

# A PRELIMINARY CALIBRATION OF THE NEW AIRBORNE GAMMA-RAY SPECTROMETER SURVEY SYSTEM OF EGYPT

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## الخلاصة :

نعرض في هذا البحث أول معايرة لجهاز المسح الإشعاعي الطيفي (جاما ١٠٠٠) الخاص بنظام المسح الجوي المصري الجديد. ونظراً لأهمية الحصول على قراءات دقيقة وحقيقية لأي جهاز قياس جديد لا بُدَّ من معايرته. ولذلك بعد أن تم تركيبه على طائرة الاستكشاف الجوي المصري الحديثة (بيتش كرافت C 90 A/B). قمنا بتجهيز أربع عينات عيارية من اليورانيوم والبوتاسيوم والثوريوم ذات إشعاعات خلفية ضعيفة (Back ground) حصلنا عليها من الوكالة الدولية للطاقة الذرية. استخدمنا ثلاثة كواشف إشعاعية للنظام المصري المستخدم مع برنامج المعايرة الذي تمَّ تجهيزه بمعرفتنا وتحميله على نظام المسح الجوي في وحدة معالجة البيانات (PDAS - 1000). وتم أخذ القراءات لكل كاشف على حدة لكل العينات وإدخالها على برنامج المعايرة في مطار الغردقة بتاريخ ١٩٩٦/٣/١٩ ومن هذه القراءات وتشغيل برنامج المعايرة تمت المعايرة عن طريق تغيير المقاومات الخاصة بالتكبير (gain) في كل صندوق من صناديق الكواشف الثلاثة. ومن برنامج المعايرة والقراءات المأخوذة تمَّ أيضاً حساب كلِّ من نسب الانتزاع (stripping Ratio) لـ ألفا وبيتا وجاما وقيمة الحساسية (sensitivity) وبذلك أصبح نظام المسح الجيوفيزيقي الجوي المصري الجديد جاهزاً لمسح أيِّ منطقة بمصر بقراءات دقيقة وحقيقية.

## ABSTRACT

The calibration of any spectrometer could be considered as the principal controlling factor and the most important step in carrying out a high-quality radiospectrometric survey. Four Canadian standard concrete calibration pads 1.0 m × 1.0 m × 0.3 m, weighing approximately 675 kg each, manufactured by Grasty and supplied from the IAEA were used for the preliminary calibration of the new airborne gamma-ray spectrometer survey system of Egypt. They comprised a low radioactivity background, a potassium, a uranium, and a thorium pad. In this work, most of the gamma radiation impacting the sensors is recorded. A computer program for finding the system stripping ratios and sensitivities was designed. The computed values were found to be in good agreement with the international ones.

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### 1. INTRODUCTION

The Geological Survey of Canada (GSC) has been involved with the calibration of airborne gamma-ray spectrometers since it constructed the first calibration facility for airborne spectrometers in 1968 at Uplands airport, Ottawa, Canada [1]. Similar calibration facilities have now been constructed in many countries throughout the world.

The calibration facilities for airborne gamma-ray spectrometers are usually four (Blank, <sup>40</sup>K, <sup>238</sup>U, and <sup>232</sup>Th) or five (Blank, <sup>40</sup>K, <sup>238</sup>U, <sup>232</sup>Th, and mixed) large concrete slabs or pads with known concentrations of potassium, uranium, and thorium. They are used to derive the calibration constants for converting the spectrometer count rates (cps or cpm) in the potassium, uranium, and thorium windows to ground concentrations of potassium (%), uranium (ppm), and thorium (ppm). Recent analysis of the calibration data obtained from the GSC facilities for airborne gamma-ray spectrometers at Uplands airport, Ottawa, showed that the calibration constants were poorly known because of uncertainties in the radioelement concentrations of the pads [2]. This was also found for the smaller calibration facilities for portable gamma-ray spectrometers at Ball's Corners near Ottawa. There was clearly a requirement to improve the Canadian calibration facilities for the airborne gamma-ray spectrometers.

In 1988, sets of small transportable calibration pads 1m × 1m × 30 cm and weighing approximately 675kg for each pad were constructed specially for calibrating airborne spectrometers. However, due to problems of radon leakage and inhomogeneties in the uranium pads, a new set of uranium pads was constructed in 1989. This new set, manufactured from a uranium-rich phosphate slag, had none of the problems of the first set which had been manufactured using a high concentration uranium ore [3].

Calibration experiments with these small pads showed that they could also be used for calibrating large volume aircraft spectrometers. This paper shows how the small imported Canadian transportable calibration pads can be used for the calibration of the new airborne gamma-ray spectrometer survey system of Egypt. This calibration has been firstly done on 1996 in Hurghada Airport, on the Red Sea Coast, approximately 400 km southeast of Cairo, the capital of Egypt.

