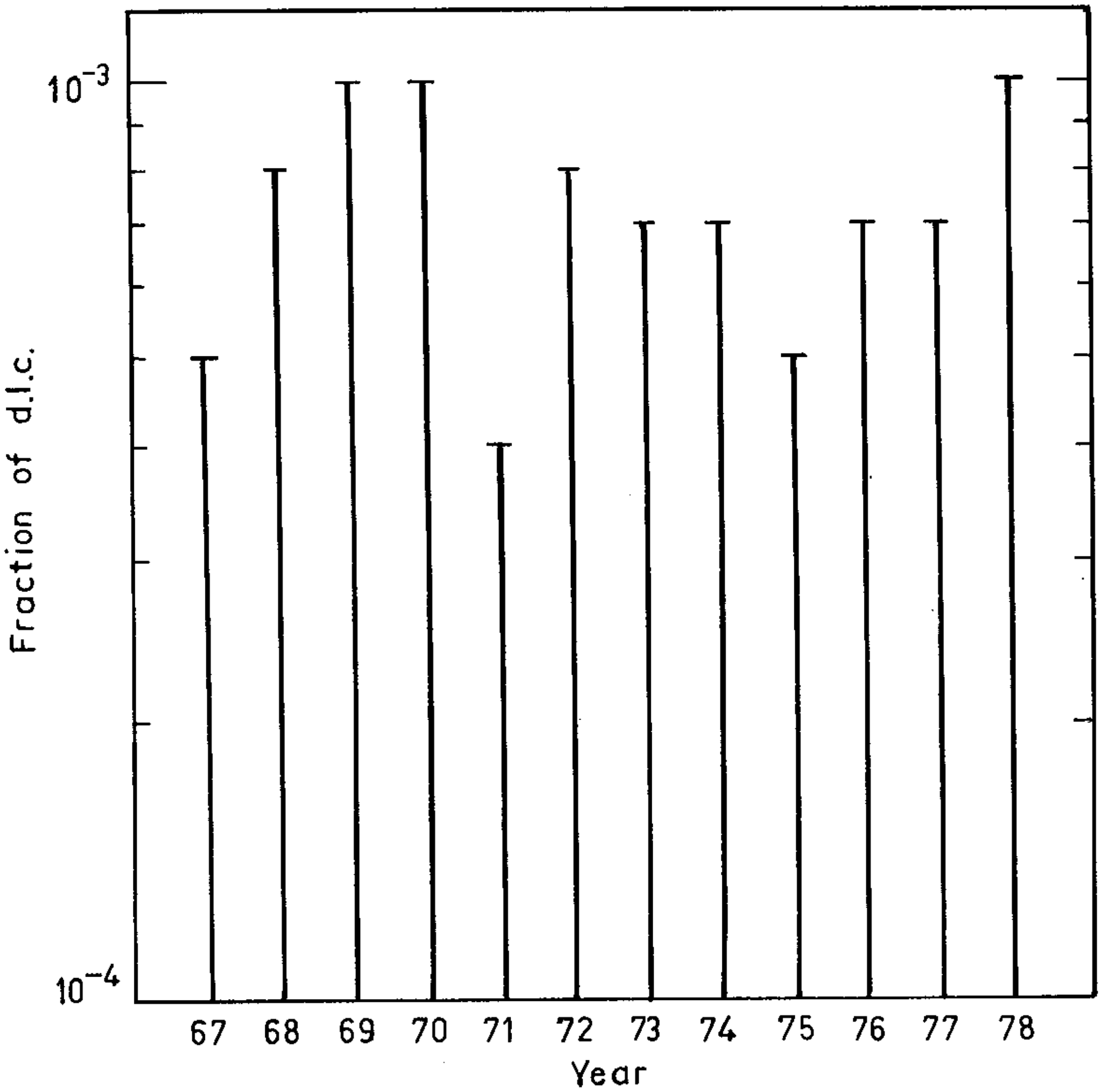

FIGURE 6. GROSS β-ACTIVITY IN WORONORA BEACH SANDS EXPRESSED AS FRACTIONS OF THE DERIVED LIMITING CONCENTRATION (d.l.c.) 1967-1978

