GEOLOGICAL SURVEY OF CANADA
COMMISSION GÉOLOGIQUE DU CANADA

PAPER 76-16

A CALIBRATION PROCEDURE FOR AN AIRBORNE GAMMA-RAY SPECTROMETER

R.L. GRASTY

Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

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Available by mail from

Printing and Publishing
Supply and Services Canada,
Ottawa, Canada K1A 0S9,

from the Geological Survey of Canada
601 Booth St., Ottawa, K1A 0E8

and at Canadian Government Bookstores:

HALIFAX
1683 Barrington Street

MONTREAL
640 St. Catherine Street West

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171 Slater Street

TORONTO
221 Yonge Street

WINNIPEG
393 Portage Avenue

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800 Granville Street

or through your bookseller

Catalogue No. M44-76-16

Price: Canada: $2.00
Other countries: $2.40

Price subject to change without notice

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A CALIBRATION PROCEDURE FOR AN AIRBORNE GAMMA-RAY SPECTROMETER

Abstract

This paper describes the procedure adopted by the Geological Survey of Canada in converting airborne gamma-ray spectrometry measurements to equivalent ground concentrations. Spectral stripping corrections are measured experimentally at ground level using large calibration slabs and then calculated theoretically at aircraft altitude with the assumption that the source of radiation is uniform and infinite in extent. Altitude corrections, carried out exponentially, and the conversion of the correction data to ground concentration is achieved by using experimental data at different altitudes over a uniformly radioactive test strip of known composition. It is shown that this calibration procedure is adequate in most practical circumstances but can be appreciably in error for radioactive sources whose diameters are much less than 600 m.

Résumé

L'auteur décrit la méthode employée par la Commission géologique du Canada pour convertir en concentrations au sol équivalentes les données obtenues du spectromètre à rayons gamma aéroporté. Les corrections d'absorption différentielle du spectre sont mesurées expérimentalement au niveau du sol à l'aide de grandes dalles de calibration, puis calculées théoriquement à l'altitude de l'avion; pour ce faire, on suppose que la source de rayonnement est uniforme et infinie dans l'espace. Les corrections d'altitude calculées selon une fonction exponentielle, et la conversion des données corrigées en concentrations au sol, s'effectuent au moyen de données expérimentales à différentes altitudes, au-dessus d'une bande d'essai de composition connue qui émet un rayonnement pratiquement uniforme. L'auteur montre que cette méthode d'étalonnage est satisfaisante dans la plupart des cas mais qu'elle peut comporter des erreurs appréciables lorsque le diamètre des sources radioactives est de beaucoup inférieur à 600 mètres.

INTRODUCTION

For the past six years, the Geological Survey of Canada has been operating a high sensitivity gamma-ray spectrometer for the purpose of mapping surface concentrations of potassium, uranium and thorium. The gamma-ray spectrometer, which has been described by Darnley (1970) utilizes an array of twelve, 22.9 x 10.2 cm (9- x 4-inch) sodium iodide crystals with a total volume of 50 000 cm^3. Potassium is measured directly from the 1.46 MeV gamma-ray photons emitted by potassium-40, whereas uranium and thorium are measured indirectly from gamma-ray photons emitted by daughter products in their decay chains. Uranium is monitored by means of gamma-ray photons at approximately 1.76 MeV from bismuth-214, and thorium, from 2.62 MeV photons emitted by thallium-208. The energy windows used to record these particular gamma-rays are shown in Table 1.

In order to relate the airborne count rates from the three windows to ground concentrations, it is necessary to make some assumptions on the radioacitve homogeneity of the ground. To simplify this calibration procedure, the ground is assumed to be infinite and uniformly radioactive. The validity of this assumption is discussed in detail in a later section.

Table 1

Spectral window widths

Element analysed	Isotope used	Gamma-ray energy (MeV)	Energy Window (MeV)
Potassium	K-40	1.46	1.37-1.57
Uranium	Bi-214	1.76	1.66-1.86
Thorium	Tl-208	2.62	2.41-2.81

CALIBRATION PROCEDURES

Spectral Stripping Corrections — Ground Level

From a pure thorium source, some counts will be recorded in the lower energy potassium and uranium windows. These counts may be due to Compton scattering of thallium-208 photons at 2.62 MeV which can occur in the ground or in the air. They may also arise from 2.62 MeV photons which are incompletely absorbed in the detectors or from other lower energy gamma-ray

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Manuscript received and approved for publication February 1976.

photons in the thorium decay series. Similarly, counts will be recorded in the lower energy potassium window from a pure uranium source. The ratio of the counts in a lower energy window to those in a higher energy window from a pure uranium or thorium source is termed a stripping ratio or spectral stripping coefficient. These coefficients are peculiar to each detector system and must be determined before any measurement of elemental abundance can be attempted. Due to the presence of bismuth-214 photons at 2.43 MeV in the uranium decay series, some counts will be recorded in the thorium window from a pure uranium source. The equations relating the corrected potassium, uranium and thorium count rates, K_c, U_c and T_c to the uncorrected values K_u, U_u and T_u are:-

$$T_u = T_c + bU_c \quad \dots\dots\dots\dots\dots\dots \quad (1)$$

$$U_u = \alpha T_c + U_c \quad \dots\dots\dots\dots\dots\dots \quad (2)$$

$$K_u = \beta T_c + \gamma U_c + K_c \quad \dots\dots\dots\dots\dots \quad (3)$$

where α, β and γ, are the three spectral stripping coefficients and b is the fraction of the counts in the uranium window that appear in the thorium window from a pure uranium source. In this paper α is termed the uranium stripping ratio and β and γ the two potassium stripping ratios.

