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THE CALIBRATION OF GAMMA-RAY SPECTROMETERS
FOR GROUND AND AIRBORNE USE

(Report and 13 figures)

R. L. Grasty and A. G. Darnley

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ABSTRACT

The calibration of field gamma-ray spectrometers require radioactive sources of effectively infinite size. Five large radio-active calibration slabs have been constructed for this purpose and the techniques used to determine the sensitivities and Compton scattering coefficients of field gamma-ray spectrometers are described. Results obtained for 3 gamma-ray spectrometers, used by the Geological Survey of Canada, are presented.

RÉSUMÉ

L'étalonnage des spectromètres portatifs à rayons gamma requiert des sources radio-actives de dimensions infinies. Cinq plaques d'étalonnage radio-actives de grande dimension ont été conçues; l'auteur décrit les techniques de détermination de la sensibilité et du coefficient de dispersion Compton des spectromètres portatifs à rayons gamma et présente les résultats obtenus lors de l'essai de trois appareils appartenant à la Commission gélogique du Canada.

THE CALIBRATION OF
GAMMA-RAY SPECTROMETERS
FOR GROUND AND AIRBORNE USE

In the past few years there has been a marked increase in the development and use of ground and airborne gamma-ray spectrometers. By measuring the abundance of potassium, uranium and thorium these instruments can be used as exploration tools or as aids in geological mapping. Whereas potassium can be measured directly from the 1.46 MeV gamma emitted by the radioactive potassium isotope K-40, uranium is measured indirectly from the gamma-rays of Bi-214, a daughter product in the uranium decay scheme. In a similar way thorium is determined indirectly from the gamma-rays of thallium-208, in the thorium decay scheme. Measurements of uranium and thorium by gamma analysis are only valid provided the respective decay scheme is in equilibrium.

The gamma-ray spectrum emitted by these three radioactive isotopes is extremely complex. Figures 1 and 2 on page 2 show the principal gamma-rays, exceeding 0.1 MeV in energy, that are emitted by thorium and uranium in equilibrium with their decay products. The relative abundance of photons emitted, for each disintegration in the decay chain, was determined from published data (Lederer et al., 1967), and photons with a relative abundance of less than 4 per cent have been omitted. Potassium emits only one photon at 1.46 MeV. The photons of energy 1.76 and 2.62 MeV have been generally accepted as being most suitable for the measurements of uranium and thorium respectively because they are relatively abundant, and high in energy and consequently are not appreciably absorped in the air. They can also be discriminated from other gamma-rays in the spectrum. Owing to the limited resolution of photomultiplier tubes which are used in conjunction with the crystal detector, an energy window has to be selected to register these particular gamma-rays. Table 1 gives the window width used by the Geological Survey of Canada in its three spectrometer systems.

High energy photons which are incompletely absorbed in a detector due to its finite size appear as counts in a lower energy window. Counts appearing in the potassium window may be due to potassium photons at 1.46 MeV, scattered high energy photons, or lower energy photons of the uranium and thorium decay scheme. Provided the potassium, uranium and thorium spectrum reaching the detectors remains the same, a constant fraction of the counts in the higher energy windows will appear in the lower energy windows. These factors are known as the Compton scattering coefficients or stripping ratios and will be peculiar to each detector system. They must be determined before any measurement of elemental abundance can be attempted.
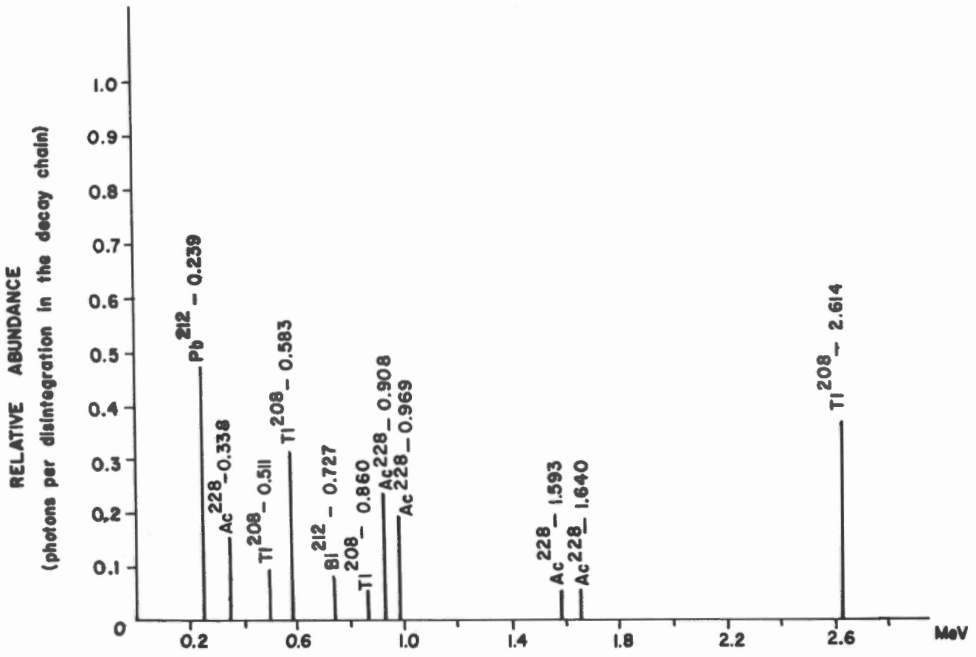
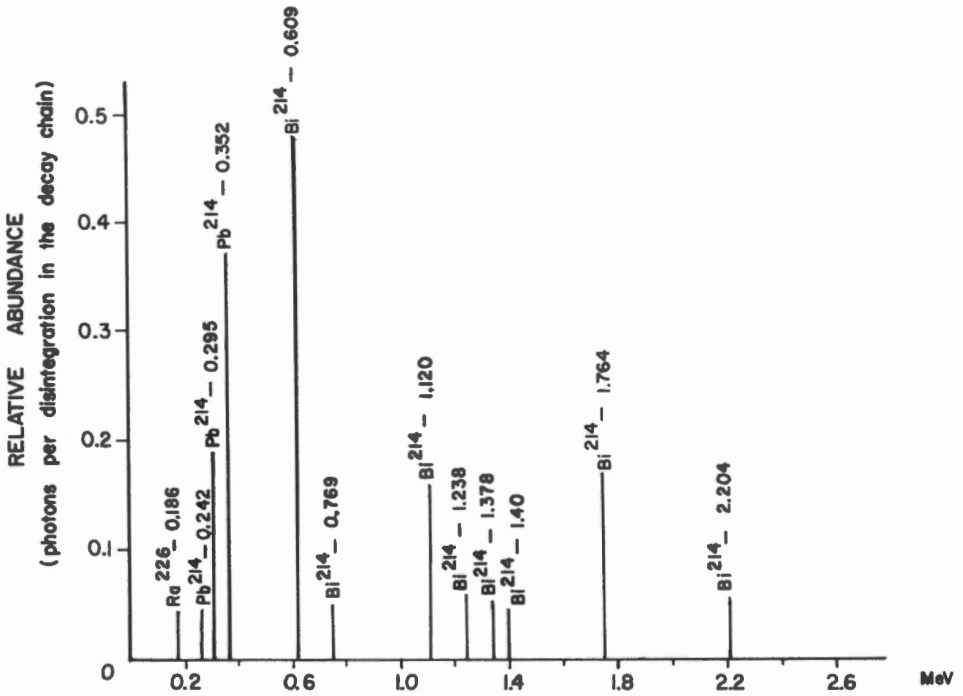Figure 1. Principal gamma-rays over 0.1 MeV emitted by thorium in equilibrium with its decay products.

Figure 2. Principal gamma-rays over 0.1 MeV emitted by uranium in equilibrium with its decay products.
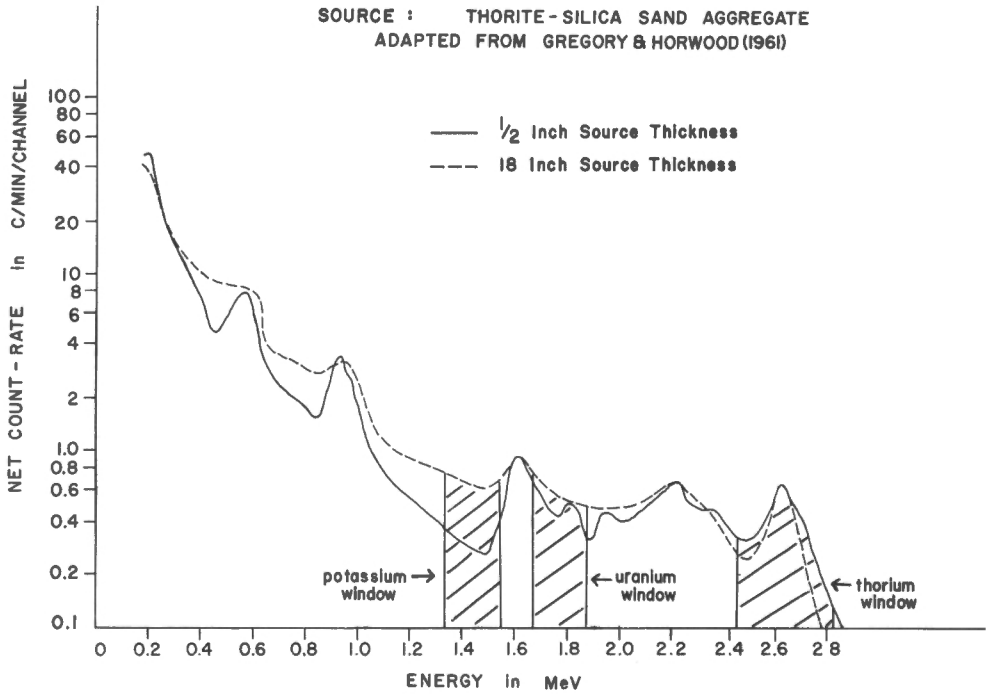
Figure 3. Variation of gamma-ray spectrum with source thickness - thorium.

