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Residual Radioactive Contamination at Maralinga and Emu, 1985

Edited by

Keith H. Lokan

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YALLAMBIE VICTORIA 3085
TELEPHONE: 433 2211

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ABSTRACT

An account is provided of residual contamination at Maralinga and Emu, in South Australia, where the United Kingdom Atomic Weapons Research Establishment conducted nuclear weapons development trials between 1953 and 1963.

Detailed information is presented about contamination levels at sites on the range where radioactive materials were dispersed. Some of these were associated with trials involving natural uranium or short-lived isotopes which are no longer present. Such sites are of little radiological significance. There are, however, four sites where plutonium-239 was dispersed in substantial quantities from minor trials and information is presented about its distribution. Much of this material has been diluted by mixing with local soil, but there is a significant quantity of material present in the form of contaminated fragments, particularly at Taranaki. A considerable quantity of uranium-235 is also present at Taranaki, but this is of minor radiological significance.

An assessment is made of the radiological significance of the dispersed plutonium, and it is concluded that the material represents a potential long term hazard while it remains in its present form.

Residual radioactivity associated with all but one of the seven major trial sites involving nuclear explosions continues to decay in a predictable way and will, in the worst case, fall below levels considered safe for continuous occupancy within about fifty years. One site, Tadje, contains significant concentrations of plutonium over a small area and is considered to be an additional plutonium-contaminated locality.

Measurements of beryllium concentrations in soil are presented.

INTRODUCTION

Between 1955 and 1963, the United Kingdom Atomic Weapons Research Establishment conducted a programme of nuclear weapons development trials at Maralinga in South Australia. These included seven major nuclear trials involving atomic explosions and many other smaller scale experiments which dispersed radioactive materials on the test range. An account of this programme has been provided by Symonds (1985).

In 1964 a survey and clean-up operation was undertaken (Operation Hercules, 1964) to bring the range to a condition where it could be sustained on a caretaker basis, without the continuing presence of a health physics team. This was followed in 1966 by a further radiological survey (Operation Radsur, 1966), which was designed to evaluate the condition of the range prior to a major rehabilitation operation, which was carried out in 1967 (Operation Brumby, 1967; Pearce, 1968).

In 1977, a further survey was conducted by the Australian Radiation Laboratory and the Atomic Energy Commission and the information obtained in these studies was assessed and published by the Australian Ionising Radiation Advisory Council (AIRAC, 1979). These surveys covered both the major trial sites, (Cooper et al., 1978), where nuclear explosions had taken place, and those minor trial sites where plutonium-239 had been dispersed (Ellis, 1979).

The present study, carried out between February 1984 and April 1985, extends the earlier field work. The major trial sites have been re-examined, those sites at which plutonium was used have been studied in much greater detail, and all other experimental sites used during the life of the range have been surveyed.

In 1953, weapons development trials including two atomic explosions were performed at Emu which is about one hundred and eighty kilometres north of Maralinga. Data, which update an earlier survey of Emu (Maclagan et al., 1979), are also presented.

CHAPTER ONE

Plutonium Contamination At Maralinga

Malcolm B. Cooper, Peter A. Burns, Geoffrey A. Williams,
Keith H. Lokan and J. Colin Duggleby.

Apart from its use in major trials in 1956 and 1957, plutonium was introduced to Maralinga in 1959, when an experiment was carried out at Wewak (Figure 1.1) in which 0.9 TBq (24 Ci) of plutonium was burnt in a high temperature fire (Stewart, 1961). In succeeding years further studies were performed at Wewak, TM100, TM101 and at Taranaki (Figure 1.1), which led to the explosive dispersal of plutonium over substantial areas (Pearce, 1968).

TARANAKI

By far the most significant area of plutonium contamination occurs at Taranaki where about 50 TBq (1350 Ci) was dispersed by (conventional) explosives in a series of trials extending from 1960 to 1963. Taranaki had been used previously in 1957 for a balloon-supported major trial, which had caused little radioactive contamination at ground level. Accordingly, the site was available for further use, and twelve trials were subsequently undertaken, each of which employed about 4 TBq (110 Ci) of plutonium (UKAWRE, 1984). The nature of these trials was such that plutonium was dispersed along particular directions and carried in finely divided form in the direction of the prevailing winds.

In 1968, the United Kingdom Atomic Weapons Research Establishment mounted a major clean-up and rehabilitation exercise (Operation Brumby, 1967), in which heavily contaminated materials were buried in a series of twenty one concrete capped pits, and the level of surface contamination was reduced in places by mixing the top 10-15 centimetres of soil, using earth moving equipment. In some areas, where this was found to be inadequate, clean topsoil was introduced, either to achieve further dilution or simply to cover an existing contaminated area. Operation Brumby sought to reduce the average concentration of plutonium to less than 1 micro-curie (40 KBq) per kilogram of soil. A high cyclone mesh (HCM) fence had been constructed, which enclosed the firing pads and the twenty-one burial pits. At the conclusion of operation Brumby, the HCM-fenced area resembled a somewhat featureless ploughed field (Operation Brumby, 1967). Beyond this fenced area, there extended along particular directions - sometimes for some kilometres - further

tilled areas which covered the deposition plumes of some of the trials. The HCM-fenced area encloses some 20 hectares and the tilled area beyond the fence encompasses a further 200 hectares.

Experimental Methods. For the present study, we set out to examine in the field the superposition of the twelve separate trials, modified by the soil processing which took place during Operation Brumby. Plutonium is formed by neutron capture from uranium-238 in a nuclear reactor and inevitably contains a mixture of three isotopes of plutonium of atomic masses 239, 240 and 241 in diminishing proportions. The isotope plutonium-241 decays with a half-life of 14.4 years to americium-241. Over the twenty to twenty-five years since the plutonium was produced, the activity of americium-241 has increased from zero to its present level in the soil, which is of the order of ten per cent of the plutonium-239 activity. This is now easy to detect through the emission of an abundant (36°/o) gamma ray at an energy of 60 keV and serves as a good indicator of the accompanying plutonium-239. Contaminated areas were therefore initially surveyed using thin (2 mm thick, 50 mm diameter) sodium iodide detectors, with single channel analysers adjusted to cover the range 40 to 80 keV.

Field measurements of the americium activity were not considered to be a quantitative measure of plutonium concentration, at least in the processed areas, because of the absorption of the 60 keV radiation through varying thicknesses of overlying soil and the presence of the gamma emitter europium-152 near the Taranaki ground zero. They did, nevertheless, provide a good qualitative indicator of plutonium and allowed us to survey a large area (1.5 km x 0.8 km) around the firing pads, using a very close measurement grid (20 m by 20 m). Further away, the field measurements were invaluable as a guide for the selection of soil samples from areas which had not been disturbed. Here they provided a valid estimate of plutonium concentration once the ratio of americium to plutonium had been established from soil analyses.

Quantitative data on americium-241 activity concentrations in the soil were obtained by gamma-ray analysis of soil samples. These were taken with a hand corer of 84 mm diameter and 25 mm depth and, for the inner Taranaki area, were gathered at every fourth americium field point (ie. on a 40 m x 40 m grid). Representative soil profiles were also taken with a split tube sampler to depths varying from 10 to 30 cm, depending on the thickness of topsoil over

the underlying limestone. Soil samples were sieved to remove limestone pebbles and other oversize material above 500 microns, and prepared in standard 30 g thin-walled PVC packs for analysis by low resolution gamma-ray spectrometry in the laboratory. The activity concentration of americium was thus determined under conditions of well defined geometry, with little uncertainty arising from self-absorption. A representative low resolution soil spectrum is presented in Figure 1.2. This spectrum shows both the 60 keV americium-241 gamma ray and a mixture of unresolved L-shell X-rays from americium and the plutonium isotopes.

Results. Figure 1.3 illustrates the distribution of americium-241 as seen in the field and Figure 1.4 as it was obtained subsequently by laboratory analysis of soil samples.

The plutonium to americium activity ratio was determined in a careful series of measurements of samples with a high resolution hyperpure germanium detector, where the low abundance emissions from plutonium-239 (51.6 keV) and plutonium-240 (45.2 keV) were compared with americium-241 (59.5 keV). The activity ratio of plutonium-239 to americium-241 varied somewhat and an average value was obtained of 7.4 ± 0.6 (standard error of the mean).

The data presented in Figure 1.4 are expressed in units of becquerel per kilogram of americium-241. Taking the factor given above for the activity ratio of plutonium-239 to americium-241, the hatched contour (3000 bq/kg) corresponds to the boundaries of the region where the soil activity concentration of plutonium-239 exceeds 20 kbq/kg (~ 0.5 μCi/kg). Similarly, for the field data, the '1000' contour of Figure 1.3 (which represents the number of 60 keV counts observed in 30 seconds in a detector held 15 cm above the surface) corresponds approximately to the same boundary.

In conducting the Taranaki field survey, it became apparent that the soil activity concentration was by no means uniform and that there were many localised areas of very high specific activity. These were quickly resolved to be fragments, generally of metal, contaminated with plutonium. There were large numbers of such fragments and a sampling survey was carried out to estimate their abundance. Traverses were run across the affected area and an attempt was made to count all identifiable fragments within each 5 metre wide survey strip. About twelve per cent of the area of the inner Taranaki region was sampled in this way. The data are presented in Figure 1.5, where the area

of each circle is made proportional to the number of fragments per unit area. The largest circles correspond to one fragment per two square metres. Near some of the firing pads this figure is greatly exceeded, as the detectors simply recorded a continuous high level of local contamination that could not be resolved into individual sources.

The distribution of these fragments clearly characterises them as ejecta from the original trials and invariably the directions coincide with the contamination plumes identifiable through the americium-241 (plutonium) concentration in the soil. Not surprisingly, they provide material of much higher specific activity than the soil and are relatively easy to assay for radioactive content.

Figure 1.6 presents a typical high resolution gamma-ray spectrum of a fragment recovered from Taranaki. Gamma-ray lines from the isotopes of plutonium-239 (387 keV, 129.3 keV), and plutonium-240 (45.2 keV) are readily identifiable, along with the very strong 59.5 keV emission from americium-241. This particular spectrum implies a plutonium-239/americium-241 activity ratio of eight. Activity ratios for plutonium-240/plutonium-239 were estimated in a similar way, and generally yielded values in the range of 0.1 to 0.2, depending somewhat on the nature of the fragment and the consequent differences in self absorption of the low energy emission lines.

There is also present in Figure 1.6 the series of characteristic gamma-ray emissions from the uranium isotope uranium-235 (143.8 keV, 185.7 keV). The activity is low, because the specific activity of uranium-235 is low, and is therefore of minor radiological consequence. However, many fragments from Taranaki exhibit these same features and indicate that quantities of uranium-235 at least comparable in mass to the plutonium were used there.

The nature of the fragments is quite variable. Sometimes they consist of fractured pieces of steel, light alloy or other material, coated on one surface with plutonium. Indeed the most active fragment encountered consists of a concave trapezoidal piece of 12mm steel plate, about 250mm long and 120 broad, with about 7 GBq (0.2 Ci) of plutonium-239 on its inner surface. More commonly, the fragments were smaller - ranging from about 0.5 mm to a few centimetres in overall dimensions - with activities of ~0.1 MBq (2.7 μCi) of americium-241 or more. In fact for operational convenience, fragments were only identified as such if their americium-241 activity exceeded this value. Figure 1.7 represents the distribution of activities for Taranaki fragments

defined in this way. There were also a number of much smaller fragments recovered, of high specific activity and of sufficient density to attenuate the low energy L-shell emissions. Most likely these consist of small (less than 1 mm) solid particles of oxidised plutonium/uranium.

In general, plutonium dispersal plumes were not readily detectable in field measurements of americium-241 beyond a few kilometres from the firing pads. However, one particular trial did lead to a more extended plume, which was deposited north west of Taranaki, and which is still detectable with americium-241 field probes 18 km from the firing pad, when it crosses the western boundary of the range (West St). This is illustrated in Figure 1.8, where the approximate limit of the 30 Bq/kg (americium-241) contour is plotted. This contour was derived from a mixture of field measurements made along the network of tracks and survey tracks north west of Taranaki, and from soil samples gathered along its central axis. This contour, which represents the limit of detectability for the field technique, corresponds to a plutonium concentration of about two per cent of the target figure (1 μCi/kg) for soil concentration in the clean-up of Taranaki during Operation Brumby. This north west plume is still (barely) detectable, at a concentration of 2.7 Bq/kg, in a soil sample taken along the new road known as Western Avenue at a distance of ~ 32 kilometres. During the tracking of this plume, the survey party noted that at the point where its central axis crosses Fifth Avenue, the topsoil had been pushed back 100m on both sides of the track for a length of 200 metres. It was also noted that the activity concentration in a soil sample taken near here was anomalously high compared with the concentration closer in and further out (Figure 1.9).

Plumes associated with other Taranaki trials are also displayed in Figure 1.8, at the same level of soil concentration, and are much more confined. Their inner areas have of course been modified by the soil mixing carried out during Operation Brumby. The roughly triangular zone, north east of Taranaki in Figure 1.8 represents an indeterminate mixture of americium-241, derived from Taranaki firings and from the close-in fallout deposited by the three major nuclear trials conducted earlier at Biak, Breakaway and Marcoo. (Cooper et al., 1978).

Sufficient data were obtained in the Taranaki surveys to make rough estimates of the quantity of plutonium-239 remaining on the ground following the clean-up program of 1967. Details of the calculation are presented in Appendix 1A. The integrated plutonium activity over the area of the inner grid

is estimated to be 0.96 TBq (26 Ci). In addition, the contaminated fragments - something of the order of a hundred thousand of them in all - contribute a further 1.2 TBq (32 Ci). The north west plume is estimated to contain about 1.1 TBq (30 Ci) - in this case about a quarter of the total quantity used in the trial. While it is not possible to estimate the contribution from the other plumes it seems likely that they contain a considerably smaller fraction of the original material.

These numbers add up to a total observed inventory of 3.3 TBq (89 Ci) and while there is considerable uncertainty in them, it is difficult to account for more than say 10 to 20 percent of the total plutonium used (50 TBq). We assume therefore that the remainder, which represents the major part of the total, is contained within the Taranaki burial pits.

WEWAK TM100 AND TM101

Plutonium trials took place at these sites between 1959 and 1961. They began at Wewak in 1959 when 0.9 TBq (24 Ci) of plutonium was burnt in a high temperature petrol fire at VK 33 (Figure 3.4). All but 0.02 TBq (0.6 Ci) was recovered and returned to the UK in the same year (Stewart, 1961). Further trials were carried out at TM100 [1.4 TBq] (37 Ci) in 1960 and at TM101 [1.4 TBq] (37 Ci) and Wewak [1.3 TBq] (37 Ci) in 1961. These trials involved the dispersal of plutonium by conventional explosives. (UKAWRE, 1984)

The sites at TM100 and TM101 were partly cleaned up in 1964 during Operation Hercules and more completely in 1967 during Operation Brumby. Pit number 22 at TM101 and pit number 23 south of TM101 were capped with reinforced concrete. These pits are currently enclosed within HCM fences (Department of National Development and Energy, 1980). The Wewak area was rehabilitated during Operation Brumby when much of the topsoil was removed for burial in the Marcoo crater and was replaced with fresh soil. The firing pads VK 60A and VK 60C were capped with concrete (Pearce, 1968). At VK33 a circular area of approximately 70 m diameter was ploughed.

These three sites were surveyed in the present study using exactly the same methodology which has been described earlier for Taranaki. The distribution of americium-241 activity in the soil and of contaminated fragments is illustrated in Figures 1.10 and 1.11 where the largest circle corresponds to a fragment concentration of two and five fragments per 20 square metres respectively. The plutonium-239/americium-241 ratios of Wewak,

TM100 and TM101 are 13, 15.5 and 6 respectively and the hatched areas in the figures define those regions where the soil activity concentration of plutonium-239 exceeds 17 kBq (0.46 μCi)/kg, 20 kBq (0.54 μCi)/kg, and 8 kBq (0.22 μCi)/kg respectively. The levels of plutonium-239 in soil at the centre of VK33 were in excess of 100 kBq (2.7 μCi)/kg, however, these decreased to less than 1 kBq (0.03 μCi)/kg within 100 m. There is no evidence of any uranium-235 at these sites.

Temporary fences were installed in July 1984 to identify the areas of contamination. These are shown in Figures 1.10 and 1.11. It is clear from the later field surveys that they will need to be extended.

Clearly the levels of contamination and the density of fragments are both lower at these three sites than is observed at Taranaki and the areas involved are much smaller.

ACKNOWLEDGEMENTS

The assistance of many of the staff at ARL, particularly M. Wilks, B. Pletikapa, R. Statham and P. Johnston is acknowledged. In the field, we were greatly dependent on the support of the Australian Protective Services at Maralinga, in particular the valuable assistance of C. Byard and S. Millard. We also wish to acknowledge the Department of Resources and Energy for logistic support. The involvement of officers from the South Australian Health Commission, in particular P. Crouch and A. Summerton, in the execution of the field work was greatly appreciated.