Since b is found experimentally to be small (~ 0.05) and the potassium count rates are generally much greater than the thorium or uranium count rates, the solution to these equations is given to a good approximation by:-

$$T_c = \frac{T_u - bU_c}{1 - \alpha b} \quad \dots\dots\dots\dots\dots\dots \quad (4)$$

$$U_c = \frac{U_u - \alpha T_u}{1 - \alpha b} \quad \dots\dots\dots\dots\dots\dots \quad (5)$$

$$K_c = K_u - \gamma(U_u - \alpha T_u) - \beta T_u \quad \dots\dots\dots\dots \quad (6)$$

Instrument manufacturers and survey companies have generally used prepared samples of thorium oxide and hand specimens of uranium in the form of pitchblende to determine the three spectral stripping coefficients, and have assumed that the spectrum from these small sources is the same as that from a large source. However, the experiments of Gregory and Horwood (1961) have shown that this assumption is not valid. By incorporating the effects of Compton scattering in the ground and in the air, Grasty (1975a) has calculated the increase in the uranium stripping ratio, α, with aircraft altitude for an infinite homogeneous ground. These calculations showed that in the measurement of uranium, this increase is important, particularly in areas of high thorium-to-uranium ratios. Over ground of average crustal composition, large errors in either of the potassium stripping ratios can be tolerated (Grasty and Darnley, 1971). The stripping corrections that are applied to the potassium window due to gamma-radiation from the thorium and uranium decay series can therefore be assumed to remain constant with aircraft altitude. Since the correction of the thorium count rate due to high energy gamma-ray photons of bismuth-214 is generally small, the value of b in Equations (4) and (5) can also be assumed to remain constant.

Since it is impossible to provide calibration sources which are relatively pure in thorium and uranium and effectively infinite in size for an aircraft at survey altitude, the approach taken by the Geological Survey has been to determine the spectral stripping coefficients at ground level by means of large radioactive calibration slabs which can be considered infinite in size for a detector close to their surface. The uranium stripping ratio at aircraft altitude is then calculated from the ground level value (Grasty, 1975a). The spectral stripping corrections at ground level are determined using five concrete calibration sources located at Uplands Airport, Ottawa. These concrete slabs 7.6 by 7.6 by 0.46 m in depth, are adjacent to an aircraft parking area so that an aircraft fitted with a gamma-ray spectrometer can be towed or taxi onto the slabs. The exact location of the five calibration slabs is shown in Grasty and Charbonneau (1974). Since 90 per cent of the gamma-radiation at the surface of an infinite source of density 2.7 g/cc, originates from the top 15-25 cm (Gregory and Horwood, 1961) these calibration sources can be considered infinite in depth. Results of laboratory analyses on core samples from each of the five pads are shown in Table 2. Complete details of their construction and the procedure for determining the three spectral stripping coefficients is given in Grasty and Darnley (1971).

The equations relating the thorium, uranium and potassium count rates, T, U, P, in the various windows to the respective concentrations Tppm, Uppm and Ppct of each pad are given by:-

$$T - T_B = k_1 \times \text{Tppm} \quad \dots\dots\dots\dots\dots\dots \quad (7)$$

$$U - U_B - \alpha(T - T_B) = k_2 \times \text{Uppm} \quad \dots\dots\dots \quad (8)$$

$$P - P_B - \beta(T - T_B) - \gamma\,[(U - U_B) - \alpha(T - T_B)] = k_3 \times \text{Ppct} \quad \dots\dots\dots\dots \quad (9)$$

Table 2

Laboratory analyses of core samples from the calibration pads

	Potassium (Per cent)	Uranium (ppm)	Thorium (ppm)
Pad 1	1.70	2.4	8.9
Pad 2	2.27	7.3	12.6
Pad 3	2.21	3.0	26.1
Pad 4	2.21	2.9	40.8
Pad 5	2.33	11.7	13.2

