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ABSTRACT

Nuclear weapons trials conducted at Maralinga from 1960 to 1963 resulted in contamination of large areas of land with low levels of plutonium. Ground and aerial surveys and soil sampling conducted between 1984 and 1987 showed that this contamination extended beyond the boundaries of the area still controlled by the Commonwealth Government into the Maralinga Tjarutja lands.

Levels of contamination beyond the boundaries of the former test range were found to be low, and were generally undetectable for all but the most sensitive measurement techniques. Soil sampling combined with long laboratory counting was initially used to define the trace levels but the contamination was found to be particulate with a surface density of particles too low for this to be a generally useful technique.

This report presents the results of in-situ gamma-ray spectrometry using a portable germanium (Ge) detector to measure contamination levels of plutonium to well below 1 kBq m^{-2} in the Maralinga Tjarutja lands to the north and north-west of the Maralinga test site.

INTRODUCTION

Between 1955 and 1963 the United Kingdom conducted a programme of nuclear weapons development trials at Maralinga in South Australia (Figure 1). In all, seven major nuclear trials involving atomic explosions, and several hundred smaller scale experiments ('minor trials') which dispersed radioactive materials to the local environment were performed. It is 12 of these 'minor trials', code-named the Vixen B trials, performed at the Taranaki site (Figure 2) between 1960 and 1963 which are responsible for the plumes of plutonium contamination which extend from the former test range site and onto the Maralinga Tjarutja lands. In the Vixen B trials about 22 kg of plutonium, as well as enriched uranium and beryllium, were explosively dispersed in a sector extending from the west, through north to the north-east of the Taranaki site (Figure 3).

The plutonium contamination close-in at Taranaki is mainly in three forms viz. as a fine dust, as small sub-millimetre particles, and as surface contamination on larger fragments (Burns et al., 1986). In the trials, the plutonium was dispersed in narrow plumes, the main ones extending to the west, north-west, north and north-east of Taranaki. The most extensive of these is the north-west plume, which can be detected crossing West Street between Fifth and Tenth Avenues (Figure 2). In the central area at Taranaki, the surface soil was 'ploughed' in the Operation Brumby clean-up in 1967. Beyond the ploughed area the plutonium contamination tends to be on the surface, and at distances beyond about 5 km from Taranaki only microscopic particles of contamination are found.

A wide-ranging ground survey of Taranaki and its environs was conducted by the Australian Radiation Laboratory (ARL) over the period 1984 to 1986. In this survey, field measurements employing thin sodium-iodide detectors and single-channel analysers were used to provide a qualitative indicator of plutonium (Cooper et al., 1985), and quantitative data were obtained by gamma-ray analyses of soil samples (Cooper et al., 1985; Burns et al., 1988). With the exception of a few measurements to the north-west, these data were confined to the area of the former test range, viz. the Taranaki site and sampling points along the major north-south and east-west tracks on the range. The results of this survey are presented in Figure 3.

Following concern by people living and working at the Aboriginal outstation at Oak Valley, soil sampling was performed by ARL in 1987 along the Oak Valley Road and along Western Avenue (Figure 2) as well as at the Oak Valley settlement. High-resolution gamma-ray spectrometry was used in the laboratory to determine levels of plutonium in these soil samples. These showed the presence of trace amounts of plutonium at many of the sampling points in the general area to the north-west of Taranaki (Williams and Burns, 1987). However, the contamination was found to be particulate in character with a surface density of particles too low for soil sampling to be a suitable technique.

A technique more suited to this particular situation is that of in-situ gamma-ray spectrometry using a portable germanium (Ge) detector. This is the method which has been employed in the present study, conducted during 1987 and 1988, to detect plutonium contamination at levels well below 1 kBq m^{-2}. The results of these measurements are presented in this report, and a preliminary assessment of radiological hazard to health is made.

APPROACH

The plutonium contamination at Maralinga contains a mixture of isotopes. While the predominant isotope is ^{239}Pu, there are significant quantities of ^{240}Pu and ^{241}Pu. ^{241}Pu decays to ^{241}Am with a half-life of 14.4 years, and consequently most of the original ^{241}Pu has by now decayed to ^{241}Am. ^{239}Pu and ^{240}Pu are not readily detected by gamma-ray spectrometry because of the low abundance of their gamma-ray emissions, whereas ^{241}Am has an abundant gamma-ray (36%) of energy 59.5 keV. This serves as a good indicator of plutonium concentration once the relevant ratios of the plutonium isotopes to americium have been established. For much of the contamination dispersed in the 12 Vixen B trials at Taranaki, the ratio of total plutonium activity to americium activity is of the order of ten (Johnston et al., 1988). Recently, the activity ratios $^{239}Pu/^{241}Am$ and $^{240}Pu/^{241}Am$ in the individual plumes emanating from Taranaki have been measured (Burns et al., 1989) and the appropriate values are used below in determining plutonium levels in the north and north-west plumes.

The program of measurements was aimed at determining the location of, and concentration levels of plutonium contamination in, the north and north-west plumes. Ideally, a suitable grid system would be available to optimise the use of measurement equipment. However, the area under consideration is only

covered by two wide bulldozed earth roads, Oak Valley Road and Western Avenue, established during mining exploration, and the original bulldozed tracks used for monitoring purposes during the time when tests were being conducted (Figure 2). Many of the tracks had not been used since the period of the tests and were only passable by four wheel drive vehicles in dry conditions after extensive clearing. Measurements were largely confined to these roads and tracks because of the difficulties of penetration of the surrounding areas. However, three 'traverses' were undertaken to measure the north-west plume away from the above tracks. These traverses were done by either walking or driving along a compass bearing. These traverses were very difficult to establish and positions estimated along them must be considered approximate (at the extremities of traverses, locations are probably accurate to ~500 m).

EXPERIMENTAL

Equipment

In-situ measurements were carried out using a Canberra planar hyperpure germanium detector (Ge[HP]) having a detector crystal with an active diameter of 35.7 mm and a thickness of 15 mm. The detector has a resolution of 283 eV full width at half maximum (FWHM) at 5.9 keV and 570 eV FWHM at 122 keV. The detector crystal is mounted in a cryostat made of copper with a 0.41 mm thick beryllium window specially selected for low background applications mounted on a Canberra 'BIG MAC' multi-attitude liquid nitrogen (LN_2) dewar. The dewar has a capacity of 7 litres and the total detector has a dry weight of 10.0 kg.

Data acquisition, storage and display of spectra obtained in the field were carried out by use of a Spectrum 88 multichannel analyser (MCA) fitted with a 5.25 inch floppy disk drive for data storage. Spectral data were returned to the Laboratory for analysis.

The activity of ^{241}Am was determined from its associated 59.5 keV gamma ray.

Calibration for field spectrometry

A completely experimental calibration of the Ge[HP] spectrometer for use in the field is not a practical option. Instead, the calibration is performed using a combination of experiment and calculation. A small ^{241}Am source was placed on the ground at a number of distances from the axis of the

detector. Figure 4 shows the position of the calibration source relative to the detector.

For a source of activity A at an off-axis distance r, producing a count rate C, the detection efficiency, E_r, is C/A. For a uniform source covering an infinite plane the overall efficiency of the detector is given by

$$\epsilon = \int_0^\infty 2\pi r E_r \, dr$$

where it is assumed that the activity is on the surface of the soil. In general, depth profiles of the contaminated areas have shown that most of the activity is in the top centimetre.

The detector used in this work has copper side walls which effectively limit the 'view' of the detector, so that the product rE_r has diminished to less than 5% of its peak value by r of 4.8 m. Contributions to the integral beyond this distance are ignored.

This calibration does not take account of real features encountered in the field such as the unevenness of the soil surface and attenuation due to vegetation. These vary and introduce random uncertainty into the results.

