TRN AU8105537

COMMONWEALTH DEPARTMENT OF HEALTH

Australian Radiation Laboratory

Residual Radioactive Contamination of the Test Site at Emu from Nuclear Weapons Tests conducted in 1953

by

D.S. Maclagan, M.B. Cooper, J.C. Duggleby

ARL/TR 012
ISSN 0157-1400
AUGUST 1979

AUSTRALIAN RADIATION LABORATORY
LOWER PLENTY ROAD
YALLAMBIE VICTORIA 3085
TELEPHONE: 433 2211

AUSTRALIAN RADIATION LABORATORY

RESIDUAL RADIOACTIVE CONTAMINATION OF THE TEST SITE AT EMU FROM NUCLEAR WEAPONS TESTS CONDUCTED IN 1953

by

D.S. Maclagan, M.B. Cooper, J.C. Duggleby

ARL/TR012
ISSN 0157-1400
AUGUST 1979

LOWER PLENTY ROAD,
YALLAMBIE, VIC, 3085.
TELEPHONE: 433 2211

ABSTRACT

The detailed distributions and soil concentrations of long-lived radionuclides remaining from nuclear weapons trials conducted at Emu in October 1953, are presented in this study.

Significant radiation levels due to long-lived neutron activation products in soil - ^{60}Co and ^{152}Eu - occur only in the immediate vicinity of the ground zeros of TOTEM 1 and TOTEM 2.

It is shown that the levels of contamination due to fallout products in the soil are well below those which would constitute a health hazard to occupants of the area.

Introduction

The test site at Emu was the second to be used for full-scale field trials in the British program for developing nuclear weapons. The first site had been at the Monte Bello Islands in Western Australia where, in 1952, a nuclear device was detonated on an anchored ship. In order to provide more adequately for siting the arrays of instrumentation demanded by the scientific investigations, it was decided to carry out the second series of field trials at a land-based site. Emu, in the Great Victoria Desert of South Australia, was selected for this purpose. The location of Emu is shown in Figure 1.

In 1953 Operation TOTEM, comprising two full scale tests of nuclear weapons, was executed at Emu; details of the two trials are given in Table 1.

Table 1: Major trials conducted at Emu

Code Name	Date	Platform	Yield
TOTEM 1	15 Oct '53	tower	kiloton range
TOTEM 2	27 Oct '53	tower	kiloton range

While the remote desert location of Emu was essential to the nature and purpose of the field trials, it posed major problems for logistic support. Therefore, as Operation TOTEM was being planned and executed, another site affording readier access was being sought elsewhere (AIRAC 1979). Accordingly few lasting facilities were developed at Emu, the most notable being a natural clay-pan airstrip, a 232 km access track eastwards to Mabel Creek Homestead and a 205 km track southwards to Maralinga Village. Upon completion of Operation TOTEM, no further nuclear weapons trials were conducted at Emu and the site was abandoned.

As part of the trials operation, extensive radiological surveys were made of the close-in fallout fields immediately following the explosions and a year or so later. Subsequently Emu received only cursory health physics surveillance as part of the Woomera Rocket Range until, in 1966, it was investigated again in preparation for the rehabilitation of the two explosion sites. The 1966 study provided extensive data on the external radiation dose rates around the ground zeros and some limited information on activity concentrations of the soil contaminants. It was noted that heavy deposits of fused sand or "glazing", contaminated with fission products, remained around the ground zeros.

In 1967, in rehabilitating the former trials sites at Emu, "glazing" was the only residual radioactive contamination that it was feasible to clean up. The larger pieces were hand scavenged from around the ground zeros and then, in order to remove the smaller pieces from sight, circular regions of some 125 metre radius around each ground zero were tilled or covered with uncontaminated soil.

As with other tower mounted nuclear explosions (Cooper et al 1978; Cooper and Hartley 1979), residual radioactive contamination at Emu comprised neutron activation products formed in the soil around the ground zeros, and close-in fallout around and downwind of them.

Activation products are formed by irradiation of the soil with neutrons from the explosion. They generally describe roughly circular symmetry around ground zero, extending to greatest depth in soil closest to it. Residual radioactivity in close-in fallout derives mainly from fission products but is also likely to include some unspent fissile material and neutron activation products of the tower and weapons-related materials. Table 2 lists the radionuclides which are considered when evaluating any potential health hazard.

Table 2: Radionuclides remaining at Emu considered when evaluating potential hazards to health

Nuclide (radiation and half-life)*		Origin	Principal organ at risk	Pathway
ACTIVATION PRODUCT IN SOIL				
^{60}Co β, γ;	5.3 yr	^{59}Co (n, γ)	whole body	external radiation
^{152}Eu β, γ;	12.4 yr	^{151}Eu (n, γ)	whole body	" "
^{154}Eu β, γ;	7.8 yr	^{153}Eu (n, γ)	whole body	" "
CLOSE-IN FALLOUT				
^{60}Co β, γ;	5.3 yr	^{59}Co (n, γ)	whole body	external radiation
^{90}Sr-^{90}Y β;	27.7 yr	fission products	bone	ingestion
^{137}Cs-^{137m}Ba β,γ	30 yr	fission products	whole body	external radiation
^{155}Eu β, γ;	4.6 yr	fission products	whole body	external radiation
^{239}Pu α;	24390 yr	fissile material	lung & bone	inhalation
^{240}Pu α;	6580 yr	^{239}Pu (n, γ)	" " "	inhalation
^{241}Pu-^{241}Am α,β,γ	(13.2 yr, 458 yr)	^{240}Pu (n, γ)	" " "	inhalation

* Lederer et al (1967); Blachot and Fiche (1977)

For TOTEM 1 the close-in fallout was deposited with minimal wind shear and extended north east of ground zero in a classical narrow cigar shaped plume. By contrast, close-in fallout from TOTEM 2 was subjected to considerable wind shear so that the first part of the close-in fallout plume extended south-south west from ground zero for some two kilometres then broadened and veered to the south east. For both explosions the main cloud of radioactivity proceeded directly to the north east, crossing the coast in Northern Queensland.

A major radiological survey of Emu was made in 1978, completing the Laboratory's environmental studies of nuclear weapon test sites in Australia (Cooper et al 1978, Cooper & Hartley 1979). It is the purpose of this report to present results of that survey in order to allow assessment of the data in terms of the potential hazards to health.

The Environment of the Emu Test Site

The two ground zeros lie 1700 m from each other in an area known as Emu Plain in the Great Victoria Desert of South Australia. Land access can only be gained by four wheel drive vehicle along the tracks from Mabel Creek Homestead to the east and Maralinga Village to the south. A natural claypan airstrip approximately 20 km to the north-west of the test site may still be suitable for light aircraft, and a hard dirt road exists between the airstrip and the test site.

The ground zeros lie on a reasonably flat area, but a low ridge rises from near the ground zero of TOTEM 2 and runs in a general southerly direction, corresponding to the direction taken initially by close-in fallout from that test. In the immediate vicinity of the ground zeros there is a liberal covering of desert-type vegetation up to one metre high. Vegetation is well established at the actual ground zeros and the latter are only distinguishable from the surrounding areas by the dirt tracks which skirt them at a distance of some 30 metres. Between a half and one kilometre from the ground zeros there remain the skeletons of trees killed at the time of the explosions and, beyond about one kilometre, there are living trees up to six metres or so in height.

The ground surface throughout the region is of firm sandy soil with some patches of stones. The surface differs from that at Maralinga in that there is little evidence of drift sand. The sandy soil forms a hard surface crust upon which a person can usually walk without leaving footprints. However, a vehicle would generally break through the crust into the softer sand beneath. In some areas there is a complete surface coverage of small rounded stones on top of the soil. Near the ground zeros, there are patches of solid limestone a few centimetres below the surface preventing, in some cases, the taking of horizon samples to the planned depth of 120 mm.

It appears that much of the soil in the immediate vicinity of the two ground zeros, which had been tilled in 1967, and the uncontaminated soil, which had been used to cover the ground zeros at the same time, has since blown away. This conclusion is reached because,

- many small pieces of "glazing" lie on the surface near both ground zeros,
- fixed metal plates and bolts which formed the base of the tower for the TOTEM 1 test are now exposed, and
- a few small pieces of iron are exposed on the surface at TOTEM 2 ground zero.

There have been no prolonged meteorological observations at Emu, but one might expect the climatic conditions to be not dissimilar to those at Coober Pedy, which has a mean annual rainfall of 139 mm, spread fairly uniformly throughout the year, and a mean daily maximum temperature ranging from 18.6 ^{o}C in July to 36.6 ^{o}C in January (Bureau of Meteorology, 1975).

The Present Survey

The present survey was undertaken in November 1978 to establish the activity concentrations of radioactive contaminants in soil and vegetation and to determine radiation exposure levels. In general, the field procedures followed closely those used at Maralinga in a similar study and have been discussed elsewhere (Cooper et al 1978). The locations of the field survey sites were chosen to cover

- the areas around the ground zeros where neutron activation of the soil had occurred,
- the downwind areas where close-in fallout was known to have fallen, and
- an extension of these areas, so as to determine the extent and direction of any subsequent dispersal of radioactive material by weathering.

For each nuclear weapon test site, therefore, the survey points were arranged in two separate patterns

- a circular pattern around the ground zeros extending to 680 m, and
- a rectangular pattern covering the close-in fallout plume and areas on each side of it.

