PER-77

THE CONSTRUCTION OF A RADIOMETRIC CALIBRATION FACILITY AT LANSERIA AIRPORT, REPUBLIC OF SOUTH AFRICA (REVISED REPORT SUPERSEDING PER-75)

by

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C.J.B. Smit

NUCLEAR DEVELOPMENT CORPORATION OF SOUTH AFRICA (PTY) LTD
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SAMEVATTING

Die vervaardiging van standaard bronne wat geskik is vir die kalibrering van gammaspektometerstelsels wat in vliegtuie of op vragmotors aangebring is, word bespreek. Vier bronne is gebou waarvan drie met voorafgekose hoeveelhede van uraan, torium en kalium gedoteer is. 'n Vierde bron is ongedoteerd gelaat om die agtergrondstraling in die gebied te verskaf. Die bronne het 'n deursnee van 8 m, is 0,35 m dik en is in die ongebruikte noordelike deel van aanloopbaan 17 van Lanseria-lughawe, noord van Johannesburg, gebou.

Die aanvaarde konsentrasies van die belangrikste radioelemente in die bronne is:

6,10 % K_2O in die kaliumbron
67,0 dpm U_3O_8 in die uraanbron (radiometries)
158 dpm ThO_2 in die toriumbron.

ABSTRACT

The construction of standard sources suitable for the calibration of airborne and truck-mounted gamma-spectrometer systems is described. Four sources were built, three of which were doped with preselected quantities of uranium, thorium or potassium. A fourth source was left barren so as to provide a measure of the background radiation in the area. The sources are 8 m in diameter, 0,35 m thick and are recessed into the disused northern portion of runway 17 at Lanseria Airport, north of Johannesburg.

Adopted concentrations of the major radioelements in the

sources are:

6,10 % k_2O in the potassium source
67,0 ppm U_3O_8 in the uranium source (radiometric)
158 ppm ThO_2 in the thorium source

1. INTRODUCTION

Since its completion in 1972, the Pelindaba radiometric calibration facility of the Nuclear Development Corporation of South Africa (Pty) Ltd has become a household name amongst the uranium exploration and mining fraternities of South Africa. In view of the overall acceptance of the principles of calibration and the extensive use of this facility, as well as the increasing usage of sophisticated multichannel airborne and truck-mounted spectrometer systems, it soon became apparent that a similar facility, designed especially to accommodate the latter two types of systems, was urgently needed.

This goal was attained early in 1981 with the completion of the Lanseria calibration facility. The facility currently comprises four cylindrical concrete pads, each 8 m in diameter and 0,35 m thick, which have been recessed into the disused northern portion of runway 17 at Lanseria Airport (see Fig. 1). One pad was left barren so as to provide a measure of the background radiation on the site, whilst the other three were doped with selected radioelements to constitute potassium, uranium and thorium sources.

In this report the construction and relevant chemical properties of the standard sources are briefly discussed and some recommendations pertaining to the determination of altitude corrections and conversion to ground concentrations are presented.

The adopted source concentrations have been revised slightly in view of additional analyses having been made. This report thus supersedes its original version, PER-75.

2. SITE SELECTION AND SOURCE LAYOUT

The close proximity of Lanseria Airport to both Pelindaba and Johannesburg, the latter being host to a large number of exploration and mining companies, made th s location a logical choice. In addition, the airport management afforded excellent cooperation in making the disused northern portion of runway 17 available for the facility. Added expenses relating to the construction of an additional asphalt taxiway and turnaround were thus obviated. The airport is, however, situated on the potassium-rich Halfway-House Archean Granite Dome and some doubts existed as to the suitability, from a gamma-radiation viewpoint, of the proposed terrain. A limited field survey was conducted, therefore, to gain sufficient information on the distribution and concentration levels of the radioelements in the residual soils underlying the runway prior to final acceptance of the site.

Five parallel traverses, each 120 m long and spaced 7,5 m laterally, were radiometrically surveyed at 5 m intervals with a calibrated Geometrics Disa 400A spectrometer, using a 30 s sampling period. Reduced total count values, in cps, are plotted and contoured in Fig. 2. The contour map clearly displays the even distribution of the radioelements in both the soil as well as in the runway base-course fill, which was probably obtained locally. All the spectrometric readings were converted to <u>in situ</u> concentrations and yielded an average radiometric assay of 3,71 $\pm$ 0,25 % K_2O; 5,11 $\pm$ 0,22 ppm U_3O_8; and 9,51 $\pm$ 0,38 ppm ThO_2 for the proposed site. Additional random spot checks in the vicinity displayed essentially the same distribution and concentrations. Although these values were regarded as being somewhat high, the envisaged source concentrations were at least ten times higher, and the site was thus deemed suitable.

In accordance with the IAEA recommendations regarding the construction of concrete standards for airborne systems, the source diameters were fixed at 8 m. However, the source thicknesses were reduced to 0,35 m. These dimensions were considered to be sufficient in providing an infinite half-space, although corrections will have to be applied for detector systems raised to heights greater than 0,5 m above the pads. The background, potassium and uranium sources are spaced 12 m apart, but the relatively high envisaged concentration of the thorium source, which could result in source cross talk, led to the approximate doubling of this spacing between the uranium and thorium pads. The outlay of the standard sources as well as the location of the facility in relation to the airfield runways is shown in Fig. 1.

3. CONSTRUCTION

3.1 Aggregate Selection

The bulk of the material used during the construction of the Lanseria standard was a mixture of Bushveld norite aggregate (Rustenburg Suite of the Bushveld Igneous Complex), with a nominal particle size of 20 mm, obtained from Hippo Quarries, north of Brits. Magaliesberg quartzite crusher sand (Pretoria Group of the Transvaal Sequence), with a 2 mm particle size, was obtained from Ergo Quarries, west of Hartebeespoort Dam. Both the stockpiled construction material and the respective quarries were surveyed spectrometrically to ensure that the radioelement concentrations in the aggregate were acceptably low. These were indeed found to be less than 2 ppm for both uranium and thorium. Portland cement, similarly verified as having very low radioelement abundances, was used throughout the construction.