For the detector used in the present work at 1.04 m above the ground, the overall efficiency was

$$\epsilon = 9.8 \times 10^{-5} \text{ cps m}^2 \text{ Bq}^{-1}$$

or expressed differently, 1 cps corresponds to a surface activity density of 10.2 kBq m^{-2}.

Field procedures

Liquid nitrogen (LN_2): Support of a detector cooled by LN_2 in a remote field location is not a simple matter. In field use, the detector consumes 1 to 2 litres per day, and a bulk supply of 150 litres has been found to last only 2 to 3 weeks. LN_2 supply within the detector was monitored daily by weight.

Test source: An ^{241}Am test source of known activity was counted at routine intervals to check equipment operation. These check measurements were usually performed after every ten measurements, after changes in equipment configuration, after operational problems or after changes in MCA parameters.

The spectrum from the check source enabled setting of regions of interest in the field. Gross and nett counts in the region of interest about the 59.5 keV peak were used to estimate ^{241}Am activity density and fractional error due to counting statistics which was used to estimate adequate measurement times.

Field test equipment: A full range of electronic test equipment was found to be essential to maintain reliable operation.

Measurements

The criterion applied to determine sufficient measurement time was that the fractional error due to counting statistics was less than ten percent. At this level it was considered that uncertainties due to terrain and vegetation would be dominant and further improvement in the accuracy of counting statistics was unwarranted. This criterion could not always be applied in practice because of low activity levels or demands of field operation.

In cases where the fractional error was greater than fifty percent the result is described as not detected (ND). Where a positive result is given a peak is observable in the spectrum, with low values corresponding to a small peak on a very large background.

RESULTS

Activity densities of ^{241}Am detected by the in-situ gamma-ray spectrometry are presented in Tables 1 -- 10 and in Figures 5 - 10. In these presentations, the uncertainties given in parentheses are from counting statistics alone and do not include any estimate of errors due to systematic effects or uncertainties due to variation of vegetation or the texture of the soil or other causes.

The technique is capable of detecting surface deposits of americium at surface densities as low as 0.05 kBq m^{-2} (corresponding to 0.4 kBq m^{-2} of plutonium in the north-west plume). The results indicate that the plumes extend well beyond the limits of the Maralinga range and traces of the north-west plume persist to beyond 80 km from Taranaki (see Figure 2).

Detailed descriptions of the measurements performed are presented in the Appendix for each of the areas identified on Figure 2. These are summarised

by contours (Figure 2) of the observed activity concentration at 0.1 kBq m^{-2} of ^{241}Am which is close to the present limit of detection, and is approximately one order of magnitude lower than the activity at the boundaries of the shaded contour on the Figure. The shaded areas were defined by previous ARL soil sampling and counting (Burns et al., 1988). The 0.1 kBq m^{-2} contour presented in Figure 2 is indicative only, as the measurements were mainly confined to available tracks and a limited number of traverses chosen to intercept the north-west plume in particular.

DISCUSSION

The aim of this work has been to provide advice to the Maralinga Tjarutja about those areas of land in which, due to either the absence of plutonium or the presence only of very low levels, there is no significant risk to health.

At present there are no internationally recommended limiting values for the concentration of plutonium in soil, and the definition of limits appropriate to the Maralinga region will follow from other scientific studies. These are currently taking place, under the auspices of a Technical Assessment Group appointed by the Australian Government.

In the meantime, we can make use of a conservative value of 7.4 kBq m^{-2} of plutonium proposed by the U.S. Environmental Protection Agency in 1985 as a recommended 'screening level', below which land can be considered suitable for unrestricted use (USEPA, 1985). This corresponds to a concentration of approximately 0.5 Bq g^{-1} for the soils in the region, where the observed penetration of plutonium into the soil is about 1 cm, or to a surface density of approximately 1 kBq m^{-2} of ^{241}Am in the north-west plume for which the measured ratio of plutonium to americium is ~7 (Burns et al., 1989).

This level is exceeded outside of the Maralinga Range immediately adjacent to the western boundary and extending for the first few kilometres in a north-westerly direction (see Figure 6). At greater distance, the surface density falls off and the plume is observed to veer more to a westerly direction, consistent with meteorological data from the time of the particular test, and passes south of the Oak Valley area.

Similarly, the north and north-east plumes are still detectable at the boundaries of the Range at Twentyfifth Avenue and East Street respectively (c.f. Figures 9 and 10) although the concentrations are somewhat lower.

On the basis of the levels described in this report, it is reasonable to conclude that there is no cause for concern in the area north west of Western Avenue, and no reason to restrict access. Equally, there is no reason to restrict use of Western Avenue, West Street north of the intersection with Western Avenue, or Twentyfifth Avenue.

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APPENDIX. Some Details of In-situ Ge[HP] Measurements Made in the Areas Identified in Figure 2.

Area	Location(s)	Duration of counts (s)	Peak activity density of ^{241}Am (kBq m^{-2})	Comment
1	Taranaki and HVAS sites	600-1000	250 at CNE	Caution must be exercised in interpretation of values from ploughed areas (see Note 1)
2	N along West St. to Western Ave.	1000 except N of Western Ave. were 15000-27000	2.1 at 5.5 km N along West St. from 5th Ave.	Splitting of NW plume is suggested
3	9 km traverse starting 5 km N along West St. from 10th Ave. bearing 235°	2000	1.1 at 5 km SW along traverse	
4	Western Ave.	5000-19000	0.78, 0.47 at 6 and 19 km W along Western Ave.	Two peak values recorded are due to splitting of the NW plume
5	20 km traverse starting from the corner of Oak Valley Rd. and Western Ave. at bearing 020°	14000-17000 (day) and 62000-65000 (overnight)	0.77 at 17 km NNE along traverse	
6	Oak Valley Road	Various	0.2 where NW plume cuts Oak Valley Rd.	
7	Oak Valley	10000-40000	None found (see Note 2)	
8	16 km traverse starting 29.5 km NW along Oak Valley Rd. from Western Ave. bearing 225°	76000-80000	0.16 at 8 km SW along traverse	

9	10th Ave. and East St.	7000-16000 (day) and 62000-65000 (overnight)	Several 0.83, 1.3, 0.33 and 0.57 at 13.5, 17.0, 26.6 km along 10th Ave. from East St. and at corner	These maxima represent the main N plume, a branch of N plume, the NE plume and a plume tentatively ascribed to a minor trial
10	25th Ave.	9000-15000 (day) and 68000-70000 (overnight)	0.64 at 21.4 km east along 25th Ave. from West St.	Measurement made on surface of claypan (see Note 3)

Notes

1. In ploughed areas, viz. CNE, CN, CNW, CW, FENE, FNE, FN and FNNW, the distribution of activity is known to differ markedly from the distribution assumed for calibration purposes.

2. Minimum detectable limits in the Oak Valley area at a 95% confidence level for these measurements are as follows:-

North-east of school 60 m	0.1 kBq m^{-2}
West of school 120 m	0.06 kBq m^{-2}
West of water tanks 20 m	0.09 kBq m^{-2}

3. An exploratory measurement was carried out on the surface of a claypan 14.9 km east along 25th Avenue from West Street; the reading was below the limit of detection. To either side of this measurement, higher ^{241}Am activity densities were recorded on relatively undisturbed soil. The fact that ^{241}Am was not detected on the surface of the claypan is likely to be more a result of nearly 30 years of weathering rather than lack of initial deposition.