### 2. CALIBRATION - PRINCIPLES

Figure 1 shows a typical airborne gamma-ray spectrum recorded at a survey altitude of 120m using a 50 liter sodium-iodide thallium-activated detector system [4]. Gamma-ray peaks at 2.62 MeV, 1.76 MeV, and 1.46 MeV representing thallium-208 in the thorium decay series, bismuth-214 in the uranium decay series, and potassium-40 can be readily distinguished. These particular gamma-ray emissions have been generally accepted as the most suitable for the measurement of thorium, uranium, and potassium, because they are relatively abundant at ground level and their energies are high enough that they are not appreciably attenuated at survey up to 120 m.

The spectral windows used to monitor the gamma-rays for the airborne gamma-ray spectrometer survey systems suggested by [2] are used to monitor the gamma-rays for the new airborne gamma-ray spectrometer survey system of Egypt as shown in Table 1. The total-count window is useful in geological mapping, since it reflects the general lithological variations [2, 5].

**Table 1. Spectral Windows Used to Monitor the Gamma-Rays for the Airborne Gamma-Ray Spectrometer Survey Systems [2].**

Element Analyzed	Isotope Used	Gamma-ray Energy (MeV)	Energy Window (MeV)
Potassium	<sup>40</sup> K	1.46	1.37–1.57
Uranium	<sup>214</sup> Bi	1.76	1.66–1.86
Thorium	<sup>208</sup> Tl	2.62	2.41–2.81
Total Count			0.41–2.81

In calibrating the airborne gamma-ray spectrometer so that the count rates in the three radioelement windows may be converted to isotope concentrations, two basic sets of calibration constants are required, they are [2]:

- (1) the system sensitivities, and
- (2) the stripping ratios.

The system sensitivities serve the first aspect of the airborne  $\gamma$ -ray spectrometer calibration process. They are normally determined from the four transportable calibration pads which are mounted on small trolleys that can be moved by hand under each of the detector packages. The airborne spectrometer is first tuned using a Cesium-137 source placed underneath each detector package. The gain of each detector is adjusted so that the Cs-137 photopeak at 662 keV falls in channel 55 and each channel covers an energy range of 12 keV. The potassium, uranium, thorium, and total-count windows will then be in their correct positions provided that there is a linear relationship between the channel positions and channel energies. Each pad is positioned directly under the each of the three detector packages (boxes) being calibrated. The measurements are then recorded for at least 600 seconds. A measurement time of 300 seconds on each pad gives at least 10 000 counts in all energy windows on all four pads, thus the errors in the window count rates due to random counting statistics are less than 1% [2]. With the Beechcraft King-Air C90A/B, there is enough room for the pads on their trolley to fit under the aircraft. The top of each block is approximately 60 cm below the centre of each detector package. Each pad is placed in exactly the same position under each detector package so that the background radiation is the same for all four pads. The four series of measurements for the four calibration pads are repeated five times for all the three detector packages.

The system sensitivities are normally determined from flights over airborne test strips whose radioelement concentrations are measured on the ground at the time of the calibration flights using a portable gamma-ray spectrometer. The three sensitivities which are determined at the nominal survey altitude are normally expressed as [2]:

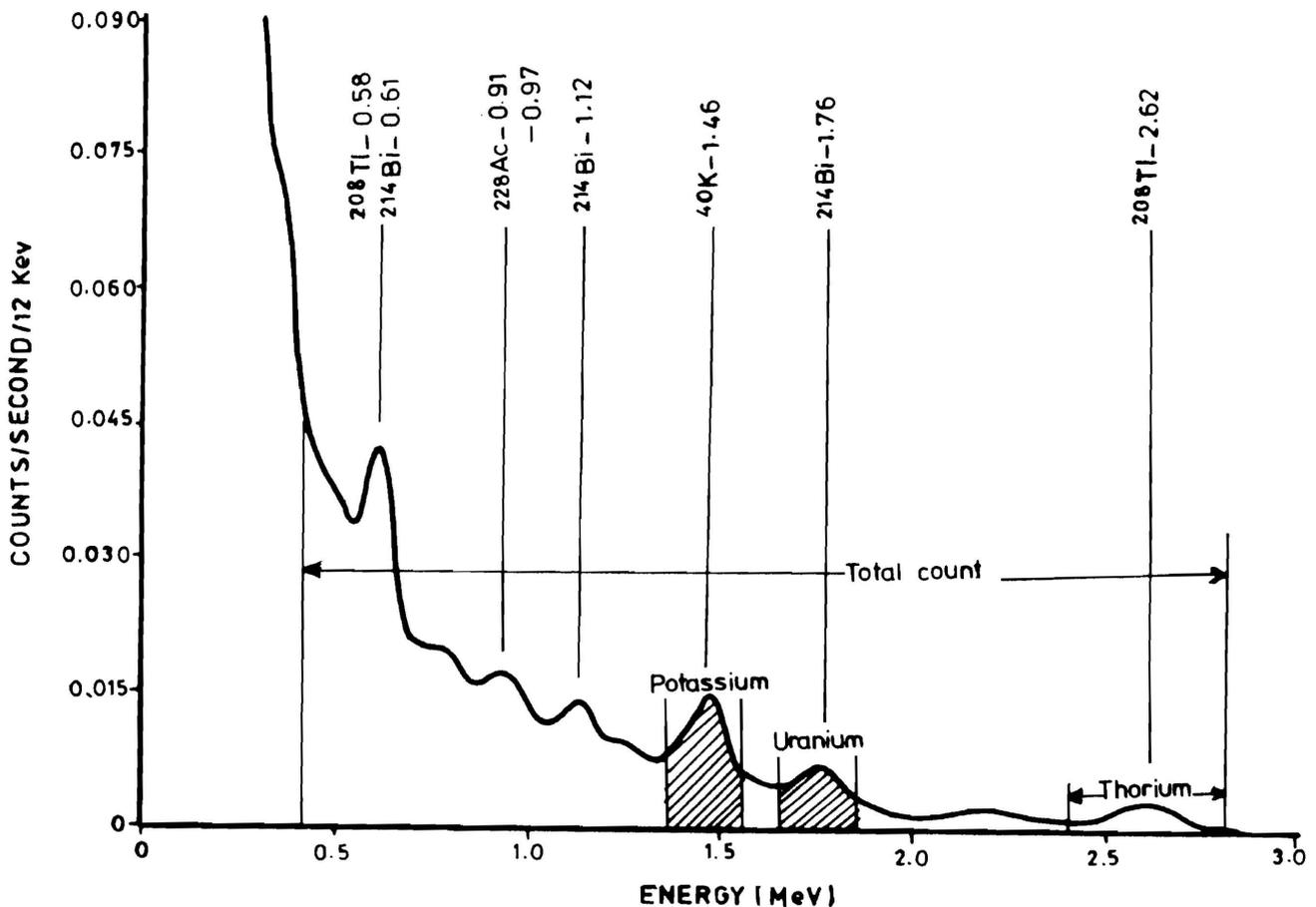


Figure 1. An airborne gamma-ray spectrum showing the gamma-ray peaks of all the three radioelements, along with the energy windows used to detect the three radioelements [4]

- (1) Counts per second in the potassium window per percent potassium,
- (2) Counts per second in the uranium window per ppm uranium, and
- (3) Counts per second in the thorium window per ppm thorium.

The stripping ratios serve the other aspect of the airborne  $\gamma$ -ray spectrometer calibration process. They provide information on the shape of the gamma-ray spectrum of the three radioelements. This information is determined from the measurements carried out on the four transportable calibration pads. The stripping ratios are the ratios of the counts detected in one window to those in another window from a pure source of potassium, uranium, and thorium.

The stripping ratios :  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $a$ ,  $b$ , and  $g$  [3] are defined as:

$\alpha$ : the ratio of counts detected in the uranium (U) window to those detected in the thorium (Th) window from a pure thorium source.

$\beta$ : the ratio of counts detected in the potassium (K) window to those detected in the thorium (Th) window from a pure thorium source.

$\gamma$ : the ratio of counts detected in the potassium (K) window to those detected in the uranium (U) window from a pure uranium source.

$a$ : the ratio of counts detected in the thorium (Th) window to those detected in the uranium (U) window from a pure uranium source.

$b$ : the ratio of counts detected in the thorium (Th) window to those detected in the potassium (K) window from a pure potassium source.

$g$ : the ratio of counts detected in the uranium (U) window to those detected in the potassium (K) window from a pure potassium source.

The airborne transportable calibration pads were used to derive these stripping ratios, so that the gamma-ray counts rates originating from each of the three radioelements (K, U, and Th) can be determined.