3.2 Radioelement Selection

Approximately 10 t of Bird Reef ore (Central Rand Group of the Witwatersrand Supergroup), crushed to a particle size of 20 mm, were kindly donated by GENCOR Ltd (West Rand Consolidated Mine). This ore, which contains approximately 200 ppm U_3O_8 and 20 ppm ThO_2 was used previously to dope the Pelindaba uranium standards. Laboratory tests made on samples derived from these standards showed the ore to be in secular equilibrium. Extended spectrometric monitoring of the uranium standards clearly indicated that the activity of the pads remained constant over the first six months after completion of construction, thus excluding the possibility of excessive radon buildup in the concrete.

Monazite sand obtained from the defunct Steenkampskraal mine near Vanrhynsdorp (Nama Sequence), containing 10 000 ppm ThO_2 and 650 ppm U_3O_8, was used to dope the thorium standard. The 350 kg of ore available were initially split into 25 portions displaying nominally equal activities and subsequently stored in 50 l metal containers, from whence carefully weighted fractions were added to subsequent concrete mixes during construction. Pure microcline of unknown geological derivation was purchased from Ceramic Minerals Ltd for the potassium source. Spectrometric verification had shown the radioelement concentrations to be 12 % K_2O and less than 1 ppm for both U_3O_8 and ThO_2. Close on 10 t were used in the construction of the potassium source.

3.3 Excavation and Casting

Four circular pits, each 8 m in diameter, were carefully excavated to a precise depth of 0,35 m below

the surface of the allocated portion of runway 17. The base course of the runway, being as it is a very homogeneous artificial fill, was easily excavated by backactor and handtrimmed to the exact dimensions. Plastic sheeting was used as a liner in all the pits to inhibit moisture penetration into the concrete and to assist in slow drying of the mix immediately after pouring. A 50 mm metal pipe was driven into the centre of each pit to act as a guide for a bar vibrator used during the final surfacing of the sources.

All the concrete was prepared and mixed on site in close proximity to the excavations, using a portable 0,3 m^3 concrete mixer. Subsequent mixes were chuted from the mixer to a front-end loader which was used to transport and place the concrete into the individual excavations. Every mix was spread evenly over the entire surface of the excavation in a deliberate attempt to minimise the possibility of gross radioelement heterogeneity in the sources. In view of the high relative density of the norite aggregate, the water content of the concrete mix was maintained at a very low level in order to counter segregation and bleeding of the mix.

The background source was cast without additional quality checks other than spreading the individual mixes evenly over the excavation surface. Steel mesh reinforcements were emplaced at 100 mm and 200 mm above the excavation floor to avoid cracking of the aggregate during drying.

Quality assurance checks were maintained throughout the construction of the remaining standards. To attain a high activity in the potassium standard, it was initially envisaged to use cement and pure

microcline only, i.e. the latter in the form of crusher sand and crushed aggregate. Unfortunately, the excellent pinacoidal cleavage of the microcline, resulting in extremely flaky particles, militated against this practice by consistently yielding friable concrete during preliminary tests. In order to attain a suitable slump consistency in the concrete, the microcline content had to be reduced to approximately 50 % of the bulk constituents. Sand, aggregate and microcline proportions used during concrete preparation were controlled volumetrically rather than by mass, primarily due to the large percentage of microcline that was incorporated. Every mix was radiometrically screened, using a constant sample-detector configuration, to ensure the rejection of unacceptable concentrations in the samples prior to their being added to the source. In addition, the partly finished source was surveyed periodically with a spectrometer to verify homogeneity of the placed material. Mesh reinforcments in the potassium, uranium and thorium sources were placed in the same way as in the case of the background source.

Additional control measures were used during homogenisation and casting of the uranium source. The entire bulk of crushed uraniferous ore was spread very evenly on the asphalt turnaround of runway 17 and subsequently screened radiometrically, simultaneously removing all anomalously high material thus detected. Volumetric control over ore and aggregate proportions was again employed, but additional radiometric screening of the ore constituents of every mix was also conducted. All subsequent mixes were again screened prior to placement, and evenly distributed over the entire source surface.

The previously homogenised thorium sand was added to

the concrete aggregate in carefully weighted portions, due to the small volume of the concrete mixer. Double radiometric screening was again performed on every mix. Initial mixes were found to be somewhat rich in thorium, and consequently the ore mass was reduced by 13 % per batch after five mixes had been cast in the bottom section of the thorium source. The effect of this at surface is considered to be negligible.

4. SAMPLING AND ANALYSIS

During placement of the concrete, 2 kg grab samples were taken from every 0,3 m^3 mix for subsequent laboratory analysis. A total of 227 samples was thus obtained comprising 57, 51, 59 and 60 from the background, potassium, uranium and thorium sources respectively. After initial drying, the samples were crushed, pulverised, homogenised and split into four fractions. The fraction sets were sent, initially, to four independant analytical laboratories.

Past experience gained during the construction of the Pelindaba facility clearly indicated that large discrepancies are often encountered amongst analytical results presented by different laboratories on sample sets that should be identical. This universal problem not only severely hampers the final assignment of radioelement concentrations in concrete standards, but must inevitably lead to incongruency between in situ radiometric assays and laboratory grade determinations. The large discrepancies amongst sample averages derived from laboratories 1 to 4, reported below in Table I, therefore came as no surprise. These discrepancies were analysed statistically in an attempt to find an acceptable explanation. Average values ($\bar{x}$) and standard deviations (S.D.) of the assay results are presented in Table I, in which values enclosed in brackets indicate that a large

nuber of assays, if not all of them, were below the detection limits of the apparatus and method used during analysis.