Table 1. Ge[HP] Measurements Area 1.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location	^{241}Am (kBq m^{-2})
C ring road	
CW-F50 HVAS site	31.1(6)
CNW-F50 HVAS site	141(1)
CN-F50 HVAS site	80(1)
CNE-F50 HVAS site	251(1)
F ring road	
FW-F50	10.5(4)
FW-F50	12.4(4)
FW-F50 HVAS site	12.3(4)
FNW-F50 west of ploughed area	10.4(5)
FNW-F50 between windrows	8.0(5)
FNW-F50 between windrows	11.6(4)
FNW-F50 over windrows	11.5(5)
FNW-F50 over windrows	11.9(4)
FNW-F50 HVAS site	14.5(4)
FNW-A50	12.3(4)
FNNW-F50	7.8(4)
FN-F50 between windrows	22.7(7)
FN-F50 over windrows	65(1)
FN-F50 HVAS site	70.9(9)
FENE-F50 HVAS site	40.4(7)
Intersecting north west plume, off 'ploughing'	12.3(4)
	14.2(4)
G ring road	
South of western radial - 200 m west	1.3(2)
- further 200 m south	1.0(2)
Intersecting north west plume, off 'ploughing'	14.7(4)
- ditto	13.8(4)
2 km south of western radial	ND

Table 1. (cont.)

Location	^{241}Am (kBq m^{-2})
<u>I ring road</u>	
Centre of north west plume	9.3(4)
- ditto	11.6(4)
- ditto	9.9(4)
IW-F50 HVAS site	0.7(2)
INW-F50 HVAS site	20.4(5)
IN-F50 HVAS site	20.4(5)
INE-F50 HVAS site	2.3(3)
<u>Miscellaneous</u>	
TM100 HVAS site	26.6(6)
TM101 HVAS site	43.3(7)
Wewak HVAS site	ND
Tadje HVAS site	26.1(6)

Table 2. Ge[HP] Measurements Area 2.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location		^{241}Am (kBq m^{-2})
<u>West Street</u>		
Intersection of West St./5th Ave.		1.7(2)
North along West St. from West St./5th Ave.	- 0.5 km	0.8(2)
	- 1.0 km	1.2(2)
	- 1.5 km	2.0(2)
	- 2.0 km	1.0(2)
	- 2.5 km	1.5(2)
	- 3.5 km	1.2(2)
	- 3.5 km	1.1(2)
	- 4.5 km	1.2(2)
	- 5.5 km	2.1(2)
Intersection of West St./10th Ave.		1.2(1)
North along West St. from West St./10th Ave.	- 2.0 km	0.19(5)
Intersection of West. St./Western Ave.		ND

Table 3. Ge[HP] Measurements Area 3.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location		^{241}Am (kBq m^{-2})
<u>South-West Traverse: 235° 5 km north West St./10th Ave.</u>		
South-west along traverse	- 1.0 km	ND
	- 5.0 km	1.1(1)
	- 7.0 km	ND
	- 9.0 km	ND

Table 4. Ge[HP] Measurements Area 4.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location		^{241}Am (kBq m^{-2})
<u>Western Avenue</u>		
Intersection of Western Ave./West St.		ND
West along Western Ave. from intersection	- 2.0 km	ND
	- 4.0 km	0.31(3)
	- 6.0 km	0.78(5)
	- 7.9 km	0.38(2)
	- 9.0 km	0.41(7)
	-11.0 km	0.11(3)
	-13.0 km	0.10(2)
	-15.0 km	0.10(4)
	-17.0 km	0.24(2)
	-19.0 km	0.47(7)
	-21.0 km	0.38(2)
	-23.0 km	0.11(4)
	-25.0 km	0.05(2)
	-27.0 km	ND
	-29.0 km	ND
	-33.0 km	ND
(Intersection of Western Ave./Oak Valley Rd.)		
	-36.0 km	0.08(2)
5 km north at 21 km west along Western Ave.		0.12(5)

Table 5. Ge[HP] Measurements Area 5.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location	^{241}Am (kBq m^{-2})
North-East Traverse: 020° corner of Oak Valley Rd./Western Ave.	
Intersection of Oak Valley Rd./Western Ave.	0.08(2)
Dist. along traverse from intersection - 3.75 km	ND
- 5.0 km	0.10(2)
- 6.25 km	ND
- 7.5 km	0.06(2)
-10.0 km	ND
-10.9 km	0.09(2)
-11.2 km	ND
-11.7 km	ND
-12.5 km	0.21(4)
-13.4 km	0.37(2)
-14.3 km	0.41(6)
-15.0 km	0.77(5)
-15.8 km	0.26(6)
-16.4 km	ND
-17.5 km	0.14(5)
-20.0 km	ND

Table 6. Ge[HP] Measurements Area 6.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location	^{241}Am (kBq m^{-2})
Oak Valley Road	
47 km south-east of Oak Valley Rd./Western Ave.	ND
18.6 km north-west of Oak Valley Rd./Western Ave.	ND
88.7 km north-west of Oak Valley Rd./Watson Rd.	ND
West of above location - 4 m	0.20(6)
South-west of above location - 1.0 km	0.09(3)
- 2.0 km	ND

Table 7. Ge[HP] Measurements Area 7.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. ND indicates not detected; minimum detectable levels are given in the Appendix.

Location	^{241}Am (kBq m^{-2})
Oak Valley	
North-east of school 60 m	ND
West of school 120 m	ND
West of water tanks 20 m	ND

Table 8. Ge[HP] Measurements Area 8.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location	^{241}Am (kBq m^{-2})
South-West Traverse: 225° 29.5 km NW of Oak Valley Rd./West St.	
Along traverse - 0 km	0.06(2)
- 2.0 km	0.05(2)
- 4.0 km	0.10(2)
- 8.0 km	0.16(3)
-12.0 km	0.07(2)
-16.0 km	0.10(2)

Table 9. Ge[HP] Measurements Area 9.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location		^{241}Am (kBq m^{-2})
<u>10th Avenue</u>		
Intersection of 10th Ave./West St.		1.2(1)
East along 10th Ave. from 10th Ave./West St.	- 8.0 km	0.28(2)
	- 9.0 km	0.22(7)
	-10.5 km	0.69(6)
	-12.0 km	0.19(2)
	-13.0 km	0.16(6)
	-13.5 km	0.83(7)
	-14.0 km	0.38(2)
	-15.0 km	0.60(5)
(Intersection of 10th Ave./Central St.)	-16.0 km	1.28(3)
	-17.0 km	1.30(7)
	-18.0 km	0.40(7)
	-19.0 km	0.05(2)
	-20.0 km	ND
	-22.5 km	ND
(Intersection of 10th Ave./Right St.)	-24.5 km	0.16(5)
	-25.5 km	0.29(3)
	-26.5 km	0.33(5)
	-27.5 km	0.12(5)
	-30.0 km	0.10(2)
	-32.5 km	ND
	-34.5 km	0.15(5)
(Intersection of 10th Ave./East St.)	-36.2 km	0.57(3)
South along East St. from 10th Ave./East St.	- 2.0 km	ND

Table 10. Ge[HP] Measurements Area 10.

Activity densities of ^{241}Am detected by in-situ gamma-ray spectrometry. Counting errors at the one standard deviation level are given in brackets and refer to the last significant figure.

Location		^{241}Am (kBq m^{-2})
25th Avenue		
Intersection of 25th Ave./West St.		ND
East along 25th Ave. from 25th Ave./West St.	- 4.4 km	ND
	- 5.4 km	0.08(2)
	- 6.4 km	0.05(2)
	- 7.4 km	0.18(5)
	- 8.4 km	0.12(6)
	- 9.4 km	0.22(2)
	-10.4 km	ND
	-11.4 km	0.24(5)
	-12.4 km	0.14(5)
	-13.4 km	0.09(2)
	-13.95 km	ND
	-14.15 km	0.34(3)
	-14.4 km	0.42(6)
	-14.9 km	ND
	-15.4 km	0.38(2)
	-16.4 km	0.40(6)
	-17.4 km	0.56(7)
	-18.4 km	0.25(6)
	-19.4 km	0.36(7)
	-20.4 km	0.27(3)
	-21.4 km	0.64(7)
	-22.4 km	0.27(5)
	-23.4 km	0.13(3)
	-24.4 km	0.22(7)
	-25.4 km	ND
	-27.4 km	ND
	-29.4 km	ND