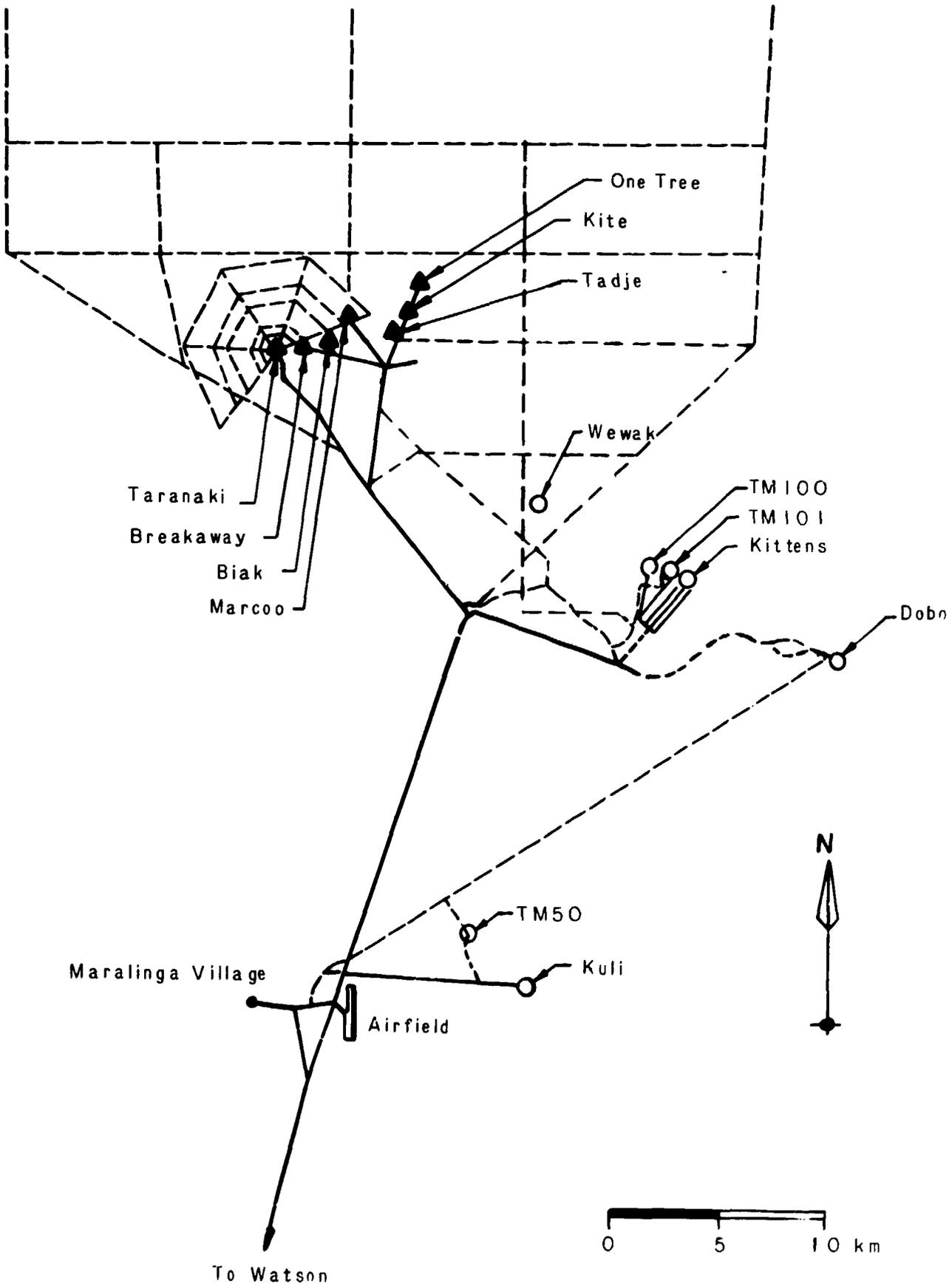
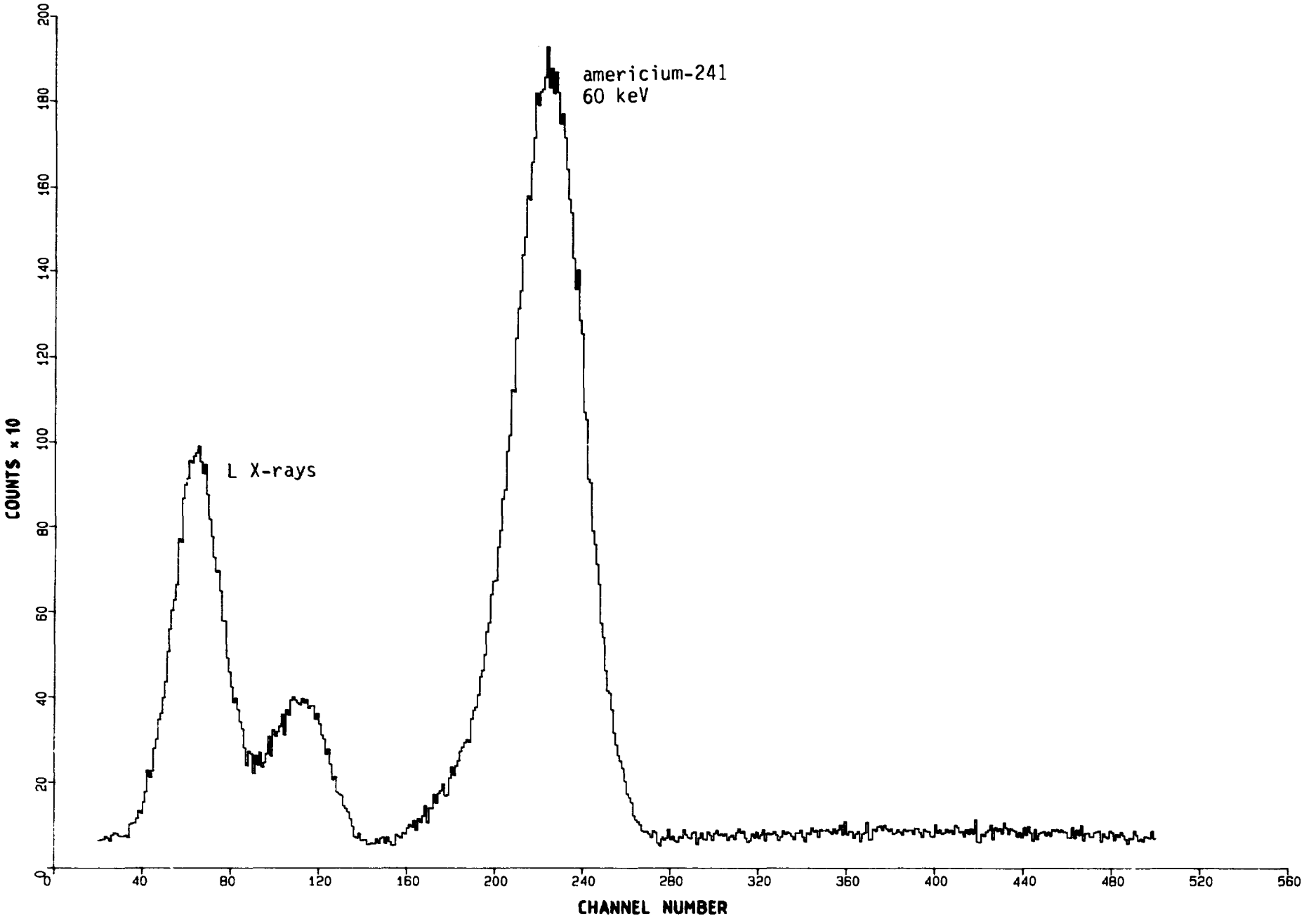


Figure 1.1: General map of Maralinga Area, including 'major' trial sites (solid triangles) and the 'minor' trial sites (open circles). Taranaki was also used for 'minor' trials employing plutonium.

Figure 1.2: Low resolution gamma-ray spectrum from Taranaki soil.


americium-241
60 keV
L X-rays
COUNTS × 10
CHANNEL NUMBER
0
20
40
60
80
100
120
140
160
180
200
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560

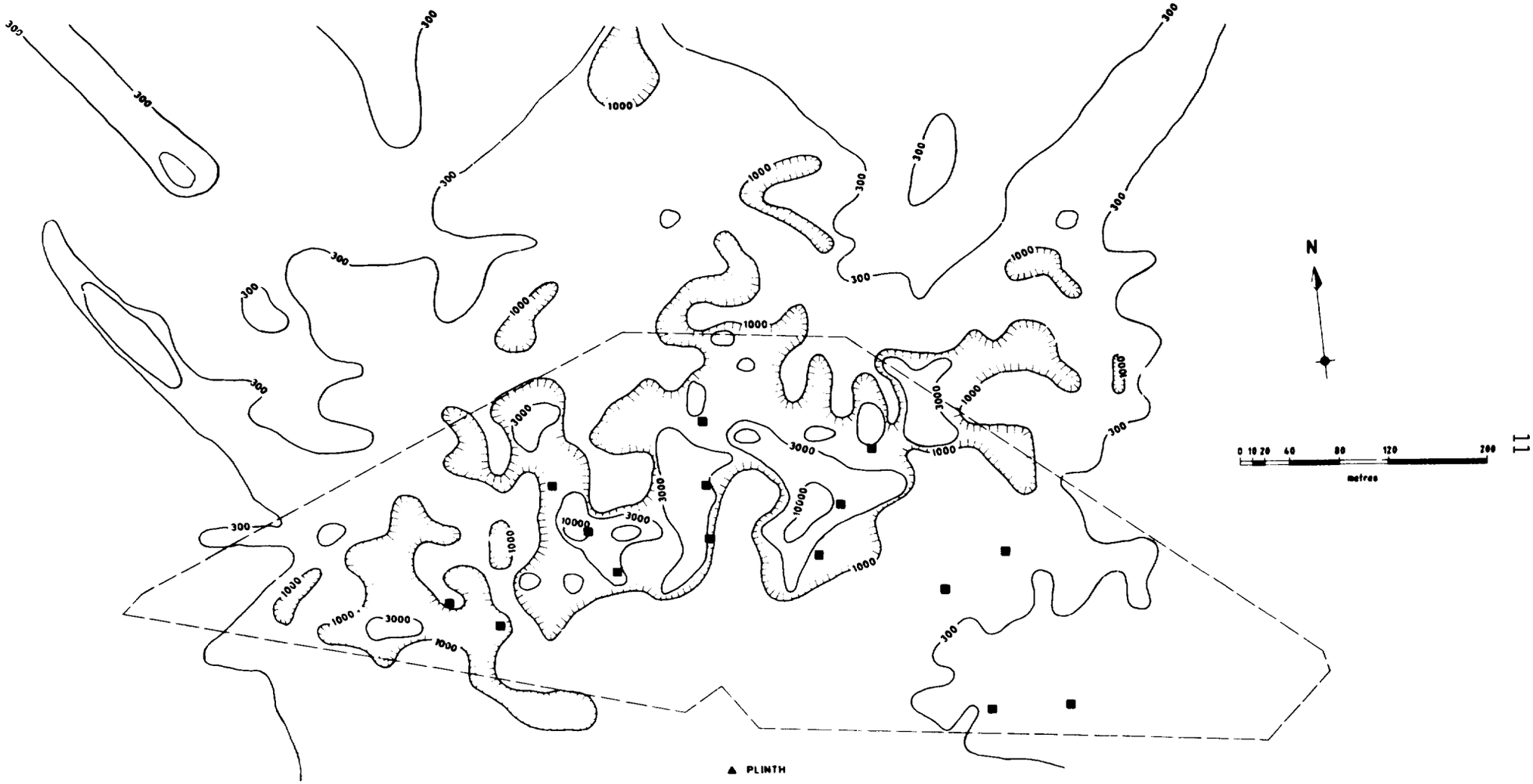


Figure 1.3: Distribution of americium-241, Taranaki inner grid: field data

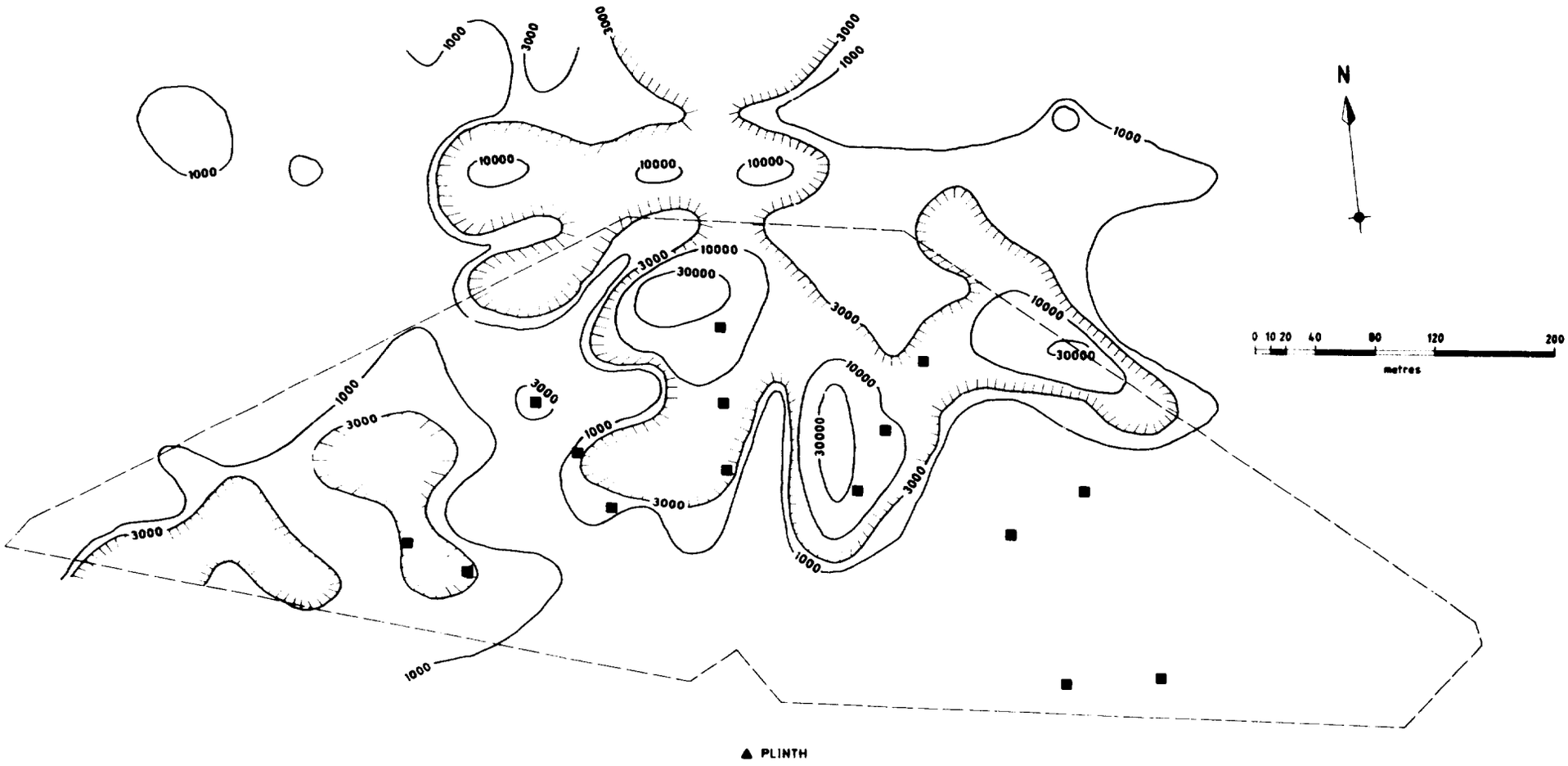


Figure 1.4: Activity Concentration of americium-241 (Bq/kg), Taranaki inner grid: soil analyses

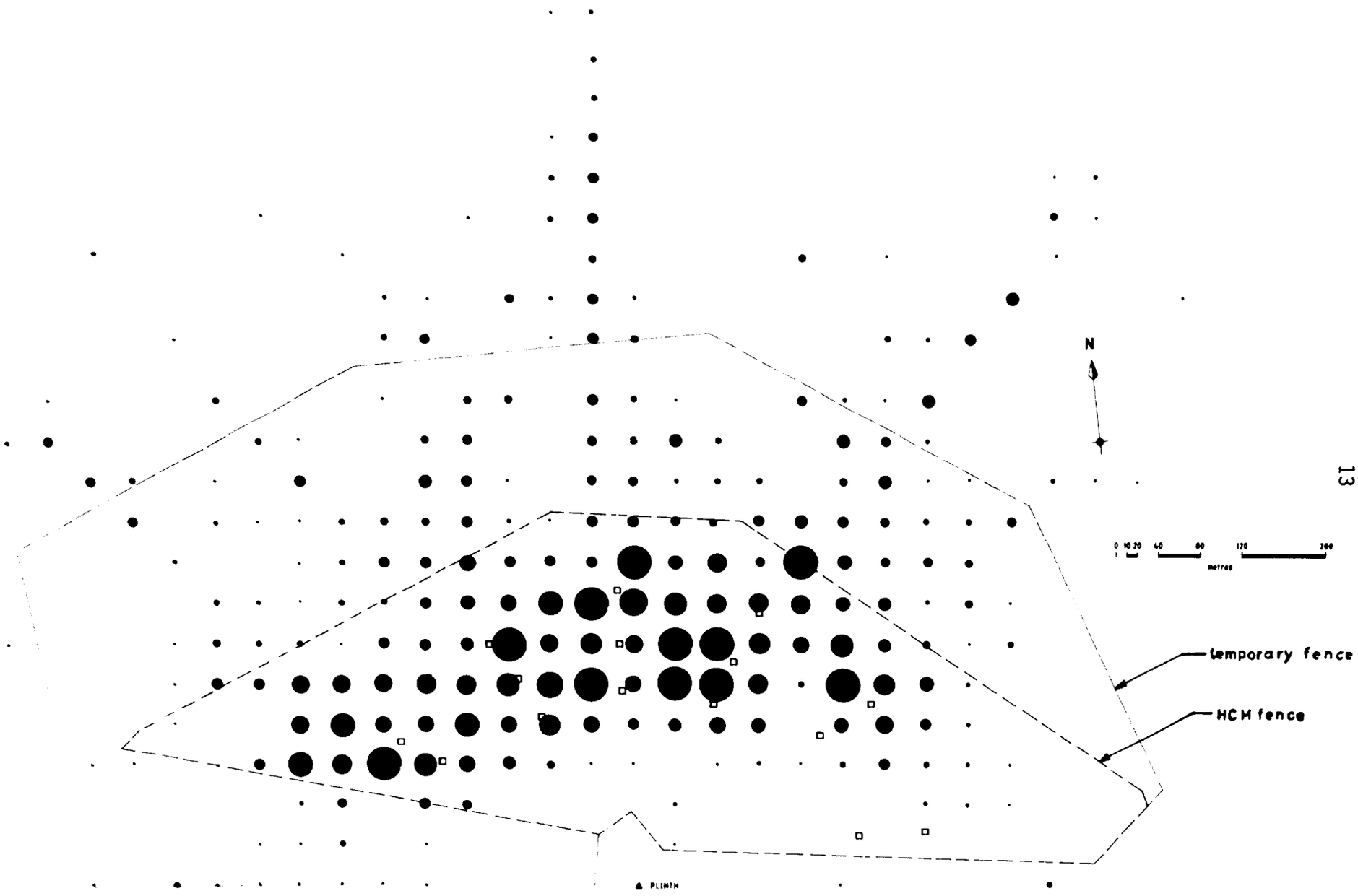
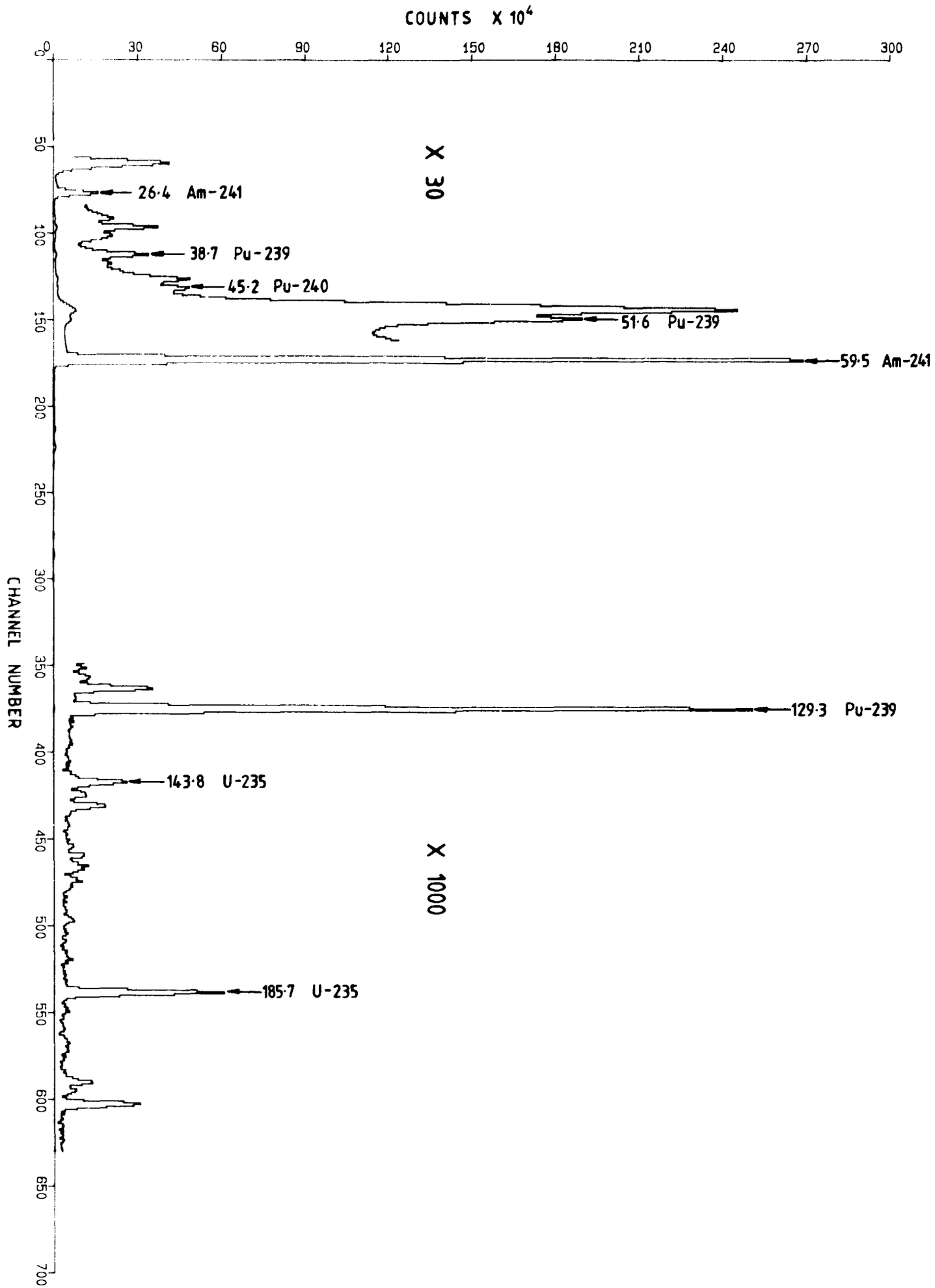


Figure 1.5: Distribution of Contaminated Fragments, Taranaki inner grid. The areas of the solid circles are proportional to the number per unit area. The largest circle represents a fragment surface density of 0.5/m^2.