The array of survey points and their positions relative to the two ground zeros are shown in Figure 2.

(i) External Radiation Measurements.

At each designated survey point, external radiation measurements were made at a height of one metre above the ground using a Studsvik 'Gammameter'. The dose-rates were taken as the average over an area of approximately five metres radius around the survey point. The monitor was calibrated in the laboratory before and after the field survey, and frequent checks against a test source were made in the field. The dose-rates measured in the surveyed areas in the vicinity of TOTEM 1 and TOTEM 2 are shown in Figures 3 and 4 respectively.

All dose-rates in the rectangular grids covering the close-in fallout plumes were less than 16 μR/h, compared with background dose-rates of 5-11 μR/h measured at locations at Emu that were well away from the region contaminated by the plumes. Whilst each individual dose-rate reading in the grids was equal to or only slightly above the typical background dose-rate, the higher readings were concentrated in the areas of the original fallout plumes. Dose-rates of this magnitude are not a health hazard and are of limited scientific interest.

The much higher dose-rates measured in the circular pattern of survey points around each ground zero will be discussed in greater detail below.

(ii) Radioactivity in soil.

At the survey points designated for the collection of soil samples, a simple hand corer, 82 mm in diameter and 40 mm in depth, was used to extract the soil core. The masses of samples ranged from 250 g to 450 g. At each point, except where rocky terrain prevented the taking of the deeper samples, soil samples were taken from the following horizons:-

- surface to 40 mm
- 40 mm to 80 mm
- 80 mm to 120 mm

At each survey point in the rectangular grids two additional surface samples were taken to assess the variability of radionuclide concentrations. Similar sets of samples were taken at five points well away from the areas likely to be contaminated; these were used to determine background parameters. In all, 330 soil samples were collected from 82 sites.

Back at the Laboratory the soil samples were placed in standard polypropylene jars (85 mm diameter, 500 ml volume) and analysed by γ-spectrometry, using the method developed for similar samples collected in the Monte Bello Islands survey (Cooper & Hartley 1979). All samples were measured initially for 1000 seconds and 29 of them were then selected for measurement for 4000 or 10,000 seconds to validate the procedures and to improve statistics for some radionuclides.

The four radionuclides of greatest interest are ^{152}Eu, ^{60}Co, ^{137}Cs and ^{241}Am. Data on the concentrations of these radionuclides in the soil samples will be published in detail elsewhere (Cooper et al, 1979). The data relevant to the surface soil are here summarised in Figures 5 to 12. In these Figures, each dot represents a survey point where a set of soil samples was collected.

Because of the varying influences of other radionuclides on any portion of the gamma-ray spectrum, a unique minimum detectable level for each radionuclide cannot be determined which will apply to all soil samples. A "base level" has therefore been chosen for each radionuclide to represent the minimum detectable level which would apply in the worst conceivable case where the concentrations of other radionuclides in the sample are a maximum. For ^{241}Am and ^{152}Eu the "base level" is 0.5 nCi/kg, and for ^{137}Cs and ^{60}Co the "base level" is 0.2 nCi/kg. The soil concentration of a particular nuclide at a survey point is recorded in Figures 5 to 12 only where that concentration exceeded the "base level".

Data obtained from the analysis of soil collected during the 1977 survey of major trial sites at the Maralinga range had indicated that for a particular weapons trial the ratio of ^{90}Sr activity to ^{137}Cs activity in the soil close to ground zero is constant within the limits of overall measurement uncertainties (Cooper et al, 1978). This observation is consistent with studies of isotopic ratios in fallout extremely close to trials sites at the Nevada Range in USA (Heft, 1968). Therefore, in order to determine the ^{90}Sr concentration in soil it is only necessary to measure the ratio ($^{90}Sr/^{137}Cs$) for a limited number of amples at each site and apply this ratio to the ^{137}Cs concentrations measured by γ-spectrometry.

Results in Figures 7 and 11 indicate that ^{137}Cs concentrations are of significance only in regions in close proximity to the ground zeros of TOTEM 1 and TOTEM 2. Consequently, samples for ^{90}Sr analysis were selected from survey points in these areas. Six samples from each trial site were analysed for ^{90}Sr concentrations by the modified ARL procedure for calcareous soils (Cooper et al, 1978). The ratio $^{90}Sr/^{137}Cs$ was calculated for each of the chosen samples and the results for both trial sites were found to be very similar. For samples collected very close to the ground zeros, the mean value for the ratio was 0.18 ± 0.09. It was found that for samples collected beyond 100 metres from ground zero, the ratio was consistently below 0.10. By applying the ratios to the data for ^{137}Cs soil concentrations throughout the Emu area, it can be concluded that ^{90}Sr concentrations in surface soil are well below levels that would present a hazard to health for an occupant of the area.

(iii) Plutonium in Soil.

Two additional isotopes of plutonium, ^{240}Pu and ^{241}Pu are produced by neutron capture during the manufacture of ^{239}Pu for nuclear weapons material; they may also be formed by neutron activation of the weapons material during the explosion itself. For a particular explosion, therefore, the three isotopes of plutonium will be present in the close-in fallout in constant proportions. Thus, the presence of plutonium was detected by ^{241}Am, a decay product which has an accessible γ-ray spectrum. The concentration of $^{239,240}Pu$ was measured using an ion-exchange process followed by α-counting (Cooper and Hartley 1979).

The $^{239,240}Pu/^{241}Am$ ratio was determined in a total of four samples; three from TOTEM 2 and one from TOTEM 1. Only one sample was chosen from TOTEM 1 as it was the only one with a significant concentration of ^{241}Am. The concentrations of $^{239,240}Pu$ and the ratios ($^{239.240}Pu/^{241}Am$) for the selected samples are presented in Table 3.

Table 3: Concentrations of Plutonium ($^{239,240}Pu$) in selected soil samples and ratios of ($^{239,240}Pu/^{241}Am$)

Sample Code	Location	Activity (nCi/kg) $^{239,240}Pu$	Activity (nCi/kg) ^{241}Am	Ratio ($^{239,240}Pu/^{241}Am$)
	TOTEM 1			
104 A0	25 m G.Z.	736	31.2	23.5
	TOTEM 2			
204 A0	25 m G.Z.	687	41.2	16.7
207 A0	" "	597	62	9.6
210 A0	150 m G.Z.	670	65	10.3

(iv) Vegetation.

Four samples of vegetation were collectad, one near each ground zero and one in each close-in fallout area. Only the tips of the plants were collected as these are the most likely parts to be grazed. The samples were ashed, without being washed, and then analysed for radionuclide content by γ-spectrometry. The results, presented in Table 4 as nCi/kg of fresh material, are similar to those obtained during the Maralinga survey (Cooper et al 1978).

Table 4: Concentrations of principal radionuclides in vegetation samples

Region Sampled	Activity (nCi/kg) tissue ^{152}Eu	^{137}Cs	^{60}Co
TOTEM 1 GZ	3.8	0.15	0.94
TOTEM 1 Fallout area	-	-	-
TOTEM 2 GZ	3.9	0.39	0.55
TOTEM 2 Fallout area	-	0.04	-

Discussion

Figures 5 to 12 show the average concentrations in the top 40 mm layer of soil of the radionuclides ^{152}Eu, ^{60}Co, ^{137}Cs and ^{241}Am. The fallout radionuclides ^{137}Cs and ^{241}Am display similarities in their distributions which are different from the distribution characteristics of the activation products ^{152}Eu and ^{60}Co. It is immediately obvious that, as would be expected, ^{137}Cs and ^{241}Am are distributed throughout the fallout areas and the immediate environs of the ground zeros, whereas ^{152}Eu and ^{60}Co are restricted to near the ground zeros.

Each point in the rectangular grids, which cover the fallout areas, represents the average of three surface soil samples. It was found when compiling these averages that there is usually a wide variation in the concentrations of each radionuclide within the three samples. Similarly, near the ground zeros, the concentrations of the fallout products show wide variations between adjacent sampling points. Therefore, other than a tendency for the fallout products to be more concentrated in the soil near the ground zeros, their present distribution within the contaminated areas is haphazard. Although not shown in the Figures, the fallout products are generally restricted to the top 40 mm of soil in the fallout plume areas where one would expect little or no human interference to the soil structure since 1953. Near the ground zeros, the top layer of soil contains the bulk of the two fallout products, but they also appear in smaller concentrations in a few of the samples from the lower layers; this can be attributed to the tilling of the soil during the 1967 clean-up operations.

The distribution patterns of the activation products ^{152}Eu and ^{60}Co in the soil around the ground zeros are very similar to each other. In both cases there is strong circular symmetry around each ground zero with the radionuclide concentrations decreasing rapidly with increasing distance. Though not shown in the Figures, the concentrations in the 40-80 mm and 80-120 mm soil layers are generally comparable with those in the top layer at a given point. If one accepts that the relaxation depth* for the radionuclide distribution is 38 cm to 40 cm, as assumed for the Maralinga survey (Cooper et al 1978), the concentration of activation radionuclides at a given point would be fairly uniform throughout the top 120 mm of soil. Any disturbance to the surface layers of soil which might have occurred in 1967 would not radically alter this pre-existing uniform concentration.