An elaborate statistical analysis of these results(laboratories 1 to 4) is beyond the scope of this report, and only a few relevant aspects will therefore be discussed. Firstly, the overall cross-correlation amongst the four laboratories, taking all samples into account, is r = 0,99, which is excellent. This suggests, although it does not prove, that all the laboratories did indeed receive representative samples. This conclusion is further substantiated by the fact that all laboratories clearly detected the reduction in the concentration of the thorium source after the pouring of the initial mixes as previously mentioned (Section 3.3). Particular ambiguity in the results was found for the assayed values of the minor radioelements in each pad, as well as for thorium in the thorium pad.

As a result of the somewhat discrepant results, fractions of the samples were analysed or reanalysed at NUCOR, by means of delayed neutron counting, for uranium and, by means of neutron activation analysis, for thorium. In situ concentrations were determined radiometrically with a Geometrics DISA 400A spectrometer (75 x 75 mm NaI detector crystal), calibrated at Pelindaba. The latter survey is described in Section 6 below. The in situ values given in Table I differ slightly from those quoted in the original version of this report since corrections have now been applied for the effect of high source concentrations (Pelindaba facility) on calculated stripping ratios. In addition, representative composite samples of each source were carefully prepared and forwarded to the Riso National Laboratory at Roskilde in Denmark. These were analysed for uranium and thorium utilising delayed neutron counting

and gamma-ray spectrometry respectively. Additional *in situ* radiometric assays were performed by Løvborg in January 1983 as part of an IAEA international calibration-pad monitoring program.

A total of nine sets of analytical results were thus obtained for the sources. These are presented in Table I and discussed in Section 5 below.

5. SOURCE CONCENTRATIONS

The mean of the values obtained from each laboratory for each of the radioelements in each of the sources is presented in histogram form in Figs. 3a and 3b. The frequency is expressed in terms of the number of laboratories which yielded the indicated mean concentrations. Each histogram bar is identified with the laboratory number as given in Table I. Omission of a laboratory's results arises from no assays being given; assays which were below the detection limits of the analytical technique; or assays which were obviously too high.

The histograms clearly indicate the spread of concentrations for each of the sources. Until the additional delayed neutron, neutron activation, laboratory spectrometric and intercalibration values were obtained for uranium and thorium (laboratories 8 and 9), adopted source concentrations could only be determined, at best, from the mean of the values derived from laboratories 1 to 7. These mean values are quoted in the original version of this report (PER-75).

Some reserve must be attached to these original figures, particularly for the minor radioelements (U, Th) in each of the sources, in view of the poor low-concentration

detection limits of the XRF technique used by laboratories 1 to 5. The improved consistency of the results obtained from laboratories 6, 7, 8 and 9, coupled with the known low-concentration resolution of the techniques used, made it clear that the finally adopted mean concentrations should rather be based on the latter laboratories only. This procedure was adopted, particularly for the minor radioelements, and the finally adopted concentrations for the Lanseria pads are given in Table II.

The in situ radiometric uranium determinations (laboratories 7 and 9), as well as the laboratory spectrometric values of laboratory 8a, clearly indicate disequilibrium in the uranium pad by comparison with the delayed neutron values. This is somewhat disconcerting since the ore used was from the same reef previously sampled for the Pelindaba facility and which was verified as being in equilibrium. Uranium loss is the likely cause of disequilibrium in the uranium ore used. Additional laboratory analyses will be conducted to verify this.

The mean radiometric assay of 67 $\pm$ 4 ppm U_3O_8 in the uranium pad is prescribed for all radiometric calibrations.

The concentrations are similar to those reported for the Vantaa facility at Helsinki, Finland, but somewhat higher than the Walker Field facility at Grand Junction, United States of America. Increasing usage of multichannel airborne spectrometer systems, capable of analysing very high count-rates, prompted the decision to increase the radioelement concentrations of the sources. This was considered necessary in order that high count-rates may be obtained, particularly within the high-energy portion of the gamma spectrum where stripping is often problematic.

6. SOURCE HOMOGENEITY

Homogeneity of the sources was quantified by taking 120 s spectrometric readings with an unshielded Disa 400A spectrometer directly on the surface of the pads on a one metre square grid, yielding 29 data points on each source. Total count values were normalised to the mean total-count value of each pad and the standard deviation calculated. Contours and standard deviations of the four sources are displayed in Figs. 4a and 4b. The *in situ* radiometric concentrations (laboratory 7) given in Table I were derived from 120 s samples in the K, U and Th channels using calibration constants derived at the Pelindaba calibration facility. Considering the 29 grid points on each source, a total counting time per source of 58 min was achieved. This was sufficient to reduce any errors due to counting statistics to less than 0,5 % in the determination of the major radioelement in each of the doped sources and to less than 2,5 % in the determination of the minor radioelements in all four sources. Background counts were determined by plotting stripped count-rates against the average source concentrations as determined from laboratories 1 to 6.

From Figs. 4a and 4b it is evident that the homogeneity of the sources is acceptable, displaying standard deviations of 0,02; 0,01; 0,06 and 0,09 for the background, potassium, uranium and thorium sources respectively. However, the degree of homogeneity of the uranium and thorium sources is not as high as for the other two sources. A relatively barren area is present in the southeast sector of the thorium pad. This probably results from segregation of the high-grade ore from the concrete mix during mixing or pouring. A relatively high zone of radioactivity is prevalent in the northwest corner of the uranium pad. The effects of these inhomogeneities is considered to be negligible for truck-mounted or

aircraft detector systems, which will mostly be raised at least 0,5 m above each source.

7. RECOMMENDED CALIBRATION PROCEDURES

7.1 Calculation of Stripping Ratios

Aircraft and vehicles intending to use the facility must comply, under all circumstances, with the instructions given by the airport air-traffic controller. After permission to use the facility has been granted and the appropriate landing fees have been settled, the aircraft or truck may proceed to the facility. All the sources should be surveyed with the detector stable and stationary above the centre of each of the pads, taking due account of the counting statistics required for individual purposes.