α, β, γ, are the three spectral stripping corrections and k_1, k_2, k_3 are the sensitivities in terms of counts per unit concentration per unit time. T_B, U_B, and P_B are the background count rates in the various windows which originate from the surrounding soil and concrete apron, the material of the aircraft, cosmic radiation and atmospheric radioactivity due to radon. The contribution to the thorium window of gamma-radiation from the uranium decay series can be neglected, since the uranium-to-thorium ratios of the pads are not abnormal (Table 2). The data from the five pads can be fitted to Equations (8) and (9) 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. The mathematical technique is similar to that described by Killeen and Carmichael (1970) for analyzing gamma-ray spectrometry data from ground measurments using a portable gamma-ray spectrometer. The thorium data are first fitted to Equation (7) to determine the thorium background and thorium sensitivity of the instrument. The computed thorium background is then used in Equation (8) to calculate the uranium stripping ratio, uranium background and uranium sensitivity. The two potassium stripping ratios, the potassium sensitivity and the potassium background are then calculated using Equation (9). These results are illustrated in Figures 1, 2 and 3. The excellent fit of the corrected count rates in each window to the compositions of each pad indicate that the laboratory analyses are representative of the overall composition of the pads. The results of seven measurements of the three stripping ratios, taken from Grasty and Darnley (1971) are shown in Table 3.

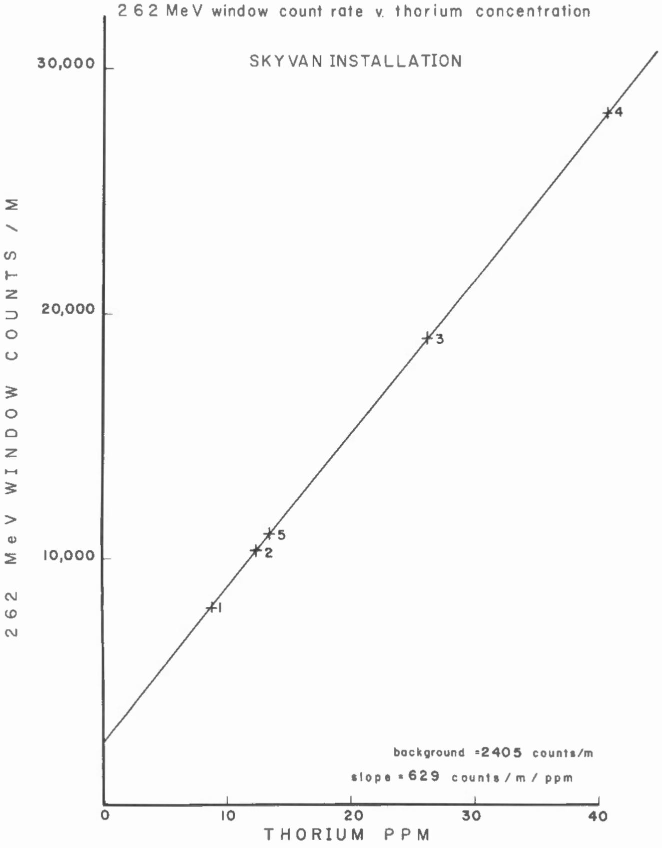

Figure 1. Thorium count rate and pad concentration for the GSC Skyvan system.

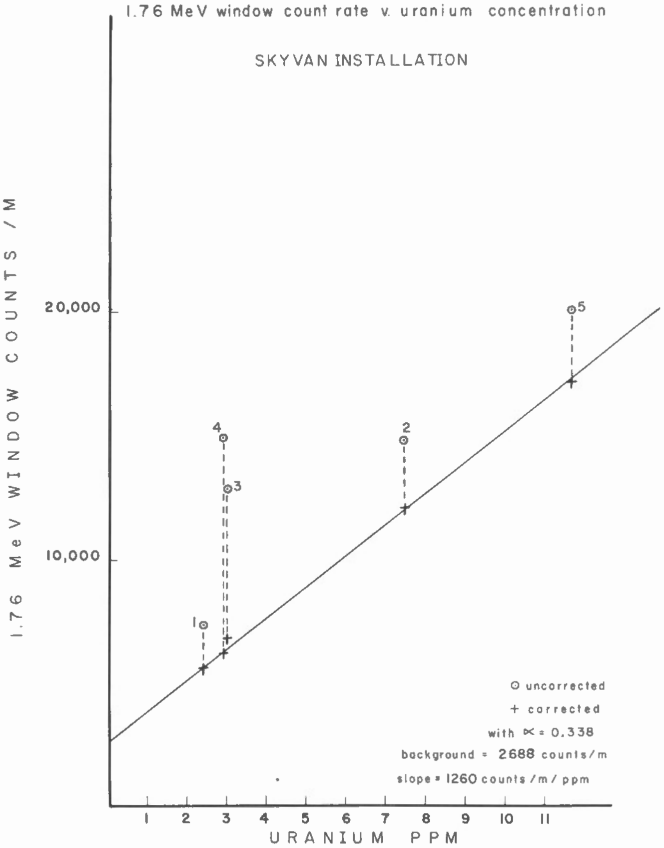

Figure 2. Uranium count rate and pad concentration for the GSC Skyvan system.