Figure 1.6: High Resolution Gamma-Ray Spectrum from a Taranaki fragment.


COUNTS X 10⁴
0
30
60
90
120
150
180
210
240
270
300
CHANNEL NUMBER
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
X 30
X 1000
26·4 Am-241
38·7 Pu-239
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129·3 Pu-239
143·8 U-235
185·7 U-235

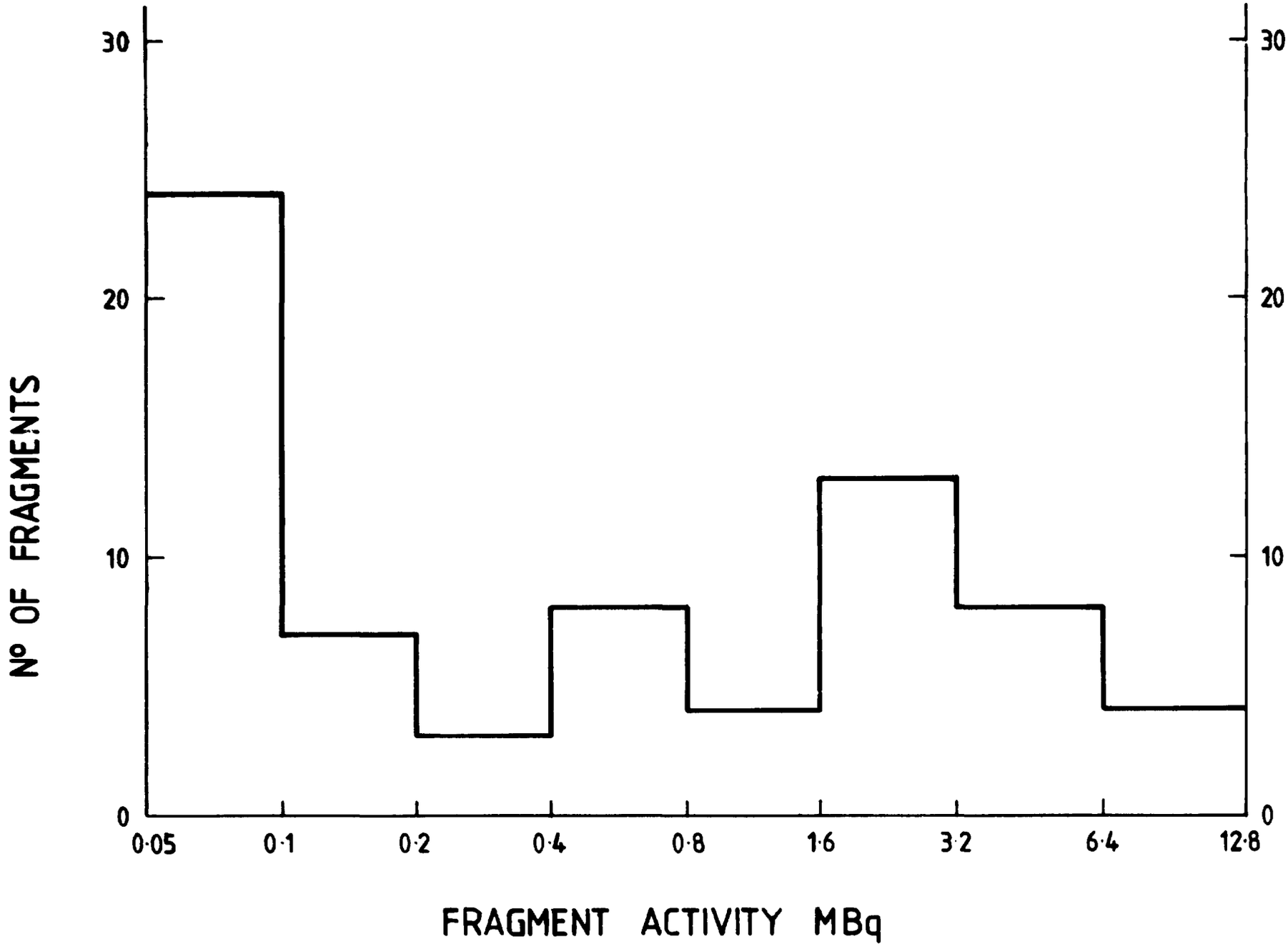


Figure 1.7: Distribution of Taranaki fragment activities.

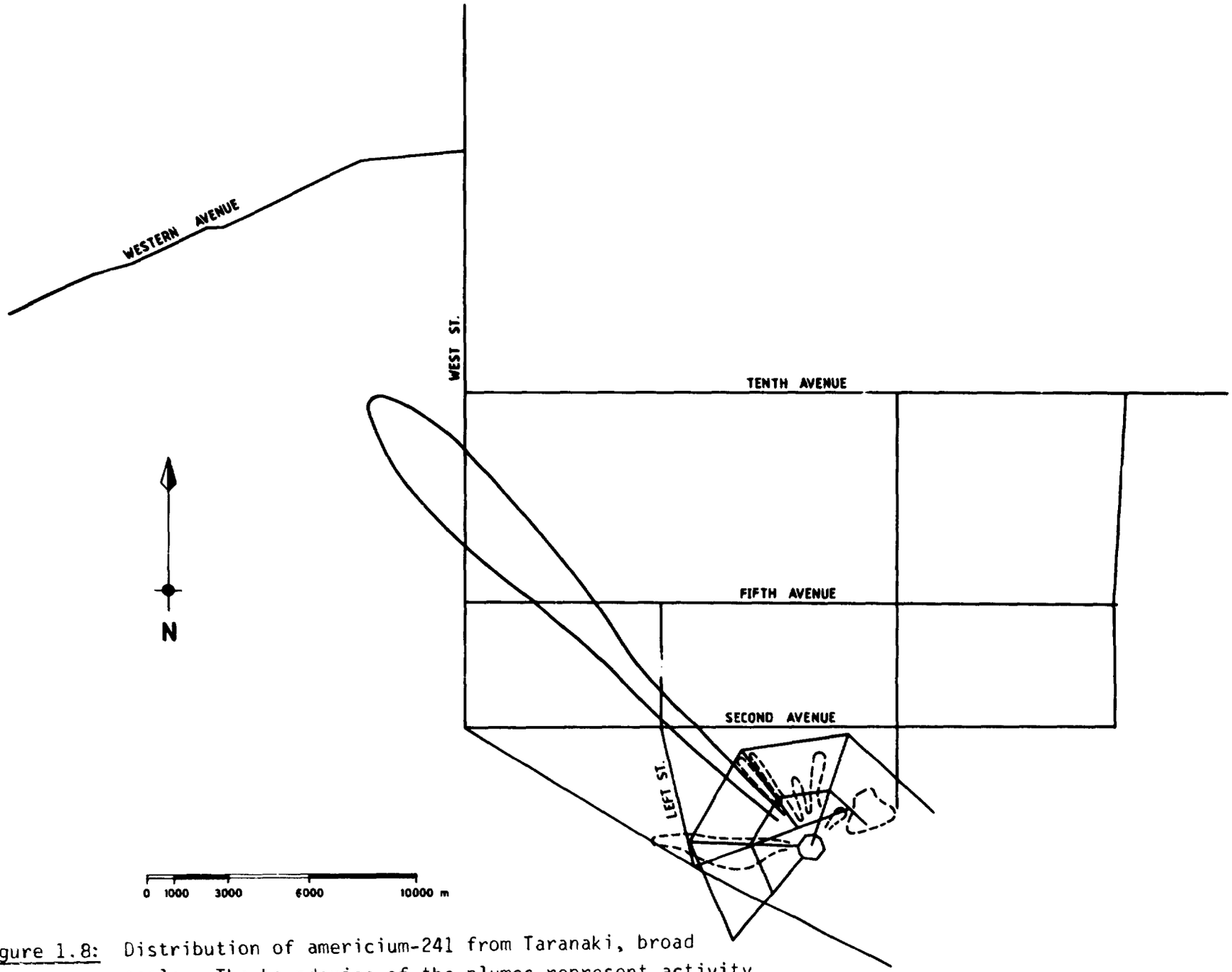


Figure 1.8: Distribution of americium-241 from Taranaki, broad scale. The boundaries of the plumes represent activity concentration of 30 Bq/kg, and correspond to a plutonium-239 concentration ~200 Bq/kg (0.02 μ Ci/kg).

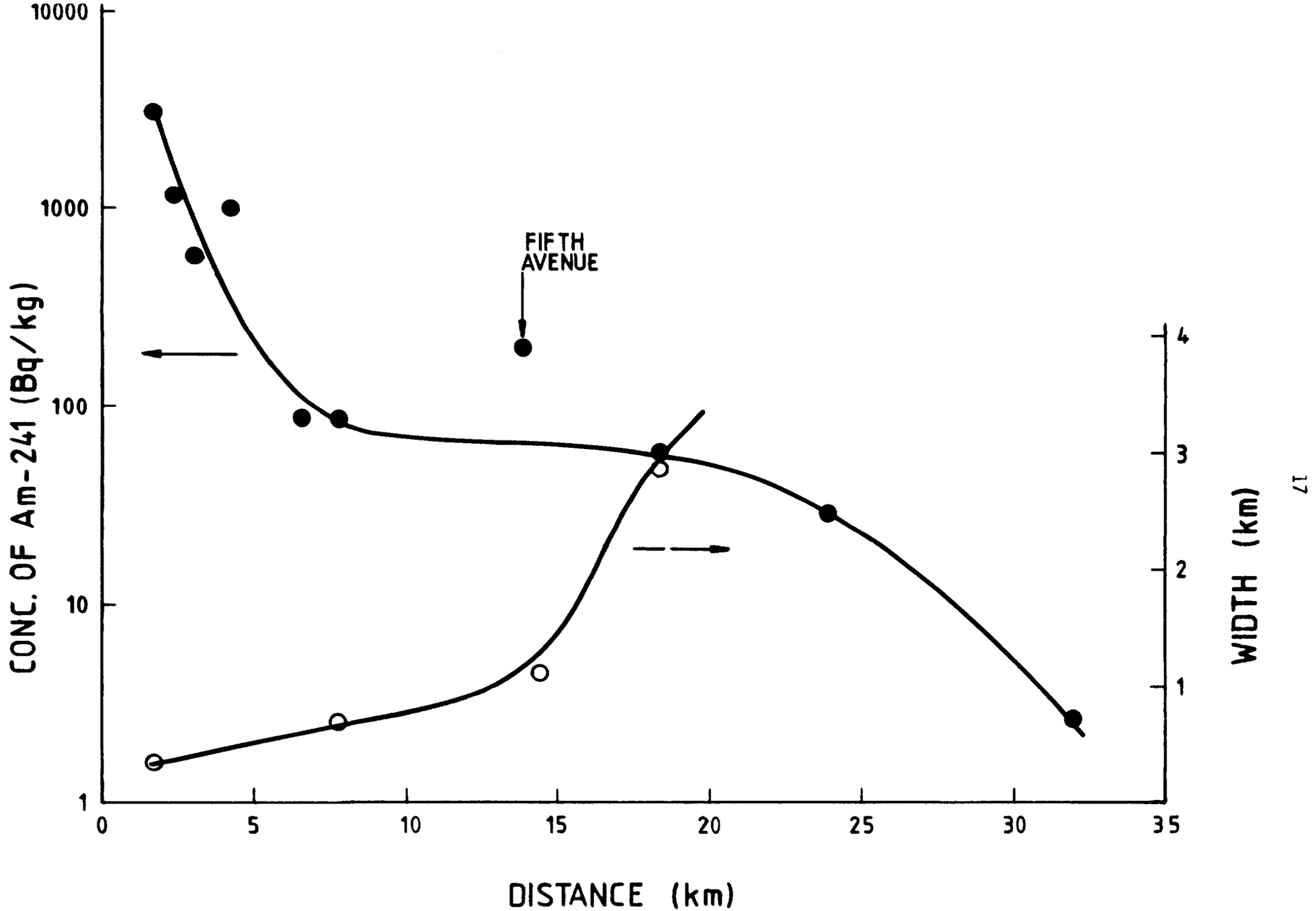


Figure 1.9: Variation in central axis activity concentration (Bq/kg) and width (km) of north west plume as a function of distance along plume.