Mathematical procedures pertaining to the calculation of stripping ratios are thoroughly treated by Richards (1977) and Corner et al. (1979) and will therefore not be repeated here. An extensive computer program with the capability of correcting for variations in source-detector geometry, is available free of charge to users of the facility at the Pelindaba Nuclear Development Corporation. This program is currently being upgraded so as to include the calculation of stripping ratios pertaining to multichannel spectrometer systems.

7.2 Elevation Corrections

Procedures for obtaining elevation corrections directly on the Lanseria sources by means of shielding material placed between the source and detector, are omitted at this stage although research on this aspect will be undertaken. The close proximity of enormous

flat-topped mine dumps, containing significant concentrations of uraniferous sludge, facilitates a dynamic determination of the elevation corrections applicable to different flying altitudes and system configurations. Although the thorium content of these dumps is low, numerous tests conducted by the Geological Survey of South Africa have clearly indicated that even multichannel spectrometer systems detect sufficient counts in the high energy portion of the gamma spectrum to enable these corrections to be made with sufficient accuracy.

7.3 Ground Concentrations

A dynamic test strip for the determination of air-to-ground conversion coefficients has been established near the Vaal Dam by the Geological Survey, and is thoroughly described by Day (1978). However, it was found that the radioelement concentrations of this strip are somewhat low and therefore not entirely suited to multichannel airborne systems. It should be noted that the mine dumps cannot be used quantitatively due to gross disequilibrium in the uranium decay series brought about by gold ore processing procedures. The effects of this disequilibrium on the detected gamma spectra and hence on the elevation correction factors remain to be investigated.

8. ACKNOWLEDGEMENTS

The assistance received from the West Rand Consolidated Mine and New Wellington of Africa Ltd who donated the ore material used for the uranium and thorium sources, as well as the analyses conducted by Anglo American Research Laboratories, Gencor Ltd Group Laboratories and Johannesburg Consolidated Investment Company Ltd, are gratefully acknowledged. The analyses conducted by the Riso National Laboratory in Denmark as well as the input, in the form of informative discussions and in-situ radiometric analyses, provided by Dr. L. Lovborg are greatly appreciated.

The assistance afforded by the Lanseria Management Committee in making the disused portion of runway 17 available for the calibration facility is also gratefully acknowledged.

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TABLE I AVERAGE VALUES ($\bar{x}$) AND STANDARD DEVIATION (S.D.) OF ANALYSES SUBMITTED BY THE PARTICIPATING LABORATORIES

Note : Values enclosed in brackets were below detection limits or are considered to be erroneous due to poor counting statistics. The uranium assays of the uranium and thorium pads were duplicated by laboratory 1.

LABORATORY	SOURCE	ANALYSIS					
		K_2O %		U_3O_8 ppm		ThO_2 ppm	
		$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1	B	0,24	0,02	1,11	5,92	-	-
(XRF,	K	6,10	0,29	0,42	0,07	-	-
AAS,	U	0,26	0,01	57,03	30,07	10,77	2,98
fluorimetry)				53,71	26,51		
	Th	0,31	0,02	5,14	1,22	136,23	33,50
				5,32	2,37		
2	B	0,23	0,02	(10,68)	(5,17)	(12,06)	(3,18)
(XRF)	K	6,29	0,34	(10,00)	(0,00)	23,80	1,96
	U	0,23	0,01	54,80	26,24	26,20	4,30
	Th	0,27	0,01	(10,00)	(0,00)	270,77	59,98
3	B	0,21	0,01	2,11	7,98	2,79	2,92
(XRF)	K	5,99	0,35	2,24	1,25	(1,00)	(0,00)
	U	0,19	0,01	54,54	24,65	12,52	3,39
	Th	0,22	0,01	4,39	1,78	190,59	45,71
4	B	0,16	0,01	4,56	6,40	3,79	2,17
(XRF,	K	1,88	0,27	7,15	1,12	7,17	1,28
flamephotometry)	U	0,21	0,04	57,85	27,46	9,88	2,24
	Th	0,18	0,01	8,90	1,46	135,88	31,39
5	B	0,25	0,02	-	-	1	-
(XRF)	K	6,36	0,34	-	-	5,8	0,6
	U	0,29	0,03	44,4	12,8	8,4	1,7
	Th	0,32	0,01	8,0	1,1	-	-
6	B	0,18	0,03	0,79	0,25	1,83	0,33
(NUCOR - XRF,	K	6,45	0,42	0,98	0,28	1,82	0,40
delayed neutron,	U	0,21	0,04	55,3	2,0	7,00	1,93
neutron activa-	Th	0,23	0,02	4,54	0,75	152	36
tion)							
7	B	-	-	-	-	-	-
(NUCOR in situ	K	5,61	0,07	0,41	0,14	-	-
radiometric)	U	0,45	0,09	66,2	0,9	7,4	0,7
	Th	0,27	0,06	4,7	0,8	151	2
8a							
(RISØ -	B	0,20	0,01	1,23	0,07	2,05	0,11
composite,	K	6,20	0,07	0,75	0,11	2,05	0,23
spectrometric)	U	0,20	0,02	69,8	1,53	7,85	0,18
	Th	0,28	0,02	4,13	0,15	167	2,7
8b							
(RISØ-composite	U	-	-	59,4	2,71	-	-
delayed neutron)							
9							
IAEA INTER-	B	-	-	-	-	-	-
CALIBRATION	K	5.65	0,06	0,25	0,11	-	-
(in situ	U	0,11	0,05	61,6	1,3	7,28	1,18
radiometric)	Th	0,06	0,04	4,84	0,35	157	2

TABLE II FINALLY ADOPTED RADIOELEMENT CONCENTRATIONS AT THE LANSERIA CALIBRATION FACILITY

Source	K_2O %	U_3O_8 ppm	ThO_2 ppm
Background	0,21 ± 0,03	1,3 ± 0,1	1,9 ± 0,2
Potassium	6,10 ± 0,20	0,9 ± 0,2	1,9 ± 0,2
Uranium (radiometric assay)	0,24 ± 0,05	57,0 ± 3,0 67,0 ± 4,0*	7,4 ± 0,6
Thorium	0,26 ± 0,06	4,3 ± 0,3	158 ± 7

* The mean radiometric assay is quoted separately in view of the fact that it falls well outside the limits of the standard deviation quoted for the mean of the other seven laboratories. This value (67 ± 4 ppm U_3O_8) is <u>recommended</u> for all calibrations (see Section 5).