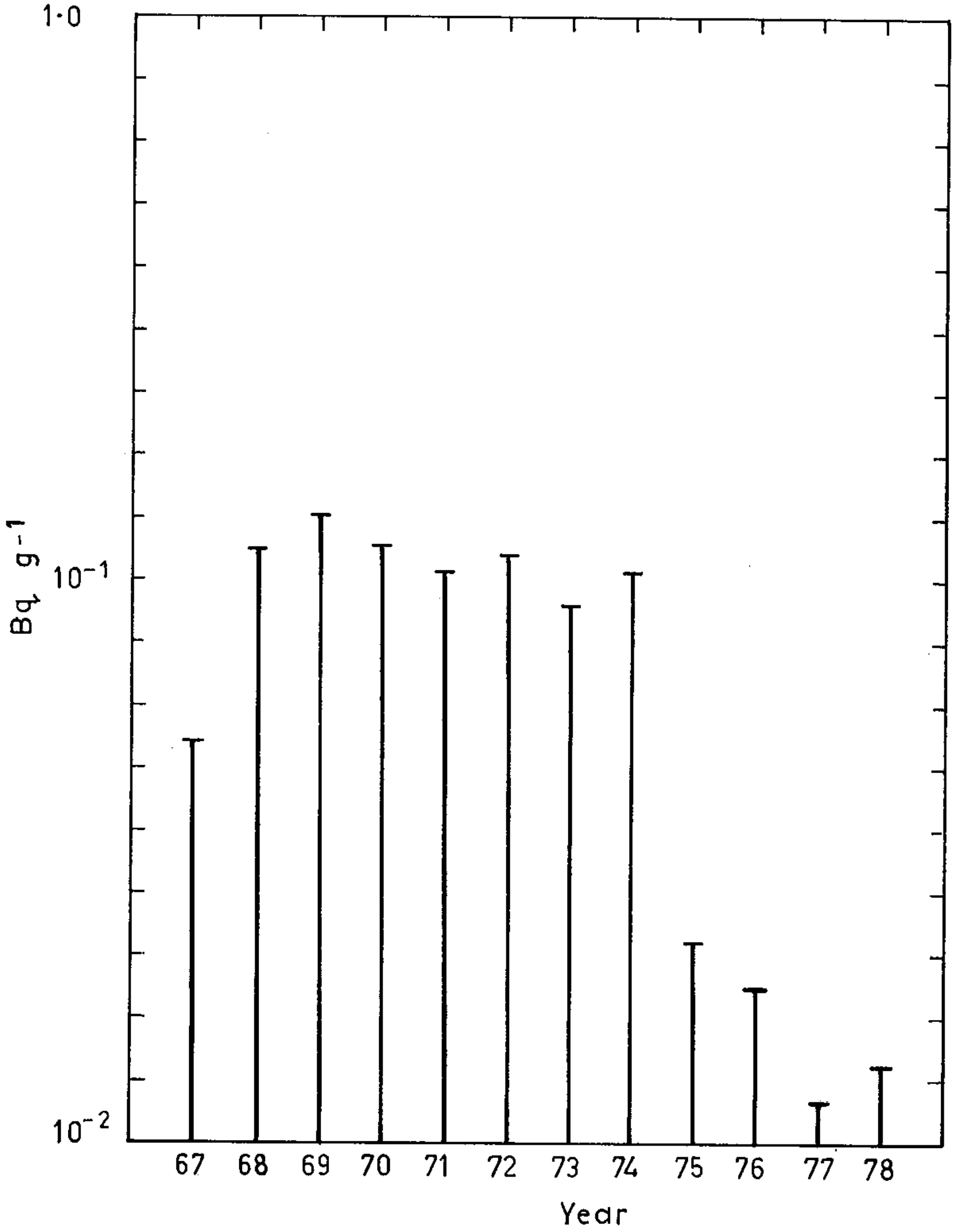

FIGURE 7. ^{60}Co IN WORONORA ZOSTERA (STATION E1.6) EXPRESSED AS BECQUERELS PER GRAM (FRESH WEIGHT) 1967-1978

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

APPENDIX B
LIQUID EFFLUENT DISCHARGES FROM AAECRE - 1978
Compliance with Authorisation