It will be noted that at the end of the rectangular grid nearest to the ground zero of TOTEM 1 (Figures 5, 6), ^{60}Co was recorded in surface samples at two points and ^{152}Eu at four points. In each case there was no activation product detected below 40 mm in contrast to the points nearer ground zero where the products extend well below the surface. One must assume that the activation products detected at the points within the rectangular grid arrived there by prevailing wind dispersion from points nearer to ground zero. This effect would not be detected in the rectangular

*Relaxation depth is the soil depth at which the radionuclide concentration falls by 1/e.

grid of TOTEM 2 which lies in the opposite direction with respect to ground zero. This indicates that downwind dispersion of radionuclides over the past twenty six years has been small, extending for a distance of the order of a kilometre.

As seen in Figures 3 and 4, the only areas remaining at Emu where the external radiation exposure levels are significantly above normal background levels are in the immediate vicinity of the two ground zeros. Approximately 175 metres from TOTEM 1 ground zero and 150 metres from TOTEM 2 ground zero the γ-dose rates fall below 57 μR/h, the limit recommended for continuous exposure for members of the public (NHMRC, 1977).

In order to represent the decreasing dose-rate with time the curve generated for the study at Maralinga (Cooper et al, 1978) can be used for the period 1977 onwards. Applying this curve which is presented in Figure 13, to the ground zero dose-rates in Figures 3 and 4 it can be seen that the maximum dose-rates will have diminished to 57 μR/h by 2024 AD for TOTEM 1 ground zero and 2020 AD for TOTEM 2 ground zero.

For a visitor to the area, the only significant path for intake of radionuclides is by inhalation of airborne contaminants. Under normal conditions, dust loadings in the atmosphere are unlikely to exceed 1 mg/m^3, although it is possible that higher dust loadings may be raised from time to time under adverse conditions (Trefry, 1978).

Table 5 presents the average surface soil concentrations within a radius of 150 metres of the ground zeros together with airborne concentrations based on dust loadings of 10 mg/m^3. Maximum recommended limits for continuous exposure to these isotopes are also presented (ICRP, 1959). It is apparent from this Table that plutonium is the only contaminant of significance, in this context. For TOTEM 2, with a dust loading of 10 mg/m^3, the airborne concentration is five times the recommended limit for continuous exposure. Therefore the allowed occupancy factor at this dust loading would be 0.2 or 1750 hours per year. For TOTEM 1 ground zero, the airborne concentration is equal to the limit at this dust loading and continuous exposure would be permissible. In both grids covering the close-in fallout plumes the concentrations were lower and well within the recommended limits.

Table 5: Worst case estimates for airborne contaminants.

Isotope	Average Concentration within 150 m of G.Z. (nCi/kg)		Corresponding Concentration in air ($\mu Ci/cm^3$)		Maximum Recommended Limit ($\mu Ci/cm^3$)
	TOTEM 1	TOTEM 2	TOTEM 1	TOTEM 2	
^{60}Co	32	19	3.2×10^{-13}	1.9×10^{-13}	1×10^{-7}
^{90}Sr	35	55	3.5×10^{-13}	5.5×10^{-13}	4×10^{-10}
^{137}Cs	28	44	2.8×10^{-13}	4.4×10^{-13}	2×10^{-8}
^{152}Eu	300	190	3×10^{-12}	1.9×10^{-12}	2×10^{-7}
$^{239,240}Pu$	70	192	7×10^{-13}	1.9×10^{-12}	6×10^{-13}
^{241}Am	3	16	3×10^{-14}	1.6×10^{-13}	2×10^{-12}

Acknowledgements

The authors wish to acknowledge the generous co-operation of the South Australian Health Commission for providing the technical assistance of M. Scanlan in the field work, and of Mrs. J. Fitch, in particular, for much helpful advice during the planning of the survey.

We wish also to acknowledge the invaluable assistance of the other members of the party who executed the field survey during November 1978, namely, P. Smith (ARL); P. Rumbold, J. Wohling and R.J. Graham (Australian Survey Office, South Australian Branch); R. Robinson (Dept. of Defence, Woomera).

The authors are particularly grateful for the contributions of the other officers from ARL who participated in the various stages of the survey, namely, F. Armenio, A. Coventry, A. Farrugia, B. Joyce, L. Kotler, D. Tingey, P. Van Velzen and K. Wise. The contributions of Mr. J. Moroney for his advice and guidance during the project are much appreciated.

References:

AIRAC (1979). "Radiological safety and future land use at the Maralinga atomic weapons test range". The Australian Ionising Radiation Advisory Council Report No. 4, January 1979.

Blachot, J. and Fiche, C. (1977), Atomic Data and Nuclear Data Sheets 20, 241.

Bureau of Meteorology (1975), Climatic Averages, South Australia.

Cooper, M.B., Duggleby, J.C., Kotler, L.H. and Wise, K.N., (1978) "Residual Radioactive Contamination of the Maralinga Range from Nuclear Weapons Tests conducted in 1956 and 1957", Australian Radiation Laboratory Report No. ARL/TR005, November 1978.

Cooper, M.B., Duggleby, J.C., Maclagan, D., Kotler, L.H., (1979) "Field and Analytical Data from the 1978 Surveys of the Atomic Weapons Test Ranges at the Monte Bello Islands and Emu", Australian Radiation Laboratory Report - in preparation.

Cooper, M.B. and Hartley, B.M., (1979), "Residual Radioactive Contamination of the Monte Bello Islands from nuclear weapons tests conducted in 1952 and 1956", Australian Radiation Laboratory Report No. ARL/TR010, April 1979.

Heft, R.E. (1968). "The characterization of radioactive particles from nuclear weapons tests". Advances in Chemistry Series 93, 254-281 (1968).

ICRP (1959), "Recommendations of the International Commission on Radiological Protection". Report of Committee II on Permissible Dose for Internal Radiation 1959 ICRP Publication 2, 1959.

Lederer, C.M., Hollander, J.M., Perlman, I. (1967), "Table of Isotopes" 6th Ed., J. Wiley & Sons, New York, 1967.

NHMRC (1977), "Revised radiation protection standards for individuals exposed to ionising radiation", National Health and Medical Research Council, Canberra, 1977.

Trefry, G.R. (1978), "Soil suspension and migration at Maralinga". Bureau of Meteorology Report, 1978.

FIGURE CAPTIONS

Figure 1. Map of Emu Area.

Figure 2. Relative locations of TOTEM 1 and TOTEM 2 with the network of sampling points.

Figure 3. Gamma Ray Dose distributions in the survey area around TOTEM 1.

Figure 4. Gamma Ray Dose distributions in the survey area around TOTEM 2.

Figure 5. Concentrations of ^{152}Eu (nCi/kg) in surface soil at survey points around TOTEM 1.

Figure 6. Concentrations of ^{60}Co (nCi/kg) in surface soil at survey points around TOTEM 1.

Figure 7. Concentrations of ^{137}Cs (nCi/kg) in surface soil at survey points around TOTEM 1.

Figure 8. Concentrations of ^{241}Am (nCi/kg) in surface soil at survey points around TOTEM 1.

Figure 9. Concentrations of ^{152}Eu (nCi/kg) in surface soil at survey points around TOTEM 2.

Figure 10. Concentrations of ^{60}Co (nCi/kg) in surface soil at survey points around TOTEM 2.

Figure 11. Concentrations of ^{137}Cs (nCi/kg) in surface soil at survey points around TOTEM 2.

Figure 12. Concentrations of ^{241}Am (nCi/kg) in surface soil at survey points around TOTEM 2.

Figure 13. Time Distribution of γ-ray dose near ground zeros normalised to unity in November 1978.