As part of its continuing research program in gamma-ray spectrometry, the Geological Survey has been conducting field radiometric measurements with three different spectrometer systems, two of these being airborne systems and one a portable ground instrument. The airborne systems have been described by Darnley (1970). A large part of the ground work took place in the Bancroft area of Ontario in 1967 and 1968 and subsequently a detailed airborne survey was carried out in the summer of 1969. In order to determine ground level concentrations of the radioelements and permit the correlation of ground and airborne measurements, it was necessary to determine the Compton scattering coefficients and also the sensitivities of each system in terms of counts per unit concentration.

The calibration of laboratory gamma spectrometers is relatively easy compared to the calibration of field equipment. Standard samples of known concentration, the same weight and geometry can be used to compare with the unknowns. Field spectrometers, however, receive a spectrum from a source of effectively infinite size, which may or may not be homogeneous.

Doig (1968) has calibrated his ground instrument using carefully selected outcrops covering the normal range of radioelement concentration. Homogeneous outcrops were selected on the basis of systematic field measurements. Large specimens were taken and analyzed in the laboratory, and the rock was assumed to be homogeneous in depth. This approach is not convenient for routine use due to the difficulty of finding suitable homogeneous outcrops in reasonable proximity to one another in an easily accessible location. Neither can the method be used for the calibration of any airborne systems.

TABLE 1

SPECTRAL WINDOW WIDTHS

ELEMENT ANALYZED	ISOTOPE USED	γ-RAY ENERGY	ENERGY WINDOW (MeV)
K	K-40	1.46	1.37 – 1.57
U	Bi-214	1.76	1.66 – 1.86
Th	Ti-208	2.62	2.40 – 2.80

Instrument manufacturers and operators have generally used pre-pared samples of thorium oxide and hand specimens of pitchblende to deter-mine the Compton scattering coefficients. The validity of this technique is somewhat doubtful. Gregory and Horwood (1961) carried out experiments with different source thicknesses. Figure 3 shows the two spectra they obtained for a thorite-silica sand aggregate of 1/2-inch and 12-inch thickness. The figure has been adapted so that the spectral shape can be compared easily by normalizing the count-rates of the thorium photo-peak. The potas-sium, uranium and thorium energy bands are also shown. It is apparent that there is a marked build-up of scattered radiation within the low energy region in the thick source, particularly in the energy region around and below the potassium window. The low energy peaks have been absorbed to a greater extent and lack resolution. The proportion of the thorium counts appearing in the potassium window, commonly called the stripping ratio α, is quite different for the two sources. For larger crystals, the stripping ratios are smaller, and the variation in the stripping ratios due to source geometry will therefore be more important. From these considerations it is evident that the stripping ratios used are ideally dependent on the geometry of the source.

In order to provide suitable calibration sources for gamma-ray spectrometers it is thus necessary that the coefficients should be determined as closely as possible to the condition of use of the instrument. As it is impossible to know in advance the geometrical shape of the source, a homo-geneous source of effectively infinite size would appear to be most suitable. Gregory and Horwood (1961) have shown that 90 per cent of the detected gamma radiation from a source of infinite size is emitted from the upper-most 6-9 inches of rock of density 2.7 gm/cc, the precise thickness depend-ing on the energy of the radiation. For mineral aggregates of density 1.5 gm/cc the emission depth is approximately doubled. The calibration sources should have comparable concentration to that obtained in the field, to avoid loss of counts due to dead time, and they should be easily accessible to airborne equipment and ground instruments.

With these controlling factors in mind, five calibration sources, each in the form of a slab or pad 25 feet by 25 feet and 18 inches thick, were constructed in 1968 at Uplands airport, Ottawa. The pads are adjacent to and level with an existing concrete parking area, so that an aircraft fitted with a radiometric system could taxi, or be towed, onto one of the slabs, and the detectors positioned over the centre. For a detector on or very close to

the surface, the slabs can be considered of infinite extent. The exact location
of the slabs in relation to the airport terminal and concrete apron is shown
schematically in Figure 4. The slabs are positioned 50 feet apart so that
each has a similar environment with respect to the concrete apron and sur-
rounding soil and so that the influence of one source on another is negligible.

The pads were prepared in the following manner. Standard con-
struction specification concrete was the starting material, and the aim was
to spike two pads with small amounts (x and 2x ppm respectively) of uranium,
as uniformly as possible and to spike two with small amounts of thorium
(y and 2y ppm respectively).

Uranium in equilibrium was obtained in the form of hand specimens
of pitchblende ore taken from Eldorado Mine, Saskatchewan. This was known
to contain a negligible amount of thorium. Thorium was obtained in the form
of an already powdered thorite concentrate, held in store by the Mines
Branch, Department of Energy, Mines and Resources, Ottawa originally
received from the Belgian Congo. This thorite concentrate was known to have
a very low uranium content. The pitchblende ore was powdered and approx-
imately 5.25 pounds were mechanically mixed with ten times its weight of
hematite, to give increased bulk and then weighed out into 21 equal amounts
and bagged. In addition 12.6 pounds of the thorite concentrate was similarly
mixed with ten times its weight of hematite and also divided into 21 parts.

It was ascertained from the contractor who was constructing the
.slabs that the 35 cubic yards of concrete required for each slab would be
delivered in seven loads each of five cubic yards. Accordingly it was decided
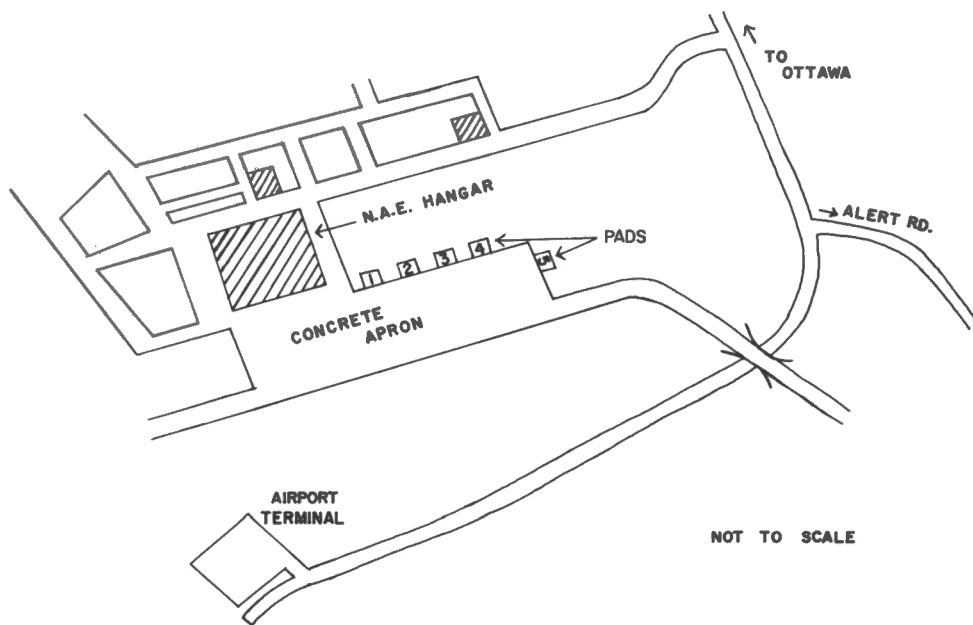to spike each load of concrete with known amounts of concentrate after sand,

Figure 4. Map showing location of calibration pads, Uplands airport, Ottawa.

gravel and cement was loaded from storage hoppers into ready-mix trucks at the contractor's depot. The concentrate was sprinkled in slowly as mixing commenced and was thoroughly mixed with the other constituents for approximately 30 minutes whilst the truck was in transit to the construction site. For the two low concentration pads (Pads 2 and 3) one bag of the appropriate concentrate was added to each truck load. For the high concentration pads (Pads 4 and 5) two bags of the appropriate concentrate were added to each load. An equal quantity of hematite blanks were mixed with Pad 1 in case any radioactivity was associated with the hematite. It was hoped that an identical mix of raw concrete would be used for all pads, but Pad 1 was poured several days before the others, which were completed in succession in one day, and it is apparent from the analyses that there was a change in matrix composition between Pad 1 and the remainder. The aggregate for the concrete consisted of glacially derived gravel composed of a variety of Canadian Shield rock types.

No gross variations in the distribution of the radioelements was found by taking 16 total count measurements on a grid pattern over the surface of the pads, the variation being less than 10 per cent. In order to use the slabs as calibration sources it was necessary to have an accurate knowledge of the concentration of each of the 3 radioelements in the 5 pads. For this purpose, 6 cores were drilled to a depth of 18 inches through the slabs, 2 cores being taken close to the centre and 4 from each of the 4 corners. These cores were split in half and one half crushed and mixed and used for the analysis of potassium, uranium and thorium. Potassium was determined by X-ray fluorescence, and uranium and thorium using a laboratory gamma-ray spectrometer which had been calibrated using samples of known concentrations.

Table 2 gives the results of the measurements from each of the six cores taken from the five pads. The variation between each core from the same pad is due to the variation of rock type encountered in the aggregate of the concrete. The composition of Pad 1 is noticeably different from the other pads; in particular the potassium content is much lower.

It was originally intended to use the potassium, uranium and thorium counts of Pad 1 as a background for the remainder of the pads. Then, for instance, the only change in counts of Pad 3 over Pad 1 would be because of the addition of 1 part of thorium to Pad 3. Quite a simple calculation would then give the values of α, the thorium contribution to the uranium channel, and β, the thorium contribution to the potassium channel. Similarly Pad 2 because of the addition of 1 part of pitchblende, could be used to determine γ, the uranium contribution to the potassium channel. However, because of the difference in chemical composition of Pad 1, an alternative procedure was developed.