Spectral Stripping Corrections — Aircraft Altitude

The three stripping ratios determined using the calibration slabs are for infinite sources at ground level. Due to Compton scattering in the air, the uranium stripping ratio will increase with altitude. The two potassium stripping ratios can be assumed to remain

Table 3

Spectral stripping corrections for twelve (22.9 x 10.2) cm detectors using the calibration pads

Uranium Counts per Thorium Count (α)	Potassium Counts per Thorium Count (β)	Potassium Counts per Uranium Count (γ)
0.348 ± 0.015	0.331 ± 0.044	0.560 ± 0.102

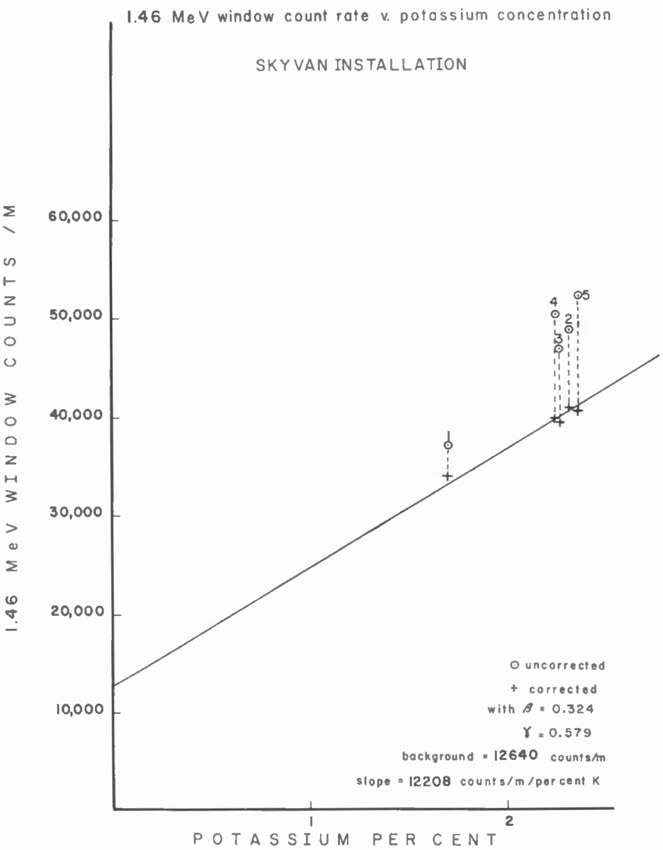

Figure 3. Potassium count rate and pad concentration for the GSC Skyvan system.

constant. Grasty (1975a) has derived an analytical solution for the increase of the uranium stripping ratio with altitude over an infinite homogeneous source, due to scattered radiation from thallium-208 gamma-ray photons at 2.62 MeV. The increase in the uranium stripping ratio, $\alpha_p(H)$, from the point source value, in which only scattering in the detector is considered, to that at an altitude H, where scattering is considered in the detector, the ground and in the air, is given by: -

$$\alpha_p(H) = \frac{\dfrac{\lambda_T k_U \varepsilon_U/\varepsilon_T}{\lambda_U - \lambda_T}\left[E_2(\mu_T H) - \dfrac{\lambda_T}{\lambda_U} E_2(\mu_U H)\right]}{E_2(\mu_T H) + k_T e^{-\mu_T H}} \qquad (10)$$

where,

μ_T and μ_U are the linear absorption coefficients in air at 2.62 MeV and 1.76 MeV,

λ_T and λ_U are the linear absorption coefficients in the ground at 2.62 MeV and 1.76 MeV,

k_T and k_U are the fraction of 2.62 MeV photons that are scattered into the thorium and uranium windows,

and $\varepsilon_U/\varepsilon_T$ is the ratio of the detector photopeak efficiency at 1.76 and 2.62 MeV, where photopeak efficiency is defined as the fraction of gamma-rays incident on the detector that are completely absorbed. $E_2(x)$ is given by: -

$$E_2(x) = \int_1^\infty \frac{e^{-xt}}{t^2}\,dt$$

The increase in the uranium stripping ratio from the point source value to that measured by the pads, α_g, will be the value given by Equation (10) for H = 0, i.e.

$$\alpha_g = \frac{\lambda_T \varepsilon_U/\varepsilon_T}{\lambda_U(1 + k_T)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

The increase in the uranium stripping ratio with altitude from the value at ground level will be the difference between $\alpha_p(H)$ in Equation (10) and α_g from Equation (11). This increase is plotted in Figure (4) using the values of the parameters as presented in Table (4). The function E_2 was calculated from a series expansion given by Grosjean and Bossaert (1965) and terms involving the absorption coefficient of the ground only appear in the form of ratios which will be the same as for air.

In the range of altitudes from 50 to 300 m, this increase from the value at ground level, $\alpha(H)$ can be approximated by a straight line given by: -

$$\alpha(H) = 0.02 + 0.00025 \times H \quad \ldots\ldots\ldots\ldots \quad (12)$$

where H is in meters. This line is shown in Figure 4 and is the simplified relationship used by the Geological Survey in calculating the increase of the uranium stripping ratio with aircraft altitude from the value measured experimentally using the calibration pads.