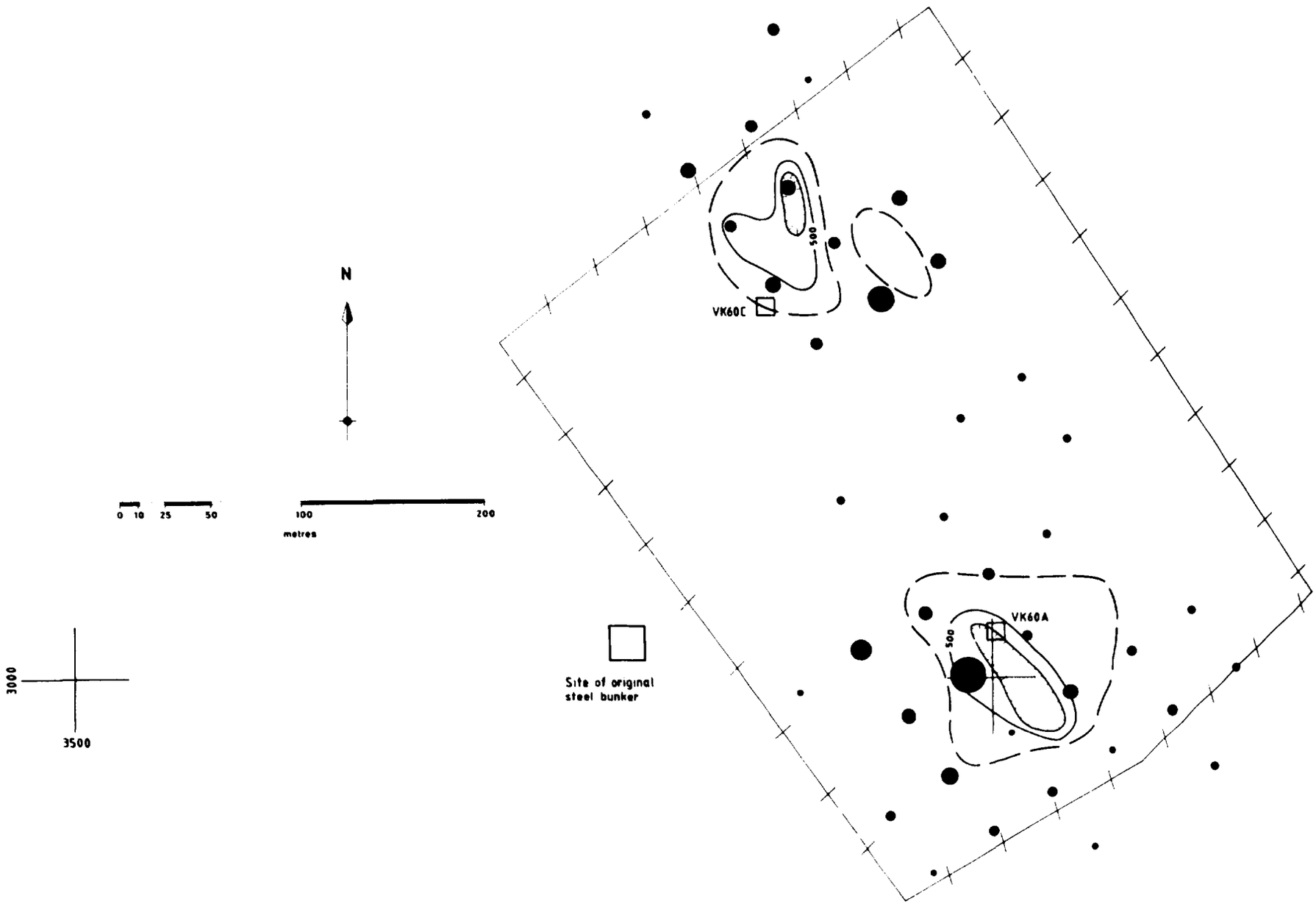
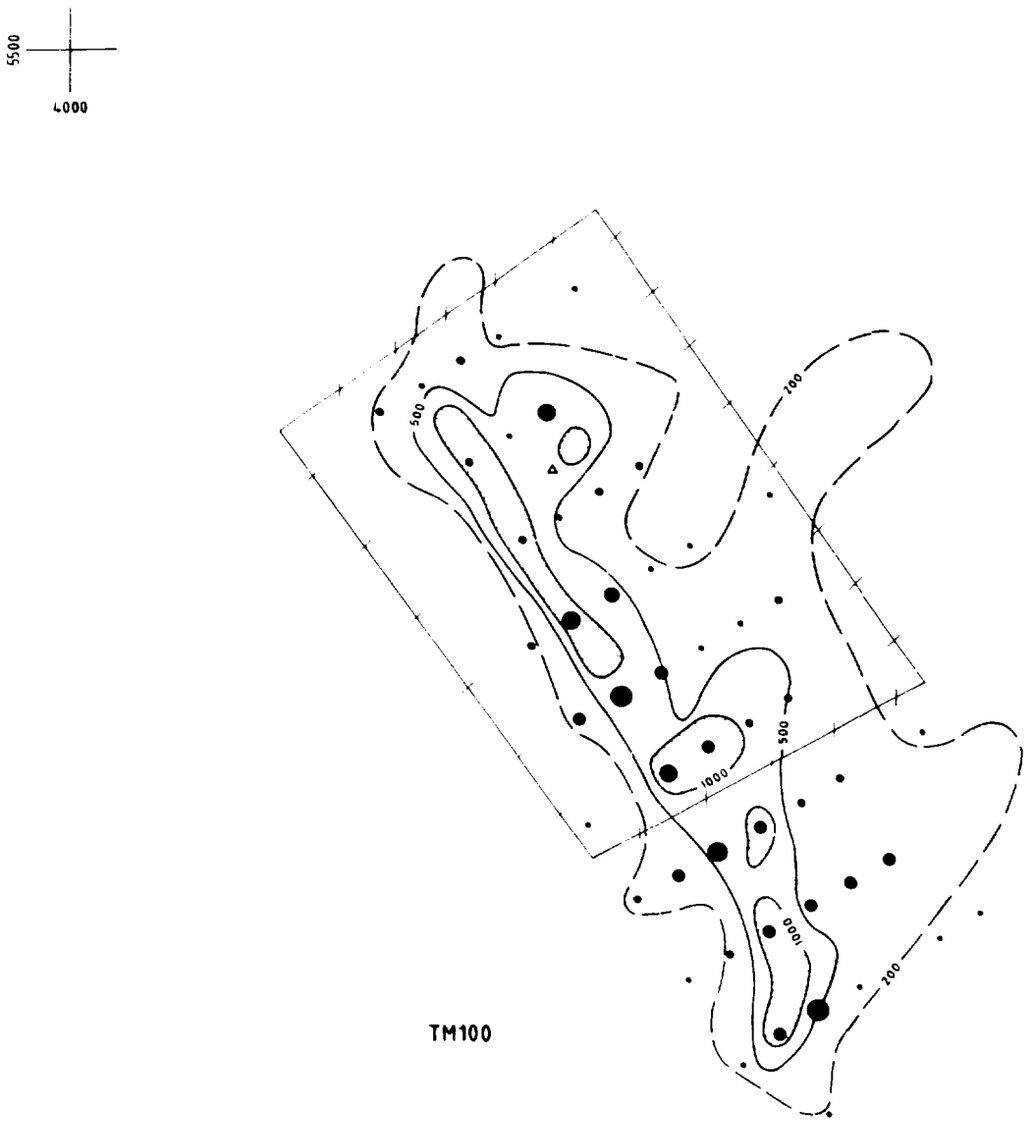
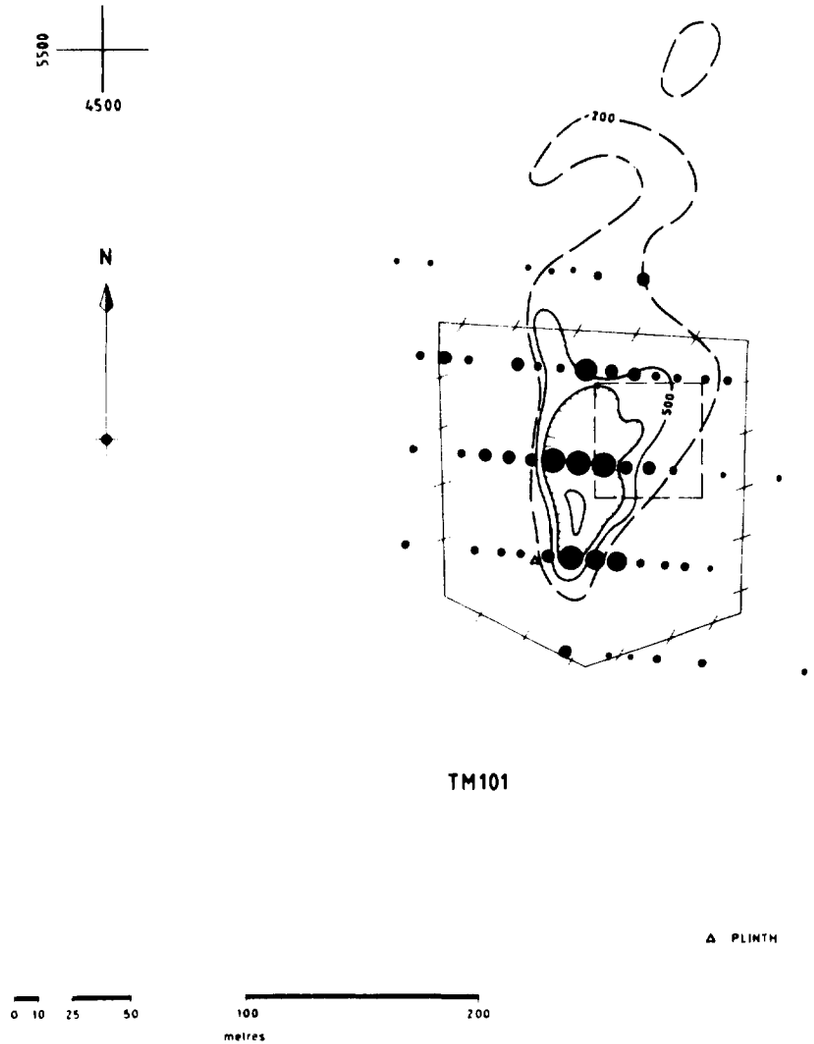


Figure 1.10: Distribution of americium-241 activity, and fragments at Wewak. The largest circle represents a surface density of fragments of 0.1/m².

Figure 1.11: Distribution of americium-241 activity and fragments at TM100 and TM101. The largest circle represents a surface density of fragments of 0.25/m^2. The ARL temporary fences are indicated by hatched lines.


5500
4000
500
700
1000
500
1000
700
5000
4000

TM100


5500
4500
N
700
500
△ PLINTH
0 10 25 50
100 200
metres
5000
4500

TM101

APPENDIX 1A

ESTIMATE OF PLUTONIUM AT TARANAKI

1. Inner Grid

The mean concentration of americium-241 from the soil analysis is throughout the inner grid at Taranaki (416 data points) is 1720 Bq/kg. The area of each surface soil sample, taken to a depth of 25 mm is .0055 m^2, with an average mass of 0.19 kg. Thus each square metre of surface to a depth of 25 mm contains 35 kg of soil and the mean activity per square metre is therefore 35 x 1720 = 6.0 x 10^4 Bq/m^2. However, most of this area was processed during Operation Brumby, and the soil depth in the tilled area is of the order of 150 mm. Soil profiles taken to a depth of 150 mm yield a ratio of 0.6 for the average concentration over the profile compared with the first 25 mm.

$$\text{Thus the total activity per } m^2 = 0.6 \times \frac{150}{25} \times 6.0 \times 10^4 = 2.2 \times 10^5 \text{ Bq/m}^2$$

The total area of the grid is 480 x 1200 = 0.58 x 10^6 m^2 and the corresponding total americium-241 activity is therefore 2.2 x 10^5 x 0.58 x 10^6 = 0.13 TBq (3.4 Ci).

For Taranaki, the mean ratio of plutonium-239 to americium-241 is 7.4 so that this figure corresponds to a total plutonium-239 content of 0.96 TBq (26 Ci).

2. Fragments

The total number of fragments, defined as localised americium-241 activity in excess of 0.1 MBq (2.7 μCi), was observed to lie between 25,000 and 50,000. The uncertainty in this number derives from the uncertainty associated with the areas where the fragment density was too high for them to be individually resolved.

It is likely that this number is under-estimated by at least a factor of 2 because of fragments which were missed and because more deeply buried fragments would have been detected with diminished efficiency. This suggests for an upper limit a total number of fragments of the order of 100,000. The mean value of the fragment activity is 1.6 MBq, yielding a total americium-241 activity of 0.16 TBq, corresponding to a plutonium-239 activity of 1.2 TBq (32 Ci).

3. The North West Plume

Figure 1.9 illustrates the concentration of americium-241 (Bq/kg) along the central axis of the plume and its full width at half maximum (km) as a function of distance from Taranaki.

Integrating numerically along this axis, and assuming a gaussian distribution with distance from the central axis, we obtain, using the factor 35 kg/m^2 to convert soil mass to area, a total quantity of americium-241 of 0.15 TBq (4.1 Ci). A soil sample taken from the main stem of the plume at a distance of 1.6 km from Taranaki gave a value of 6.9 for the plutonium-239/americium-241 ratio so that the estimated total plutonium-239 within the contour is 1.0 TBq (27 Ci).

Beyond this distance the plume was still detected at a much reduced level (2.7 Bq/kg) in a soil sample taken at a distance of 32 km. Assuming that the concentration falls linearly from 30 Bq/kg at 24 km and that the plume expands from a width of 3 km at 18 km to 5.3 km at 32 km we can estimate an additional contribution of 0.02 TBq (0.54 Ci) of americium-241, corresponding to 0.14 TBq (3.8 Ci) of plutonium-239.

CHAPTER TWO

Residual Radioactive Contamination of the Maralinga and Emu Major Trial Sites

J. Colin Duggleby, Malcolm B. Cooper and Philip A. Smith

The test site at Emu was used for two nuclear weapons trials in October 1953 and that at Maralinga for seven trials in September - October 1956 and September - October 1957. Details of the individual trials have been presented elsewhere (Symonds, 1985).

In 1977 and 1978 there were extensive surveys of the major trial sites at Maralinga and Emu (Cooper et al., 1978, Maclagan et al., 1979). As a result of these surveys it was concluded that in the regions near the ground zeros gamma radiation dose rates were in excess of the maximum recommended dose rate for continuous occupancy. Based on a knowledge of the radionuclide content of soil in the environs of the ground zero at each site predictions were made of the date by which the dose rate would have diminished to levels which would be acceptable for continuous exposure of members of the public. It was recognised in the 1977 survey that the presence of considerably higher levels of plutonium in the soil at the Tadje test site compared with the other major trial sites possibly presented an additional, long-term risk to continuous occupation of the area by members of the public. In 1979 concrete plinths were erected at each ground zero to mark its location and identify it permanently as the site of a nuclear explosion.

Due to the comprehensive nature of the 1977 survey of the major trial sites, only a limited number of measurements of radiation dose rates and concentrations of radionuclides in soil was made during the surveys performed in May 1984 and February 1985. However, a more detailed examination of the distribution of plutonium in the soil around the Tadje trial site was carried out.

THE PRESENT SURVEY

At each of the major test sites, external dose-rate measurements were made at a height of one metre above the ground using a 'Studsvik' Gammameter. At Totem 1, Totem 2, One Tree, Breakaway and Biak, dose-rates were measured at twenty metre intervals in two mutually perpendicular directions from each ground zero until the dose-rate dropped below 0.30 μSv/h (i.e. approximately half of the dose-rate for continuous occupation). At Tadje, measurements were taken at greater intervals from ground zero to 800 metres in the direction in which it was known that close-in fallout had been deposited. At Marcoo, dose-rates were recorded along a line extending from 100 metres south of ground zero to 500 metres north of it, being the approximate line of fallout from the explosion. A spot dose-rate measurement was made at Kite ground zero.

At Totem 1, Totem 2, One Tree, Breakaway and Biak, surface soil samples were taken at 60 and 120 metres from ground zero along the two directions in which dose-rate measurements were taken. At Tadje, soil samples were taken at 60, 100, 120 and 600 metres along the line of dose-rate measurements; at Marcoo, they were taken at 100 metres south and 500 metres north of ground zero; at Kite, a surface soil sample was taken at ground zero. All soil samples were prepared in the manner described in Chapter 1 and analysed by high-resolution gamma-ray spectrometry.

Results. The radionuclide concentrations in the soil samples collected at the trial sites are listed in Table 2.1. The 1977 and 1978 surveys showed that fission products are to be found mainly in the surface layer where the soil had remained undisturbed, and spread throughout the depth of ploughing where this had taken place. Activation products, on the other hand, extend to greater depths, especially near ground zeros.

The principal activation products are europium-152 and cobalt-60 derived from activation of natural europium and cobalt in the soil by thermal neutrons. The concentrations of the two stable nuclides varies from point to point in the soil and the degree of activation depends on the distance from ground zero. This is reflected in the data in Table 2.1, and it should be noted that, except for Tadje, the ratios of concentrations of europium-152 to cobalt-60 are reasonably consistent, lying within a factor of 2. The situation at Tadje is complicated by the known presence of cobalt-60 as a deposited fallout product.

Table 2.1: Radionuclide concentrations in soil collected at major sites

Site	Location	Dose rate	Activation products (bq/g)				Fission products	
		µSv/h	Am-241	Co-60	Ba-133	Eu-154	Eu-152	Eu-155	Cs-137
Kite	GZ	0.07	0.19	0.01			0.1	0.02	0.08
Marcoo	500m N	0.09	0.03					0.04	0.23
	100m S	0.11	0.04	0.01			0.1	0.02	0.09
Tadje	600m N	0.12	0.07					0.01	0.04
	120m N	0.26	1.83	0.15	0.01	0.04	0.4	0.12	0.65
	100m N	0.35	9.93	0.53		0.07	0.6	0.68	4.9
	60m N	0.40	0.66	0.12		0.06	0.6	0.04	0.15
Biak	120m E	0.60	0.39	0.21		0.11	1.6	0.16	0.81
	120m N	0.65	0.37	0.09		0.09	1.1	0.18	0.88
	60m E	2.0	0.34	0.40		0.23	3.1	0.16	0.61
	60m N	2.0	0.57	0.38		0.27	3.4	0.22	0.96
Totem 1	120m E	0.70	0.61	0.13	0.16	0.10	1.1	0.33	3.3
	120m N	0.45	0.14	0.09	0.03	0.05	1.1	0.08	1.0
	60m E	1.7	0.21	0.19	0.06	0.18	2.6	0.09	1.2
	60m N	1.4	0.22	0.22	0.08	0.20	3.0	0.11	1.5
Totem 2	120m E	0.55	0.93	0.10	0.12	0.06	0.9	0.25	3.3
	120m N	0.35	0.05	0.06	0.01		0.7		0.19
	60m E	1.2	2.27	0.25	0.32	0.17	2.5	0.61	6.7
	60m N	1.1	0.78	0.18	0.11	0.15	2.0	0.20	2.3
Breakaway	120m E	1.1		0.38		0.24	4.0		0.03
	120m N	0.9	0.02	0.19	0.02	0.11	2.1		0.13
	60m E	3.5	0.41	1.01		0.75	8.8	0.26	1.2
	60m N	3.5		1.31		0.64	9.8		0.09
One Tree	120m E	1.5	0.15	0.19		0.15	1.9	0.12	0.85
	120m N	1.2	0.22	0.22		0.17	2.0	0.20	1.5
	60m E	4.0	0.56	1.68		1.15	12.1	0.51	3.0
	60m N	3.5	0.09	0.62		0.48	5.5	0.06	0.58
Approximate minimum detectable limit			0.03	0.01	0.01-0.02	0.06	0.1	0.01	0.01

The dose-rates measured at each site, with the exception of Tadje, confirmed the steady decrease with distance from GZ noted in the 1977 and 1978 surveys. In Table 2.2, the approximate radius of the area within which the dose-rate was above 0.57 μSv/h is listed for each trial site in addition to the highest dose-rate recorded at each site. Because of work which had been carried out at the ground zeros in the past, including the construction of the concrete plinths, the point having the highest dose-rate was usually a few metres from ground zero. The activation products europium-152 and cobalt-60 are the major contributors to the gamma-ray dose-rates close to the ground zeros (Cooper et al., 1978). The average ratio of europium-152 to cobalt-60 in soil from each test-site was used to calculate the dose-rate contribution from each of the two nuclides and the earliest date at which the dose-rate would fall below 0.57 μSv/h (the dose-rate for continuous exposure for members of the public). The highest dose-rate and the date for continuous occupation of each site except Tadje based on data from the recent surveys is given in Table 2.2 and compares well with estimates made in 1977 and 1978 (Cooper et al., 1978, Maclagan et al., 1979).

Table 2.2: Dose-rates and date for continuous occupation at each site.

Site	Approx. radius of area above 0.57μSv/h (metre)	Highest dose-rate at site (μSv/h)	Date for continuous occupation	
			1977-8 survey	1984 survey
Kite	-	0.07	-	-
Marcoo	-	0.27	-	-
Tadje	Few metres (irregular)	0.70	1992	See text
Biak	150	4.0	2018	2015
Totem 1	130	5.5	2024	2022
Totem 2	90	3.8	2020	2015
Breakaway	170	8.0	2034	2028
One Tree	190	9.0	2035	2030

Radionuclide Contamination at Tadje. In February 1985 additional field measurements and soil sampling were performed at Tadje in order to assess in more detail the distribution of plutonium in the vicinity of ground zero and to the north. Field measurements were carried out with a thin sodium iodide detector described in Chapter 1 with a single channel analyzer adjusted to cover the range 40 to 80 keV. Although this setting was not specific for americium-241 due to interference from other radionuclides in the soil, a qualitative description of radioactive contamination at Tadje was obtained. The most significant regions of contamination lie in two small areas each of approximately 200 m x 100 m; one area immediately to the north of ground zero and the other a further 600 m north-east.

A total of 48 soil samples were taken over the same area. Samples were prepared as described in Chapter 1 and the fractions below 500 μm particle size were analysed by high-resolution gamma-ray spectrometry. The distribution of americium-241 activity in the soil is illustrated in Figure 2.1. The plutonium-239/americium-241 activity ratio for Tadje soil had been determined in the 1977 survey (Cooper et al., 1978) to be 55. The areas of highest americium levels therefore correspond to activity concentrations of plutonium-239 in excess of 25 kBq/kg.

Glazing. Following the six tower-mounted tests at Emu and Maralinga the immediate areas surrounding the ground-zeros were covered in glazing or fused sand. Incorporated in the glazing were trapped fission products which contributed significantly to the external gamma and beta dose rates (Pearce, 1968). The glazing was largely removed by scavenging or dispersed during treatment of the areas in Operation Brumby. However numerous pieces of glazing can still be located on the surface at several sites, namely Totem 1 at Emu and Biak, Breakaway and One-Tree at Maralinga.