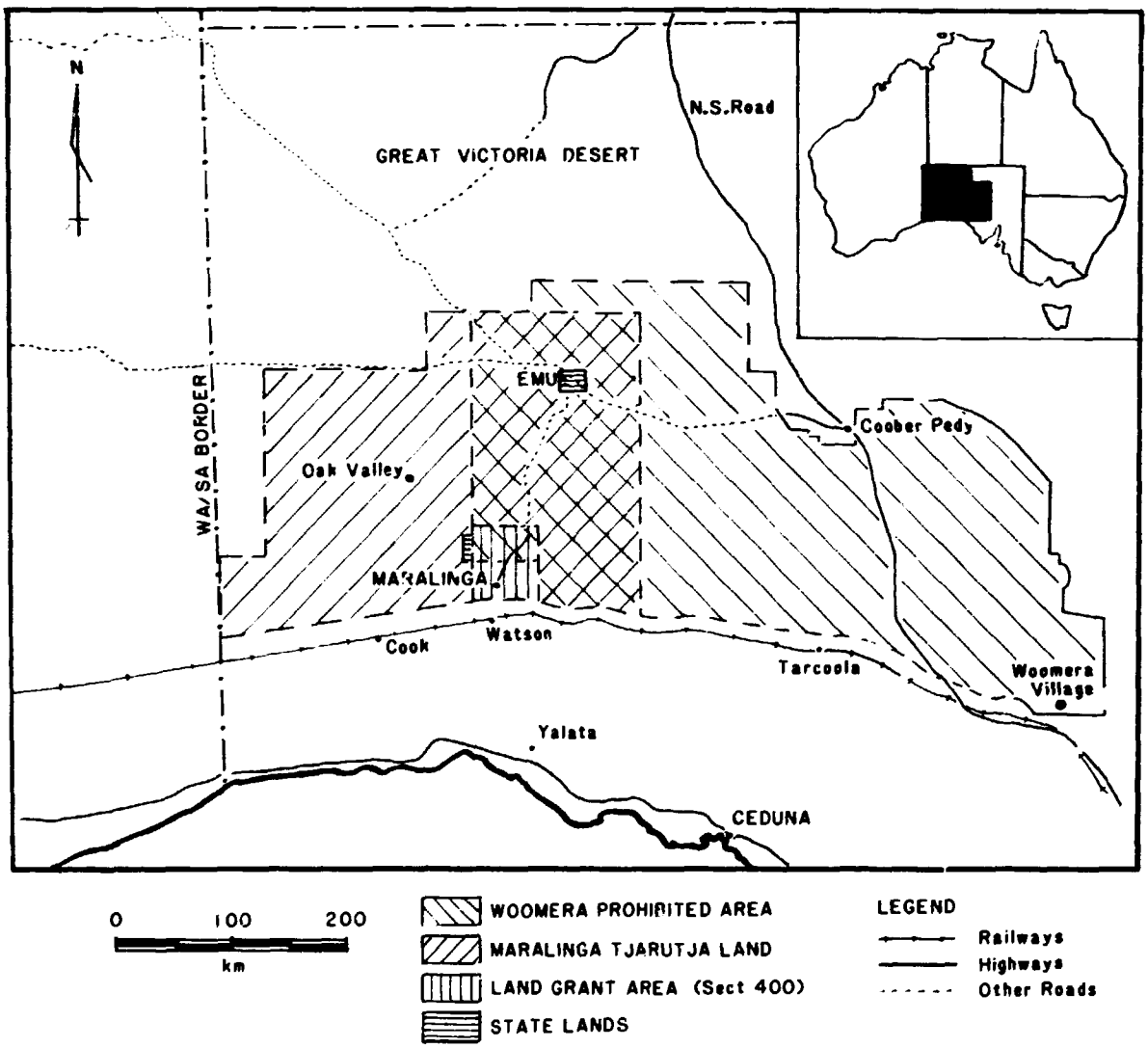

Figure 1. Map of southern Australia showing the locations of Maralinga and Oak Valley and areas under Commonwealth control.

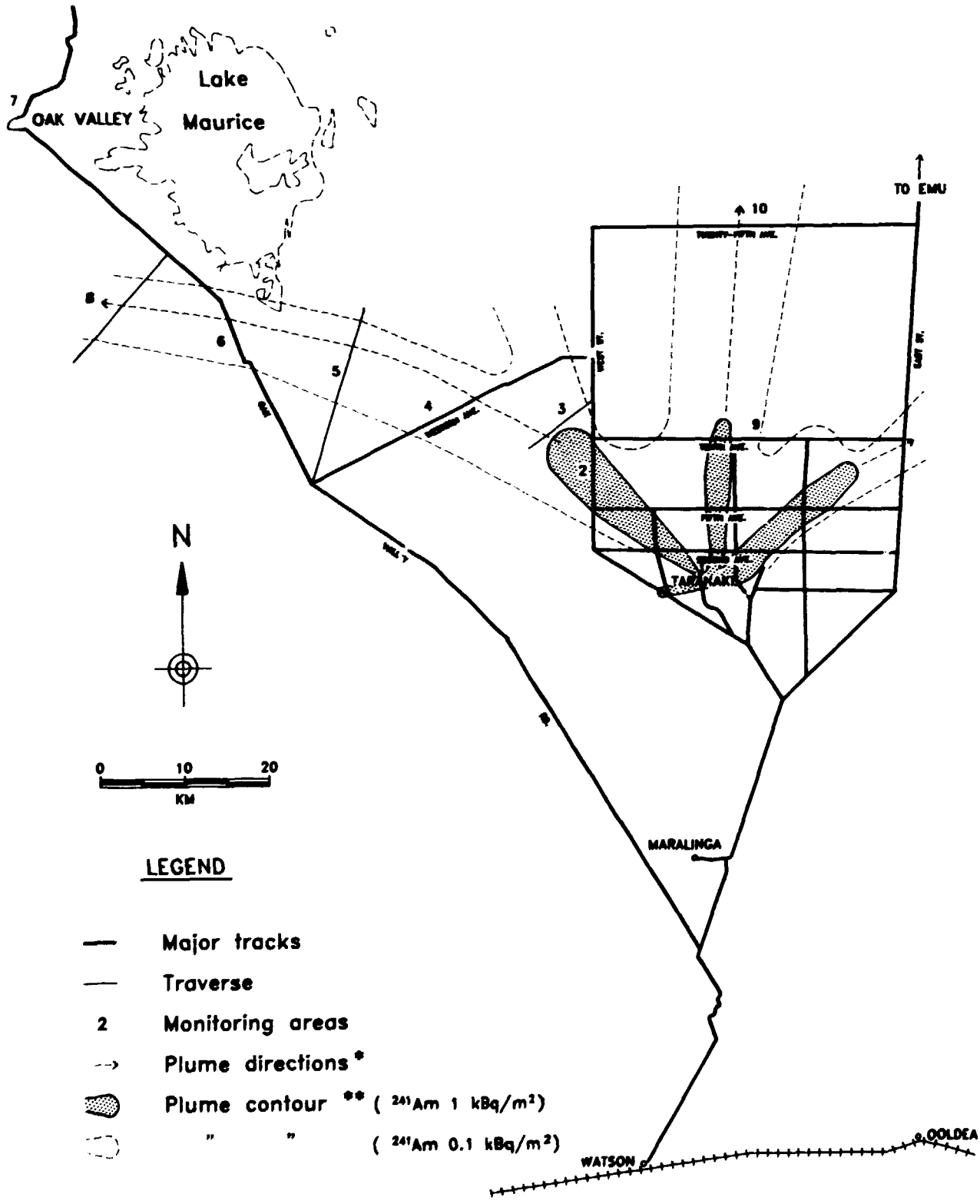

Figure 2. Map of the Maralinga area showing major tracks and Oak Valley. Measurement areas are identified (e.g. Area 1).

* Inferred directions of the major plumes are based on the present measurements, and are indicative only.