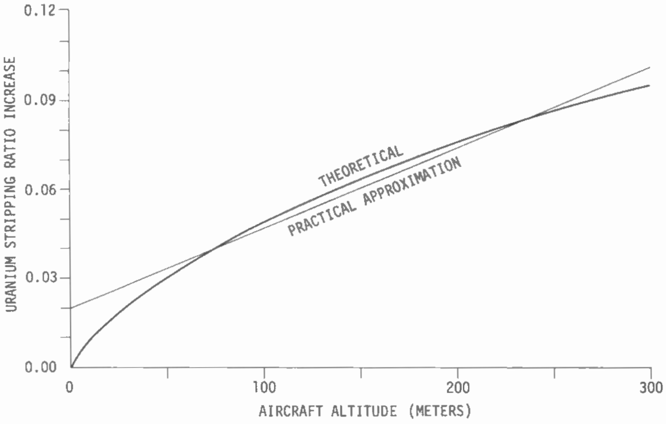

Figure 4. Increase of the uranium stripping ratio with aircraft altitude.

Table 4

Parameters used in the calculation of the uranium stripping ratio increase with altitude

Parameter	Mathematical Symbol	Value
Linear Absorption Coefficient of 2.62 MeV photons in air at 20°C and 76 cm Hg	μ_T	4.61×10^{-3} per metre
Linear Absorption Coefficient of 2.62 MeV photons in air at 20°C and 76 cm Hg	μ_U	5.72×10^{-3} per metre
Fraction of 2.62 MeV photons scattered into the thorium window	k_T	0.0655
Fraction of 2.62 MeV photons scattered into the uranium window	k_U	0.0767
Ratio of Detector Photopeak Efficiency at 1.76 and 2.62 MeV	$\varepsilon_U/\varepsilon_T$	1.27

Altitude Corrections

The detector count rates are dependent on the altitude of the aircraft. The relation between the count rate, N, and aircraft altitude H, over a homogeneous ground is given by Kogan *et al.*, (1969): -

$$N = \int_1^\infty \frac{e^{-\mu Hx}dx}{x^2} = N_o E_2 \text{ (uH)} \quad \ldots\ldots\ldots \quad (13)$$

where μ is the linear absorption coefficient of gamma-rays in air at the energy considered, and N_o is the count rate at ground level.

In the range of altitudes normally encountered in airborne survey operations, the count rates in the three windows can be adequately represented by a simple exponential expression of the form: -

$$N = Ae^{-\bar{\mu}H} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

where A and $\bar{\mu}$ are constants (Kogan *et al.*, 1969; Darnley *et al.*, 1969).

From flights at different altitudes over the Breckenridge test strip (Grasty and Charbonneau, 1974), the count rates, after correction for background and Compton scattering were computer fitted to Equations (13) and (14) by a least squares technique described by Powell (1965) to determine the linear absorption coefficients (μ) and the exponential height correction parameters ($\bar{\mu}$). Figure 5 shows the corrected potassium count rate variation with aircraft altitude and the two curves given by Equations (13) and (14). It is apparent that the theoretical expression given by Equation (13) shows a much greater attenuation of the count rate with aircraft altitude close to the ground than is indicated by the more simplified exponential expression. In the range of altitudes from 75 to 250 m, the two curves are both found to fit the experimental data satisfactorily.

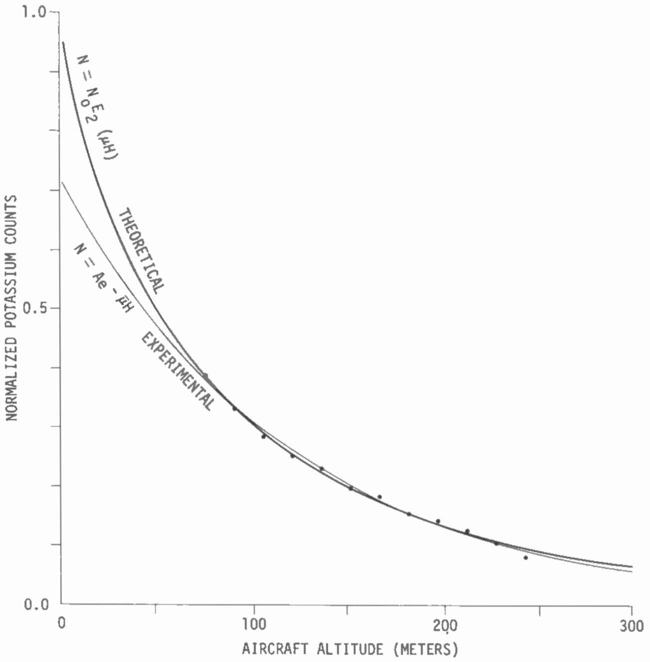

Figure 5. Theoretical and experimental potassium count rate variation with altitude.