The equations relating the counts T, U, P in the various channels to the respective concentrations T ppm, U ppm, P per cent of each pad, are as follows:

$$T - T_B = k_1 \times T \text{ ppm} \tag{1}$$

$$U - U_B - \alpha(T - T_B) = k_2 \times U \text{ ppm} \tag{2}$$

$$P - P_B - \beta(T - T_B) - \gamma\left[(U - U_B) - \alpha(T - T_B)\right] = k_3 \times P \text{ per cent} \tag{3}$$

α, β and γ are the stripping ratios or Compton scattering coefficients, k_1, k_2 and k_3 are the sensitivities of the instrument in terms of counts per unit

TABLE 2

COMPARATIVE ANALYSES OF SIX CORES FROM EACH OF THE UPLANDS TEST PADS

| | PAD 1 | | | PAD 2 | | | PAD 3 | | | PAD 4 | | | PAD 5 | | |
% K	ppm U	ppm Th	% K	ppm U	ppm Th	% K	ppm U	ppm Th	% K	ppm U	ppm Th	% K	ppm U	ppm Th
1.50	2.2	6.9	2.56	7.4	14.0	2.36	3.0	23.4	2.26	3.5	48.1	2.49	11.7	15.5
1.90	2.6	8.7	2.31	7.7	10.2	2.32	3.1	25.5	2.28	2.4	43.1	2.21	10.6	14.3
1.90	2.0	10.7	2.19	6.9	13.6	2.11	4.4	27.1	2.07	2.5	38.8	2.55	11.3	13.2
1.70	2.0	8.1	2.41	6.9	14.1	2.37	2.6	24.6	2.66	2.5	38.4	2.00	11.6	13.7
1.50	3.4	8.8	1.90	7.4	11.8	2.21	2.9	29.2	2.12	4.0	36.3	2.30	12.7	10.8
1.70	2.3	10.2	2.23	7.6	11.6	1.90	2.2	26.7	1.86	2.7	39.9	2.41	12.5	12.0
1.70	2.4	8.9	2.27	7.3	12.6	2.21	3.0	26.1	2.21	2.9	40.8	2.33	11.7	13.2

POTASSIUM BY X-RAY FLUORESCENCE, URANIUM AND THORIUM BY GAMMA ANALYSIS

Figure 5.   Thorium count rate and concentration for portable field instrument.

Figure 6. Thorium count rate and concentration for helicopter system.

Figure 7. Thorium count rate and concentration for skyvan system.

1.76 MeV window count rate v. uranium concentration

PORTABLE FIELD INSTRUMENT

⊙ uncorrected
+ corrected
with ∝= 0.710
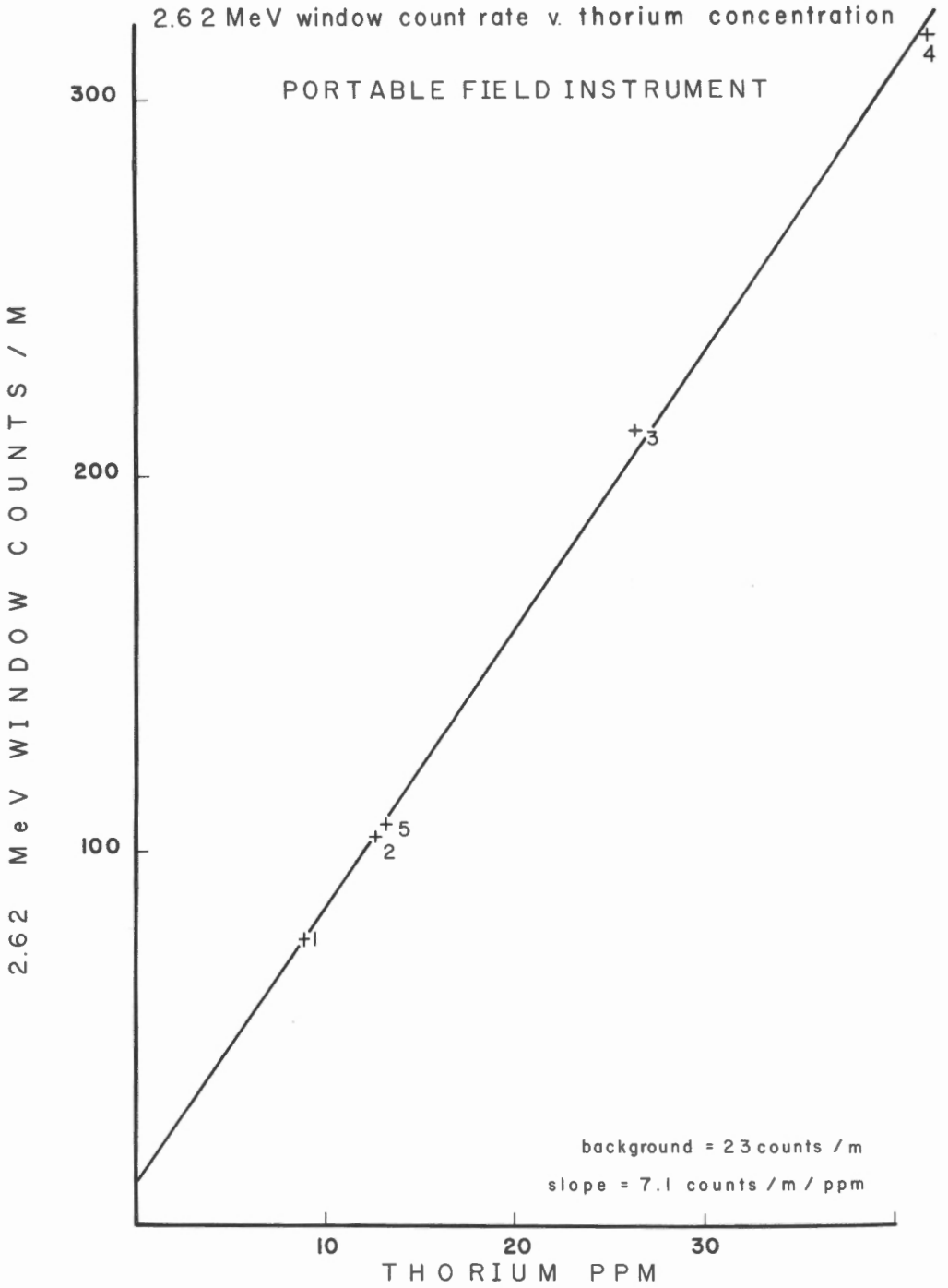background = 26 counts /m
slope = 22 counts /m/ ppm

Figure 8.   Uranium count rate and concentration for portable field instrument.

Figure 9.   Uranium count rate and concentration for helicopter system.

concentration per unit time and T_B, U_B and P_B are the background counts appearing in the thorium, uranium and potassium channels respectively, but which are unrelated to the concentrations of the pads. These backgrounds will be from the surrounding soil and concrete apron, atmospheric activity due to radon, cosmic rays and any other extraneous activity.

The data from each of the 5 pads can be fitted in sequence to these 3 equations by a least squares technique, to determine the unknowns α, β, γ, k_1, k_2, k_3 and T_B, U_B and P_B. This standard mathematical technique has been used by the Geological Survey for the past two years and has been described by Killeen and Carmichael (1970) in their study of over 100 field calibration stations in the area of Quirke Lake syncline of Ontario.

Equation (1) is the equation of a straight line and Figures 5, 6 and 7 show the line computed from data obtained for 3 gamma-ray spectrometers. This line gives the thorium background received by each instrument over the pads and also the sensitivity in counts/ppm/minute. The close fit of the experimental data to a straight line, implies that our core samples were representative of the pads as a whole.

The background thorium count determined using equation (1) is used to solve equation (2). This equation is the equation of a plane, as the uranium counts are dependent both on the uranium concentration and on the counts appearing in the thorium window. In order to represent this 3-dimensional data graphically, the corrected or stripped uranium counts (thorium contribution removed), have been plotted against the uranium concentration (Figs. 8, 9 and 10). These points should fall on a straight line. The computed line has been drawn in and the data points appear to fit extremely well. This line gives the background uranium counts over the pads and the sensitivity in counts/ppm/minute as well as the stripping ratio α.

The counts in the potassium window are related to the potassium concentration of each pad and also to the counts appearing in both the higher energy uranium and thorium windows. Hence equation (3) is the equation of a linear surface in 4-dimensional space and the best surface can be computed using the previously determined α, T_B, and U_B. Using the computed values of β, γ, k_3 and P_B the corrected potassium counts (both uranium and thorium removed) have been plotted against the potassium concentration for each pad (Figs. 11, 12 and 13). These points should fall on a straight line. The line plotted is obtained from the computed values of k_3 and P_B.

A computer program to solve these 3 equations using a C.D.C. 3,100 machine is given in the Appendix. For each of the five pads, the count rates of the three channels and the respective analyses, from Table 2, are fed into the computer. A typical computer output is shown in Table 3 and the results of the stripping ratios for the three field spectrometers, and their respective crystal sizes are tabulated in Table 4. As expected the stripping ratios are reduced with the increasing size of the crystals.

Over the past two years seven completely independent calibrations have been carried out by different operators using the Skyvan system and it has been possible to estimate the accuracy of our measurements of the stripping ratios. The errors will be a combination of errors due to statistical variation, setting up procedures and any variation in resolution of the crystals. The errors in α, β and γ were determined to be 4, 13 and 18 per cent respectively and it is interesting to see how these errors affect a typical survey measurement. Table 5 shows that in a typical case a 25

Figure 10. Uranium count rate and concentration for Skyvan system.