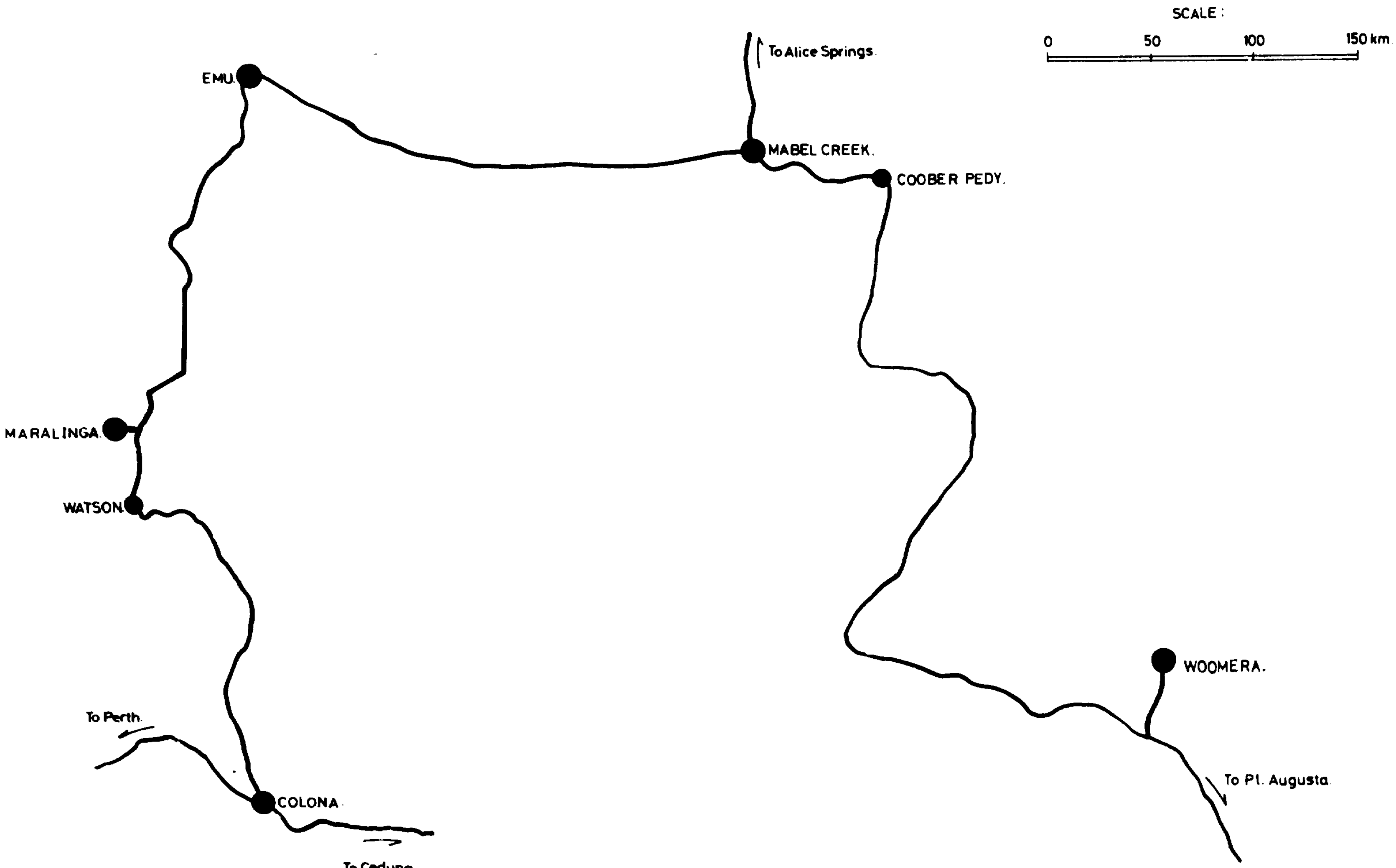

SCALE :
0
50
100
150 km
To Alice Springs.
EMU.
MABEL CREEK.
COOBER PEDY.
MARALINGA.
WATSON.
WOOMERA.
To Perth.
COLONA.
To Pt. Augusta.
To Ceduna.

FIG 1.

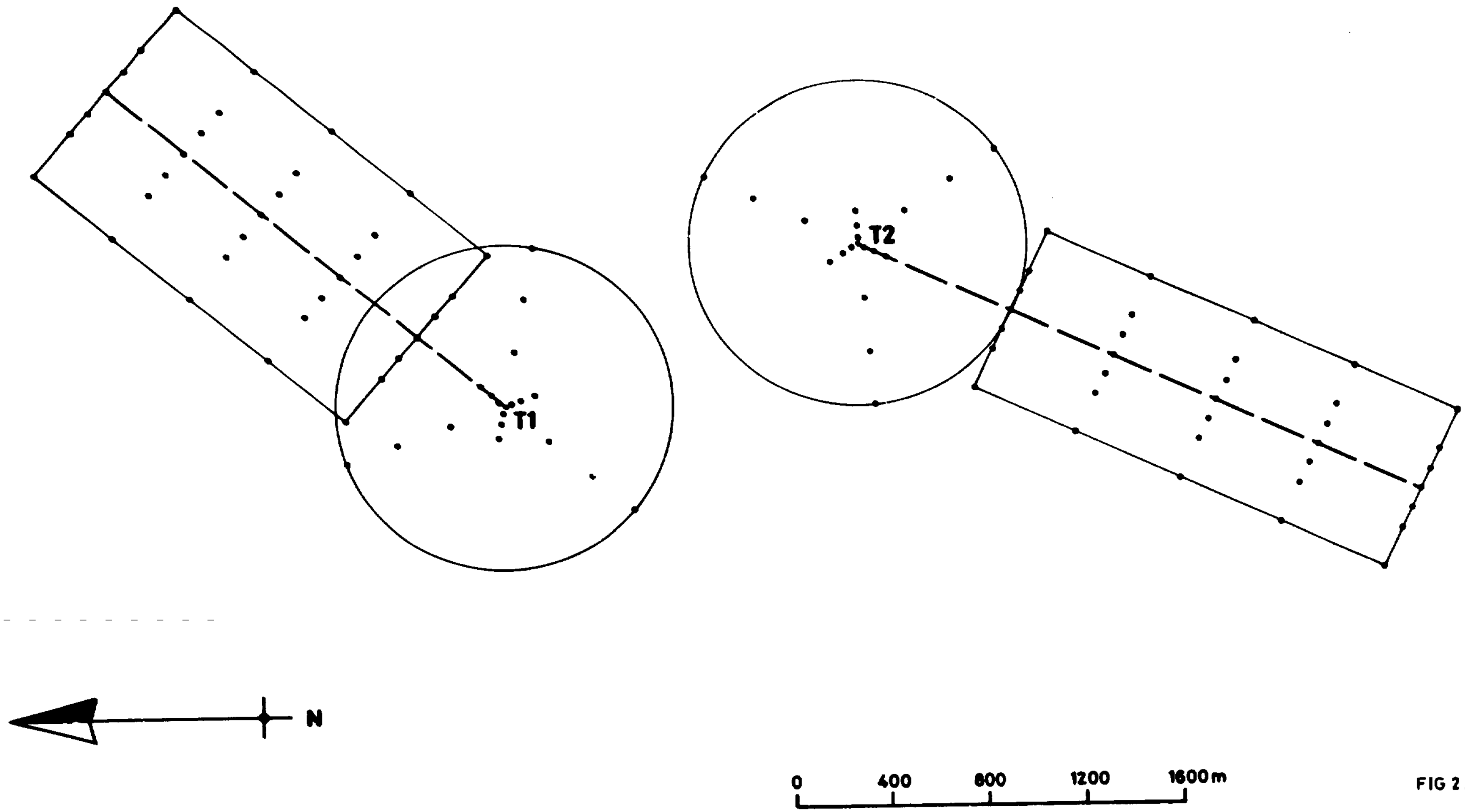
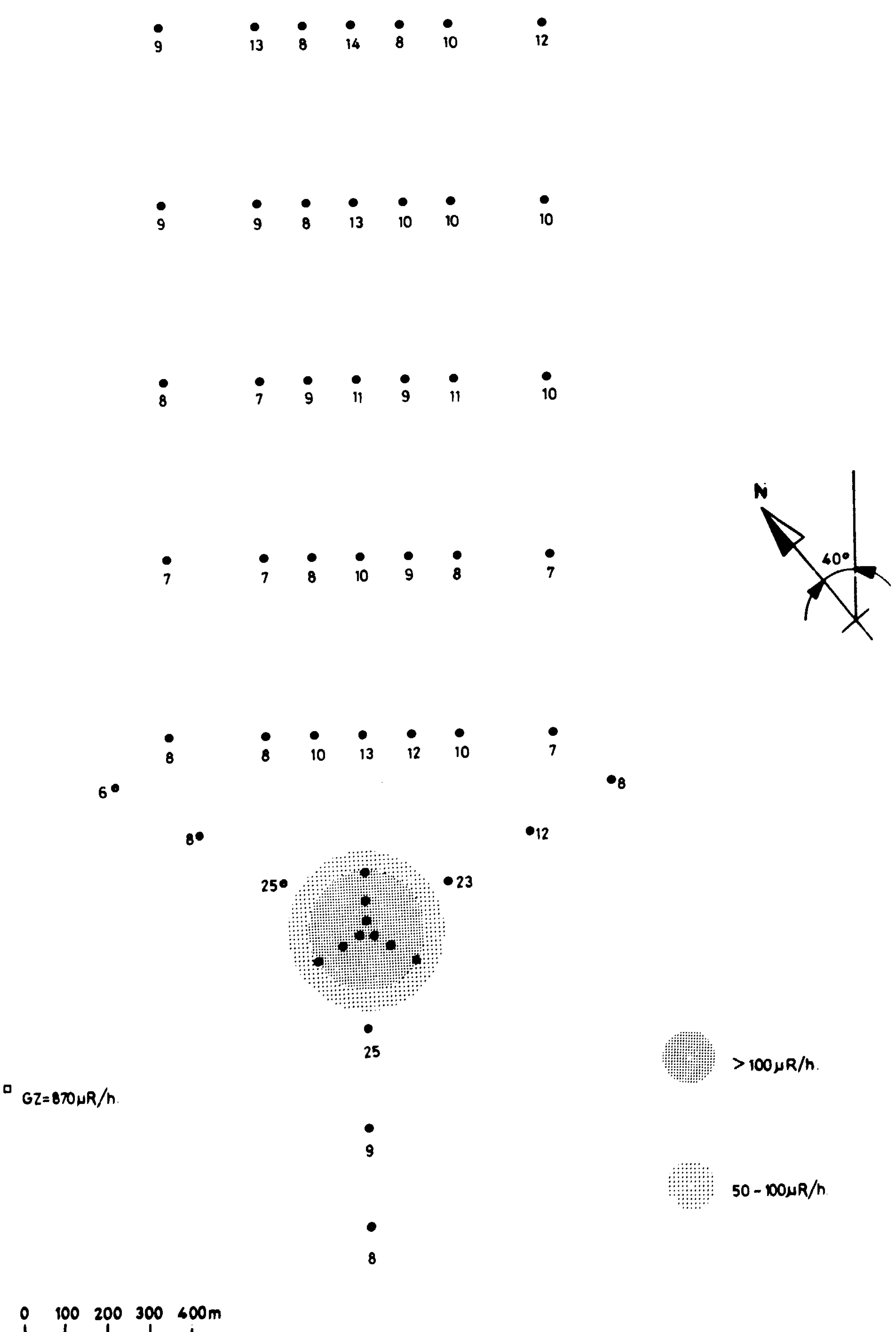
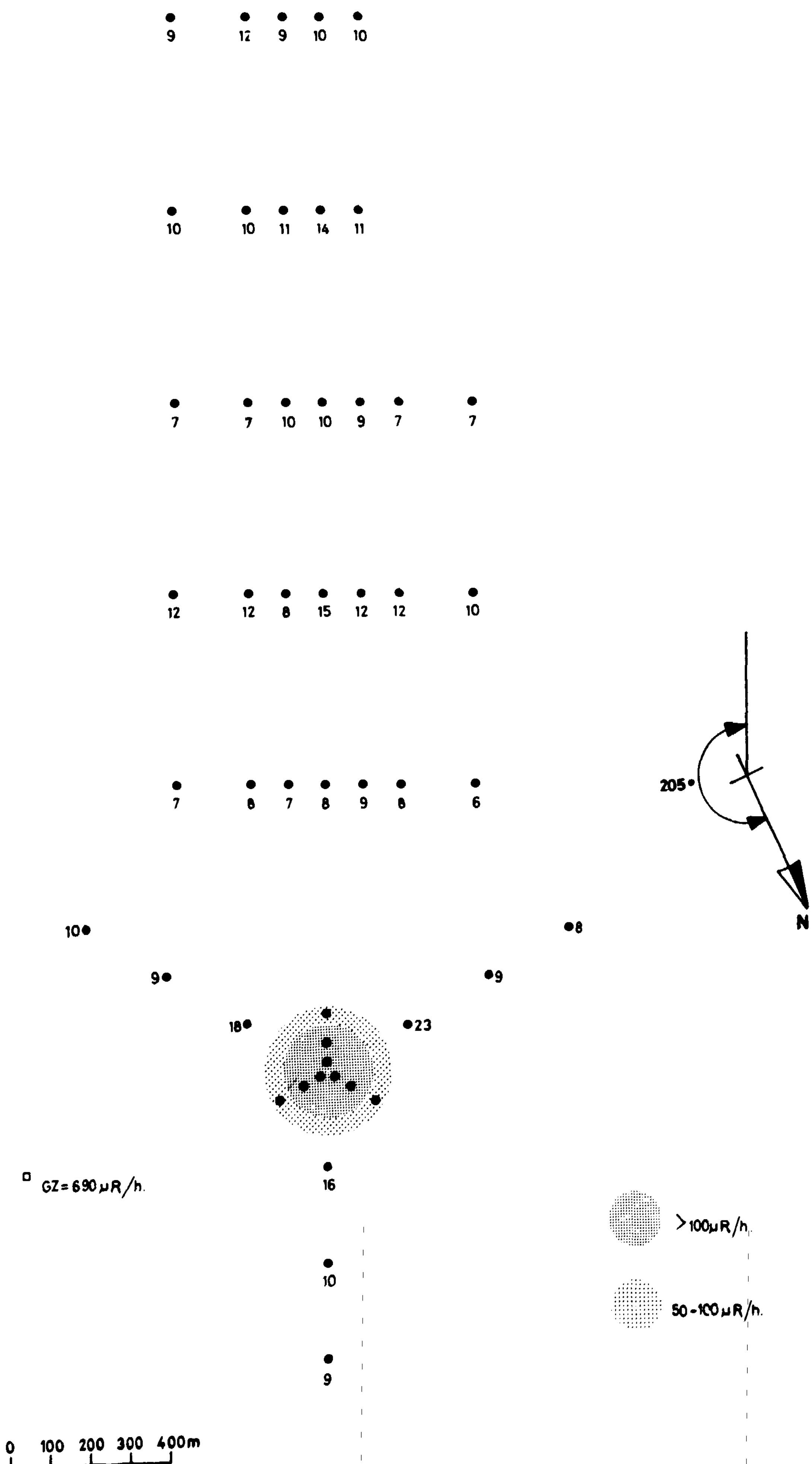