** Plume boundaries are based on this and previous ARL studies and are indicative only.

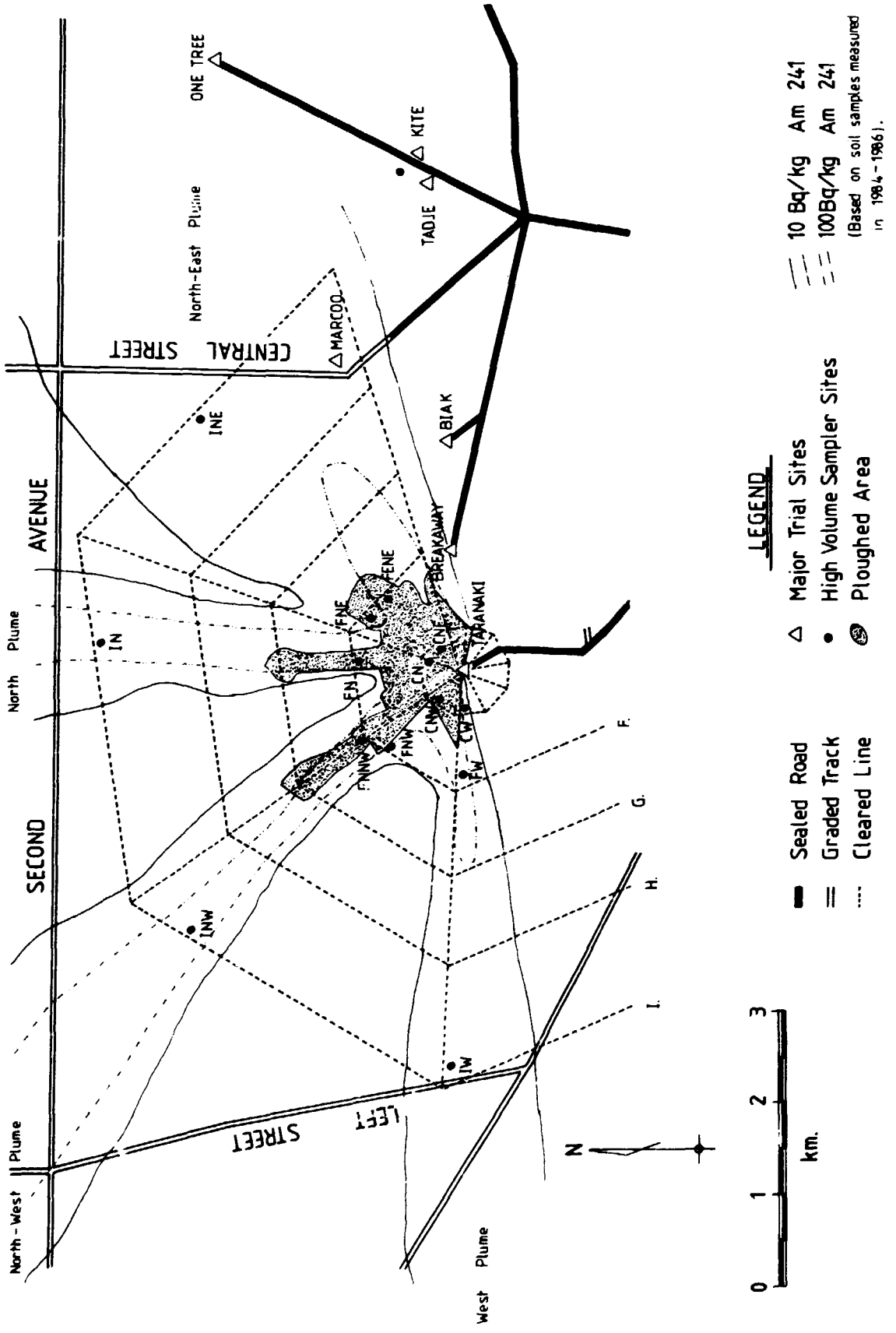

Figure 3. Map of the Taranaki area and major trial sites. High Volume Air Sampling sites are marked as are contours of ^{241}Am activity showing the plumes of plutonium contamination.

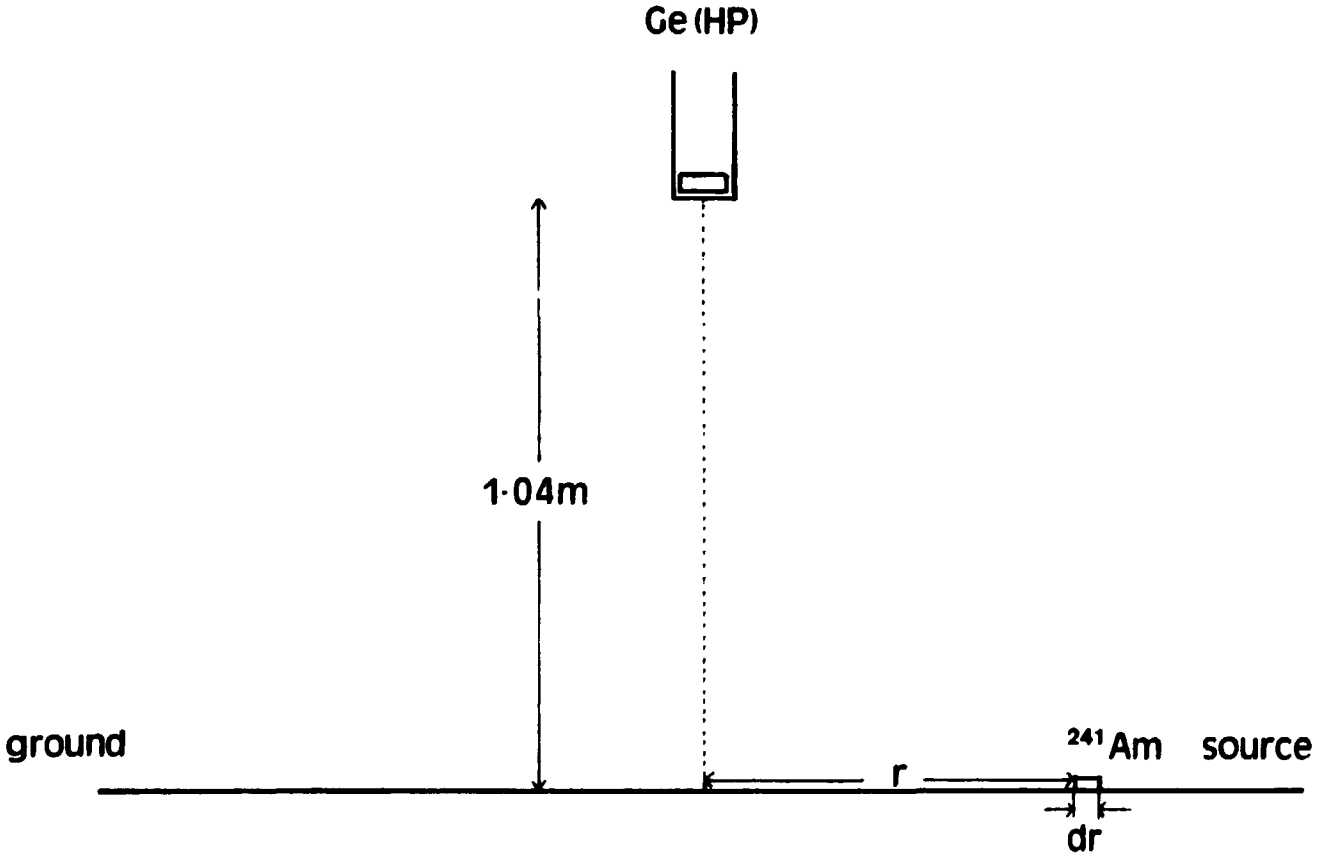

Figure 4. Geometrical relationship of source and detector for calibration procedure.