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

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

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

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

V = the volume, in gallons, of effluent discharged in a quarter, or 9 x 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. Note that AAEC/E156 gave the $(\text{mpmd})_i$ in curies; the becquerel is used here because it is the standard SI unit of activity.

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

In this formula, the measured number of megabecquerels 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 fact 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 have been caused by 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 have been caused by the next most restrictive nuclide.

The use of this procedure gives a double advantage. Since it is assumed that the radioactivity is caused by 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 quarterly radioactivity discharges to the Woronora, for the period 1 January 1978 to 31 December 1978 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 the greatest discharge for the year represents less than 20 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 RIVER 1978

Quarter	Radioisotope Measured (megabecquerel)				
Ending	^{210}Po	αu	^{3}H	βu	$^{114m.114}In$
31.3.78	7.1×10^{-1}	14.0	2.3×10^{5}	6.6×10^{2}	8.7×10^{-2}
30.6.78	8.2×10^{-2}	11.8	1.3×10^{5}	7.03×10^{2}	1.04×10^{-1}
30.9.78	8.1×10^{-2}	11.8	2.4×10^{5}	6.66×10^{2}	1.15×10^{-1}
31.12.78	4.4×10^{-2}	9.6	1.04×10^{5}	5.2×10^{2}	8.14×10^{-2}

αu = a mixture of unidentified α emitting nuclides.

βu = a mixture of unidentified β emitting nuclides.