FIG 2.



9 13 8 14 8 10 12
9 9 8 13 10 10 10
8 7 9 11 9 11 10
7 7 8 10 9 8 7
8 8 10 13 12 10 7
6
8
8
12
25
23
25
9
8
N
40°
>100µR/h
50-100µR/h
GZ=870µR/h
0 100 200 300 400m

FIG 3



9 12 9 10 10
10 10 11 14 11
7 7 10 10 9 7 7
12 12 8 15 12 12 10
7 8 7 8 9 8 6
10
8
9
9
18
23
205°
N
GZ = 690 μR/h.
16
10
9
>100μR/h.
50-100μR/h.
0 100 200 300 400m

FIG 4.

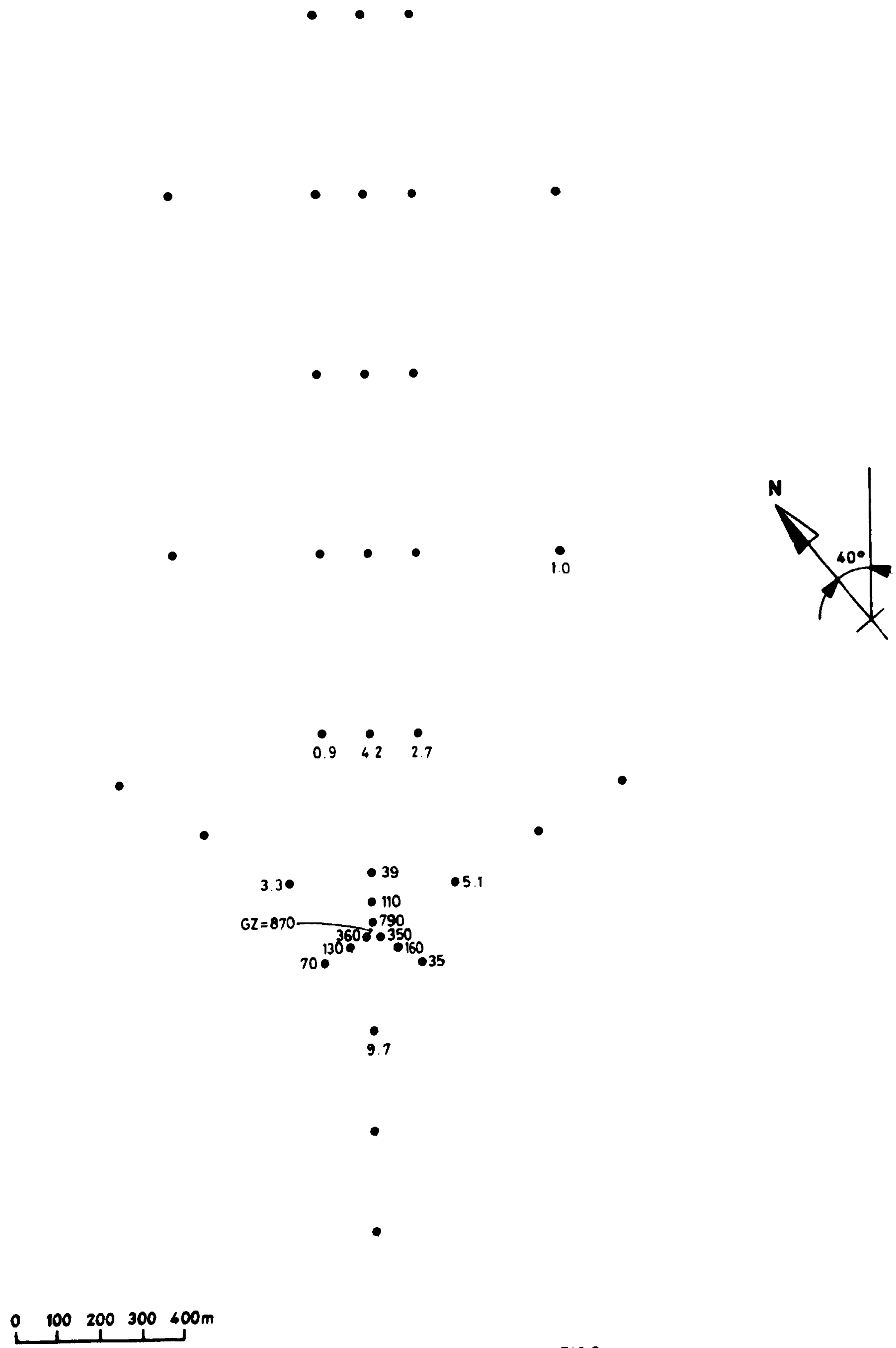
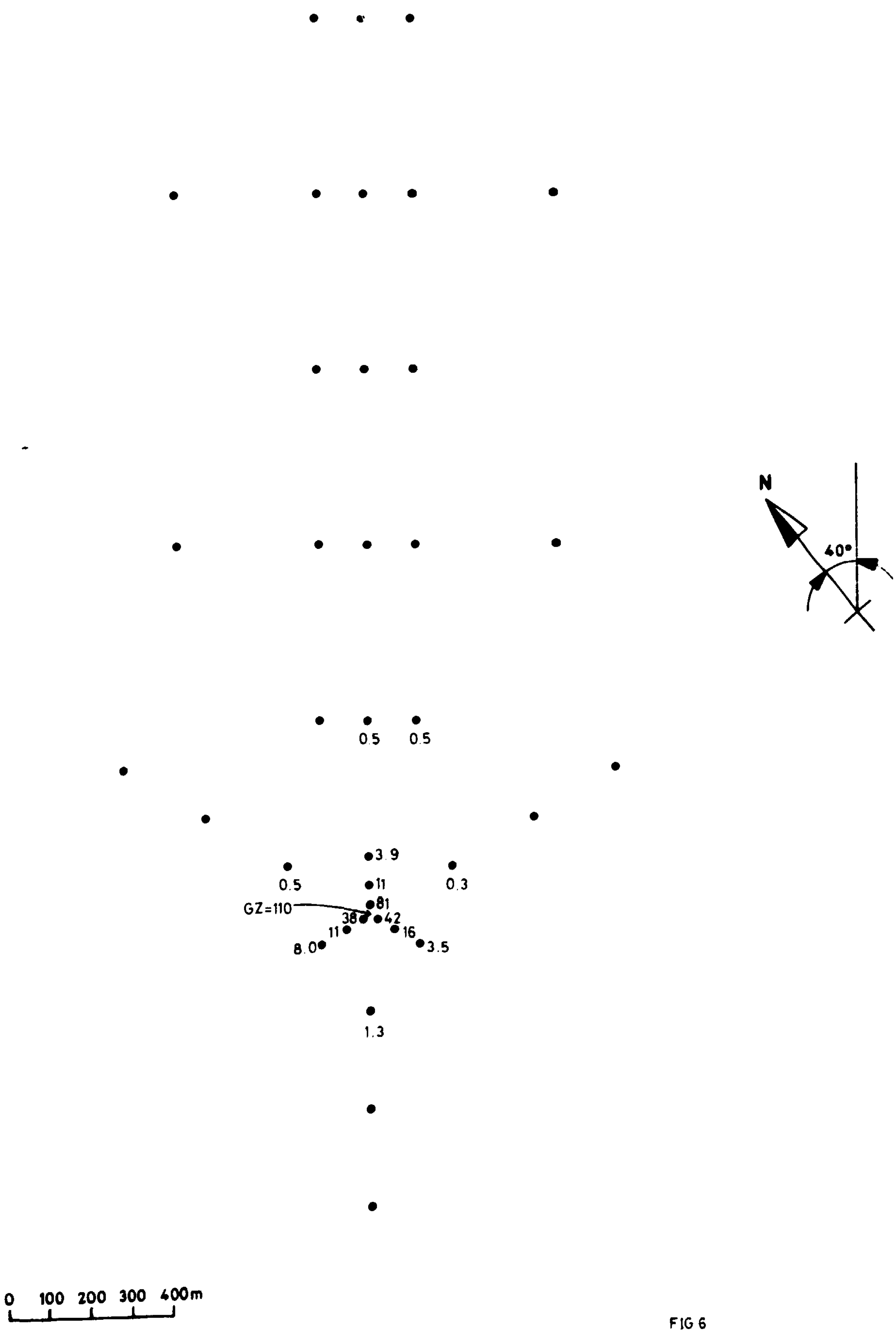