### 3. CALIBRATION-THEORY

In calibrating an airborne gamma-ray spectrometer, it is necessary to derive the system stripping ratios. From the measurements carried out on the four calibration pads ; the potassium, uranium, and thorium window count rates  $N_K$ ,  $N_U$ , and  $N_T$  are linearly related to their potassium, uranium, and thorium concentrations  $C_K$ ,  $C_U$ , and  $C_T$ . Consequently, the equations are as follows [2]:

$$N_K = S_{KK} C_K + S_{KU} C_U + S_{KT} C_T + B_K \tag{1}$$

$$N_U = S_{UK} C_K + S_{UU} C_U + S_{UT} C_T + B_U \tag{2}$$

$$N_T = S_{TK} C_K + S_{TU} C_U + S_{TT} C_T + B_T \tag{3}$$

$B_K$ ,  $B_U$ , and  $B_T$  are the background count rates arising from the radioactivity of the ground surrounding the pad, the radioactivity of the aircraft and equipment plus the contribution from the cosmic radiation and the radioactivity of the air. The  $S_{ij}$ 's are the nine sensitivity constants to be determined and give the count rate in window  $i$  per unit concentration of element  $j$ . The six stripping ratios  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $a$ ,  $b$ , and  $g$  are related to the various  $S_{ij}$ 's by the following equations [2]:

$$\alpha = S_{UT}/S_{TT} \tag{4}$$

$$\beta = S_{KT}/S_{TT} \tag{5}$$

$$\gamma = S_{KU}/S_{UU} \tag{6}$$

$$a = S_{TU}/S_{UU} \tag{7}$$

$$b = S_{TK}/S_{KK} \tag{8}$$

$$g = S_{UK}/S_{KK} \tag{9}$$

Each of the equations (1), (2), and (3) possesses four unknowns: the window sensitivities for potassium, uranium, and thorium plus the background. Consequently, from the measurements on all four transportable calibration pads, the four unknowns can be uniquely determined. In practice, the four sets of equations and unknowns corresponding to each of the equations (1), (2), and (3) can be reduced to a set of three equations with three unknowns by subtracting the count rates and concentrations of the blank pad from those of the potassium, uranium, and thorium pads. With this method, the unknown backgrounds,  $B_K$ ,  $B_U$ , and  $B_T$  are removed from the computation. The  $3 \times 3$  count rate matrix  $N$  (background corrected count rates on the K, U, Th pads) is then related to the  $3 \times 3$  pad concentration matrix  $C$  (concentrations of the pads) and the unknown  $3 \times 3$  window sensitivity matrix  $S$  (spectrometer window sensitivities for small pads) by the matrix equation:

$$\begin{bmatrix} N_{KK} & N_{KU} & N_{KT} \\ N_{UK} & N_{UU} & N_{UT} \\ N_{TK} & N_{TU} & N_{TT} \end{bmatrix} = \begin{bmatrix} S_{KK} & S_{KU} & S_{KT} \\ S_{UK} & S_{UU} & S_{UT} \\ S_{TK} & S_{TU} & S_{TT} \end{bmatrix} \times \begin{bmatrix} C_{KK} & C_{KU} & C_{KT} \\ C_{UK} & C_{UU} & C_{UT} \\ C_{TK} & C_{TU} & C_{TT} \end{bmatrix} \quad (10)$$

The  $N_{ij}$  is the  $3 \times 3$  matrix representing the count rate in window  $i$  on pad  $j$  minus the count rate in window  $i$  on the blank pad. Similarly,  $C_{ij}$  is the  $3 \times 3$  matrix representing the concentration of element  $i$  on pad  $j$  minus the concentration of element  $i$  of the blank pad. In matrix notation [2]:

$$N = SC \quad (11)$$

from which the sensitivity matrix containing the nine  $S_{ij}$ 's in Equation (1), (2), and (3) may be evaluated using [2]:

$$S = N C^{-1} \quad (12)$$

In calibrating a spectrometer, it is necessary to determine the window sensitivities for an infinite source. Making use of the geometric correction factors [6] as shown in Table 2, the stripping ratios can then be determined from the window sensitivities for the transportable calibration pads using Equations (4) to (9) in terms of infinite source sensitivities as follows:

$$S_{KK} = s_{KK} \times g_K \quad (13)$$

$$S_{UU} = s_{UU} \times g_U \quad (14)$$

$$S_{TT} = s_{TT} \times g_T \quad (15)$$

where  $S$  and  $s$  represent the potassium, uranium, and thorium window sensitivities for infinite and small sources respectively. The  $g$  factors are the geometric correction factors for the transportable calibration pads (Table 2).

**Table 2. Percentage of Infinite Source and Geometric Correction Factors for Transportable Calibration Pads\* [6].**

Radioelement	Principal energy (MeV)	Percentage of infinite source	Geometric correction factor
Potassium	1.46	86.47	1.156
Uranium	1.76	85.84	1.165
Thorium	2.62	84.17	1.188

\*The transportable calibration pads are 1m×1m× 30 cm. It is assumed that the center of the detector is 60 cm above the surface of the transportable calibration pads.