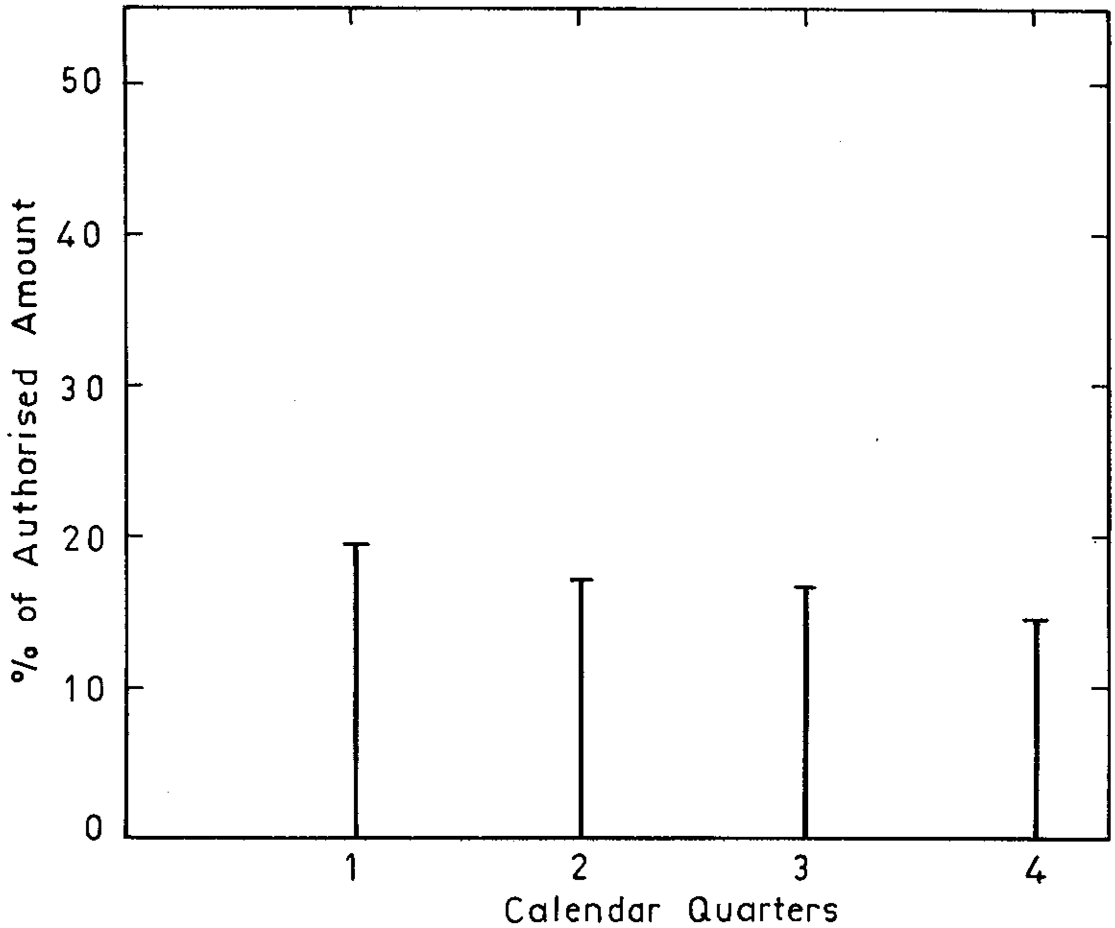

FIGURE B1. DISCHARGES TO THE WORONORA 1978
DISCHARGED RADIOACTIVITY EXPRESSED AS A PERCENTAGE OF THE AUTHORISED AMOUNT

APPENDIX C

AIRBORNE RADIOACTIVITY DISCHARGES FROM AAECRE 1978

Compliance with Authorisation

The International Commission on Radiological Protection (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 may 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 workforce.

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. In 1978, weekly limits were not exceeded at any discharge point.

Table C1 gives the measured quarterly discharges, from each discharge point, of airborne radioactivity for the period 1 January 1978 to 31 December 1978. 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 are expressed as fractions of the permitted quarterly discharges. It shows that in no case was the limit exceeded; and that with the exception of ^{41}Ar from Building 15, the discharges represent only small fractions of the permissible discharges.

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 discharges in 1978 were below those permitted. Hence, the probability that a member of either the public or the AAECRE staff could suffer radiation damage as a result of the discharges is very small.

TABLE C1

MEASURED AIRBORNE RADIOACTIVITY DISCHARGES 1978

Quarter Building	Gross α (kBq)	^{131}I (MBq)	^{3}H (GBq)	^{41}Ar (GBq)	Other βγ (MBq)
Quarter No.1					
2	16	5.9×10^3	-	-	<10
15	<10	<10	0.41×10^3	1.75×10^4 (1)	47 (5)
19	43	30	-	-	<10
23A	<10	1.6×10^3	-	-	<10
23B	<10	1.9×10^3	-	-	17
41	<10	0.9×10^3	-	-	<10
Quarter No.2					
2	0.6×10^3	4.7×10^3	-	-	<10
15	<10	<10	0.8×10^3	2.13×10^4 (2)	38 (6)
19	11	<10	-	-	<10
23A	16	0.5×10^3	-	-	<10
23B	<10	0.64×10^3	-	-	<10
41	13	24	-	-	<10
Quarter No.3					
2	84	3.8×10^3	-	-	<10
15	<10	<10	0.7×10^3	1.99×10^4 (3)	33 (7)
19	13	<10	-	-	<10
23A	<10	0.2×10^3	-	-	<10
23B	<10	1.9×10^3	-	-	<10
41	<10	<10	-	-	<10
Quarter No.4					
2	<10	9.7×10^3	-	-	<10
15	<10	<10	0.7×10^3	2.0×10^4 (4)	42 (8)
19	<10	<10	-	-	<10
23A	<10	0.3×10^3	-	-	<10
23B	<10	3.5×10^3	-	-	<10
41	<10	<10	-	-	<10