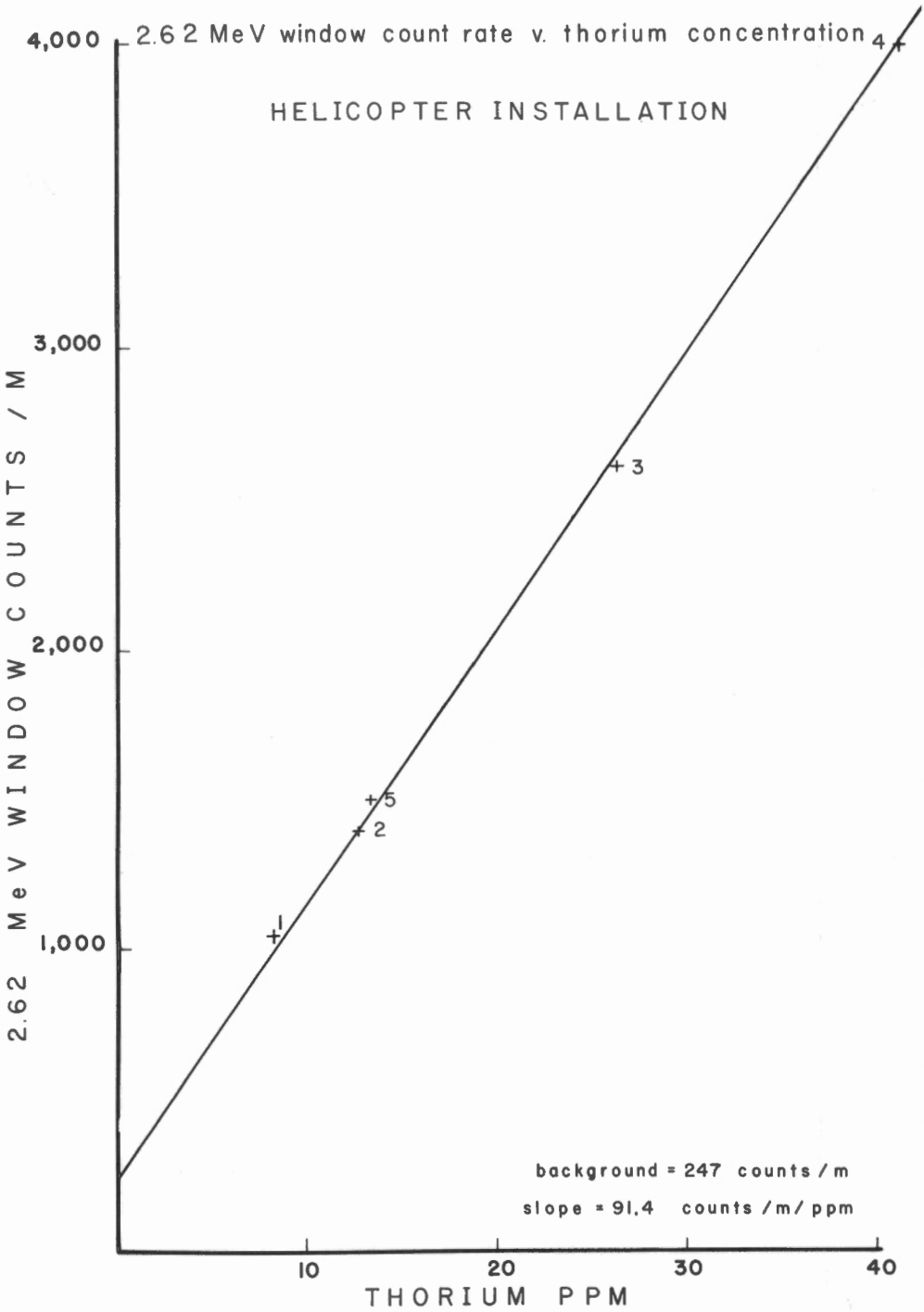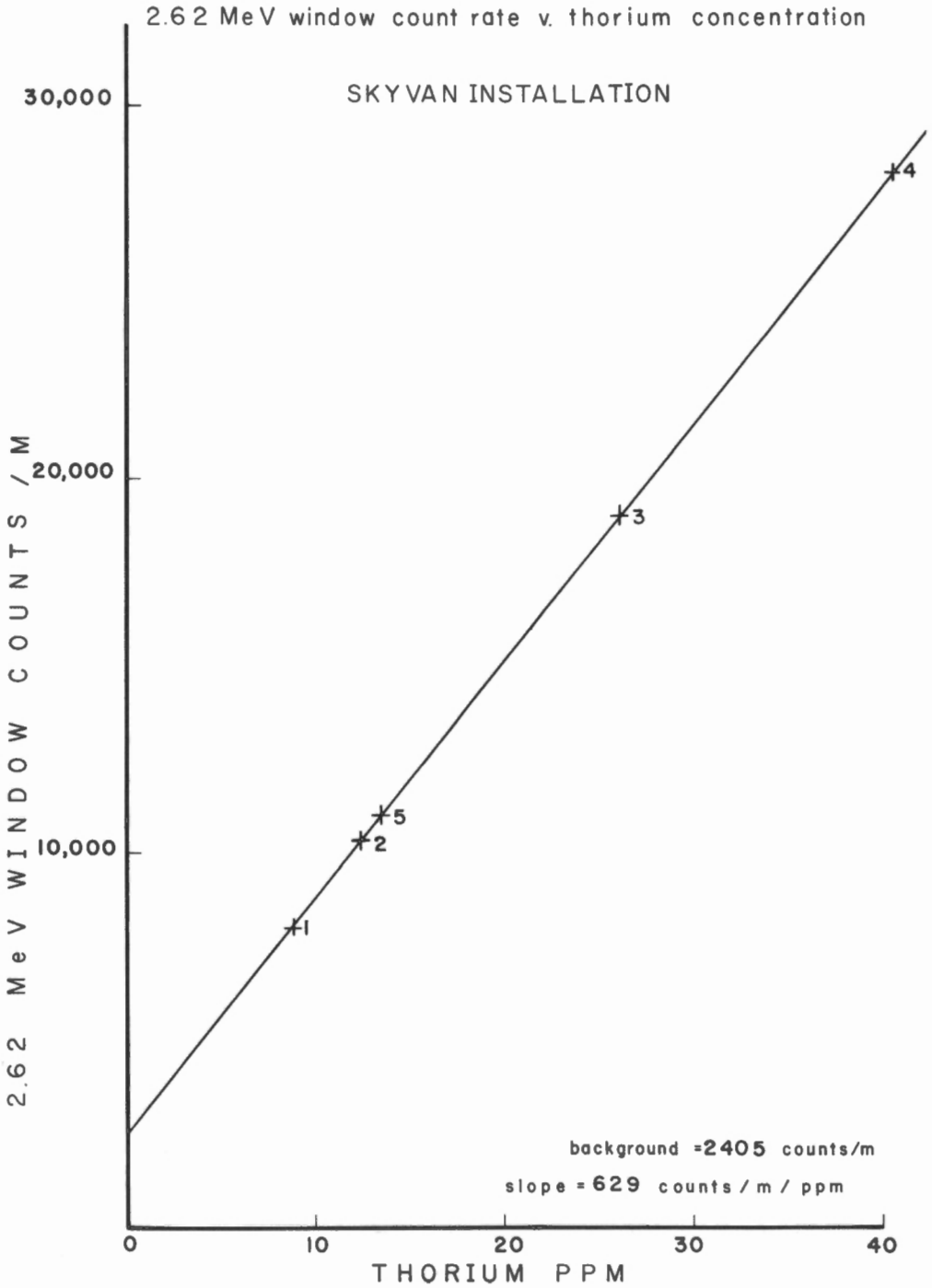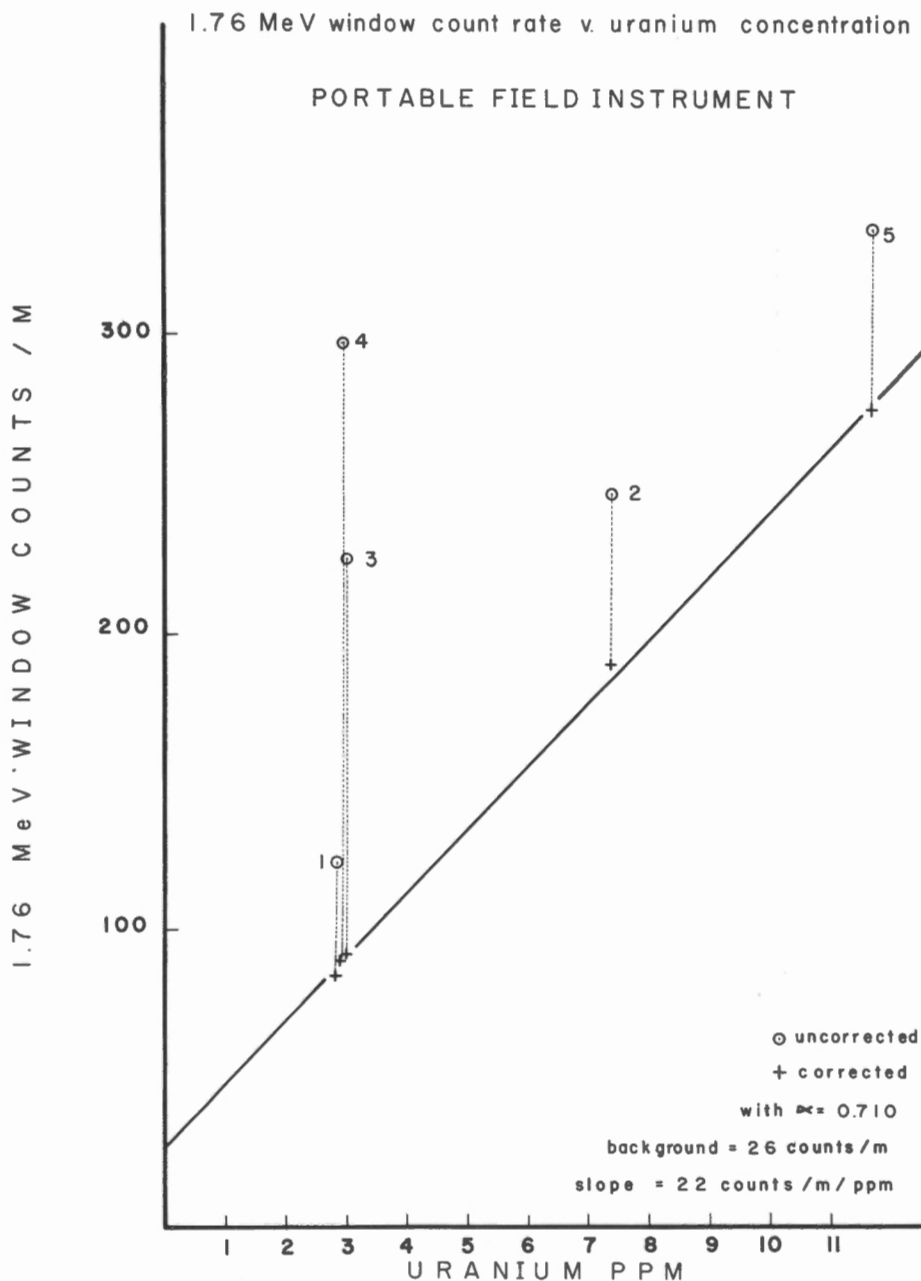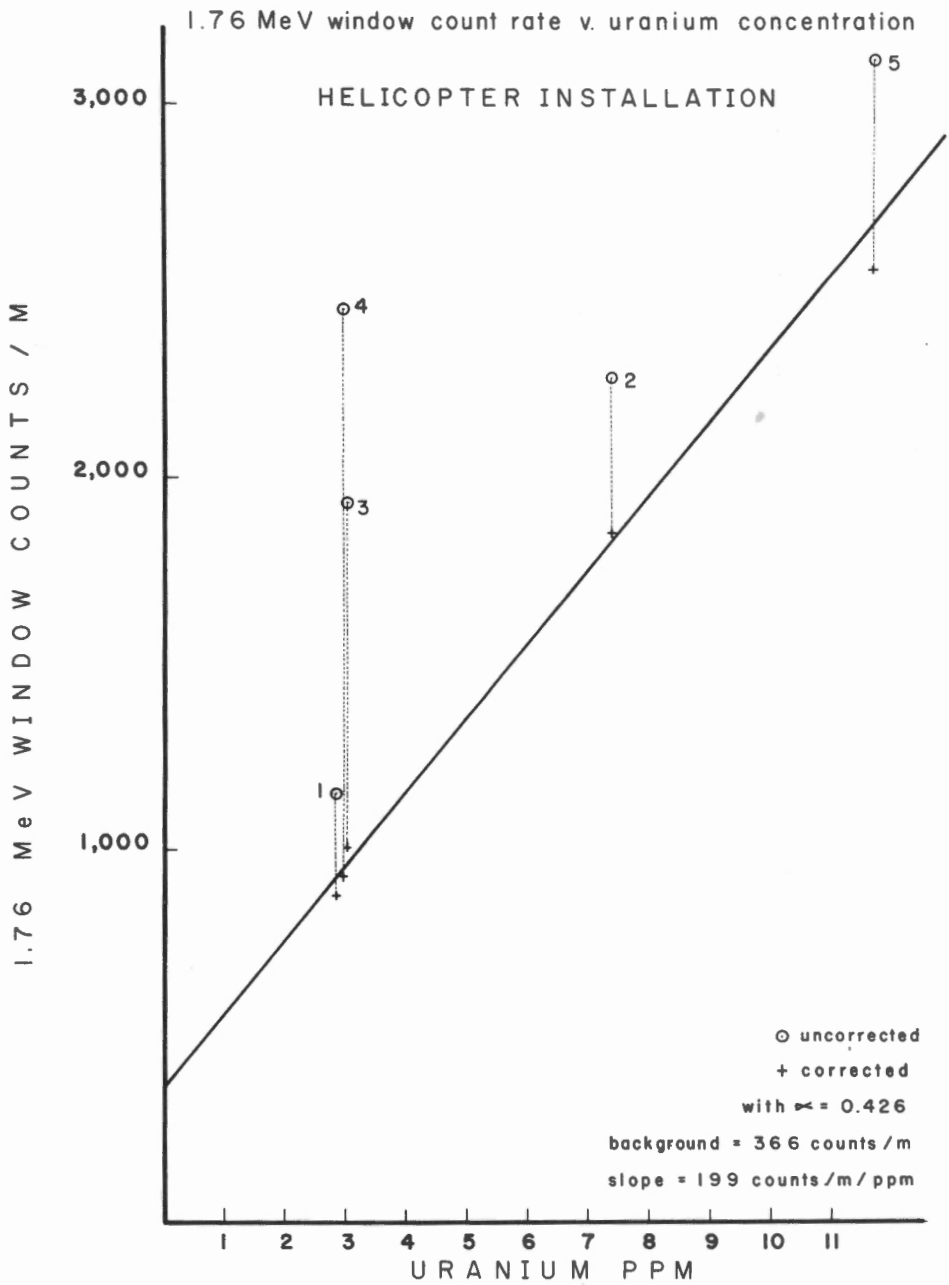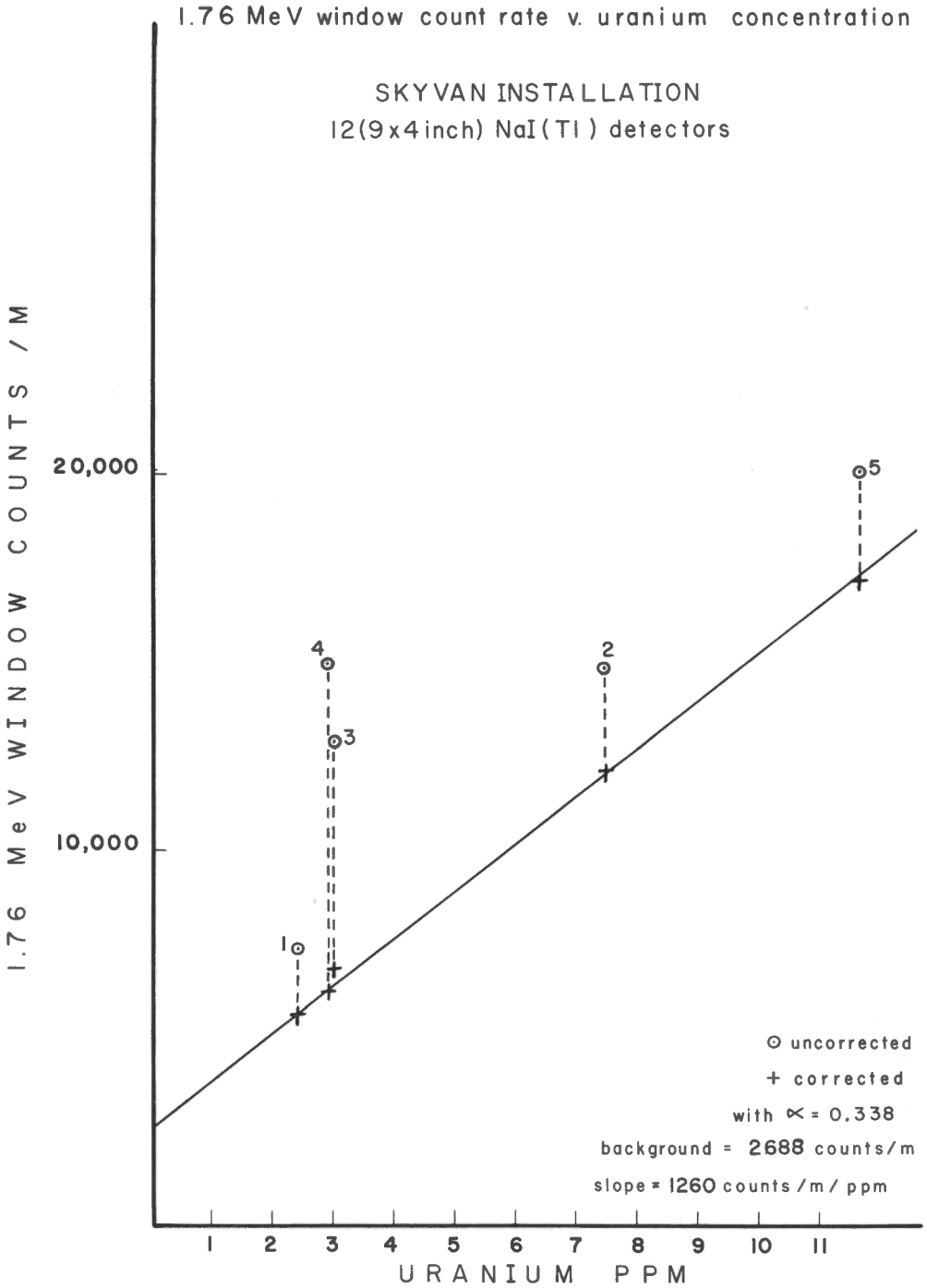