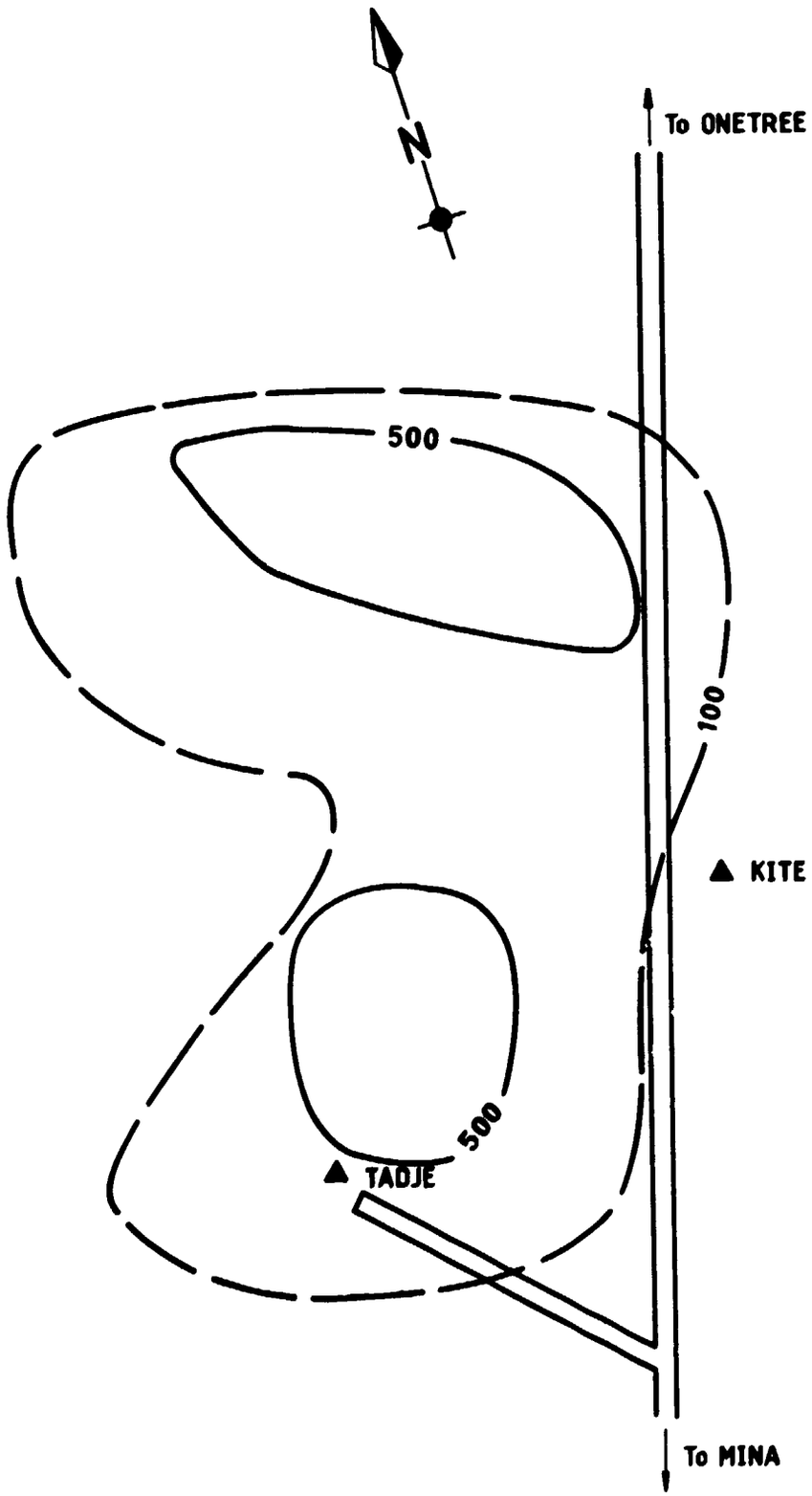
The glazing represents a potential souvenir easily removed by any visitor to the area. In order to assess the potential risk to someone removing this material, samples were gathered from each site mentioned above and analyzed by high-resolution gamma-spectrometry. The results are presented in Table 2.3 for the major gamma-emmitting radionuclides. Both activation products and fission products were detected in the glazing from each site in addition to americium-241. The presence of the latter radionuclide indicates that plutonium is also incorporated in the glazing. An additional major radioactive component of the glazing is strontium-90 which is not detected by

gamma-ray spectrometry. Based on the results of the 1977 survey (Cooper et al., 1978) it is anticipated that the level of strontium-90 is likely to be similiar to that of cesium-137. With the exception of Totem 1, where the radionuclide concentrations are rather higher, a typical piece (approximately 100 gram) of glazing is likely therefore to contain of the order of 4 kbq (0.1 μCi) of fission and activation products and based on the plutonium-239/americium-241 ratio for Tadje (Cooper et al., 1978) as much as 40 kBq (approximately 1 μCi) of plutonium.

Table 2.3: Radionuclide Concentrations in glazing collected at major trials sites

Site	Radionuclide Concentrations (bq/g)				
	^{60}Co	^{137}Cs	^{152}Eu	^{155}Eu	^{241}Am
Biak	0.62	17.3	3.1	5.3	15.3
Breakaway	0.4	16.3	2.0	2.9	4.1
One-Tree	0.76	23.9	3.9	6.9	6.8
Totem I	1.64	216	2.4	17.4	42.6

Figure 2.1: Distribution of americium-241 activity (Bq/kg) in the vicinity of Tadje ground zero.


N
To ONETREE
500
100
KITE
500
TADJE
To MINA

CHAPTER THREE

Residual Radioactive Contamination at Other Minor Trial Sites

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Apart from those 'minor-trial' sites at Maralinga where plutonium is known to have been used, there are many other sites where trials occurred and where radioactive materials of both short and long half-lives were used (Symonds, 1985). The main such trials are Rats trials performed at Naya1 and Dobo, Kittens trials performed at Naya2, and TIMS or TM trials performed mainly at the Kuli and TM50 sites.

As well as these sites, several other areas were used for 'minor trials' of various types. Whilst the execution of the present survey proceeded without reference to previous surveys, information about the existence and whereabouts of such areas was gleaned from official documents and maps held by A.R.L., particularly from maps showing areas of residual contamination at various times on the range.

With the exception of plutonium, the only radioactive materials believed to have been used at Maralinga of sufficient half-lives to be still detectable are the isotopes of uranium, uranium-238 (half-life 4.5×10^9 y) and uranium-235 (half-life 7.0×10^8 y), and possibly thorium-228 (half-life 1.91 y). Official U.K. records (Pilgrim, 1959; 1960; 1962) indicate that at Rats trials, where short-lived gamma-ray sources were employed, radionuclides

which may have been used are natural uranium, thorium-228, lead-212 and scandium-46. At Kittens trials, beryllium, uranium and short-lived alpha-particle sources including polonium-210 were used, and at TIMS trials large quantities of natural uranium and beryllium were used.

During surveys at Maralinga in May, November and December 1984 and February 1985, virtually every road and track on the range was traversed a number of times and any unusual features were investigated. Although there were, obviously, large areas of the Maralinga Range which were not examined, no area of radioactive contamination was found whose position was not defined somewhere in an official document or map.

Measurements of radioactivity levels in the field were made by use of the same hand-held 50 mm diameter thin-crystal (2 mm) NaI(Tl) probes and scalar-ratemeters described in Chapter 1, but with the 'window' set to monitor all energies of gamma-radiation above 40 keV. As well, in many areas a field-portable thin-crystal NaI spectrometer was used to record the gamma-ray spectrum and identify immediately any radionuclides present.

Surface soil samples were obtained by use of a template of 84 mm diameter and 25 mm depth. In general, a number (usually three) of samples was collected from over a small area at the site being sampled. These were combined and the composite sample was sieved (1 mm mesh) to remove larger stones before being sealed in a standard geometry (of ca. 60 g mass) and analysed by high-resolution gamma-ray spectrometry. The estimated uncertainties in quoted activities, given in parentheses, refer to the least significant figure. These were determined from counting statistics only, and are expressed as estimated standard deviations.

For most soil samples of relatively low specific activity, peaks from thorium-234 of energies 63.3 and 92.6 keV were used to determine uranium-238 activities and peaks from uranium-235 of energies 143.8 and 185.7 keV were used to determine uranium-235 activities. However, self-absorption in the sample matrix affects the peak-heights of all these peaks to some extent, and in particular those at lower energies are attenuated more than those at higher energies. This effect is probably not very significant in most of the soil samples for which results are presented below, and most uranium-235/uranium-238 activity ratios are acceptably close, within experimental errors, to the 4.6% value for natural uranium. For certain

samples such as solid pieces of uranium, the attenuation of these peaks by self-absorption within the sample can be very significant and it is difficult in such cases to use the uranium-235/uranium-238 activity ratio to distinguish between, for example, natural and depleted uranium.

NATURAL BACKGROUND LEVELS OF RADIOACTIVITY

All soil contains low levels of natural radioactivity largely due to the presence of trace amounts of uranium. To determine the background level of activity due to naturally-occurring uranium in soil from the Maralinga and Emu areas, three surface soil samples were collected from sites far removed from any trial sites. At Maralinga, soil samples were obtained from 2 km south of Roadside and from the Tietkins Well area. Activities of uranium-238 in these soil samples were 0.016(1) and 0.012(1) Bq/g respectively. At Emu, a soil sample collected from close to Emu Claypan had an activity of uranium-238 of 0.020(1) Bq/g.

RATS LANES AT NAYAI

The area around the six experimental lanes of Rats firing sites and three long lanes of sandbagged instrument bunkers at Nayal, shown in Figure 3.1, was inspected and extensively monitored for residual radioactivity in November 1984 and February 1985. In addition, the nearby Scandium site (Figure 3.2) was identified and monitored.

Visual inspection revealed that the area had been cleared of all large debris including the firing plates. Only small pieces of rusty metal, sections of wire cables and small electrical components remain, and none of these are radioactive. Several firing sites were identified (Figure 3.1) but, in the main, exact locations of firings have been obliterated. One small piece of uranium metal was identified close to a firing site (at sampling site 16, Figure 3.1), together with a small area of soil nearby which was contaminated with crumbly yellow uranium fragments. A wooden box near to several firing sites, filled with earth, was found to contain low levels of radioactivity due to the presence of natural uranium. The only other contaminated debris found in the Rats area was a piece of thick rusty steel, ca. 150 mm in length, which was highly contaminated with plutonium having a plutonium-239 activity of 46 MBq. It was assumed that this piece of metal, which was ca. 12 m from sampling site 13 (Figure 3.1), had originated from the nearby TM100 site. Upon removal for further analysis, the ground beneath the metal was also quite highly contaminated with plutonium, probably due to weathering (rusting) of the fragment.

In all, 18 surface soil samples were collected from the area, at the sites indicated in Figure 3.1, and these were analysed by high-resolution gamma-ray spectrometry in the laboratory. Results are given in Table 3.1. Whereas activities due to natural uranium are all low, the largest being 0.064(8) Bq/g, significant plutonium contamination is present in many of the soil samples. By use of the plutonium-239/americium-241 ratio value of 15.5 calculated for the TM100 area (Chapter 1), the observed range of americium-241 activities indicates a range of plutonium-239 activities in the Rats area of effectively zero to 24.2 Bq/g. As with the plutonium-contaminated metal fragment discussed above, it is assumed that this plutonium contamination of the area originated from the adjacent TM100 site.

Table 3.1. Activities (Bq/g) in surface soil samples from the Rats area at Nayal[a,b]

Site	^{238}U	^{235}U	^{241}Am
Rat-1	0.027(6)	0.001(1)	0.053(2)
Rat-2	0.035(6)	0.003(3)	0.107(2)
Rat-3	0.064(8)	0.003(3)	1.560(8)
Rat-4	0.013(4)	0.001(1)	0.024(1)
Rat-5	0.007(4)	0.001(1)	0.038(1)
Rat-6	0.047(5)	0.003(1)	0.403(3)
Rat-7	0.019(7)	0.001(1)	0.009(2)
Rat-8	0.020(7)	0.001(1)	0.132(3)
Rat-9	0.028(3)	0.001(4)	0.021(1)
Rat-10	0.018(5)	ND[c]	0.022(1)
Rat-11	0.024(12)	0.002(1)	0.001(1)
Rat-12	0.038(7)	0.001(1)	0.234(3)
Rat-13	0.019(4)	0.002(1)	0.009(1)
Rat-14	0.026(5)	0.006(6)	0.022(1)
Rat-15	0.029(5)	0.001(1)	ND
Rat-16	0.031(5)	0.002(1)	ND
Rat-17	0.028(5)	0.002(2)	0.005(1)
Rat-18	0.016(5)	0.003(5)	0.050(2)

a) Sampling sites are as marked on Figure 3.1.

b) Estimated standard deviations are given in parentheses.

c) ND indicates that the activity was below the level of detection.

KITTENS LANES AT NAYA2

The five Kittens lanes at Maralinga, shown in Figure 3.2, were inspected and extensively monitored in November 1984 and February 1985. Throughout the area, there is a light distribution of metal pieces, largely steel, which have been overlooked in earlier cleanup operations. Some of these metal pieces, in particular steel tubing and solid base supports of tripod-like supporting structures, are lightly contaminated on the surface by natural uranium. There is also a smattering of other debris including old cables and phosphor-bronze or brass canisters, none of which is radioactive. Two small pieces (of masses 17.3 and 51.3 g) of a metal of low density which were lightly contaminated with natural uranium (each with uranium-238 and uranium-235 activities of 23(2) and 0.97(1) Bq/g respectively), were found at the eastern end of lane 4.

A total of 15 surface soil samples was collected throughout the Kittens area, at the sites shown in Figure 3.2. All show low levels of natural uranium (0.010(4) to 0.036(5) Bq/g of uranium-238) close to background values.

TRIALS AT NAYA3

Three distinct areas were identified where evidence remained of tests having been performed at Naya3. These sites are shown in Figure 3.3, two of which were identified from maps as the TM2 (1955) and Rodent sites. The third area, which we will call the 'Special' Kittens site, is identified as the site of 'about 20 Kittens firings ... at a site in the Naya area near the old Tim site' (UKAWRE, 1959). At the 'Special' Kittens area, a large quantity of electrical components and other debris litters the site. A low mound of soil beside the roadway was found to be lightly contaminated with natural uranium (Table 3.2), and a piece of rusty steel from this mound was contaminated likewise.

The TM2 (1955) site consists of two large craters, each some eight metres in diameter, and a large mound of earth close to the roadway. Soil within each crater is active due to the presence of natural uranium (Table 3.2), and there were several pieces of thick twisted rusty steel plate close to the craters which were lightly contaminated on the surface with uranium. In the westernmost crater, which was the more active of the two, the activity levels were variable with localised areas of raised activities. A small piece of uranium metal was found on the surface at the bottom of this crater.

Several hundred metres west of the two active craters just described is the Rodent site, consisting of three smaller craters each ca. five metres in

diameter. No radioactivity was detected in these craters, on debris scattered around them, nor on soil samples from the vicinity (Table 3.2). A large amount of twisted sheet aluminium was present in the area, as well as many large pieces of magnesium alloy. A number of these pieces of alloy were found at distances up to 700 metres from the site of the craters in both north and south directions.

Table 3.2. Activities (Bq/g) in surface soil samples from the Naya3 area[a,b]

Site	^{238}U	^{235}U
SKIT-1	9.49(5)	0.41(1)
SKIT-2	0.068(5)	0.002(1)
SKIT-3	0.022(5)	0.002(1)
TM2-4	9.65(4)	0.45(2)
TM2-5	0.60(1)	0.027(4)
TM2-6	17.17(3)	0.82(3)
TM2-7	0.153(6)	0.005(2)
TM2-8	0.060(8)	0.002(1)
TM2-9	0.012(6)	0.001(1)
ROD-10	0.034(5)	0.002(1)
ROD-11	0.021(5)	0.001(1)
ROD-12	0.021(5)	0.001(1)

a) Sampling sites SKIT-1, 2 and 3 were at the low mound of earth at the 'Special' Kittens site, 20 m N and 50 m S of the mound respectively. At the TM2 site, samples TM2-4 and TM2-6 were within the east and west craters respectively, TM2-5 and TM2-7 were composite samples from various points 15 m from the centres of the east and west craters respectively, and TM2-8 and 9 were from areas 450 m and 700 m respectively NE of the mound of earth indicated in Figure 3.3. Samples ROD-10, 11 and 12 were composite samples from various points 5 m from the centres of the southern, central and northern craters respectively at the Rodent site.

b) Estimated standard deviations are given in parentheses.

TRIALS AT WEWAK

In this section, results of investigations at Wewak sites VK26 to VK31 are presented (Figure 3.4). Sites VK23 to VK31 were used variously for trials involving beryllium and natural uranium (AHPR), and it is our understanding that sites VK21, VK22, VK34, VK35 and VK60B were unused. To our knowledge, VK32 does not exist and, as discussed in Chapter 1, plutonium was used at sites VK33, VK60A and VK60C.

Investigation of sites VK26 to VK31 revealed the usual debris including the ubiquitous electrical cable and connectors. Radioactivity was not detected on the ground or on any pieces of debris. It was not possible to pinpoint the exact location of any of the trials, so surface soil samples were collected at each site from over a fairly wide representative area and bulked before analysis. Gamma-ray spectrometry measurements on these soil samples showed no significant levels of radioactivity due to uranium or any other gamma-ray emitting radionuclides.

Three craters to the north-east of the main Wewak site were also investigated and soil samples were taken from each. Two adjacent craters were at the site 'A' area (Figure 3.4), and the other was about 1 km north-east of the main Wewak site. No significant radioactivity levels were detected at site 'A' or at any of the craters or in the soil samples from them.

RESUSPENSION AREAS

Three small areas, shown in Figure 3.4, are known to have been used for 'resuspension trials' (Carter, 1960). At site 1, areas of 1 m^2 (site 1B) and 10 m^2 (site 1C) were contaminated with 87 g and 570 g respectively of natural uranium (as U_3O_8). Sites 1 (10 m^2), 1A (1 m^2) and 1B were also contaminated with short-lived yttrium-91. No elevated levels of radioactivity were found, possibly because of the difficulty of finding such a small area of contamination in a relatively featureless environment. A large amount of debris littered the area.

Site 2, at which 10 m^2 was contaminated with 600 g natural uranium, and site 3 at which 10 m^2 was contaminated with 560 g natural uranium, were not identified. Resuspension sites 4-6 inclusive were not used and therefore clean.

RATS TRIALS AT DOBO

Features now evident at the Dobo site are the firing pad, largely covered with earth but with bituminous material exposed in parts, the railway track leading to the firing pad, again largely covered with earth, and a mound of earth to the east of the pad covering the burial pits (Figure 3.5). A large part of the area surrounding the firing pad has been treated with fresh earth and extensively worked.

The site was monitored with hand-held probes and the field-portable thin-crystal NaI spectrometer. Levels of radioactivity above normal background were not observed in the area or on fragments. Surface soil samples were collected from on top of the burial pits, from on top of the firing pad, and from the depressed area between the pad and burial pits. As well, a composite surface soil sample was obtained from an area 46 metres south of the firing pad, beyond the access road, in untreated soil littered with debris. Analysis of these four soil samples by gamma-ray spectrometry showed no significant levels of radioactivity above background.

TM50 AREA

The TM50 site consists now of a soil-covered mound under which is the concrete base of what was a large blockhouse (Cook, 1967) immediately adjacent to the firing site, a treated area of soil covering the firing site and the burial pit, and some mounds of soil to the north and east of the treated area (Figure 3.6). To the west of the blockhouse base, on the opposite side of the access track, is a large partly-buried cubic concrete shelter.

The area was thoroughly monitored with hand-held probes, and apart from one small area of contamination due to natural uranium in the firing area (ca. 10 metres north of the blockhouse base), and two tiny fragments of natural uranium of masses 1.39 and 1.94 g, no other levels of radioactivity above background values were observed. The two fragments were found on the mounds of soil at the extremities of the treated area, one to the north and the other to the east of the firing site.