(1) Based on 6 spot samples.
(2) Based on 10 spot samples.
(3) Based on 8 spot samples.
(4) Based on 9 spot samples.
(5) Includes 23 MBq $^{197}Hg + ^{203}Hg$.
(6) Includes 19 Mbq $^{197}Hg + ^{203}Hg$.
(7) Includes 17 MBq $^{197}Hg + ^{203}Hg$.
(8) Includes 22 MBq $^{197}Hg + ^{203}Hg$.

- = not measured.

Gross α = a mixture of unidentified α emitting nuclides.

Other βγ = βγ emitting nuclides not otherwise listed.

TABLE C2

RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS 1978 EXPRESSED AS FRACTIONS OF THE PERMITTED QUARTERLY DISCHARGE

Quarter Building	Gross α	^{131}I	^{3}H	^{41}Ar	Other βγ
Quarter No.1					
2	2.4×10^{-5}	9.0×10^{-2}	-	-	6.3×10^{-6}
15	3.0×10^{-4}	6.3×10^{-4}	3.2×10^{-3}	6.5×10^{-1}	7.1×10^{-4}
19	1.3×10^{-4}	9.1×10^{-4}	-	-	1.5×10^{-5}
23A	6.3×10^{-4}	1.0×10^{-1}	-	-	3.0×10^{-4}
23B	1.5×10^{-4}	1.2×10^{-2}	-	-	1.1×10^{-3}
41	3.0×10^{-5}	5.6×10^{-2}	-	-	1.5×10^{-5}
Quarter No.2					
2	9.1×10^{-4}	7.1×10^{-2}	-	-	6.3×10^{-6}
15	3.0×10^{-4}	6.3×10^{-4}	6.2×10^{-3}	7.9×10^{-1}	5.8×10^{-4}
19	3.3×10^{-5}	3.0×10^{-4}	-	-	1.5×10^{-5}
23A	1.0×10^{-3}	3.0×10^{-2}	-	-	3.0×10^{-4}
23B	1.5×10^{-4}	4.0×10^{-2}	-	-	6.3×10^{-4}
41	3.9×10^{-5}	1.5×10^{-3}	-	-	1.5×10^{-5}
Quarter No.3					
2	1.3×10^{-4}	5.8×10^{-2}	-	-	6.3×10^{-6}
15	3.0×10^{-4}	6.3×10^{-4}	5.4×10^{-3}	7.4×10^{-1}	5.0×10^{-4}
19	3.9×10^{-5}	3.0×10^{-4}	-	-	1.5×10^{-5}
23A	6.3×10^{-4}	1.3×10^{-2}	-	-	3.0×10^{-4}
23B	1.5×10^{-4}	1.2×10^{-1}	-	-	6.3×10^{-4}
41	3.0×10^{-5}	6.3×10^{-4}	-	-	1.5×10^{-5}
Quarter No.4					
2	1.5×10^{-5}	1.5×10^{-1}	-	-	6.3×10^{-6}
15	3.0×10^{-4}	6.3×10^{-4}	5.4×10^{-3}	7.4×10^{-1}	6.4×10^{-4}
19	3.0×10^{-5}	3.0×10^{-4}	-	-	1.5×10^{-5}
23A	6.3×10^{-4}	1.9×10^{-2}	-	-	3.0×10^{-4}
23B	1.5×10^{-4}	2.2×10^{-1}	-	-	6.3×10^{-4}
41	3.0×10^{-5}	6.3×10^{-4}	-	-	1.5×10^{-5}

Gross α = a mixture of unidentified α emitting nuclides.

Other βγ = βγ emitting nuclides not otherwise listed.

For Building 15, 'Other βγ' includes ^{197}Hg + ^{203}Hg - see Table C1.