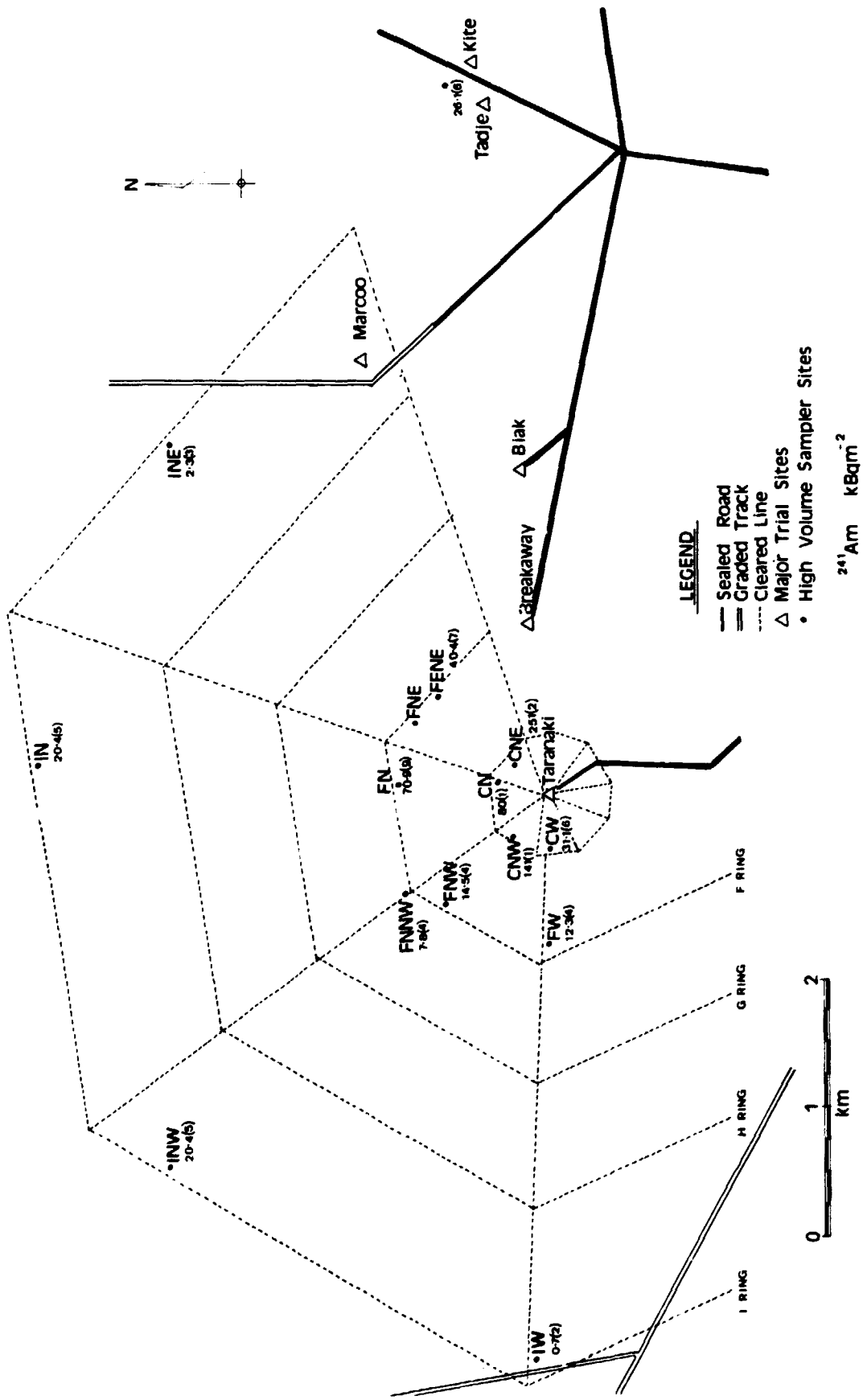

Figure 5. Locations of measurements and the resultant ^{241}Am activity densities in Area 1.

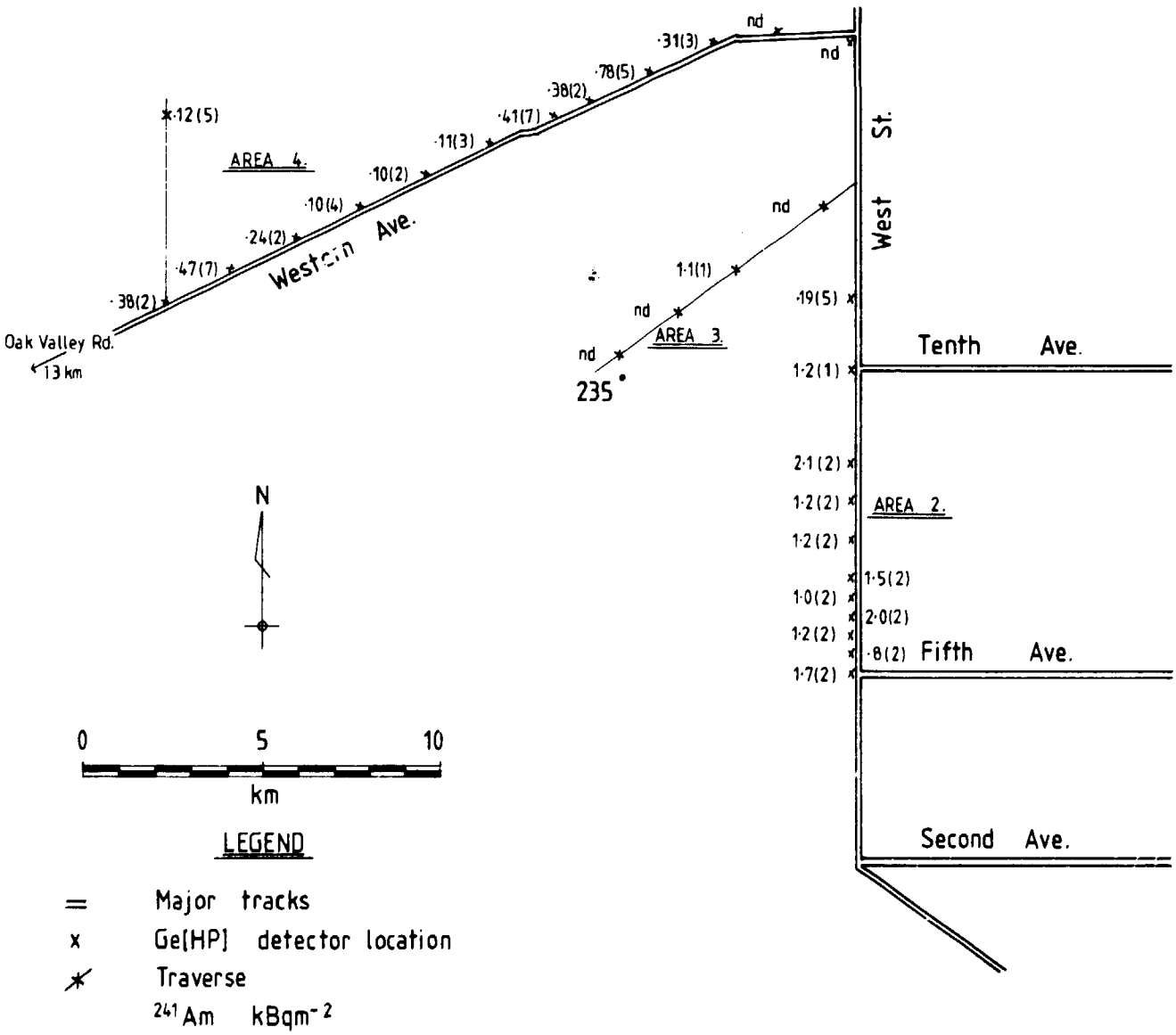

Figure 6. Locations of measurements and the resultant ^{241}Am activity densities in Area 2 and 3.