Surface soil samples were collected from four different areas, shown in Figure 3.6. The active area ca. 10 metres north of the blockhouse base was extensively sampled, and five different samples from this small area were analysed individually. Results of gamma-ray spectrometry on the samples are presented in Table 3.3. The five samples from the active area all show enhanced levels of activity due to natural uranium, whereas samples from the other three sites show no contamination.

Table 3.3. Activities (Bq/g) in surface soil samples from the TM50 area[a,b]

Site	^{238}U	^{235}U
TM50-1	0.071(5)	0.003(2)
TM50-2	2.09(1)	0.103(3)
TM50-2a	1.28(1)	0.057(3)
TM50-2b	0.147(6)	0.012(4)
TM50-2c	0.218(7)	0.007(2)
TM50-2d	7.18(3)	0.346(5)
TM50-3	0.022(4)	0.001(1)
TM50-4	0.036(5)	0.002(1)

a) Sampling sites are as marked on Figure 3.6. Samples TM50-1 and TM50-4 are each composites of three samples from the sites shown; sample TM50-2a was from alongside TM50-2, and samples TM50-2b, 2c and 2d were from 1 m NE, 1 m S and 0.8 m NW of TM50-2 respectively.

b) Estimated standard deviations are given in parentheses.

KULI

The Kuli site consists now of a series of mounds of soil covering the two firing pads TM11 and TM16 (Pilgrim, 1962), the two debris pits, and the shelter TM12. The site is shown in Figure 3.7, together with a 150 x 320 metre grid layout which was set up to identity sampling sites. The whole of the area covered by the grid is littered by small fragments of light metal, mainly magnesium or aluminium, and by fragments of natural uranium. Two main types of uranium fragments were identified; yellow crumbly material and pieces of dense uranium metal. The latter were a brown colour with tinges of yellow on the surfaces. The largest piece of uranium metal discovered on the surface was of mass 353 g.

A survey covering 8°/. of the grid area, using hand-held probes as in the surveys of plutonium fragments described in Chapter 1, revealed very few (115) fragments of uranium except in one area within the TM16 soak where a continuum of uranium activity was encountered. However, the grid area did not contain all the observed uranium. For example, fragments were observed outside of the grid and at one spot on a perimeter track (Figure 3.8), ca. 750 m north-east from the firing sites, a cluster of about a hundred small crumbling yellow fragments of uranium were encountered. The full extent of dispersed uranium was not determined.

Eighteen surface soil samples were collected from the Kuli area at the sites indicated in Figure 3.7 and the results of gamma-ray spectrometry on these are given in Table 3.4. Almost all show enhanced levels of natural uranium, with the largest levels of activity (1.30(1) to 31.24(5) Bq/g for uranium-238) being in samples from the TM16 soak area (sample KULI-10 was from the centre of the soak, and the radius of the soak is ca. 10-15 metres).

SMALL FIRING SITES

The area of the above name is shown on one map as a site on the road to Kuli, ca. 1.3 km west of the Kuli site on the north side of that road (Figure 3.8). A likely reference to the trials performed at this site is found in UKAWRE (1958) where mention is made of '72 small scale firings (S.W.A. Firings) in the Tim area at Kuli'. An investigation in this general area revealed a large horseshoe-shaped mound of sand, enclosing a similar-shaped valley with another mound of sand in the middle (Figure 3.9). In one area of the valley, there is a large amount of twisted metal and in a number of areas hundreds of small yellow fragments of uranium litter the surface of the sand. As at Kuli, there are both crumbly yellow fragments and pieces of uranium metal.

Fragments of uranium were concentrated on the surface at the northern (top) end of the horseshoe-shaped site, both in the valley and on the mounded sides as shown in Figure 3.9. Almost all the uranium was contained within an area of 60 x 50 metres which was surveyed in detail. The total amount of uranium on the surface was estimated to be about 1.5 kg (ca. 19 MBq of uranium-238).

Table 3.4. Activities (Bq/g) in surface soil samples from the Kuli area[a,b]

Site	^{238}U	^{235}U
KULI-1	0.71(1)	0.032(2)
KULI-2	0.407(8)	0.013(2)
KULI-3	0.376(5)	0.020(2)
KULI-4	0.430(7)	0.019(2)
KULI-5	0.038(5)	0.001(1)
KULI-6	0.008(4)	ND[c]
KULI-7	0.196(6)	0.007(2)
KULI-8	1.32(1)	0.068(4)
KULI-9	0.050(5)	0.002(1)
KULI-10	31.24(5)	1.40(2)
KULI-11	4.10(2)	0.181(7)
KULI-12	1.71(2)	0.079(4)
KULI-13	1.30(1)	0.058(3)
KULI-14	0.037(5)	0.001(1)
KULI-15	0.761(9)	0.036(4)
KULI-16	0.581(9)	0.026(3)
KULI-17	0.343(6)	0.016(2)
KULI-18	0.078(5)	0.005(2)

a) Sampling sites are as identified in Figure 3.7. Samples KULI-6 and 14 were from mounded fresh soil on top of the TM11 and TM16 firing pads respectively. Samples KULI-8, 10, 11 and 13 were from the TM16 soakaway, with KULI-10 from close to the centre of this area. Sample KULI-18 was collected in very sandy soil at the top of a sandhill, beside the trig. point 'TANYA'.

b) Estimated standard deviations are given in parentheses.

c) ND indicates that the activity was below the level of detection.

Surface soil samples were collected from three places within the site (Figure 3.9), in areas where uranium fragments were not evident on the surface. Analysis of these samples showed no levels of radioactivity above normal background values, indicating that uranium was dispersed around the site as fragments and not in finely divided form.

OTHER MISCELLANEOUS AREAS

Other areas at Maralinga where radioactive materials are known to have been handled are the remains (concrete base) of the radiochemical laboratory (building BL/4) in the Maralinga Village, the DC/RB (decontamination and radiobiological) area, the XA (weapons assembly) area and the airport washdown site. Each of these areas was monitored by use of hand-held probes, and several spectra were obtained by use of the field-portable thin-crystal spectrometer at the site of the radiochemical laboratory. Only background levels of radioactivity were observed. Surface soil samples were obtained from the soaks at the DC/RB and airport washdown sites, and again only background levels of radioactivity were observed.

EMU

Surface soil samples were obtained from the four Kittens test sites K1 (northernmost), K2, K3 and K4 (southernmost), from close to the metal firing plates. Analysis of these samples by gamma-ray spectrometry showed no levels of radioactivity above normal background values.

A composite surface soil sample from several areas at the old Emu Village site was analysed by gamma-ray spectrometry, and yielded activities of 0.028(8) and 0.006(1) Bq/g for uranium-238 and caesium-137 respectively. These are normal background values.

ACKNOWLEDGEMENTS

We are grateful to Mr. John Moroney for helping us to find our way around much of the official documentation concerning the 'minor trials'. Our thanks are also extended to Mr. Robin Statham for help with sample preparation and to members of the South Australian Health Commission, in particular Dr. Alvin P. Summerton, Mr. Andrew Johnston and Mr. Walter Spehr, for their help with the field work at Maralinga.

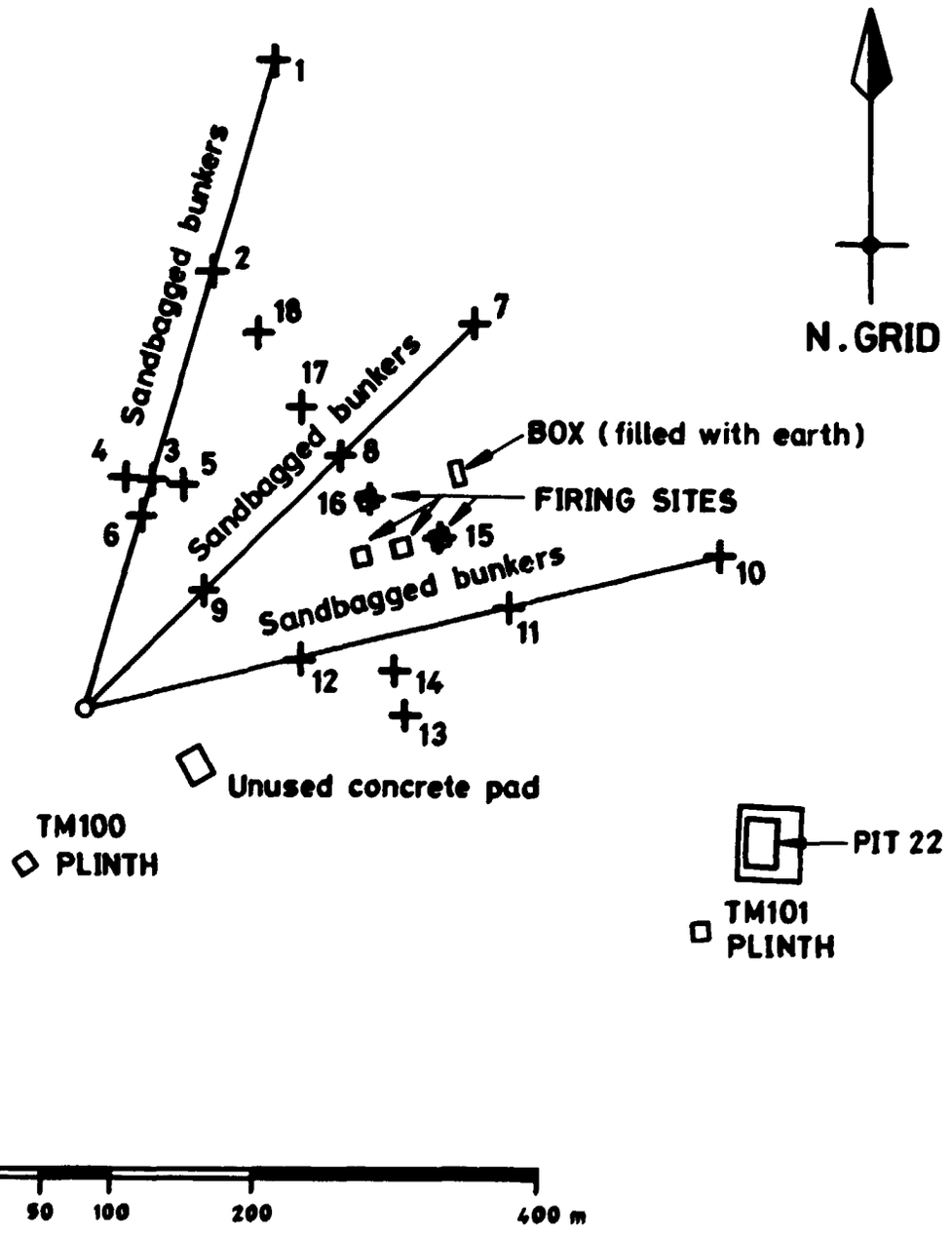

Figure 3.1: Rats site at Nayal showing the positions (+) of the 18 soil sampling sites.

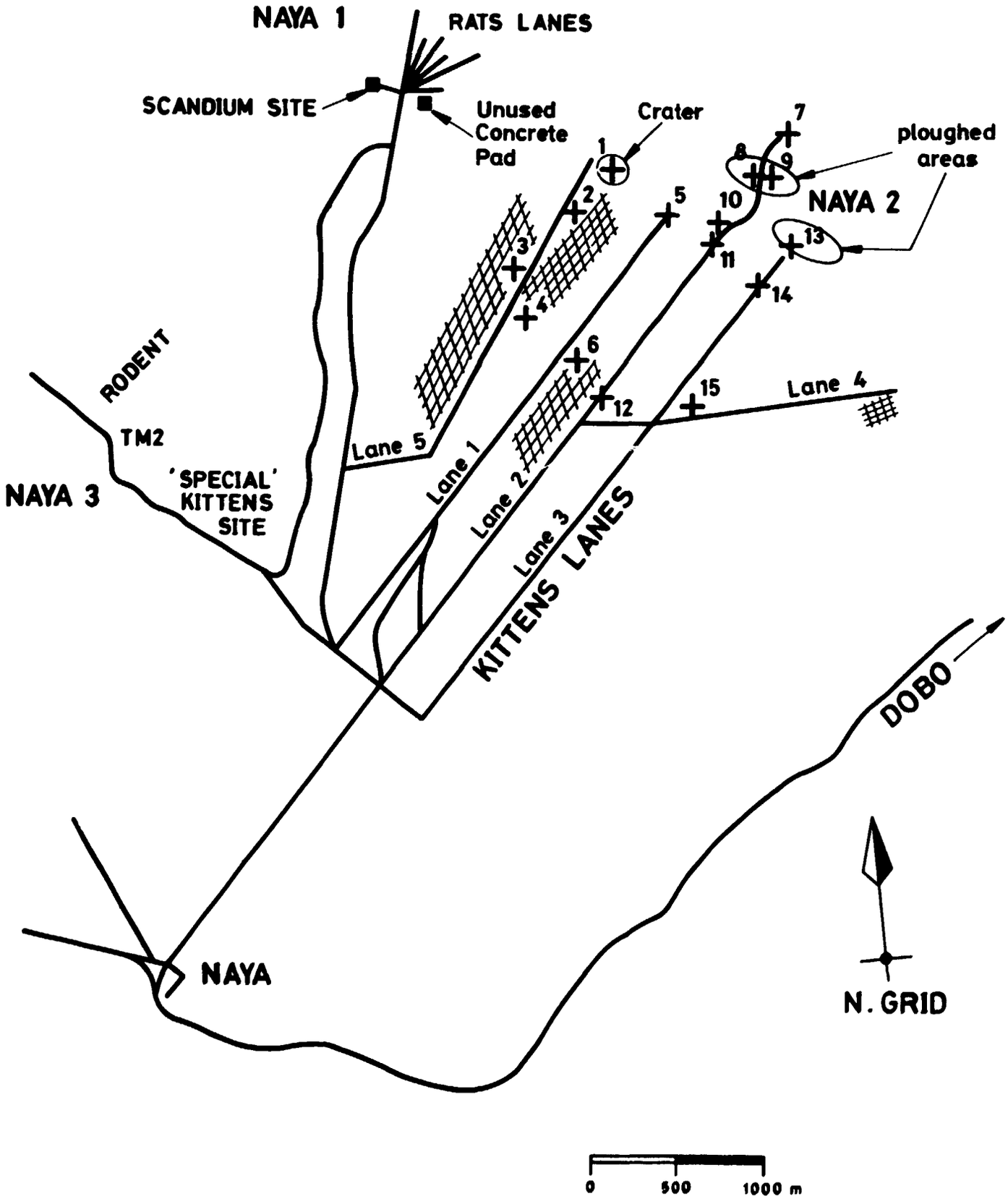

Figure 3.2: Naya area of the Maralinga Range, showing the positions of Rats and Kittens lanes and of the Scandium, Rodent, TM2 (1955) and 'Special' Kittens sites. The positions of the 15 soil sampling sites on the Kittens lanes are shown (+), and areas on the lanes where uranium-contaminated steel was found are indicated by cross-hatching.

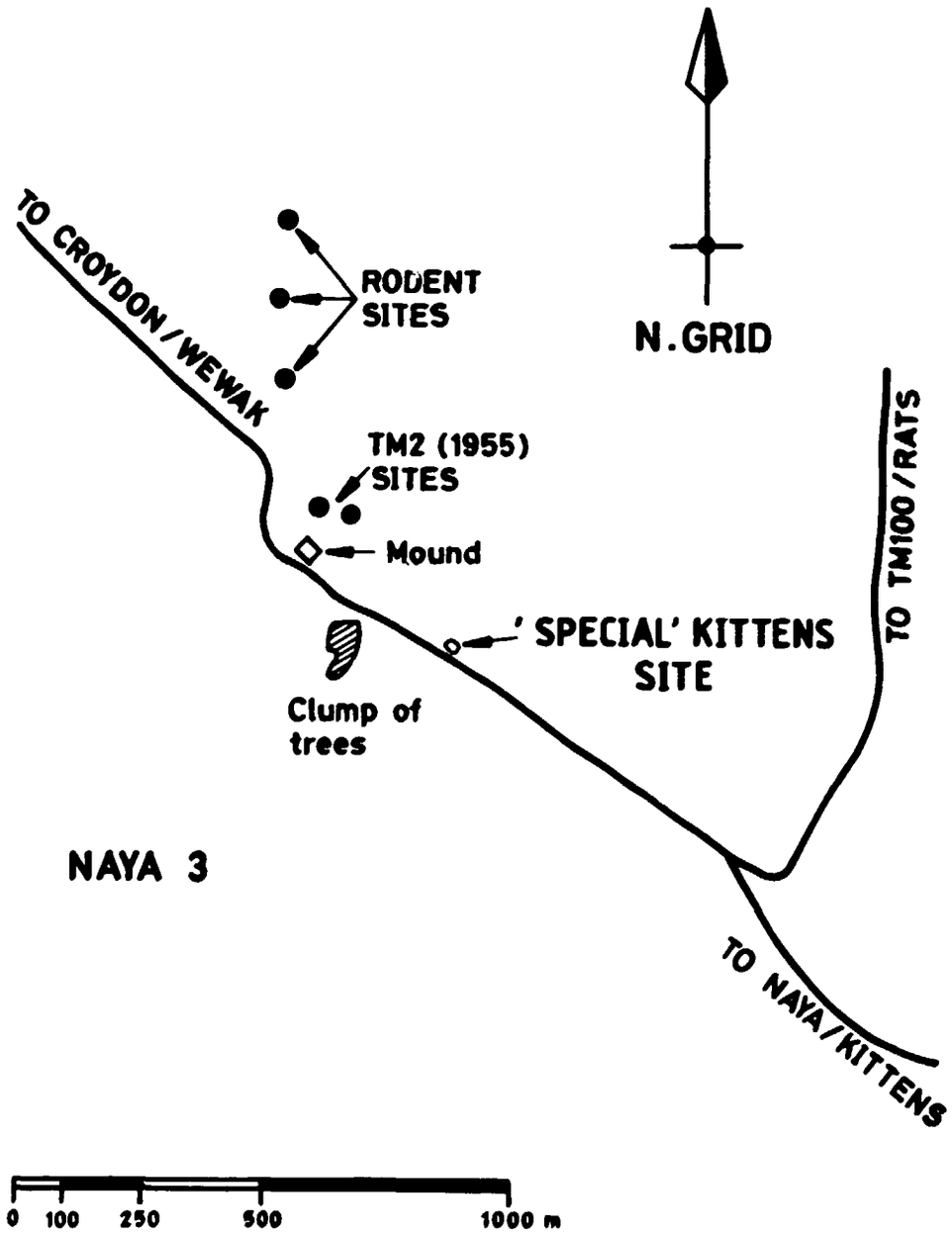

Figure 3.3: Naya3 area showing the positions of the low mound at the 'Special' Kittens site, the two craters and large mound of earth at the TM2 (1955) site, and the three craters at the Rodent site.