1.0
0.9
4 2
2.7
39
3.3
5.1
110
GZ=870
790
360
350
130
160
70
35
9.7
N
40°
0 100 200 300 400m

FIG 5.



N
40°
0.5
0.5
3.9
0.5
11
0.3
GZ=110
81
38
42
11
16
8.0
3.5
1.3
0 100 200 300 400m

FIG 6

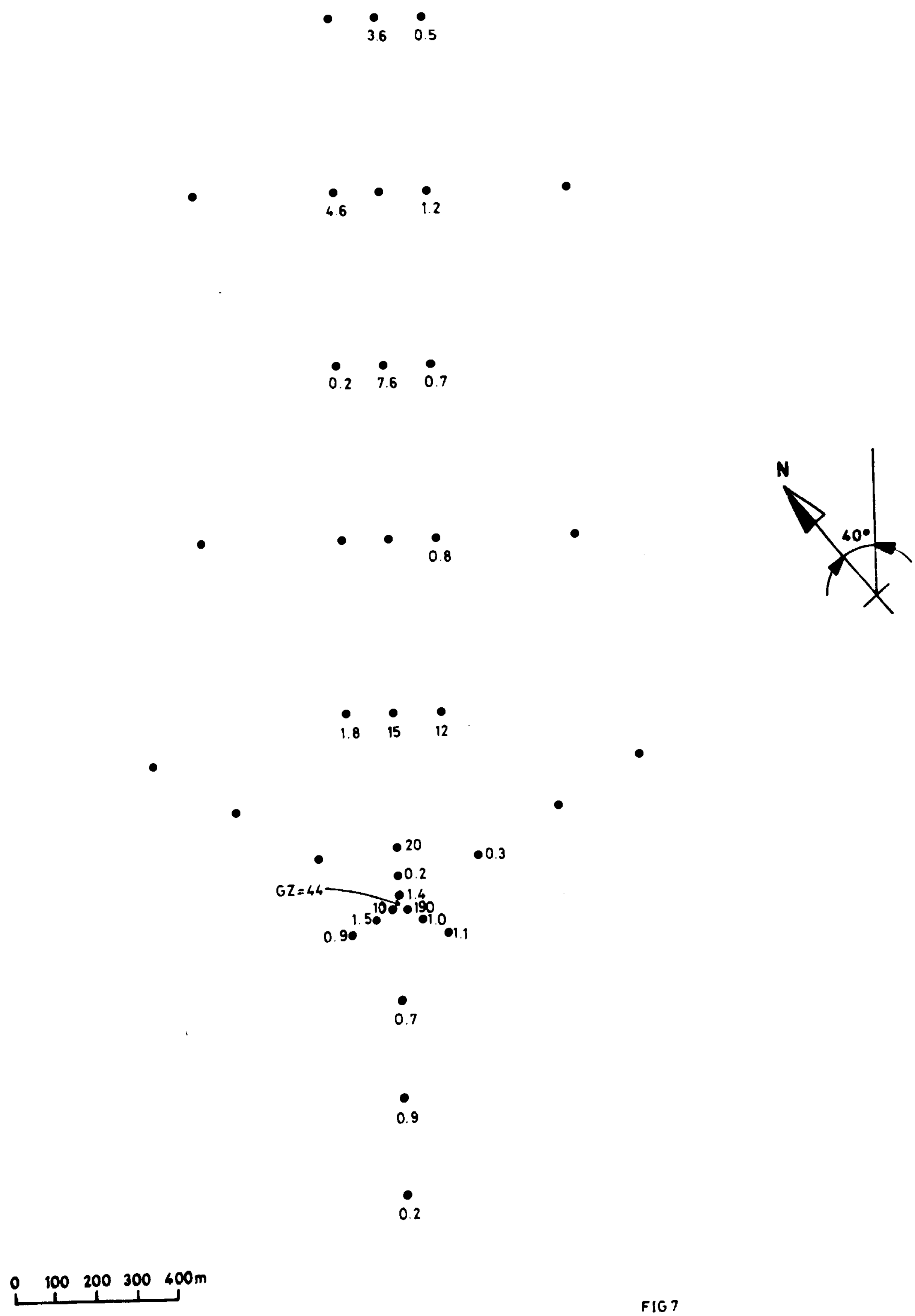

3.6
0.5
4.6
1.2
0.2
7.6
0.7
0.8
N
40°
1.8
15
12
20
0.3
0.2
GZ=44
1.4
10
190
1.5
1.0
0.9
1.1
0.7
0.9
0.2
0 100 200 300 400m