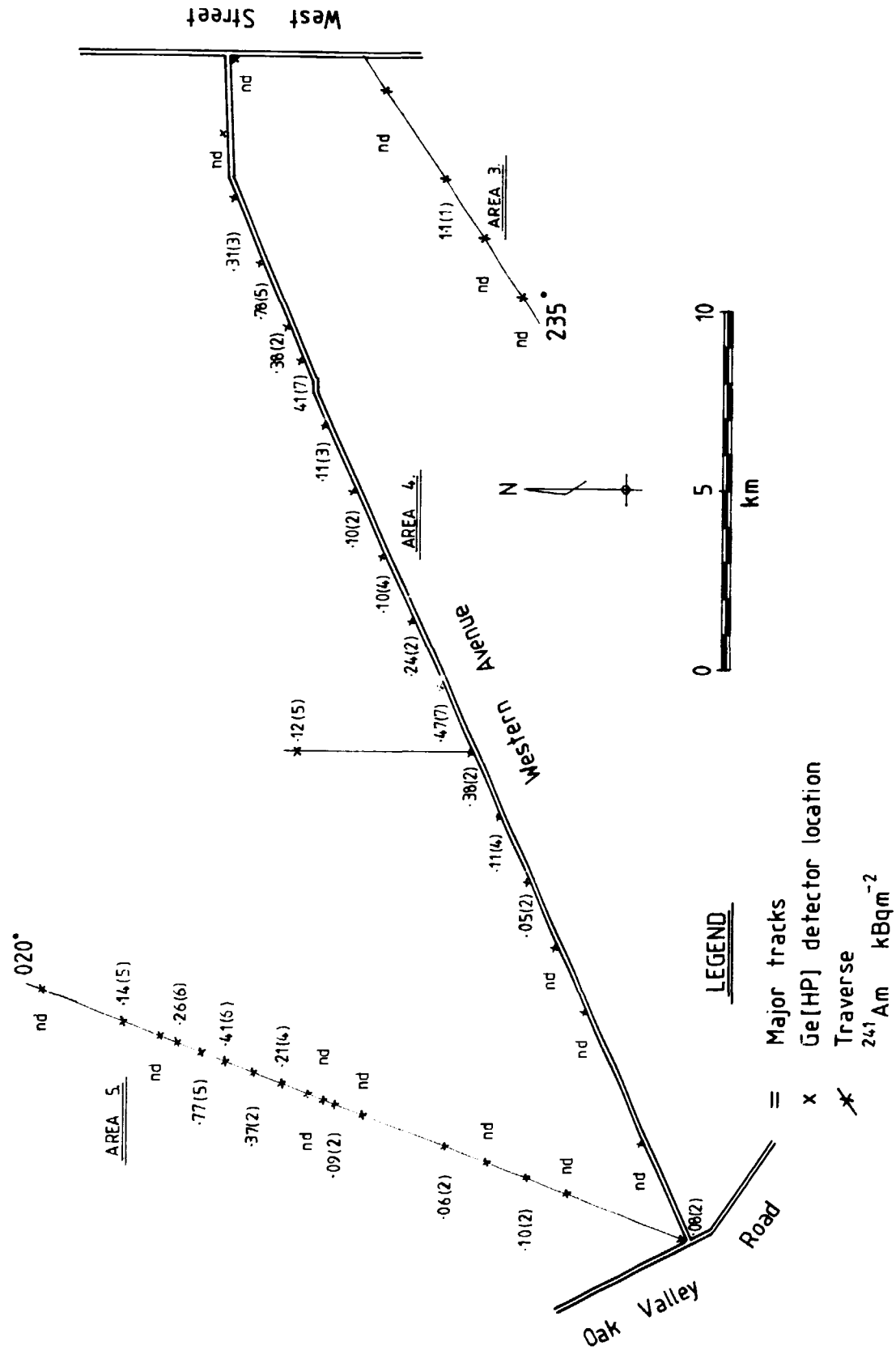

Figure 7. Locations of measurements and the resultant ^{241}Am activity densities in Area 3, 4 and 5.

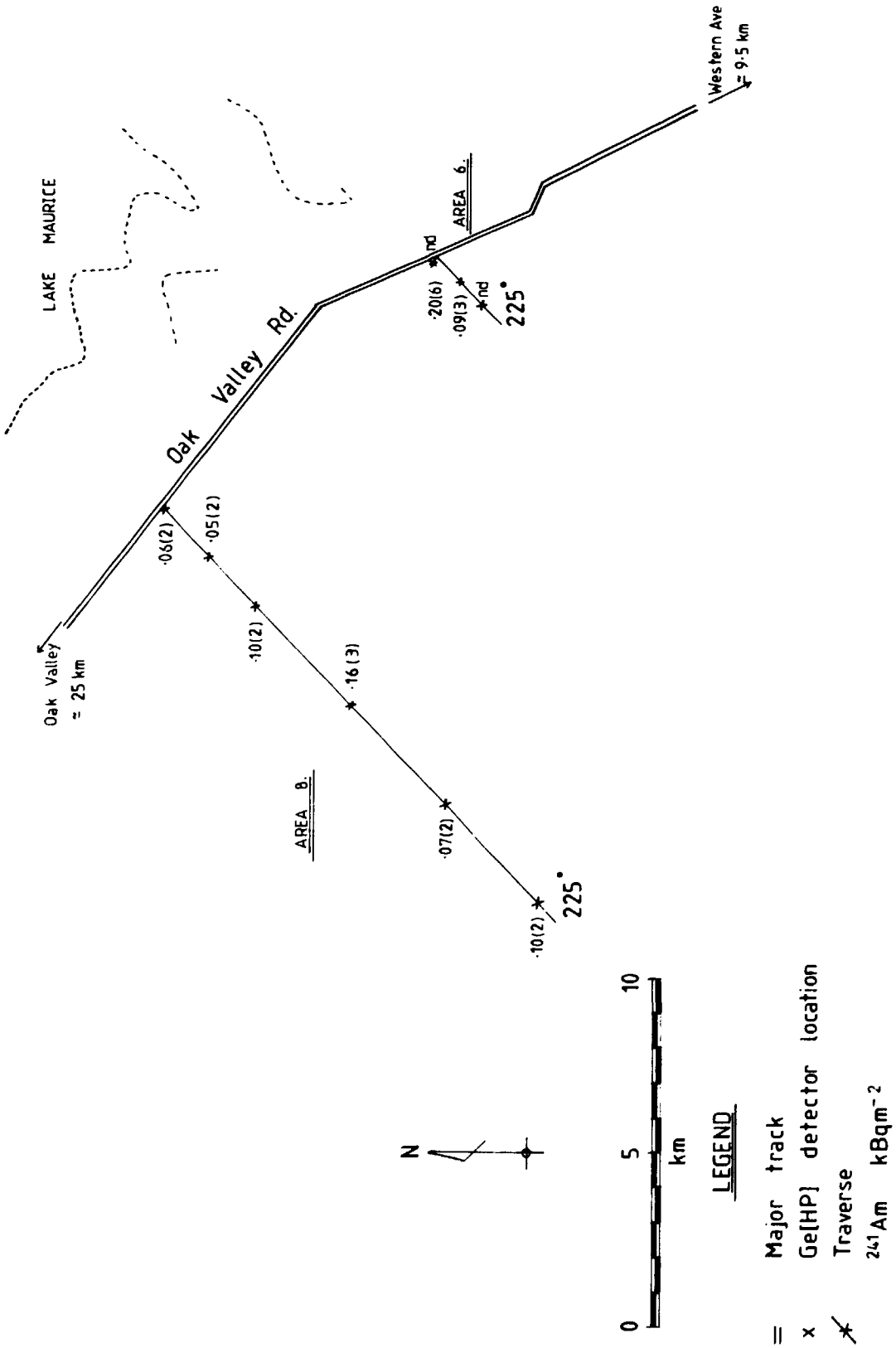

Figure 8. Locations of measurements and the resultant ^{241}Am activity densities in Area 6 and 8.