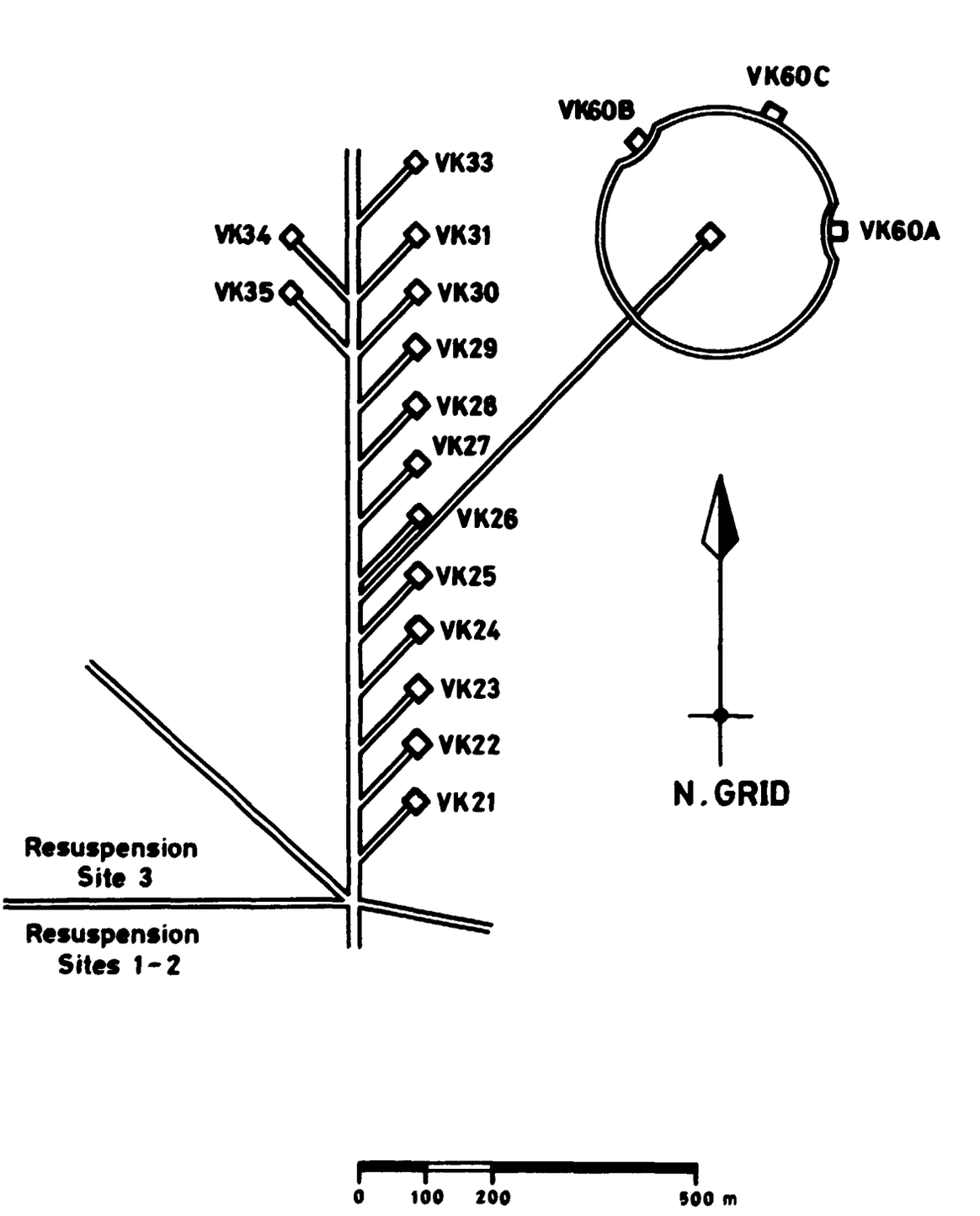

Figure 3.4: Wewak area of the Maralinga Range showing the positions of sites prepared for trials (VK21 etc.), the trials area named site 'A', and the general positions of the resuspension sites 1-3.

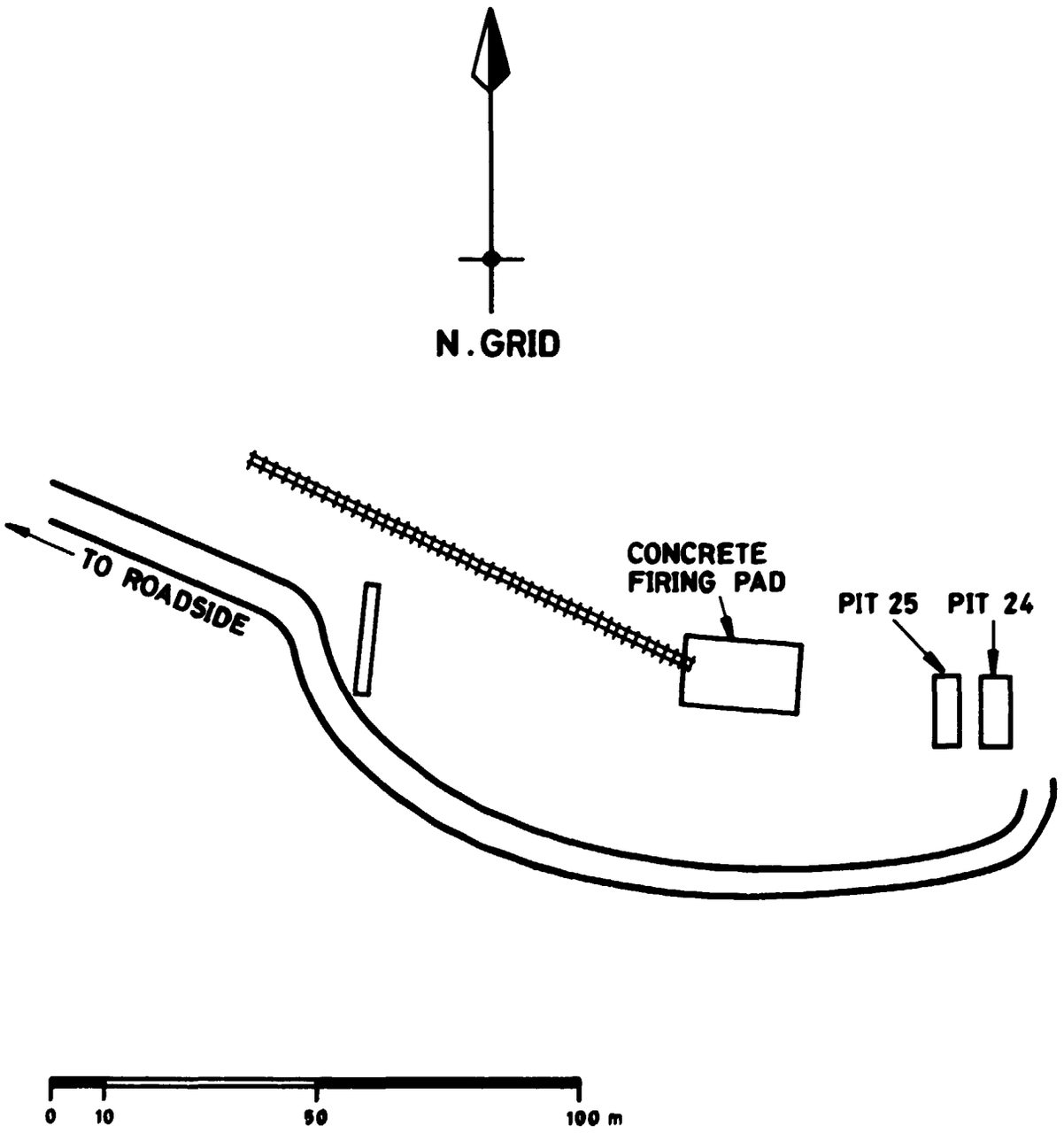

Figure 3.5: Dobo site showing positions of the firing pad, railway track and burial pits.

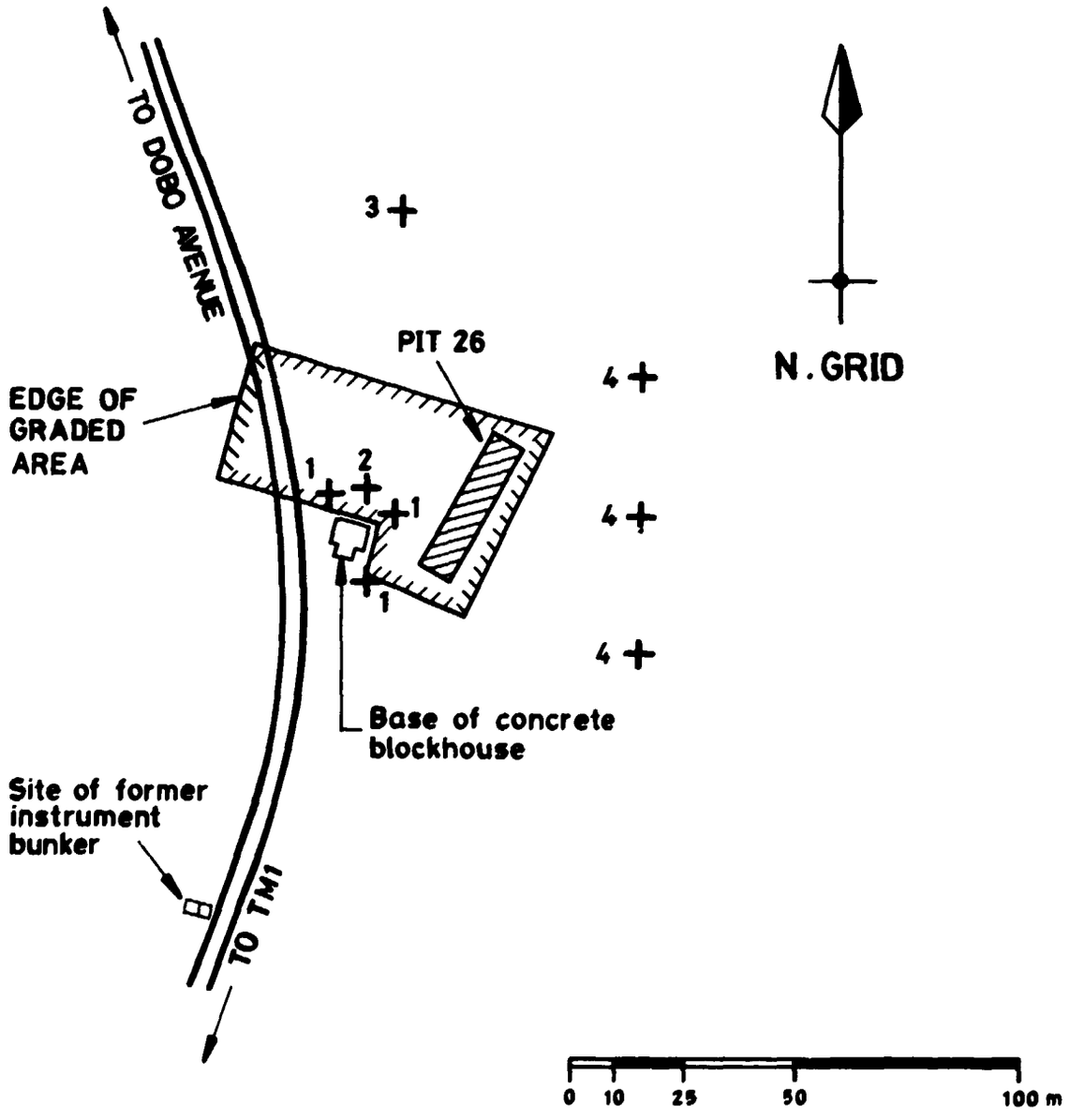

Figure 3.6: TM50 site, showing the positions of the remains (concrete base) of a blockhouse adjacent to the firing site, the burial pit and the extent of the treated area around the firing site. The positions from which soil samples 1-4 were collected are shown (+).

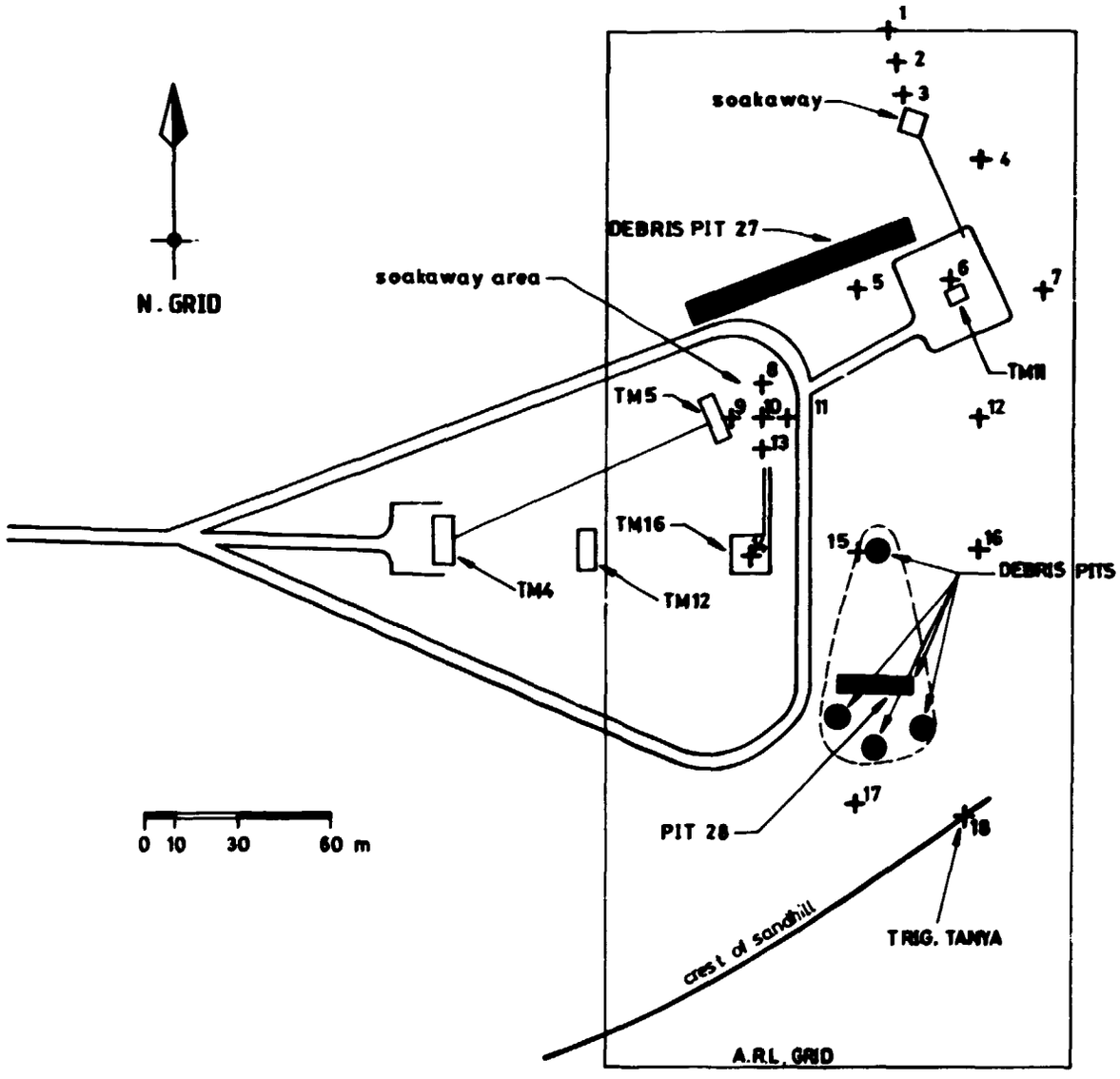

Figure 3.7: Kuli site showing positions of firing pads TM11 and TM16, debris pits, and sites TM4, TM5 and TM12. The 150 x 320 m grid set up by A.R.L. to identity sampling sites is indicated, together with the positions (+) at which the 18 surface soil samples were collected.

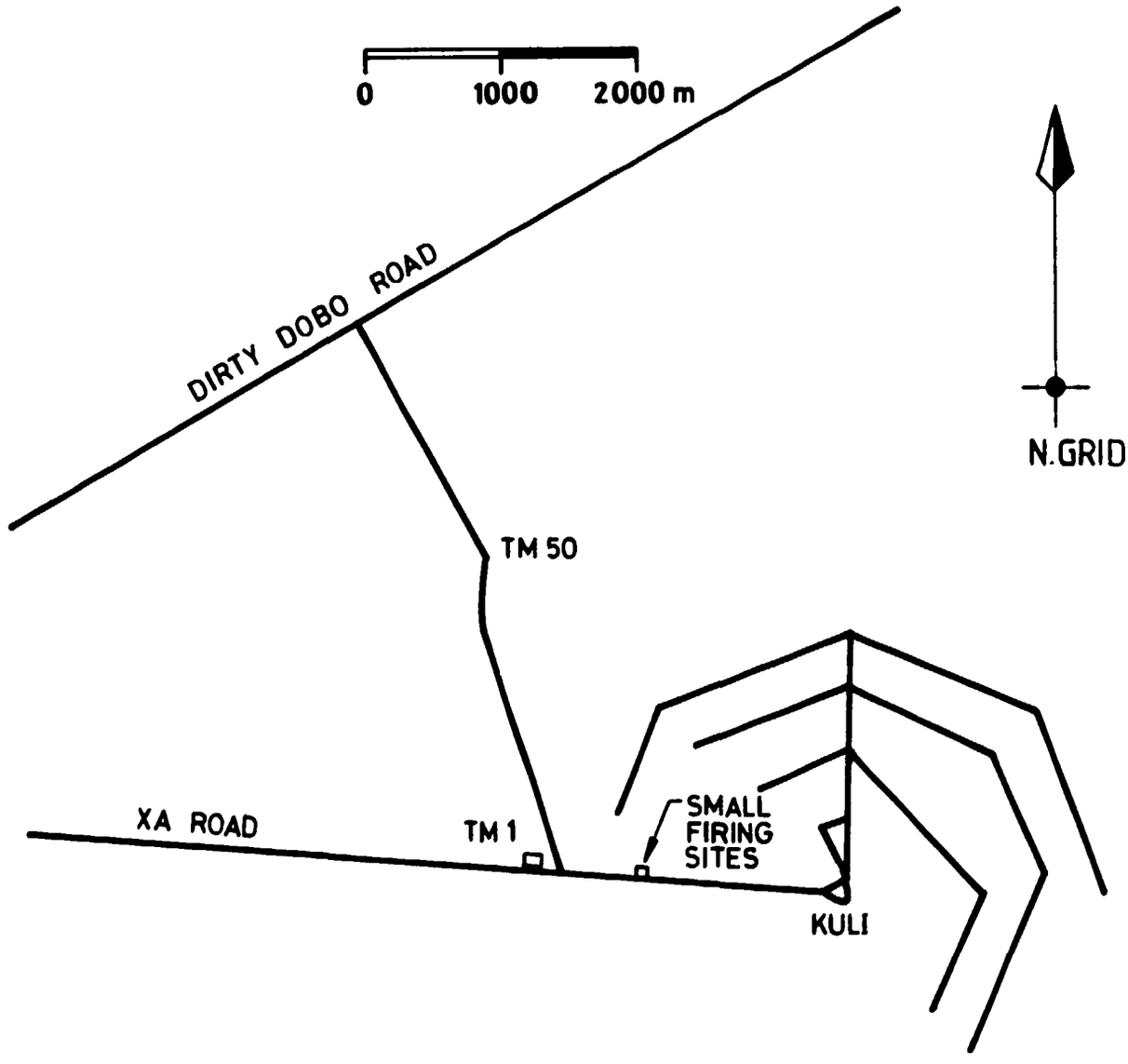

Figure 3.8: Kuli area of the Maralinga Range showing the Kuli, TM50 and Small Firing Sites, and the array of perimeter tracks beyond the Kuli site.