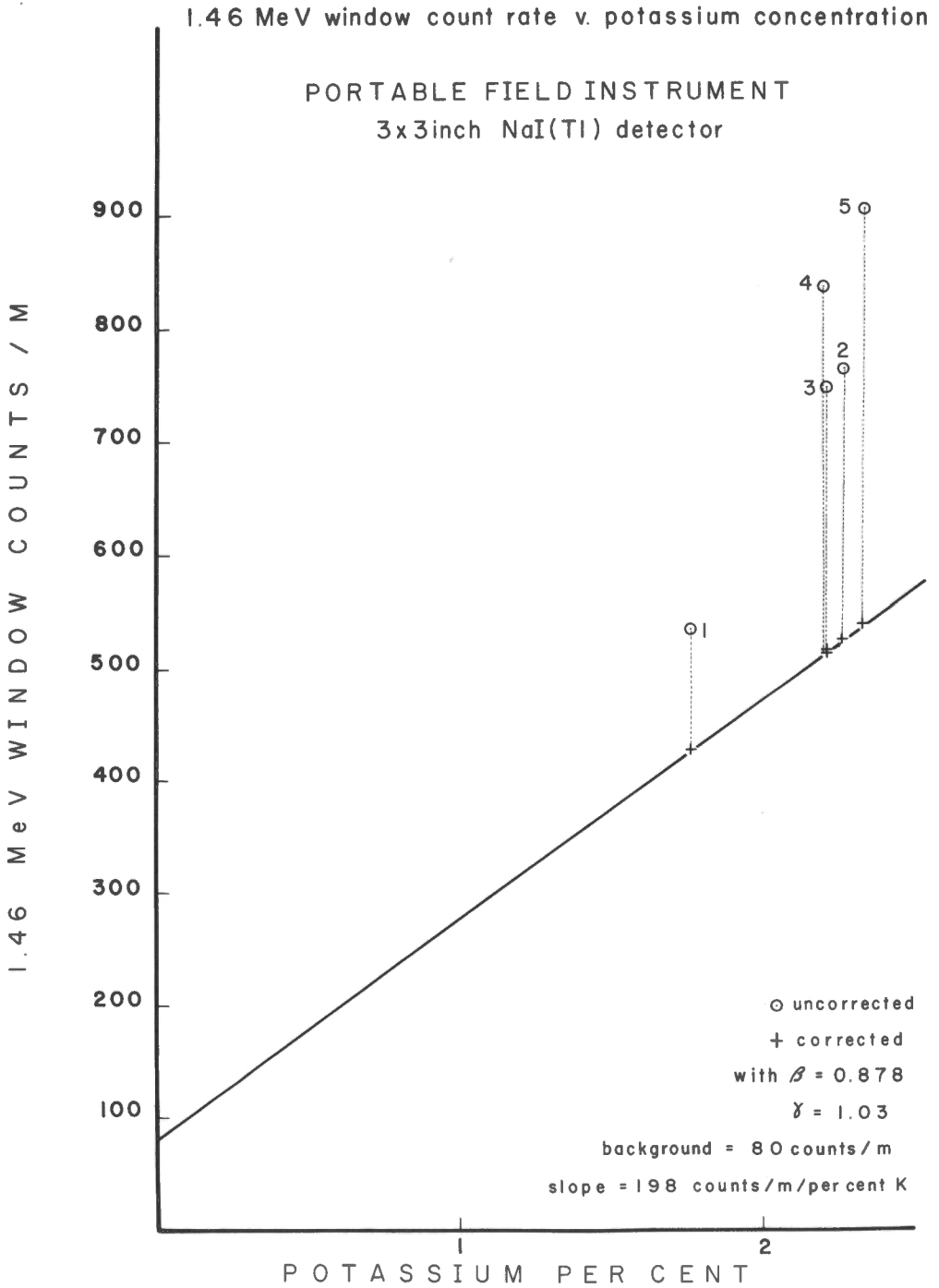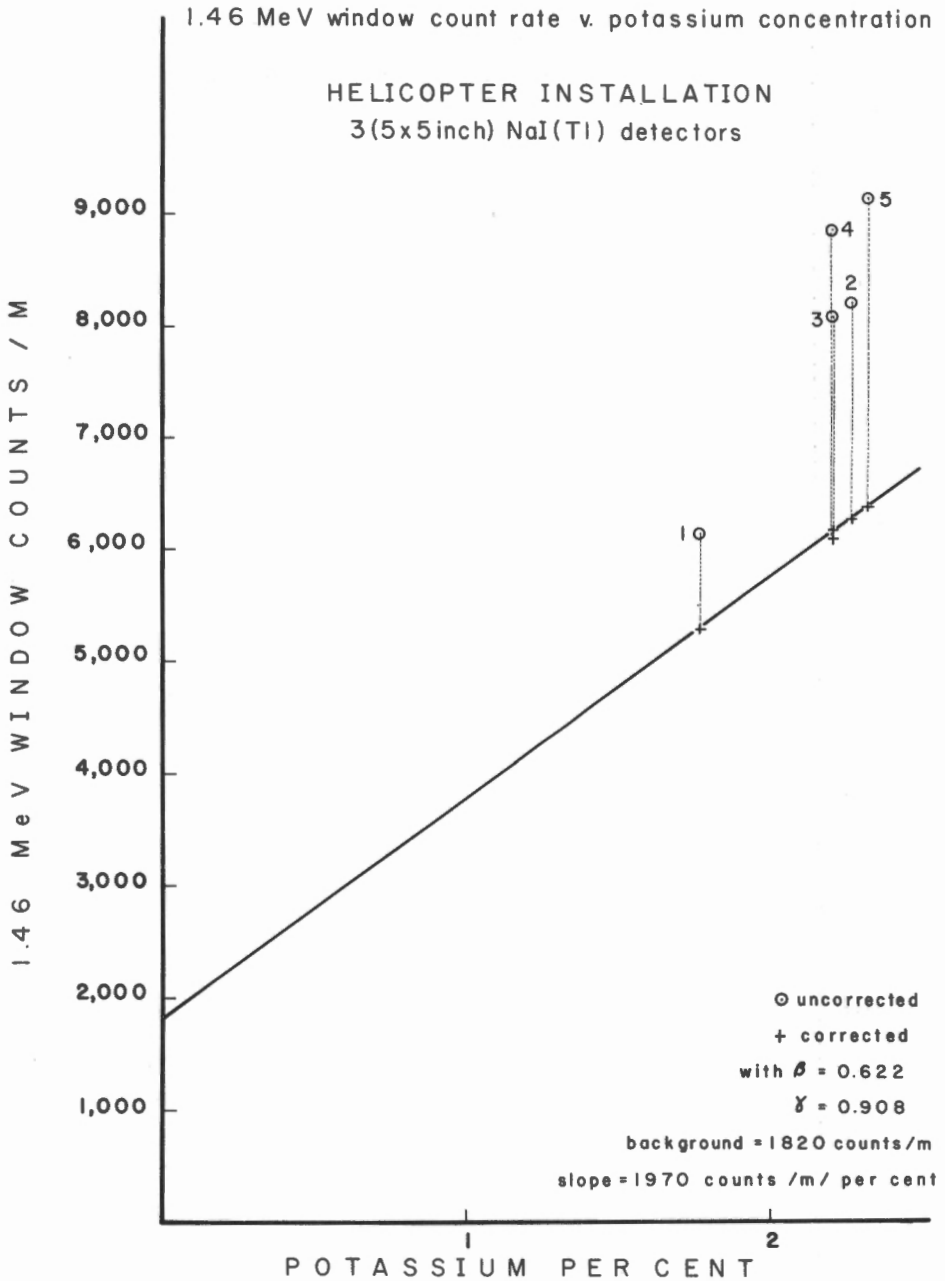Figure 11. Potassium count rate and concentration for portable field instrument.