FIG 7

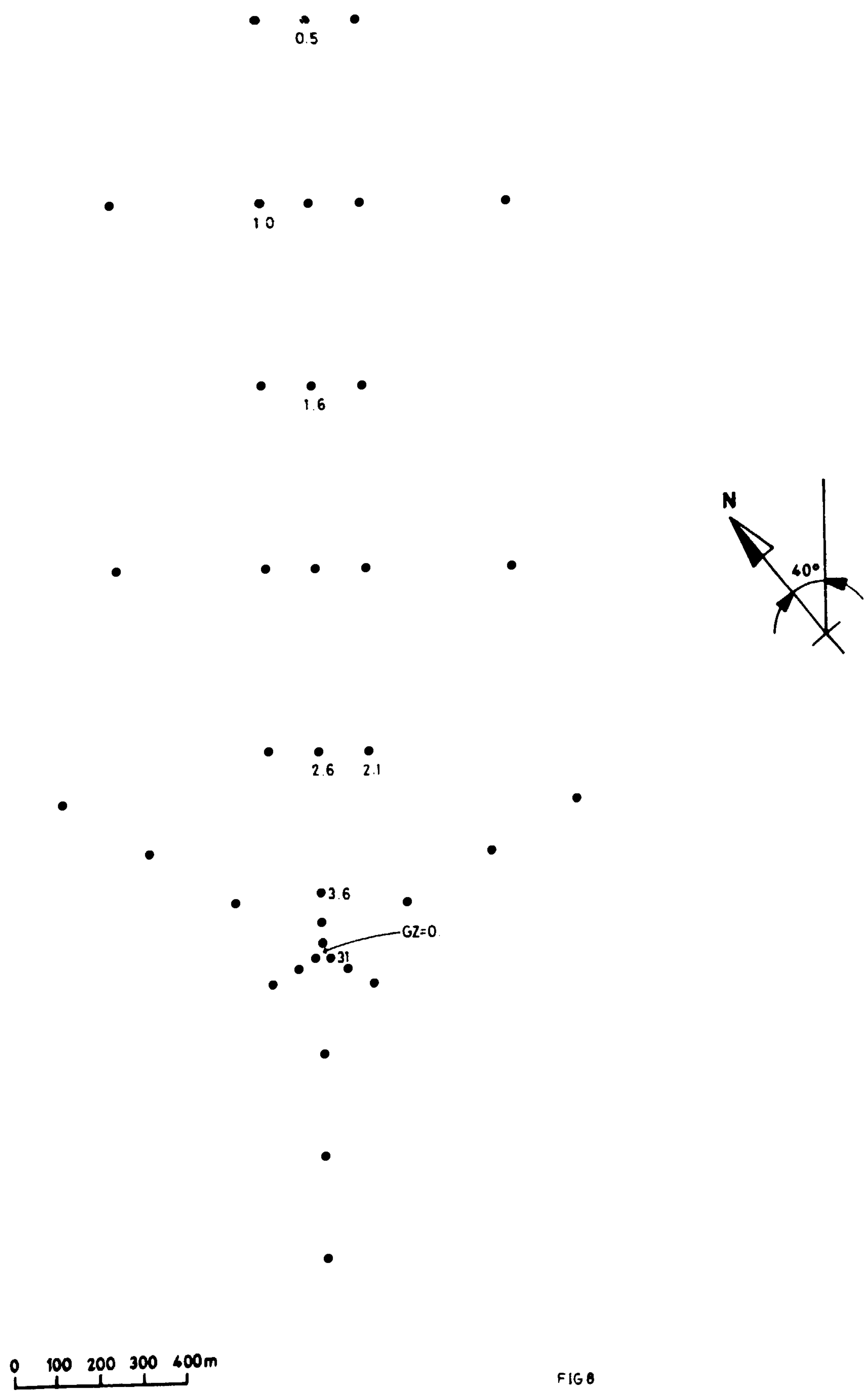


FIG 8

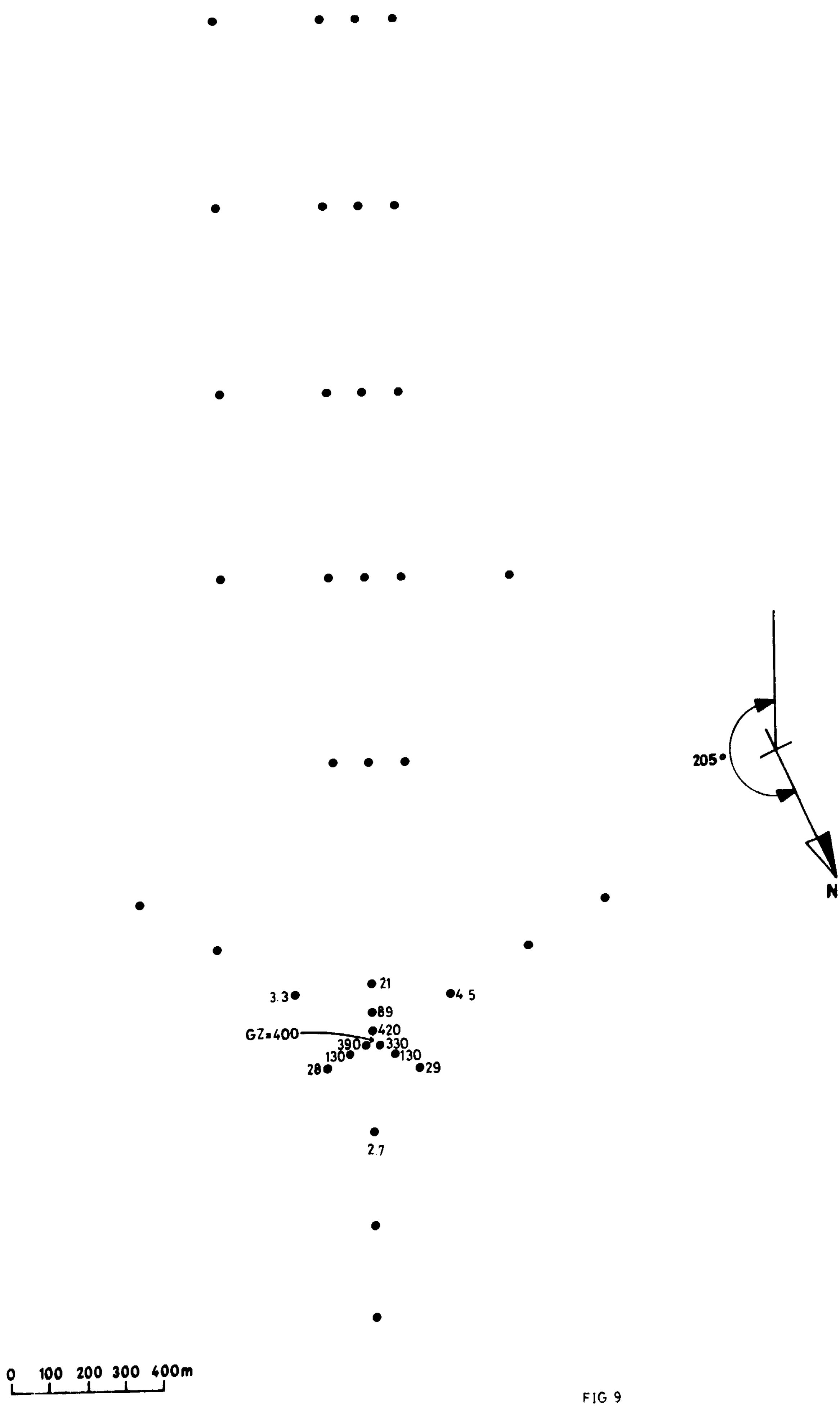

21
3.3
4 5
89
GZ=400
420
390
330
130
130
28
29
2.7
205°
N
0 100 200 300 400m

FIG 9

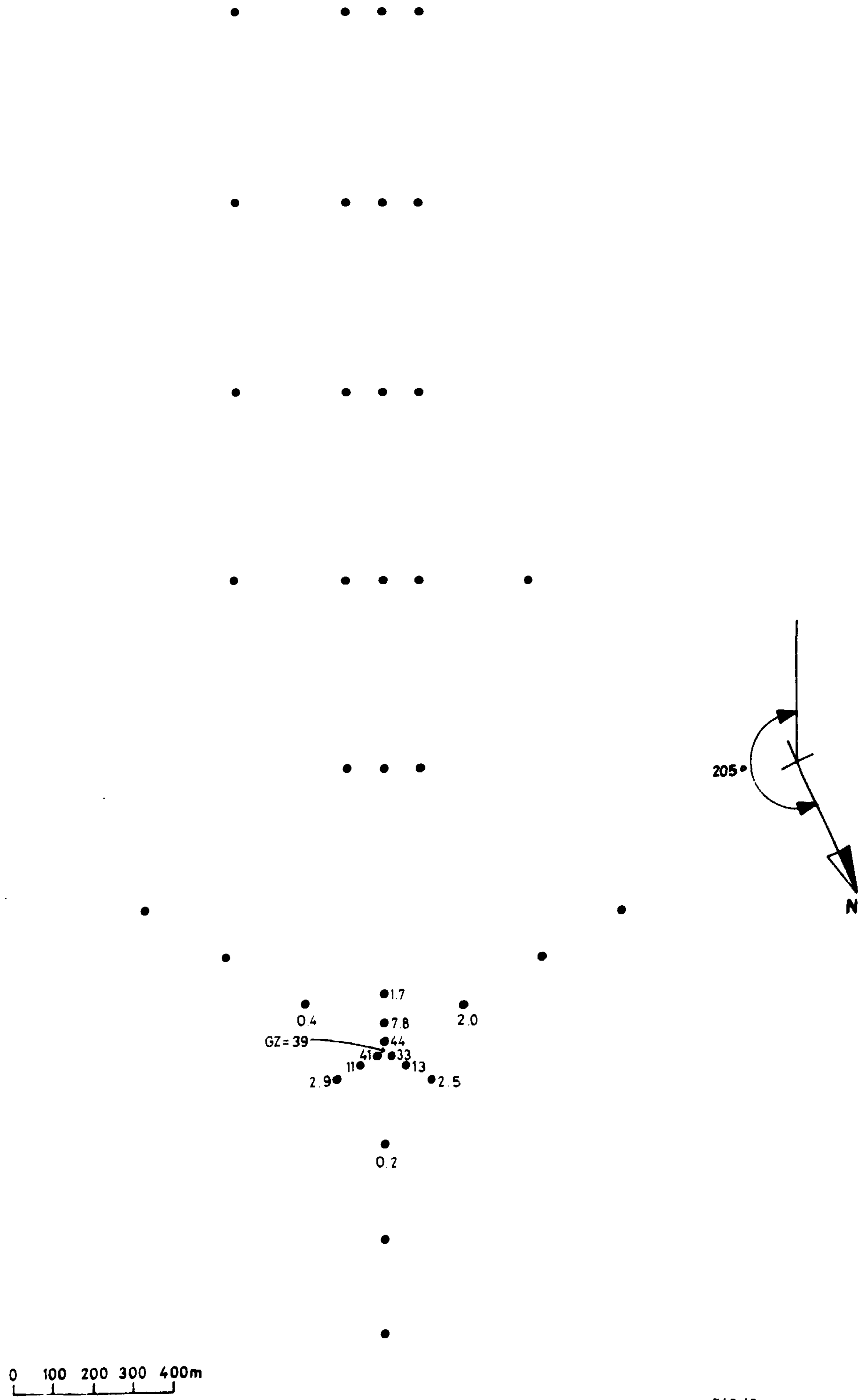


FIG 10


0.5
2.1
1.1
4.3
0.2
7.6
1.2
0.4
0.2
5.5
205°
0.2
3.2
N
0.3
0.3
0.6
180
1.1
41
GZ=51
5.7
180
130
25
15
1.6
13
0.4
1.2
0.6
0 100 200 300 400m