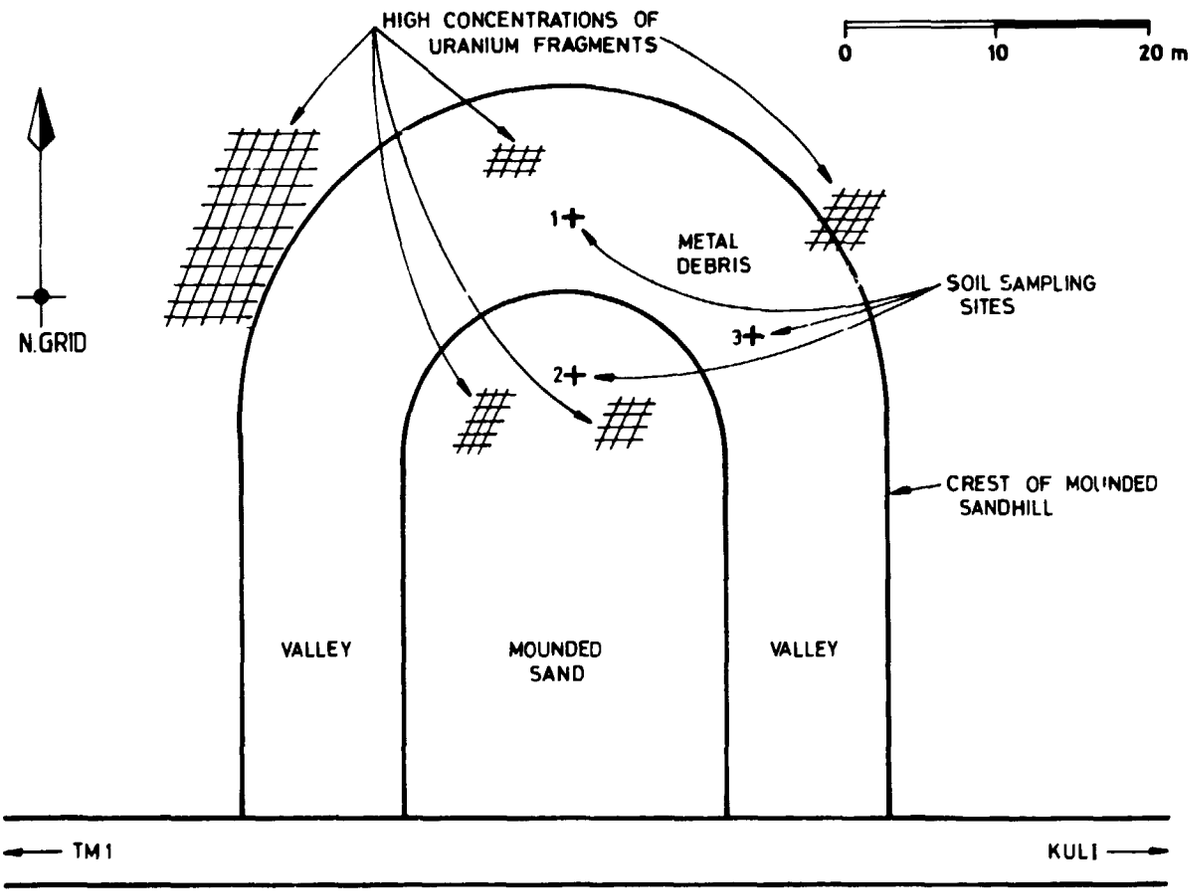

Figure 3.9: Small Firing Sites showing the horseshoe-shaped valley and areas where fragments of uranium are particularly concentrated on the sandy surface. The positions of the three soil sampling sites are indicated (+).

CHAPTER FOUR

Beryllium Contamination at Maralinga and Emu

Geoffrey A. Williams

Official records (AHPR; Operation Hercules, 1964; Pilgrim, 1959; 1960; 1962; Symonds, 1985) indicate that a 'non radioactive toxic material', viz. beryllium, was used for Rats, Kittens and TIMS trials at the Naya, Dobo, Kuli and TM50 sites, and also at Wewak and Taranaki. There is a suggestion (Pilgrim, 1960) that, in some trials, beryllium was used in kilogram amounts.

Beryllium in most chemical forms, including the metal and oxide, is a toxic material. Berylliosis, or beryllium disease, is manifested in several forms (Stokinger, 1966) which may be classified in two major groups, dermal and respiratory. The former, including dermatitis and ulcers, occurs from direct contact with beryllium materials. Respiratory diseases, including pneumonitis and bronchitis, are the result of inhalation of finely divided (respirable) beryllium material and can result in either complete recovery or in fatality (Stokinger, 1966).

Recommended limits for concentrations of beryllium in air for occupational and community exposure were established by the U.S. Atomic Energy Commission in 1949 as 2 and 0.01 $\mu g/m^3$ respectively (Stokinger, 1966). In the latter case, this was an average limit for exposure over a one month period. In Australia, the recommended threshold limit value for occupational exposure to beryllium in air is 2 $\mu g/m^3$ (NHMRC, 1980). By use of a resuspension factor of $10^{-5}/m$, an upper limit for surface beryllium concentrations of 1 mg/m^2 is acceptable based on the non-occupational limit of 0.01 $\mu g/m^3$ (Operation Hercules, 1964; Pilgrim, 1962). To assess the results presented below in terms of this limit, more knowledge would be required regarding the particle size of the beryllium, the chemical form of the beryllium (naturally-occurring beryl is significantly less toxic than either beryllium metal or oxide (Stokinger, 1966)), and the depth profile of any beryllium contamination. It must also be remembered that the non-occupational limit for concentrations of beryllium in air is for continual exposure.

It was never intended that this survey of beryllium levels at Maralinga and Emu would be exhaustive. Rather, it was recognised that only a feel for the magnitude and extent of any beryllium contamination could be obtained. The same surface soil samples which had been prepared (sieved) for the radioactivity analyses presented in Chapter 3 were used for the beryllium analyses. These were digested in acid and analysed by flame atomic absorption spectrophotometry by The Australian Mineral Development Laboratories (AMDEL). Estimates of uncertainties in the reported beryllium concentrations arising in the analytical procedure range from 0.1 ppm for concentrations of 0.2 to 1.0 ppm to 0.5 ppm for a concentration of 16 ppm. Also, 22 metal fragments collected from various trial sites were analysed semi-quantitatively by AMDEL using DC arc emission spectrography.

NATURAL BACKGROUND LEVELS OF BERYLLIUM

Beryllium occurs naturally in only a small number of minerals, the most abundant of which is beryl. As expected, natural levels of beryllium in soils vary markedly but a range of 0.1 to 1.0 ppm is quite normal (Vinogradov, 1959). Natural beryllium concentrations are higher in clay and bauxite-derived soils due to the association of beryllium with aluminium, and are much lower in soils developed from limestone (Vinogradov, 1959).

To determine background levels due to naturally-occurring beryllium in soil from the Maralinga and Emu areas, three surface soil samples were collected from sites far removed from any trial sites. At Maralinga, soil samples were obtained from 2 km south of Roadside and from the Tietkins well area and at Emu a soil sample was collected from close to Emu Claypan. Beryllium concentrations ranged from 0.7 to 0.8 ppm. Soils from the Olympic Dam (Roxby Downs) region are similar to those from Maralinga and Emu, and two such soil samples had beryllium concentrations of 0.7 and 1.6 ppm.

RATS AND KITTENS LANES AT NAYA

The 18 surface soil samples collected from the Rats lanes at the sites shown in Figure 3.1, together with a soil sample from the wooden box containing soil contaminated with uranium (Chapter 3), and 15 soil samples collected from the Kittens lanes at the sites shown in Figure 3.2 were analysed for beryllium. Concentrations of beryllium, ranging from 0.5 to 1.1 ppm, were not above normal background values. Of the metal fragments littering the area, none had the appearance of beryllium metal.

TRIALS AT NAYA3

Surface soil samples were collected from each of the three areas (Figure 3.3) where tests were performed at Naya3. The exact sites from which samples were obtained are detailed in the footnote to Table 3.2 (Chapter 3). Beryllium levels in the three soil samples from the 'Special' Kittens site, six soil samples from the TM2 (1955) site, and three soil samples from the centres of the Rodent craters, ranged from 0.6 to 1.0 ppm.

As described in the previous Chapter, there is a lot of metal debris in the area including aluminium sheet and pieces of a low-density metal. Two pieces of metal had measured densities of 1.8 Mg/m^3, very close to the density of beryllium (1.85 Mg/m^3). Seven representative metal pieces were analysed and all were alloys of magnesium or aluminium with no trace (detection limit 1 ppm) of beryllium.

TRIALS AT WEWAK

Surface soil samples collected from each of sites VK26 to VK31 at Wewak (Figure 3.4), together with those from site 'A' and a crater ca. 1 km north-east of the main Wewak site, were analysed for beryllium. Concentrations in the nine samples ranged from 0.4 to 1.5 ppm, with the highest value from VK30. These levels are comparable to normal background levels of beryllium in soils from the region.

RATS TRIALS AT DOBO

Surface soil samples were obtained at Dobo (Figure 3.5) from on top of the burial pits, from on top of the firing pad, and from the depressed area between the pad and burial pits. As well, a composite surface soil sample was obtained from an area 46 metres south of the firing pad, beyond the access road, in untreated soil littered with debris. Analysis of these four soil samples indicated beryllium concentrations ranging from 0.4 to 0.7 ppm.

TM50 AREA

Surface soil samples were collected from the four different areas shown in Figure 3.6. An area with elevated uranium activity (Chapter 3) about 10 m north of the blockhouse base was extensively sampled, and five different samples from this small area (ca. 4 m^2) were analysed individually for beryllium. Results are presented in Table 4.1. Four of the five samples from

the active area all show enhanced levels of beryllium, whereas samples from the other three sites show no contamination. Fragments of beryllium metal were not observed on the surface of the site.

From the multiple analyses presented in the Table, it is clear that beryllium levels in a sample can vary markedly within 10 g portions, but are reasonably consistent for 100 g amounts. This indicates that the beryllium is not uniformly distributed throughout the sample and is probably present as small fragments rather than in a finely divided form.

Table 4.1. Beryllium concentrations (ppm) in surface soil samples from the TM50 area[a]

Site	Analysis 1 (10 g)[b]	Analysis 2 (10 g)	Analysis 3 (100 g)	Analysis 4 (100 g)
TM50-1	1.3			
TM50-2	7.5	-	16	15
TM50-2a	4.0	7.3	6.8	6.0
TM50-2b	1.6			
TM50-2c	5.9	9.0	14	11
TM50-2d	15	16	23	26
TM50-3	0.4			
TM50-4	0.4			

a) Sampling sites are as marked on Figure 3.6. Samples TM50-1 and TM50-4 are each composites of three samples from the sites shown; sample TM50-2a was from alongside TM50-2, and samples TM50-2b, 2c and 2d were from 1 m NE, 1 m S, and 0.8 m NW of TM50-2 respectively.

b) In cases where enhanced beryllium levels were observed, two individual 10 g portions and two individual 100 g portions of the sample were selected, homogenised and analysed to give indications of the homogeneity within the original sample.

KULI

It is reported (Operation Hercules, 1964) that the highest levels of beryllium contamination ever recorded at Maralinga were at Kuli close to TM16 (Figure 3.7). The Kuli area was subsequently graded (Operation Hercules, 1964) and fragments of beryllium were buried (Operation Hercules, 1964; Pilgrim, 1966). The range of beryllium concentrations observed in the eighteen surface soil samples collected at Kuli (Figure 3.7) was 0.3 to 1.1 ppm, similar to background levels even for those samples from the TM16 soakaway which showed enhanced levels of uranium (Chapter 3).

One small piece (ca. 12 x 12 x 7 mm) of dull grey beryllium metal was found about 500 m east of TM16, but all other fragments of low-density metal collected from the area were alloys of magnesium and aluminium.

TARANAKI

Official U.K. records (Pilgrim, 1960) state that the presence of beryllium at Taranaki 'is not significant, from the safety aspect, compared with the fissile materials'. Six surface soil samples were collected from within the HCM fenced area close to firing pads at A.R.L. grid points 1360, M360, K480, K560, K720 and G840. All showed only background levels of beryllium (0.3 to 0.8 ppm).

OTHER MISCELLANEOUS AREAS

At the Small Firing Sites (Figure 3.8), surface soil samples were collected from three places indicated in Figure 3.9. In none were beryllium levels (0.2 to 0.3 ppm) above background values. Fragments of beryllium metal were not observed on the surface of the site.

Surface soil samples obtained from the soaks at the DC/RB (decontamination and radiobiological) and airport washdown sites showed only background levels of beryllium (0.3, 0.5 ppm).

EMU

Surface soil samples obtained from each of the four Kittens test sites K1 (northernmost), K2, K3 and K4 (southernmost), from close to the metal firing plates, revealed only background levels of beryllium (0.7 to 0.9 ppm). A composite surface soil sample from several areas at the old Emu Village site had a beryllium level of 0.9 ppm.

CONCLUSIONS

From a total of 104 surface soil samples from Maralinga and Emu which were analysed for beryllium, only four from one small area at the TM50 site showed significant levels of beryllium concentration. One piece of metallic beryllium was found at the Kuli site. The results suggest that beryllium was dispersed as a result of the trials as small metal fragments, which would not constitute an inhalation hazard, rather than in a finely divided form.

ACKNOWLEDGEMENTS

We thank Dr. Alvin Summerton of the South Australian Health Commission for help with the field work at Maralinga, and Mr. Robin Statham for help with sample preparation. We are also grateful to Mr. John Waters of AMDEL for performing the beryllium analyses, and for helpful discussions.

CHAPTER FIVE

Some Remarks on Risk

Peter A. Burns, Malcolm B. Cooper and Keith H. Lokan

Of the residual radioactive contamination at Maralinga and Emu the only materials present in sufficient quantities to be of continued interest are the fission and activation products from the major trials and the long lived alpha emitting nuclides of plutonium, americium and uranium which were explosively dispersed during minor trials. The radiological hazards presented by these materials can be summarized as external irradiation, ingestion of radioactive material and inhalation of radioactive material. External irradiation is only a problem at the major trials sites where the beta and gamma emitting nuclides of europium-152, caesium-137 and cobalt-60 produced by activation and fission during the atomic explosions are still present. The half lives of these nuclides vary from five to thirty years and the dose rates at the major trial sites will drop over the next forty years to levels which would permit permanent occupancy. Because of their low radiotoxicity and the low concentrations, these nuclides do not present a significant risk due to either ingestion or inhalation.

The alpha emitting nuclides dispersed during the minor trials, plutonium-239, plutonium-240, americium-241, uranium-235 and uranium-238, are not an external radiation hazard but are of concern when inhalation and ingestion are considered. Although the radiotoxicity of these nuclides are comparable, the low specific activities of the uranium nuclides and the generally small activities of these materials found are such that the risk from them is small, especially when compared to that from the plutonium and americium nuclides. The plutonium and americium nuclides are present in high concentration, are dispersed over large areas and, because of their high radiotoxicity, represent the major hazard remaining on the range. These nuclides all come from the plutonium used in trials and the activities are such that the activity of plutonium-240 is approximately 20°/o of plutonium-239 and americium-241 is less than 15°/o of plutonium-239. Using ICRP figures for Annual Limits of Intake (ALI) (ICRP, 1979) in Appendix 5A as

a guide for comparison, it can be seen that the inhalation risk under these circumstances is due mainly to plutonium-239 with that from americium-241 being approximately half. For ingestion the risk from americium-241 is approximately ten times that of plutonium-239 because of its greater solubility.

In Appendix 5B an assessment is made of the possible concentration of plutonium-239 in air at Taranaki in the most contaminated area on a windy day. The calculated air concentration due to wind resuspension is 0.002 Bq/m^3 and represents the level to which casual visitors to the area would be exposed on the few days a year when wind velocities were of the order of those quoted.

As a point of comparison the ICRP Derived Air Concentration (DAC) for plutonium-239 is listed in Appendix 5A (0.2 Bq/m^3). It must be kept in mind that this level is the level at which workers can be exposed for 2000 hours per year for 50 years of their working lives without exceeding ICRP recommended doses.

The assessment in Appendix 5B is valid for a casual visitor to the area who does not engage in dust raising activities and an air concentration of 0.002 Bq/m^3 is not significant in those circumstances. In order to provide any other risk assessment it would be necessary to determine a group at risk and make assumptions about their lifestyles and habits. Such an assessment would be so dependent on these assumptions as to make a general estimation of risk difficult. Long term occupancy of the area which involved dust raising activities would however involve exposure to an increased radiological risk due to inhalation and possibly to ingestion.

Because of the number of plutonium contaminated fragments on the range, many of which are on or close to the surface, the main risk to the casual visitor at present is probably from souvenir hunting. A fragment of metal picked up and handled could be contaminated with plutonium, and such actions could result in the ingestion or inhalation of substantial quantities of radioactive material. Again, it is not realistic to attempt a general estimate of risk for such circumstances.

The amount of plutonium buried in shallow pits and spread around an area of approximately one square kilometre at Taranaki and smaller areas at TM100, TM101 and Wewak is substantial. Disposal of radioactive waste of this nature, in this manner cannot be considered acceptable current practice.

APPENDIX 5A

ICRP Recommended Annual Limits of Intake (ALI) for workers and Derived Air Concentrations (DAC).

Nuclide	ALI (Bq)*		DAC (Bq/m^3)*
	Oral	Inhalation	
^{235}U	7×10^6	2×10^3	6×10^{-1}
^{238}U	8×10^6	2×10^3	7×10^{-1}
^{239}Pu	2×10^6	5×10^2	2×10^{-1}
^{240}Pu	2×10^6	5×10^2	2×10^{-1}
^{241}Am	5×10^4	2×10^2	8×10^{-2}

* ICRP (1979)

APPENDIX 5B

Estimation of the air concentration of plutonium above those areas of Taranaki which are most heavily contaminated.

The average soil concentration inside the 3000 contour for Figure 1.4 exceeds 20 kBq/kg for plutonium-239.

In an attempt to estimate more accurately the concentration in the fine fraction of soil which is resuspensible and inhalable, 23 soil samples were sieved down to finer fractions. It was found that 6°/o of the mass and 24°/o of the activity was in the less than 45 μm fraction. This implies that the concentration of the resuspensible and inhalable dust is four times higher or 80 kBq/kg.

For the less than 50 μm fraction, dust loadings measured by Tretrey (AIRAC, 1979) at a time of relatively high wind velocities - 6-7 m/sec were:

- 4.6×10^{-3} mg/m^3 at a height of 1.6 m
- 6.5×10^{-3} mg/m^3 at a height of 0.15 m

Using a dust loading of 6.5×10^{-3} mg/m^3 the corresponding air concentration for plutonium-239 is 0.002 Bq/m^3.

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