Figure 12. Potassium count rate and concentration for helicopter system.
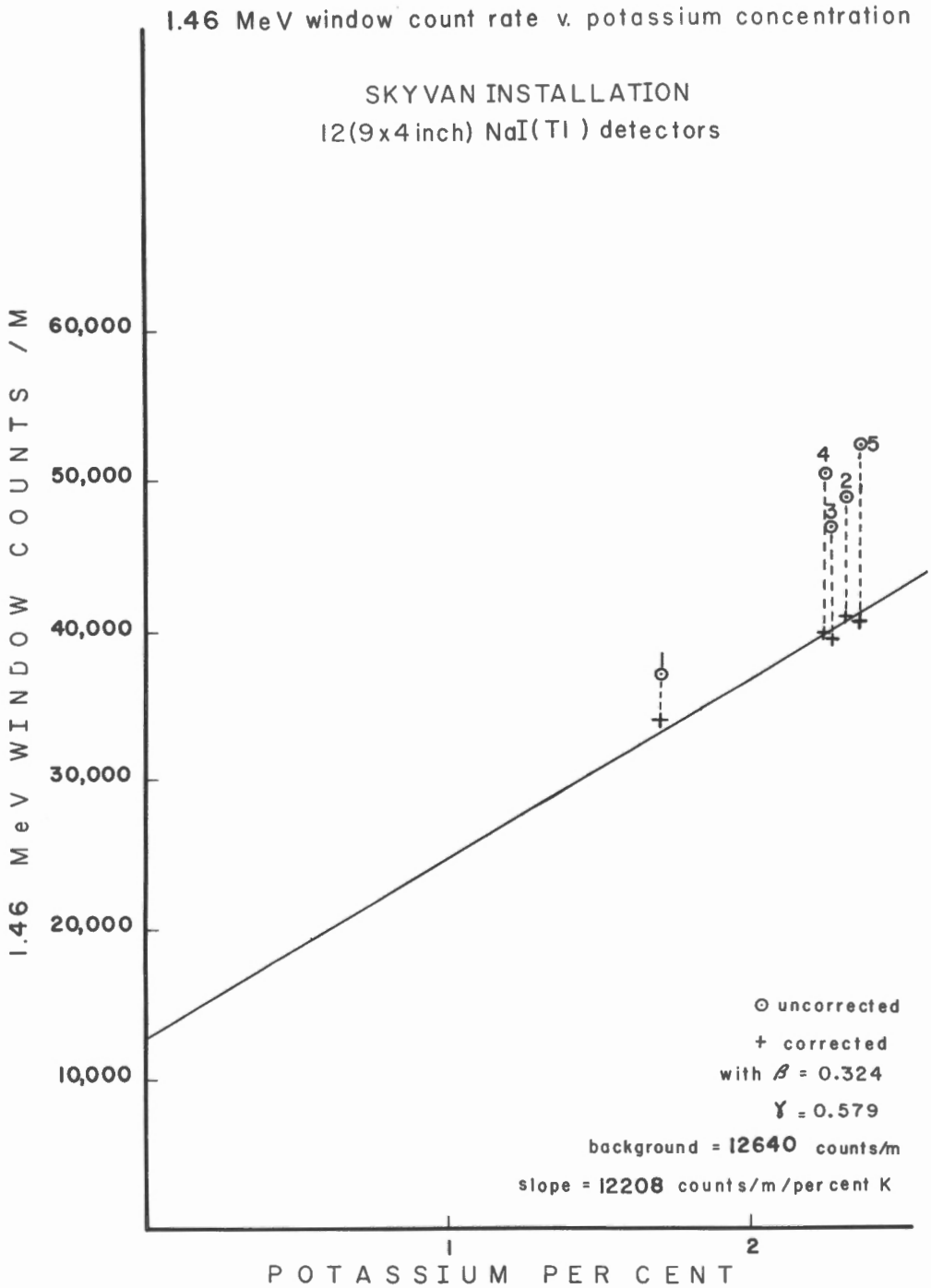
Figure 13. Potassium count rate and concentration for Skyvan system.