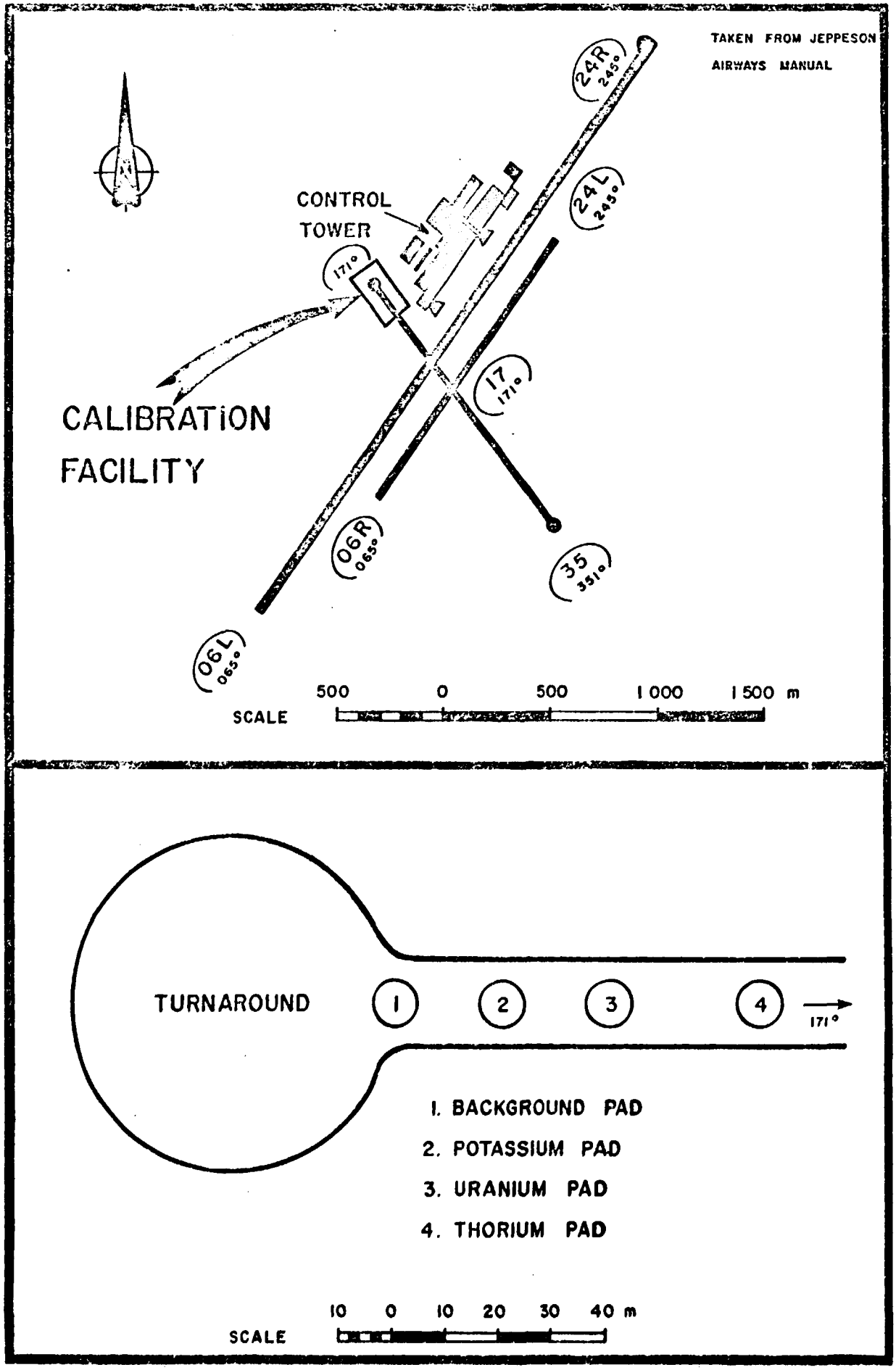

Fig. 1 Outlay of the standard sources at the Lanseria calibration facility

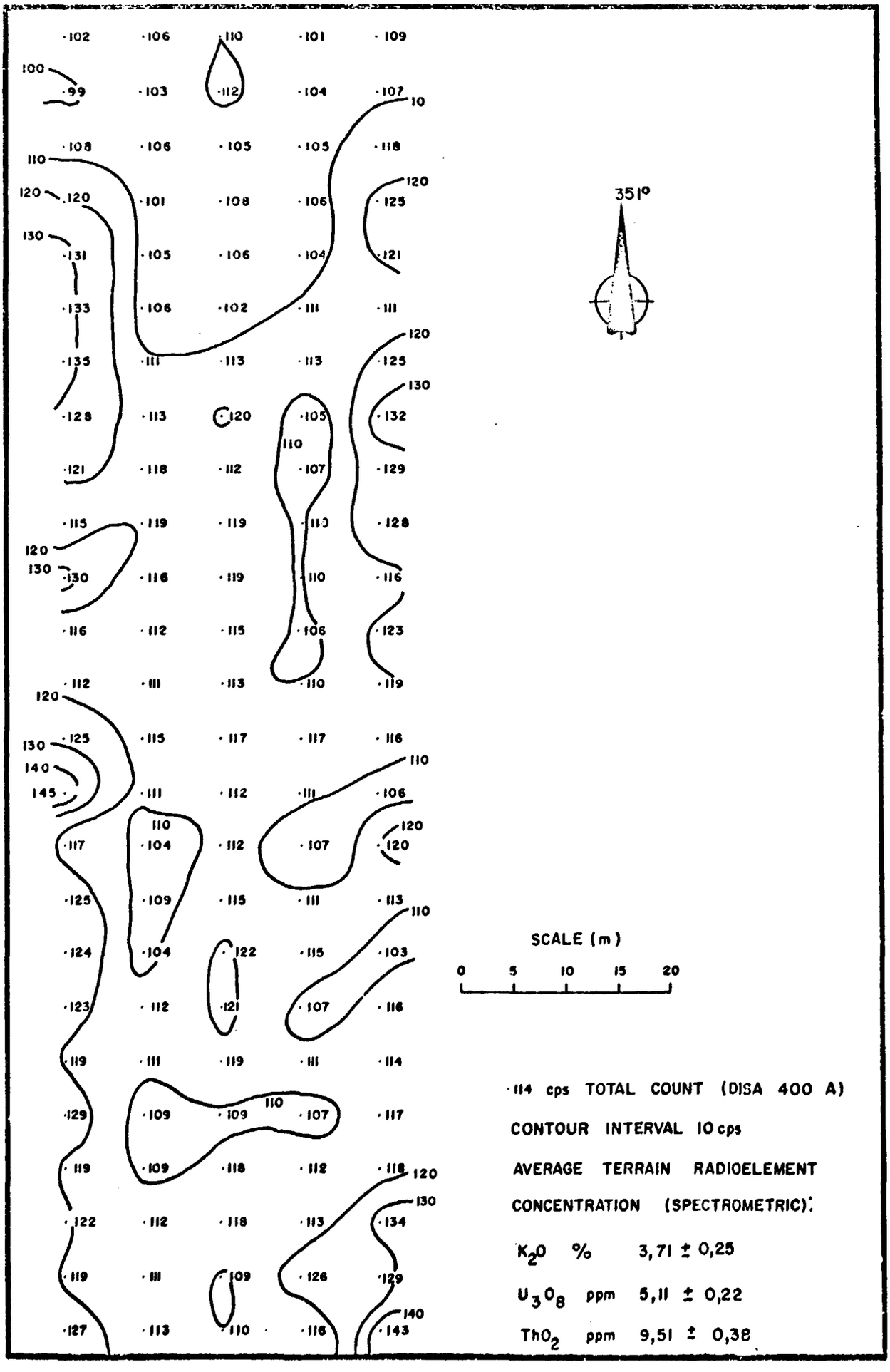

Fig. 2 Radiometric survey at the proposed Lanseria calibration facility on the disused northern portion of runway 17