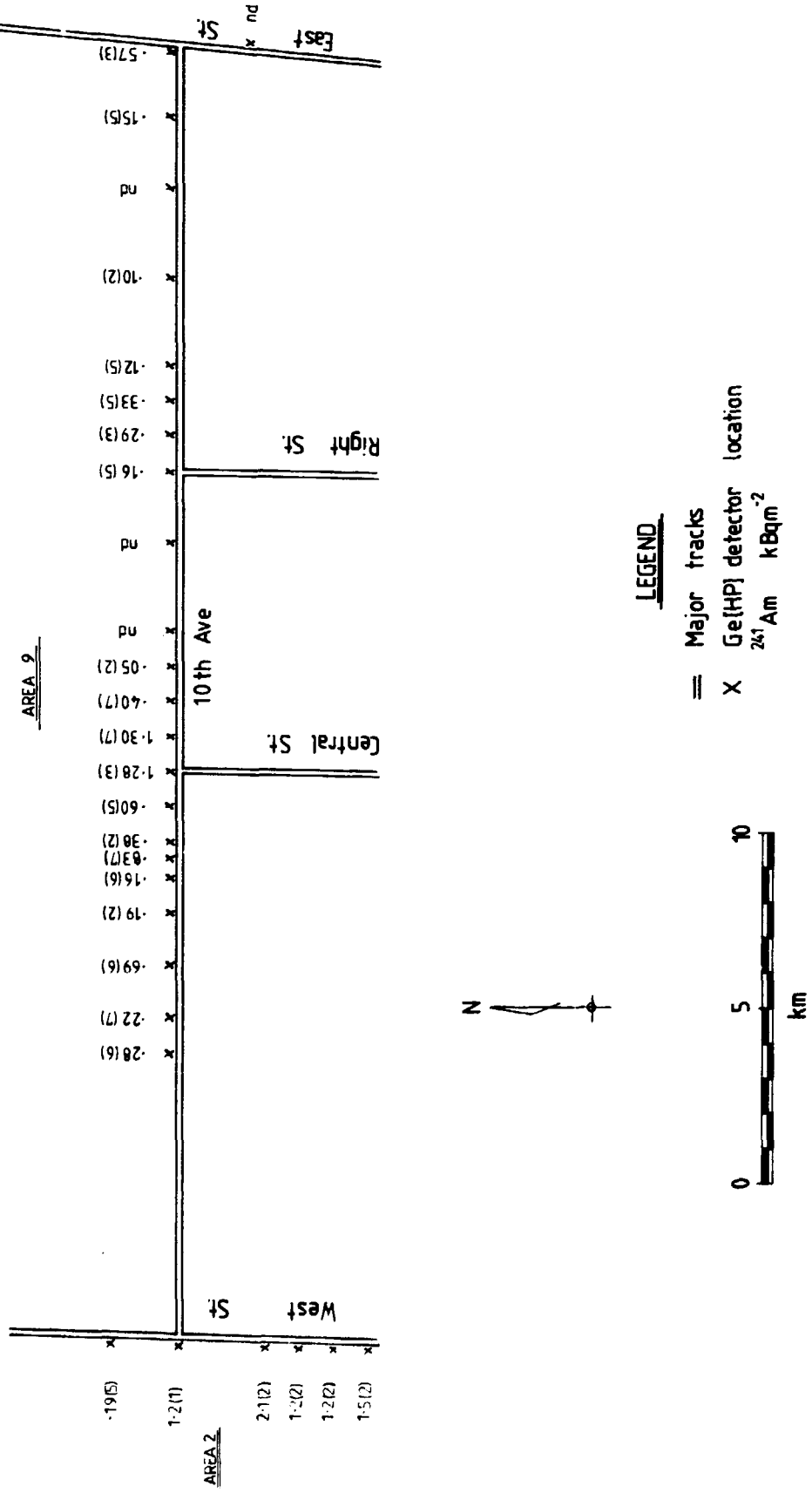

Figure 9. Locations of measurements and the resultant ^{241}Am activity densities in Area 9.

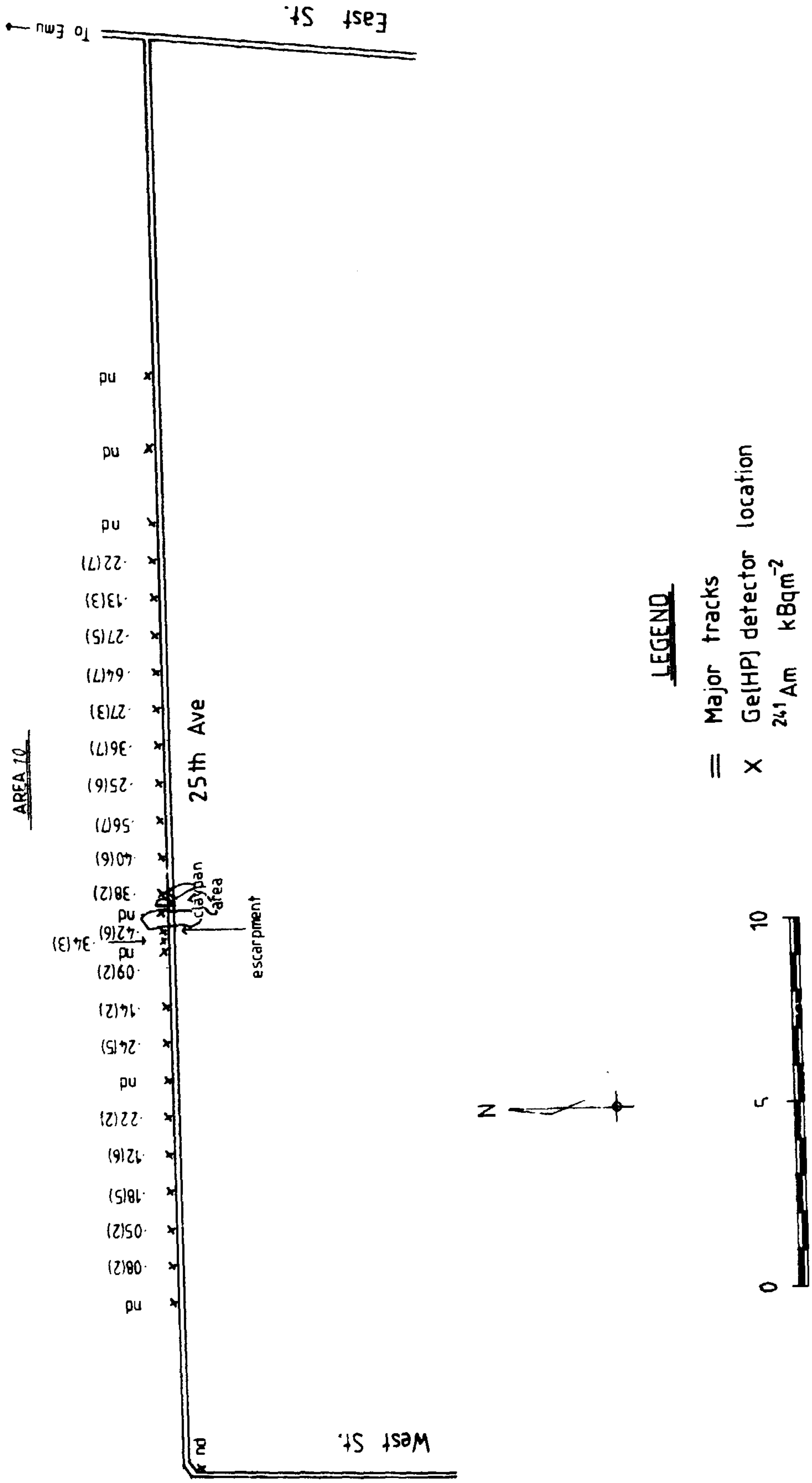

Figure 10. Locations of measurements and the resultant ^{241}Am activity densities in Area 10.