FIG 11

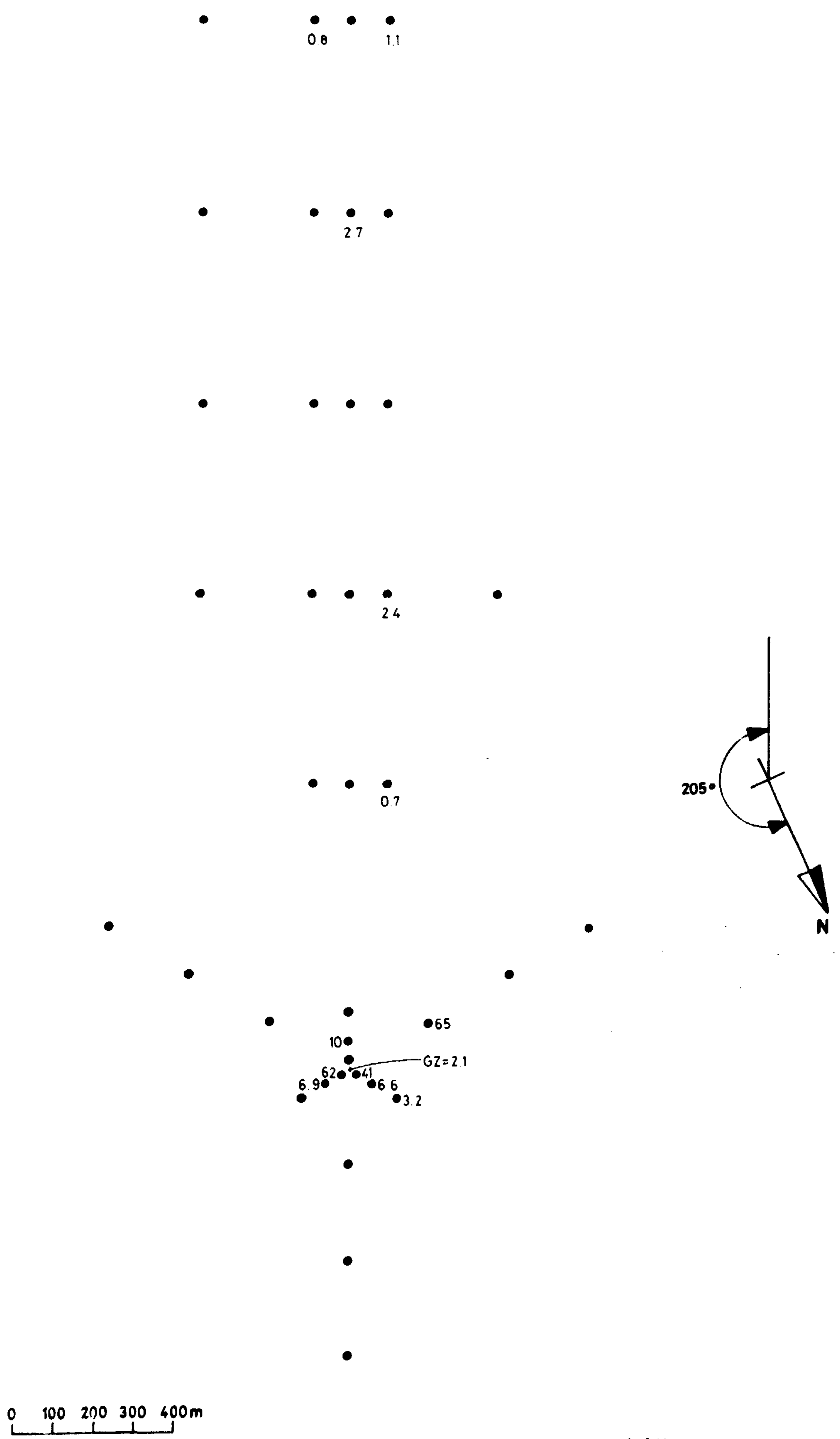


FIG 12

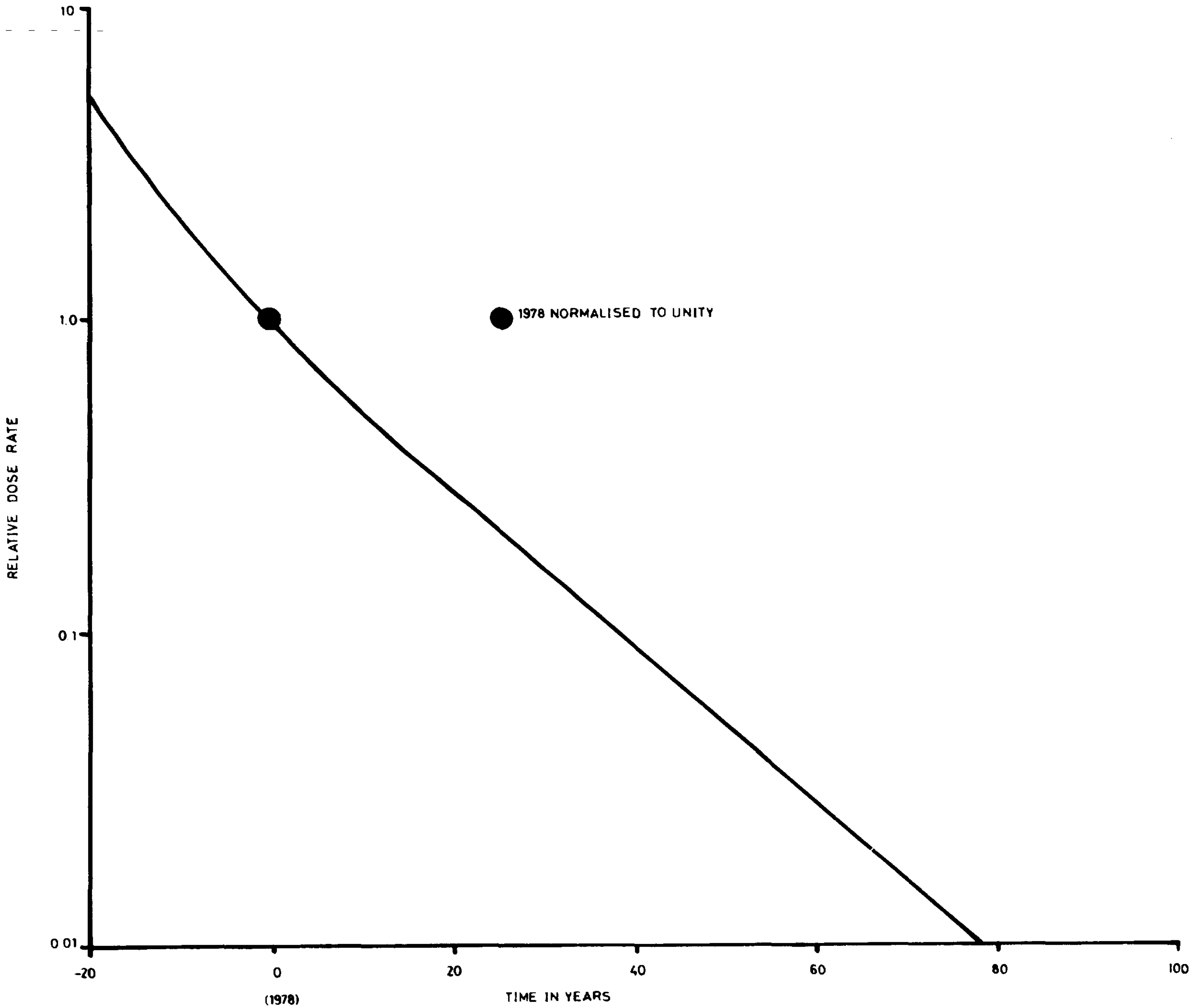

10
1.0
0.1
0.01
RELATIVE DOSE RATE
1978 NORMALISED TO UNITY
-20
0
20
40
60
80
100
(1978)
TIME IN YEARS

FIG 13