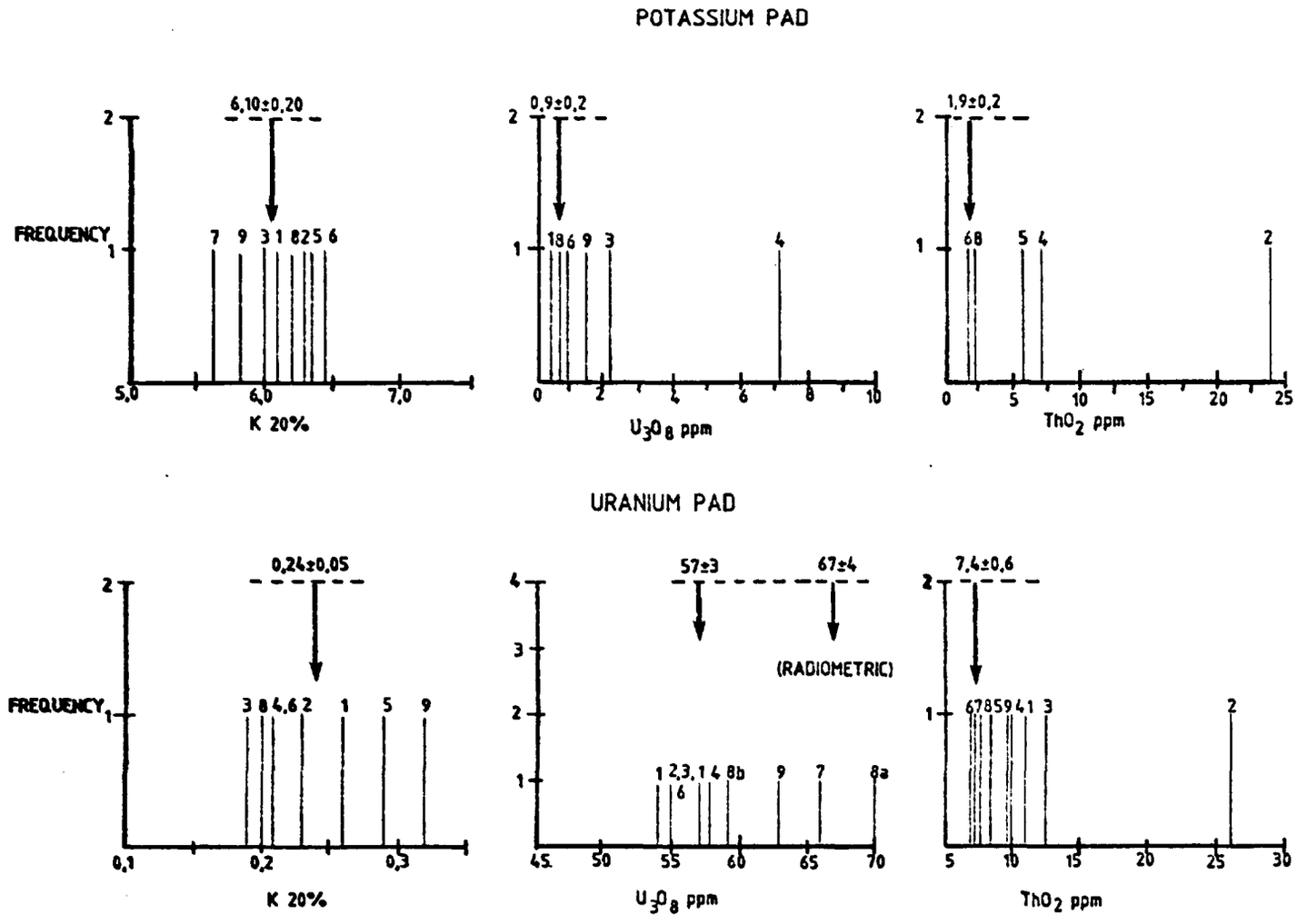

Fig. 3a. Frequency, in terms of the number of laboratoris, of assayed mean radioelement concentrations. The thick arrows and dashed lines indicate the adopted mean value and standard deviation respectively. The laboratories are numbered 1 to 9 as in Table I.