#### 4. CALIBRATION-PRACTICE

In the calibration procedure using the four transportable pads, the airborne gamma-ray spectrometer survey system, type Picodas-1000, was mounted inside the Beechcraft King-Air C90A/B in its normal flying configuration with each detector box centered on the pads. On 1996, the calibration procedure was performed using all the four pads in exactly the same position directly beneath the detector boxes. Six hundred seconds of one second spectra were recorded with all the four calibration pads placed beneath each of the three detector boxes one after the other. The calibration computer program was then executed for the all data obtained from all the three detector boxes to calculate the window sensitivities, stripping ratios, sensitivities, and total count sensitivities as shown in Tables 3–6.

**Table 3. Count Matrix = Sensitivity Matrix × Concentration Matrix (Blank Pad Removed).**

		Window Count/ Min.			Window Sensitivities			Pad Concentration		
		K	U	Th						
Box A	K-pad	1376.9	11.1	-4.7	224.2	1.5	1.1	6.1	0.3	-0.9
	U-pad	330.2	1109	53.5	8.9	24.1	1.1	-0.4	46.0	0.4
	Th-pad	282.9	508.4	1506.2	2.3	4.1	12.6	0.0	0.8	119.3
Box B	K-pad	899.3	2.1	16.2	146.4	-0.02	-1.3	6.1	0.3	-0.9
	U-pad	334.6	825.1	45.3	8.4	17.9	0.9	-0.4	46.0	0.4
	Th-pad	249.7	389.5	1089.9	2.1	3.1	9.1	0.0	0.8	119.3
Box C	K-pad	1473.4	8.4	-144.0	239.8	0.8	-0.2	6.1	0.3	-0.9
	U-pad	50.1	1281.6	73.9	11.6	27.8	1.5	-0.4	46.0	0.4
	Th-pad	368.5	586.4	1728.9	3.01	4.7	14.5	0.0	0.8	119.3

**Table 4. Computed Values of the Stripping Ratios of the Three Boxes A, B, and C of the NMA Airborne System in 1996, Using the Transportable Calibration Pads, in Comparison with the Computed Values of Reference [4] Using the Transportable Calibration Pads and the Infinite Sources at Uplands.**

Stripping Ratios	Transportable Calibration Pads						Infinite Sources (Uplands Pads)		
	Boxes (NMA, 1996)			Boxes (IAEA, 1991)			Boxes (IAEA, 1991)		
	A	B	C	A	B	C	A	B	C
$\alpha$	0.23	0.34	0.36	0.26	0.25	0.26	0.27	0.26	0.26
$\beta$	0.18	0.22	0.21	0.34	0.35	0.34	0.39	0.41	0.41
$\gamma$	0.37	0.47	0.42	0.81	0.81	0.81	0.74	0.66	0.71
$a$	0.04	0.04	0.05	0.07	0.07	0.07	0.01	0.01	0.01
$b$	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.06
$g$	0.01	0.00	0.00	0.01	0.01	0.01	0.14	0.07	0.11

**Table 5. Computed Values of the Infinite Source Spectrometric Sensitivities of the Three Boxes A, B, and C of the NMA Airborne System in 1996, in Comparison With the Computed Values of the [4] Using the Transportable Calibration Pads.**

Sensitivities	Boxes (NMA, 1996)			IAEA, 1991
	A	B	C	
K (c/min/%)	260.06	199.90	169.80	278.26
U (c/min/ppm)	28.18	21.40	20.95	32.55
Th (c/min/ppm)	15.01	7.83	10.86	17.23

**Table 6. Calculated Total Count ( T.C.) Sensitivities of the Three Boxes A, B, and C of the NMA Airborne System of Egypt:**

	T.C. measurement (c/min)	Concentration of uranium pad (ppm)	T.C. Sensitivities (c/min/Ur* )	
			Small sources	Infinite sources
Box A	29585.3	45.9	643.3	752.7
Box B	23494.8	45.9	518.9	597.8
Box C	33037.3	45.9	718.4	840.5

\*Ur = Unit of radioelement concentration.

## 5. CONCLUSIONS

Four transportable calibration pads mounted on a wooden pallet, constructed in Canada and imported for the Egyptian Nuclear Materials Authority (NMA), were used for standardizing the new airborne gamma-ray spectrometer survey system of Egypt. The procedure for the preliminary calibration of the airborne system on the four calibrating pads is presented. It includes the computation of the system stripping ratios and sensitivities, which proved to be in proper agreement with the international values.

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