per cent variation in α is most significant to the accuracy of the uranium measurement and will cause an error of 20 per cent to be introduced. A similar error in β and γ produces little effect on the potassium measurement, a fraction of a per cent. Consequently, it is most important, especially when the measurement of uranium is concerned, to know α, the thorium contribution to uranium as accurately as possible. On the other hand, in most circumstances, a large uncertainty in β and γ has little effect on the potassium measurement. Because of the large variation in the uranium and thorium concentration of the pads, the coefficient α is the most accurately determined.

From a comparison of the apparent sensitivities of the 3 detector systems, using the calibration pads, it is evident that the observed count rates are not proportional to the volumes of the crystal detectors and this is particularly noticeable in the case of the 12 (9x4) inch crystal system. This arises from the physical dimensions of the system relative to the pads. In this system the detectors are mounted in two light-alloy boxes about 8 feet apart with the centres of the crystals being about 3 feet above the ground. With this geometrical configuration the pads cannot be considered of infinite size and the count rates will be reduced accordingly. The procedure which has been used to determine the sensitivities of the airborne systems has been to use a test strip which exhibits nearly uniform radioactivity close to the Ottawa River (Charbonneau and Darnley, 1970a). This technique requires a knowledge of the stripping ratios which are determined accurately from the measurements on the pads. Although the calibration pads cannot be considered of infinite size for such a system as flown in the Skyvan, they provide an extremely useful source for frequent checks on the stability and variation in sensitivity of the system. From the results of the seven measurements on each of the 5 pads shown in Table 6 it is evident that the thorium and potassium counts can be reproduced to better than 5 per cent. However the uranium counts show a variation of up to 20 per cent. A significant part of this variation can be shown to be variations in the radon concentration in the air.

From the uranium counts obtained on the low activity Pad 1, two days of high uranium counts are particularly conspicuous. These are the days of 29/6/70 and 15/7/70. On these particular days the uranium count on Pad 1 was approximately 1,700 counts and 800 counts higher than on a typical day of 9/4/69. The computations carried out using the techniques outlined in this paper indicate increases in the uranium background of 1,800 counts and 900 counts respectively. From results obtained for over-water background for the surveys of the previous two summers, a variation of 2,000 counts/minute in the uranium channel is not unrealistic and is due primarily to variations in the atmospheric radon content. Charbonneau and Darnley (1970b) have observed an unusually high uranium count of 5 times background which was apparently the result of a heavy rainstorm depositing on the ground a high proportion of the radioactive Bi-214 associated with dust particles in the air. This could also be, in part, the result of the high background observed on 9/6/70, as it was raining at the time.

The Uplands calibration pads have proved to be suitable sources for the determination of the stripping ratios for all types of field and airborne gamma-spectrometers. They can provide a useful means of standardizing all types of field instruments, quickly and accurately, from determinations of their sensitivities. These pads are available for use at any time and computer programs are on hand for the analysis of the results. Further information on the use of the pads may be obtained from the Geological Survey of Canada.

TABLE 3

SKYVAN SYSTEM 12 CRYSTALS 9th APRIL 1969 COUNTS/MIN. AVERAGED FOR 5 MINUTES

	PAD 1	PAD 2	PAD 3	PAD 4	PAD 5
K-COUNT	36833	48800	46866	50166	52033
U-COUNT	7403	14803	12296	14873	20120
T-COUNT	7946	10366	18917	28033	10720
K%	1.70	2.27	2.21	2.21	2.33
U ppm	2.41	7.30	3.00	2.90	11.70
T ppm	8.92	12.60	26.10	40.80	13.20

URANIUM BY THORIUM = .33835 POTASSIUM BY THORIUM = .33394 POTASSIUM BY URANIUM .57859

THORIUM SENSITIVITY = 629.38 COUNTS PER PPM
URANIUM SENSITIVITY = 1260.09 COUNTS PER PPM
POTASSIUM SENSITIVITY = 12207.67 COUNTS PER K20

THORIUM BACKGROUND = 2405
URANIUM BACKGROUND = 2688
POTASSIUM BACKGROUND = 12640

ERRORS IN BACKGROUND COUNTS

	PAD 1	PAD 2	PAD 3	PAD 4	PAD 5
THORIUM	73	-31	-85	51	-7
URANIUM	197	-222	-240	141	125
POTASSIUM	-1	-418	429	-212	203

THORIUM

	TOTAL COUNTS	PPM
PAD 1	7946	8.92
PAD 2	10366	12.60
PAD 3	18917	26.10
PAD 4	28033	40.80
PAD 5	10720	13.20

URANIUM

	TOTAL COUNTS	STRIPPED COUNTS	PPM
PAD 1	7403	5528	2.41
PAD 2	14803	12109	7.30
PAD 3	12296	6709	3.00
PAD 4	14873	6202	2.90
PAD 5	20120	17307	11.70

POTASSIUM

	TOTAL COUNTS	STRIPPED COUNTS	PCT
PAD 1	36833	33395	1.70
PAD 2	48800	40770	2.27
PAD 3	46866	39191	2.21
PAD 4	46866	39831	2.21
PAD 5	52033	40881	2.33

TABLE 4

STRIPPING RATIOS FOR 3 FIELD INSTRUMENTS

USING CALIBRATION PADS

NaI(Tl) Detectors	α	β	γ
Ground Instrument 1 (3x3) in.	0.710	0.878	1.03
Helicopter 3(5x5) in.	0.426	0.622	0.908
Skyvan 12(9x4) in.	0.348 ± 0.015	0.331 ± 0.044	0.560 ± 0.102
(Average of seven measurements)			

TABLE 5

VARIATION OF CORRECTED COUNTS DUE TO ERRORS IN STRIPPING RATIOS

SKYVAN 12(9x4) CRYSTALS AT 400 FEET COUNTING TIME 2.5 SECONDS

$\alpha = 0.35$ $\beta = 0.33$ $\gamma = 0.60$

	THORIUM CHANNEL	URANIUM CHANNEL	POTASSIUM CHANNEL
TYPICAL COUNTS CORRECTED FOR BACKGROUND	40	34	425
CORRECTED FOR COMPTON SCATTERING IN THE CRYSTAL	40	$(34 - \alpha \times 40)$ 20	$(425 - \beta \times 40 - \gamma \times 20)$ 400
α INCREASED 25% (0.44)	40	16	402
β INCREASED 25% (0.41)	40	20	397
γ INCREASED 25% (0.75)	40	20	397

TABLE 6

RECORD OF READINGS ON CALIBRATION PADS UPLANDS AIRPORT

SKYVAN SYSTEM WITH 12 (9x4) NaI (Tl) DETECTORS

(counts/min. - averaged over 5 minutes)

PAD	CHANNEL 1			CHANNEL 2			CHANNEL 3			CHANNEL 4			CHANNEL 5			REMARKS
DATE	K	U	T	K	U	T	K	U	T	K	U	T	K	U	T	
9/4/69	36833	7403	7946	48800	14803	10366	46866	12296	18917	50166	14873	28033	52033	20120	10720	
6/5/69	37450	7470	7970	49650	14610	10370	48050	12270	19170	51080	15170	28150	52600	19580	10710	
15/7/69	37540	7468	7924	49120	14540	10180	47000	12020	18580	51260	15120	27900	52500	19100	10460	
4/9/69	37300	7588	7748	48540	14380	10008	47480	12580	18460	51075	15175	27425	50680	18600	10008	
21/5/70	37677	7801	8005	48486	14757	10021	48175	12838	19288	50986	15529	28086	52488	19900	10422	
29/6/70	38033	9092	8045	49134	15517	10083	47800	13320	19060	50700	16020	27760	51320	20460	10120	Raining
15/7/70	38100	8286	8184	49560	15960	10400	48240	13860	19500	50900	16720	28360	52560	20520	10660	