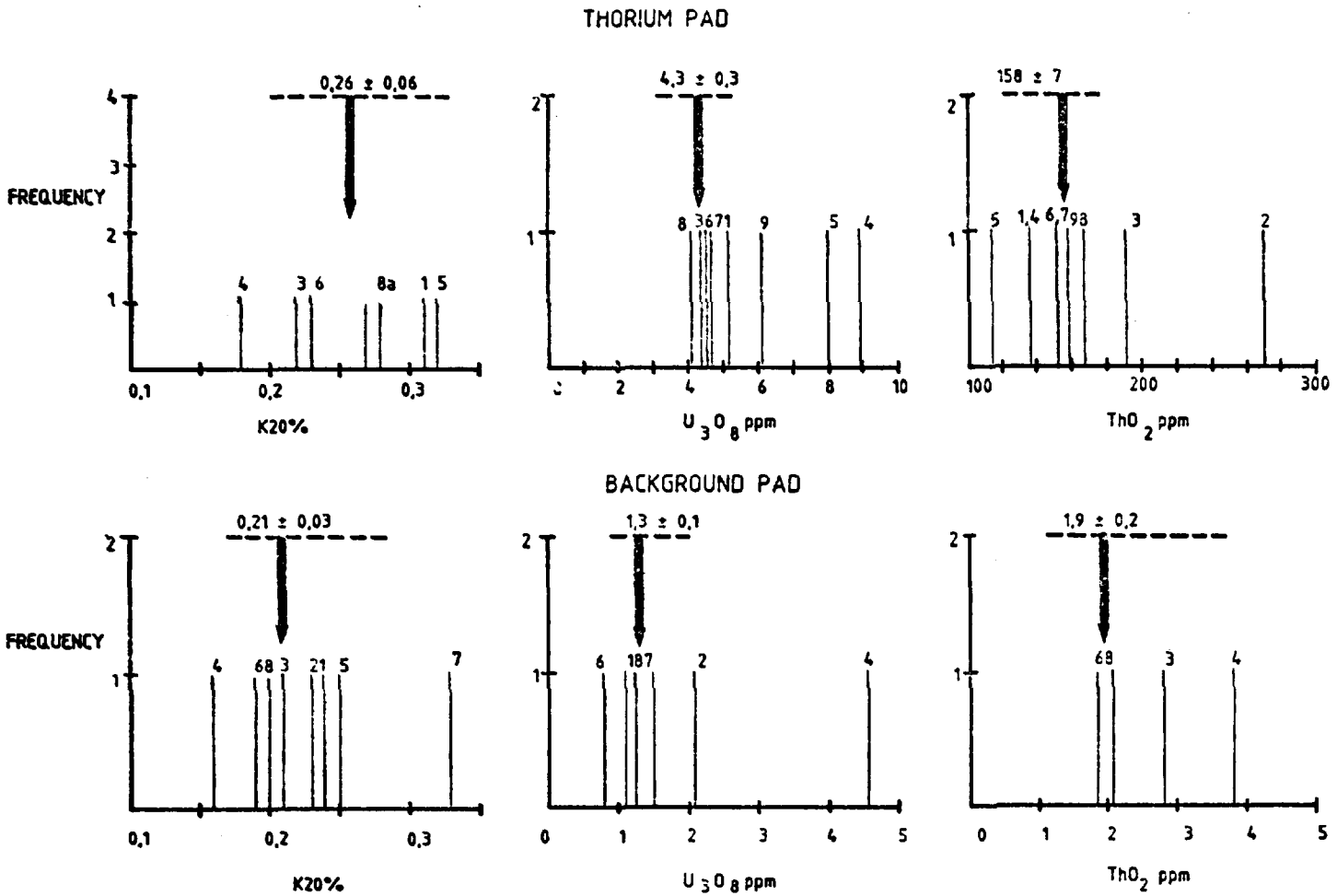

Fig. 3b. Frequency, in terms of the number of laboratories, of assayed mean radioelement concentrations. The thick arrows and dashed lines indicate the adopted mean value and standard deviation respectively. The laboratories are numbered 1 to 7 as in Table I.