The linear absorption coefficients, μ, and similarly the exponential height correction parameters, $\bar{\mu}$, are proportional to air density. The calculated exponential height correction parameters, μ were converted to the values at 0°C and 76 cm of mercury using the air temperature and pressure at the time of the flight as supplied by the Uplands weather office a few miles away from the test strip. These exponential parameters are shown in Table 5.

Table 5

Exponential height correction parameters ($\bar{\mu}$)

Window	$\bar{\mu}$ (per metre at 0°C and 76 cm Hg)
Potassium	7.97×10^{-3}
Uranium	6.79×10^{-3}
Thorium	6.73×10^{-3}

The detector count rates depend not only on aircraft altitude but also on air density. The effective flying height of the aircraft, H at 0°C and 76 cm of mercury is given by: -

$$H = H_T \times \frac{273 \times P}{T \times 76} \quad \dots\dots\dots\dots\dots\dots \quad (15)$$

in which H_T is the actual flying height, T the absolute temperature and P the atmospheric pressure. In practice, no correction is made for atmospheric pressure changes, and consequently Equation (15) reduces to: -

$$H = H_T \times \frac{273}{T} \quad \dots\dots\dots\dots\dots\dots\dots \quad (16)$$

The air temperature, T, is noted by the pilot from a thermometer mounted outside the aircraft. The count rates are then corrected to the nominal flying height at 0°C using Equation (14) and the exponential parameters shown in Table 5.

Conversion of Count Rates to Ground Concentration

From flights over the Breckenridge test strip, the sensitivity of the spectrometer in terms of counts per unit concentration per unit time can readily be determined provided the radioactive ground concentration is known.

In the summer of 1973, 70 soil samples were taken at seven separate sites along the test strip and analysed for potassium, uranium and thorium in the laboratory. The ten samples at each site were taken at different depths, up to a maximum of 15 cm, to establish the homogeneity of the test strip. Assuming there was a linear variation of radioactivity with depth, a linear correlation analysis was carried out to determine the surface concentration and the rate of increase of concentration with depth. These results, taken from Grasty (1975b) are shown in Table 6 and indicate that the potassium and uranium concentrations have no significant variation with depth. The thorium analyses show a slight increase of approximately 0. 04 ppm per centimetre. The gamma-ray spectrometer profiles are normally corrected to the nominal flying height of 122 m (400 feet) at a temperature of 0°C with the pressure assumed to be 76 cm of mercury. To determine the sensitivity of the spectrometer, it is therefore necessary to know the count rates that would be obtained over the test strip under these conditions.

As shown previously, the variation of count rate with altitude is found experimentally to fit the exponential Equation (14) given by: -

$$N = Ae^{-\bar{\mu}H}$$

where A and $\bar{\mu}$ are constants.

The flights for which A and μ were calculated were carried out at a temperature of 14°C and a pressure of 76. 96 cm of mercury. Under these conditions, a height H, where

$$H = 122 \times \frac{(273 + 14)}{273} \times \frac{76}{76.96} = 126.6 \text{ m}$$

will give the same count rate at 122 m at normal temperature and pressure. The count rates in the three windows at 126. 6 m, after background correction and spectral stripping can then be calculated using the values of A and $\bar{\mu}$ determined from the original flight data at 14°C and 76. 96 cm of mercury. The sensitivities of the spectrometer were then calculated using the ground concentrations shown in Table 6, and the results are listed in Table 7.

Table 6

Variation of radioactive concentration with depth of the Breckenridge test strip

Element	Surface Concentration	Rate of increase of concentration with depth
Potassium	2. 03 ± 0. 04 pct	-0. 001 ± 0. 002 pct/cm
Uranium	0. 92 ± 0. 09 ppm	0. 004 ± 0. 006 ppm/cm
Thorium	7. 70 ± 0. 28 ppm	0. 039 ± 0. 018 ppm/cm

Table 7

Element sensitivities of the GSC Skyvan Spectrometer at 122 metres

Element	Sensitivity (Counts/min.)
Potassium	4960 ± 150 per pct
Uranium	660 ± 80 per ppm
Thorium	365 ± 15 per ppm

EFFECT OF SOURCE CONFIGURATION

The correction of the airborne data and its conversion to ground concentration as described in this paper have all been carried out under the assumption that the ground was homogeneous and infinite both in depth and horizontal extent. Since 90 per cent of the radiation at the surface of a soil of density 1. 5 g/cc originates from the top 10-20 cm (Gregory and Horwood, 1961), for practical purposes the assumption of downward extension can be assumed to be valid.

In this section, the effect of source size on the calibration procedure is discussed. To simplify the theory, the sources are assumed to be homogeneous and circular, since otherwise the radiation fields must be approximated by analytical expressions (Kogan *et al.* 1969) or evaluated numerically.