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      PROGRAM BAKFIT
C         STRIPPING RATIOS AND SENSITIVITY DETERMINATIONS FROM FIVE PADS
      ODIMENSION S(5),X(5),Y(5),Z(5),P(5),U(5),T(5),THERR(5),POTERR(5),
     1UERR(5),USTRIP(5), PSTRIP(5),SM(20)
      IT=61
      IN=60
    2 CONTINUE
      WRITE(IT,1000)
 1000 FORMAT(1H1)
C     READ SAMPLE DATE ETC.
      READ(IN,73) (SM(I),I=1,20)
   73 FORMAT(20A4)
      WRITE(IT,74) (SM(I),I=1,20)
   74 FORMAT(20X,20A4)
C     COUNTS AND URANIUM,THORIUM AND POTASSIUM READ IN
 1003 FORMAT(1H )
      WRITE(IT,1003)
      DO 20 I=1,5
      READ(IN,1) P(I),U(I),T(I),X(I),Y(I),Z(I)
    1 FORMAT (3F6.0,3F6.2)
      IF(P(1)) 9999,9999,3010
 3010 CONTINUE
   20 CONTINUE
      WRITE(IT,201) (P(I),I=1,5),(U(I),I=1,5),(T(I),I=1,5),(X(I),I=1,5),
     1(Y(I),I=1,5),(Z(I),I=1,5)
  201 0FORMAT(15X,5HPAD 1,15X,5HPAD 2,15X,5HPAD 3,15X,5HPAD 4,15X,5HPAD 5
     1,/,13X,5(F7.0,13X),/,13X,5(F7.0,13X),/,13X,5(F7.0,13X),/,13X,5(F7.
     22,13X),/,13X,5(F7.2,13X),/,13X,5(F7.2,13X))
C     ESTIMATION OF BEST THORIUM BACKGROUND BY FITTING BEST STRAIGHT
C     LINE TO FORMULA THORIUM COUNTS-THORIUM BACKGROUND=THORIUM
C     SENSITIVITY X THORIUM CONCENTRATION OF PAD
      SUMZ=Z(1)+Z(2)+Z(3)+Z(4)+Z(5)
      SUMT=T(1)+T(2)+T(3)+T(4)+T(5)
      SUMZ2=Z(1)**2+Z(2)**2+Z(3)**2+Z(4)**2+Z(5)**2
      SUMZT=Z(1)*T(1)+Z(2)*T(2)+Z(3)*T(3)+Z(4)*T(4)+Z(5)*T(5)
      BOTTOM = SUMZ*SUMZ-5.0*SUMZ2
      IF(BOTTOM) 5,99,5
    5 CONTINUE
      THOR=(SUMZ*SUMT-5.0*SUMZT)/(SUMZ*SUMZ-5.0*SUMZ2)
       TBACK=(SUMT*SUMZ2-SUMZ*SUMZT)/(5.0*SUMZ2-SUMZ*SUMZ)
C     DETERMINATION OF RESIDUALS FOR EACH PAD TO GET EACH ERROR
      DO 3 I=1,5
      THERR(I)= TBACK+THOR*Z(I)-T(I)
    3 CONTINUE
C     DETERMINATION OF BEST URANIUM BACKGROUND BY FITTING BEST PLANE TO
C     EQUATION URANIUM COUNT-URANIUM BACKGROUND-ALPHA(THORIUM COUNT-
C     THORIUM BACKGROUND)=URANIUM SENSITIVITYXURANIUM CONCENTRATION
C     FIRST SUBTRACT THORIUM BACKGROUND
      DO 4 I=1,5
      T(I)=T(I)-TBACK
    4 CONTINUE
      SUMT=T(1)+T(2)+T(3)+T(4)+T(5)
      SUMU=U(1)+U(2)+U(3)+U(4)+U(5)
      SUMY=Y(1)+Y(2)+Y(3)+Y(4)+Y(5)
      SUMY2=Y(1)**2+Y(2)**2+Y(3)**2+Y(4)**2+Y(5)**2
      SUMT2=T(1)**2+T(2)**2+T(3)**2+T(4)**2+T(5)**2
      SUMUY=U(1)*Y(1)+U(2)*Y(2)+U(3)*Y(3)+U(4)*Y(4)+U(5)*Y(5)
      SUMTU=T(1)*U(1)+T(2)*U(2)+T(3)*U(3)+T(4)*U(4)+T(5)*U(5)
      SUMYT=Y(1)*T(1)+Y(2)*T(2)+Y(3)*T(3)+Y(4)*T(4)+Y(5)*T(5)
      0CONST=DET(1.,0.,0.,0.,5.,SUMY,SUMT,0.,SUMY,SUMY2,SUMYT,0.,
     1SUMT,SUMYT,SUMT2)
      IF(CONST) 6,99,6
    6 CONTINUE
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      0UBACK=DET(1.,0.,0.,0.,0.,SUMU,SUMY,SUMT,0.,SUMUY,SUMY2,SUMYT,0.,
     1SUMTU,SUMYT,SUMT2)/CONST
      0URAN=DET(1.,0.,0.,0.,0.,5.,SUMU,SUMT,0.,SUMY,SUMUY,SUMYT,0.,SUMT,
     1SUMTU,SUMT2)/CONST
      0ALPHA=DET(1.,0.,0.,0.,0.,5.,SUMY,SUMU,0.,SUMY,SUMY2,SUMUY,0.,SUMT,
     1SUMYT,SUMTU)/CONST
C     DETERMINATION OF RESIDUALS TO GET ERROR OF EACH PAD
      DO 9 I =1,5
      UERR(I)=UBACK+URAN*Y(I)+ALPHA*T(I)-U(I)
9     CONTINUE
C     DETERMINATION OF BEST POTASSIUM BACKGROUND BY FITTING BEST
C     FOUR DIMENSIONAL LINEAR SURFACE TO EQUATION
C     POTASSIUM COUNT-POTASSIUM BACKGROUND -BETA (THORIUM-THORIUM BACK)
C     -GAMMA(STRIPPED URANIUM COUNTS)=POTASSIUM SENSITIVITYXPOTASSIUM
C     CONCENTRATION OF THE PADS
C     FIRST WE LET S = U(1)-UBACK-ALPHAXT
      DO 10 I=1,5
      S(I)=U(I)-UBACK-ALPHA*T(I)
10    CONTINUE
      SUMX=     X(1)+X(2)+X(3)+X(4)+X(5)
      SUMT=     T(1)+T(2)+T(3)+T(4)+T(5)
      SUMS=     S(1)+S(2)+S(3)+S(4)+S(5)
      SUMP=     P(1)+P(2)+P(3)+P(4)+P(5)
      SUMX2=    X(1)**2+X(2)**2+X(3)**2+X(4)**2+X(5)**2
      SUMSX=    S(1)*X(1)+S(2)*X(2)+S(3)*X(3)+S(4)*X(4)+S(5)*X(5)
      SUMPX=    P(1)*X(1)+P(2)*X(2)+P(3)*X(3)+P(4)*X(4)+P(5)*X(5)
      SUMXT=    X(1)*T(1)+X(2)*T(2)+X(3)*T(3)+X(4)*T(4)+X(5)*T(5)
      SUMT2=    T(1)**2+T(2)**2+T(3)**2+T(4)**2+T(5)**2
      SUMST=    S(1)*T(1)+S(2)*T(2)+S(3)*T(3)+S(4)*T(4)+S(5)*T(5)
      SUMPT=    P(1)*T(1)+P(2)*T(2)+P(3)*T(3)+P(4)*T(4)+P(5)*T(5)
      SUMXS=    X(1)*S(1)+X(2)*S(2)+X(3)*S(3)+X(4)*S(4)+X(5)*S(5)
      SUMTS=    T(1)*S(1)+T(2)*S(2)+T(3)*S(3)+T(4)*S(4)+T(5)*S(5)
      SUMS2=    S(1)**2+S(2)**2+S(3)**2+S(4)**2+S(5)**2
      SUMPS=    P(1)*S(1)+P(2)*S(2)+P(3)*S(3)+P(4)*S(4)+P(5)*S(5)
      0DENOM=DET(5.0,SUMX,SUMT,SUMS,SUMX,SUMX2,SUMXT,SUMSX,SUMT,SUMXT,
     1SUMT2,SUMTS,SUMS,SUMSX,SUMTS,SUMS2)
      IF(DENOM) 11,99,11
99    WRITE(IT,106)
106   FORMAT(1X,24HONE DENOMINATOR SINGULAR)
11    CONTINUE
      0PBACK=DET(SUMP,SUMX,SUMT,SUMS,SUMPX,SUMX2,SUMXT,SUMSX,SUMT,SUMPT,
     1SUMT2,SUMST,SUMPS,SUMXS,SUMST,SUMS2)/DENOM
      0POT=DET(5.0,SUMP,SUMT,SUMS,SUMX,SUMPX,SUMXT,SUMSX,SUMT,SUMPT,
     1SUMT2,SUMST,SUMS,SUMPS,SUMTS,SUMS2)/DENOM
      0BETA=DET(5.0,SUMX,SUMP,SUMS,SUMX,SUMX2,SUMPX,SUMSX,SUMT,SUMXT,
     1SUMPT,SUMTS,SUMS,SUMSX,SUMPS,SUMS2)/DENOM
      0GAMMA=DET(5.0,SUMX,SUMT,SUMP,SUMX,SUMX2,SUMXT,SUMPX,SUMT,SUMXT,
     1SUMT2,SUMPT,SUMS,SUMXS,SUMTS,SUMPS)/DENOM
C     DETERMINATION OF RESIDUALS FOR EACH PAD
      DO 16 I=1,5
      POTERR(I)=PBACK+POT*X(I)+BETA*T(I)+GAMMA*S(I)-P(I)
16    CONTINUE
      WRITE(IT,100) ALPHA,BETA,GAMMA
100 0FORMAT(///,1X,19HURANIUM BY THORIUM=,2X,F10.5,
     1            1X,21HPOTASSIUM BY THORIUM=,F10.5,
     2            1X,21HPOTASSIUM BY URANIUM=,F10.5)
      WRITE(IT,101) THOR ,URAN,POT
101 0FORMAT(///,1X,20HTHORIUM SENSITIVITY=,2X,F10.2,14HCOUNTS PER PPM,
     1          /,1X,20HURANIUM SENSITIVITY=,2X,F10.2,14HCOUNTS PER PPM,

     2          /,1X,22HPOTASSIUM SENSITIVITY=,2X,F10.2,14HCOUNTS PER K20)
      WRITE(IT,102)  TBACK,UBACK,PBACK
102 0FORMAT(///,1X,19HTHORIUM BACKGROUND=,F7.0,
     1          /,1X,19HURANIUM BACKGROUND=,F7.0,
     2          /,1X,21HPOTASSIUM BACKGROUND=,F7.0)
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      WRITE(IT,103)
103   FORMAT(///,1X,27HERRORS IN BACKGROUND COUNTS)
      WRITE(IT,104) (THERR(I),I=1,5),(UERR(I),I=1,5),(POTERR(I),I=1,5)
104  0FORMAT(15X,5HPAD I,15X,5HPAD 2,15X,5HPAD 3,15X,5HPAD 4,15X,5HPAD 5
     1,/,3X,7HTHORIUM,5(F10.0,10X),/,3X,7HURANIUM,5(F10.0,10X),/,1X,
     29HPOTASSIUM,5(F10.0,10X))
      WRITE(61,50)
50    FORMAT(1H ,12X,7HTHORIUM,23X,7HURANIUM,21X,9HPOTASSIUM    )
      WRITE(61,51)
51    FORMAT(1X,//,1X,12HTOTAL COUNTS,2X,14HPPM.        ,1X,12HTOTAL C
     1OUNTS,1X,15HSTRIPPED COUNTS,1X,14HPPM.        ,1X,12HTOTAL COUNT
     2S,1X,15HSTRIPPED COUNTS,1X,14HPCT.        )
      DO 52 I=1,5
      T(I)=T(I)+TBACK
      USTRIP(I)=U(I)-ALPHA*(T(I)-TBACK)
      PSTRIP(I)=P(I)-(BETA*(T(I)-TBACK)+GAMMA*(USTRIP(I)-UBACK))
      WRITE(61,53)   T(I),Z(I),U(I),USTRIP(I),Y(I),P(I),PSTRIP(I),X(I)
53    FORMAT(1X,   F6.0,7X,F9.2,3X,2(5X,F6.0,9X,F6.0,7X,F9.2,3X))
52    CONTINUE
      GO TO 2
9999  CONTINUE
      END




      FUNCTION DET(A1,A2,A3,A4,B1,B2,B3,B4,C1,C2,C3,C4,D1,D2,D3,D4)
      DET1=B2*(C3*D4-C4*D3)-B3*(C2*D4-D2*C4)+B4*(C2*D3-D2*C3)
      DET2=B1*(C3*D4-C4*D3)-B3*(C1*D4-D1*C4)+B4*(C1*D3-D1*C3)
      DET3=B1*(C2*D4-D2*C4)-B2*(C1*D4-D1*C4)+B4*(C1*D2-D1*C2)
      DET4=B1*(C2*D3-C3*D2)-B2*(C1*D3-D1*C3)+B3*(C1*D2-D1*C2)
      DET=A1*DET1-A2*DET2+A3*DET3-A4*DET4
      RETURN
      END
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