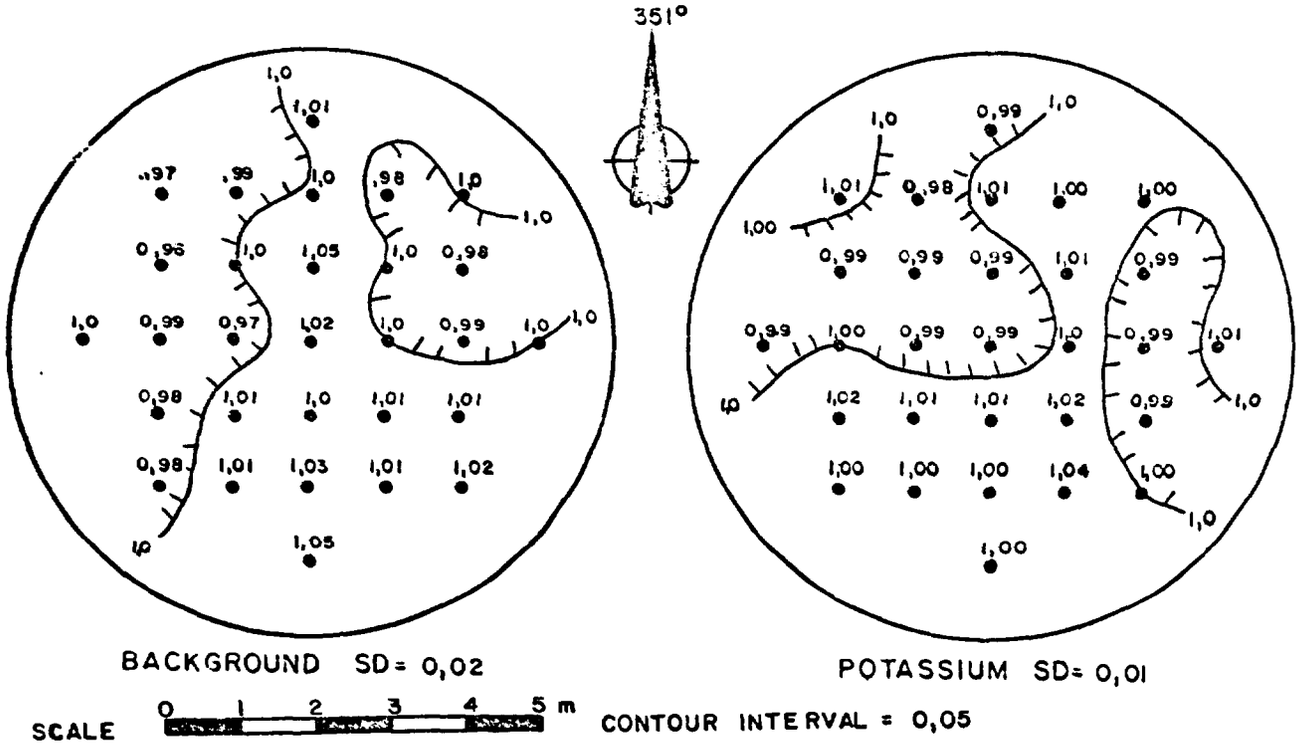

Fig. 4a. Lanseria calibration standards: background and potassium source inhomogeneities

Note: Values and standard deviations were normalised to unity for each source. An unshielded DISA 400A spectrometer with a 75 x 75mm crystal was used for the surveys. A two-minute sampling time was used and readings were taken on a 1 metre square grid at ground level.

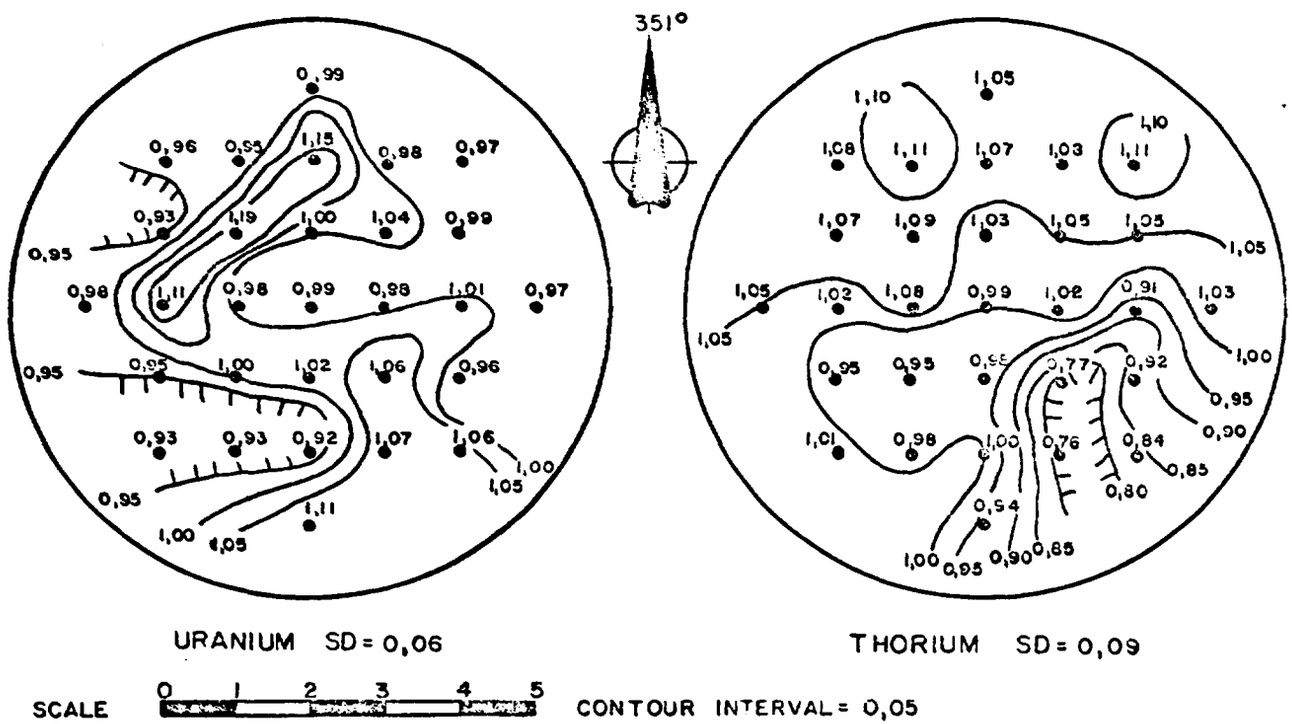

Fig. 4b. Lanseria calibration standards: uranium and thorium source inhomogeneities

Note: Values and standard deviations were normalised to unity for each source. An unshielded DISA 400A spectrometer with a 75 x 75mm crystal was used for the surveys. A two-minute sampling time was used and readings were taken on a 1 metre square grid at ground level.