Spectral Stripping Corrections — Aircraft Altitude

As discussed previously, it is only necessary to consider the altitude variation of the uranium stripping ratio. At an altitude of 122 m, over an infinite source, approximately 50 per cent of the radiation at an energy of 2.62 MeV originates from within a cone of semi-angle 45° (Duval *et al.*, 1971). The average distance travelled by the thallium-208 photons through the air from an infinite source is therefore greater than for a 'small' (diameter approaching zero) source, and consequently the increase of the uranium stripping ratio from ground level to aircraft altitude due to scattering occurring in the air, will also be greater for an infinite source. Using the equations derived by Grasty (1975a) for scattering in two media (Equations 18 and 20), the uranium stripping ratio at an altitude of 122m for the GSC system was calculated to be 0.410 for a 'small' source compared to 0.428 for an infinite source.

Using data from Grasty (1975a) the corrected uranium count rate over a 'small' source, when the infinite source value of the uranium stripping ratio is used was found to be approximately 3 per cent too low over rocks of normal crustal thorium-to-uranium ratios. This figure rose to 12 per cent over a thorium-rich area of the Fort Smith radioactive belt (Darnley and Grasty, 1972). However, in almost all practical situations, these errors would be considerably reduced, since any radioactive source must have some horizontal extension, in order to be detected.

The technique of experimentally determining the uranium stripping ratio at ground level, using the calibration pads and calculating the increase with altitude for an infinite source appears to be accurate for most practical purposes. Only over narrow sources with abnormally high thorium-to-uranium ratios would this procedure result in significant errors in the corrected uranium count rate.

Altitude Corrections

The count rate, N, at an altitude H, over a circular source of radius r, that is effectively infinite in depth is given by Kogan *et al.* (1969):-

$$N = N_o \left[E_2(\mu H) - \frac{H}{(H^2 + r^2)^{\frac{1}{2}}} \quad E_2 \left\{ \mu (H^2 + r^2)^{\frac{1}{2}} \right\} \right]. \quad (17)$$

where μ is the absorption coefficient in air of gamma-rays of the energy concerned, N_o is the count rate at ground level over an infinite source and E_2 is as defined previously.

In the height correction procedure, it is assumed that the count rate drops off exponentially with height (Equation 14). The exponential height correction parameters, $\bar{\mu}$, for sources of different radii will be given from Equation (17) by:-

$$\bar{\mu} = -\frac{d}{dh} \left[\log \left\{ E_2(\mu H) - \frac{H}{(H^2 + r^2)^{\frac{1}{2}}} \quad E_2 \left[\mu (H^2 + r^2)^{\frac{1}{2}} \right] \right\} \right] \ldots\ldots\ldots\ldots (18)$$

This equation was differentiated and the variation of $\bar{\mu}$ for sources of different radii is plotted in Figure 6 for an aircraft at an altitude of 122 m. The theoretical linear absorption coefficient of 2.62 MeV gamma-rays in air at 20°C and 76 cm of mercury was used. With increasing source size, $\bar{\mu}$ quickly approaches the theoretical infinite source value of 0.00771 per metre at a diameter of about 600 m.

From the altitude tests over the Breckenridge test strip, the experimental exponential height correction parameter shown in Table 5 is approximately 20 per cent lower than that calculated theoretically for an infinite source. The reasons for this have been discussed in some detail by Grasty (1975b) and are related to the detector response, the electronic dead-time of the spectrometer, Compton scattering within the thorium window and effects due to the aircraft structure. If the aircraft deviates appreciably from its nominal flight altitude, it is apparent that over sources smaller than about 600 m in diameter, the count rate after height correction will be considerably in error since the exponential height correction parameters can vary by a factor of 3. An exponential height correction procedure that is independent of the size of the source can therefore only be justified for sources that are greater than about 600 m in diameter.

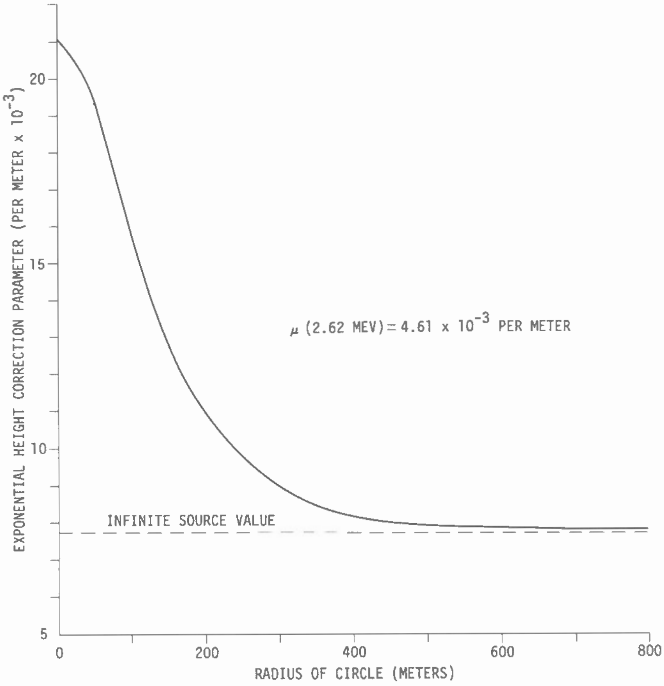

Figure 6. Variation of the exponential height correction parameter with source size.

Conversion of Count Rates to Ground Concentration

The count rate over a small source will be less than that over an infinite source with the same radioactive concentration. Consequently over small sources, ground concentrations which are calculated using sensitivities derived for an infinite source will always be less than the true ground concentration.

The percentage ratio of the count rates over a circular source of radius, r, to that over an infinite source is given by Kogan *et al.* (1969): -

$$P = 100 \times \frac{\left[E_2(\mu H) - \frac{H}{(H^2 + r^2)^{\frac{1}{2}}} E_2\left\{\mu(H^2 + r^2)^{\frac{1}{2}}\right\}\right]}{E_2(\mu H)} \quad ..\,(19)$$

where μ, H, and E_2 are the parameters used in Equation (17). This equation is plotted in Figure 7 and shows that over sources greater than 600 m in diameter, the count rates will be at least 90 per cent of the count rate that would be obtained if the source was infinite. The Geological Survey technique of converting airborne count rates to ground concentrations by using sensitivities from the Breckenridge test strip, will therefore be accurate to within 10 per cent for sources that are greater than 600 m in diameter. However, for small diameter sources considerable errors can arise. Based on the uranium sensitivity from the Breckenridge test strip (Table 7), flights over a small uranium occurrence just outside Ottawa (Grasty *et al.*, 1973) indicated that the ground concentration was approximately 6 ppm. Provisional ground follow-up work using a portable field spectrometer indicates a concentration of approximately 100 ppm. This error in converting the airborne count rates to ground concentration is undoubtedly due to the small size of the uranium anomaly. In exploration, it is normally narrow anomalies with high uranium-to-thorium ratios which are of interest. In order to evaluate these anomalies it is important to obtain a good estimate of their ground concentration. To achieve this, the width of the anomaly on the ground must be known as accurately as possible, since for narrow sources, the observed count rate is critically dependent on its width (Fig. 7). In the Geological Survey's mode of operation, counts in the potassium, uranium and thorium windows are recorded every 2.5 seconds. From flights over narrow sources, it is found that with this counting time, the anomaly can only be clearly seen for only two successive measurements, and hence it is difficult to determine its width to any reasonable accuracy. It therefore appears that for exploration a shorter recording time should be used.

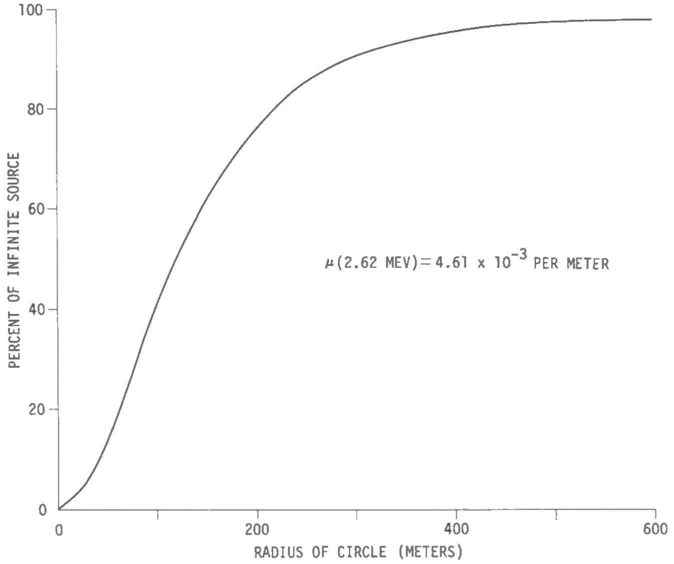

Figure 7. Percentage of the infinite source count rate for different source sizes.

SUMMARY

The Geological Survey technique of converting airborne gamma-ray spectrometry measurements to equivalent ground concentrations consists of: -

1. experimentally determining the three spectral stripping coefficients at ground level using large calibration sources;
2. calculating the theoretical increase with aircraft altitude of the spectral stripping correction that has to be applied to the uranium window due to the presence of gamma-rays in the thorium decay series;
3. converting the corrected count rates in the three windows to the nominal flight altitude at 0°C using an experimentally measured exponential variation of count rate with aircraft altitude over a uniformly radioactive test strip;
4. converting these height corrected count rates to ground concentrations from results of laboratory analyses on soil samples from the test strip.

The results presented show that the spectral stripping procedure is adequate in most circumstances. However, both height correction and the conversion of airborne count rates to ground concentrations are far from ideal for sources whose diameters are much less than 600 m. In order to convert airborne count rates to ground concentrations for all possible source sizes, a more sophisticated procedure, such as computer modelling must be used. For such a technique to be successful, a measurement time significantly less than the 2.5 seconds currently used is to be recommended.

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