RECENT DEVELOPMENTS IN AIRBORNE GAMMA RAY SURVEYING

Robert L. Grasty

GAMMA-BOB INC. CANADA

ABSTRACT

Standardized procedures have been developed for converting airborne gamma ray measurements to ground concentrations of potassium, uranium and thorium. These procedures make use of an airborne calibration range whose ground concentrations should be measured with a calibrated portable spectrometer rather than by taking geochemical samples. Airborne sensitivities and height attenuation coefficients are normally determined from flights over the calibration range but may not be applicable in mountainous areas. Mathematical techniques have been now been developed to reduce statistical noise in the airborne measurements by utilizing up to 256 channels of spectral information.

INTRODUCTION

Airborne gamma-ray spectrometry commenced in the late 1960's, primarily for uranium exploration. Since the mid-1970's, the method has been applied extensively in support of geological mapping and mineral exploration. These surveys, normally flown at a height of approximately 120 m above the ground, typically utilize between 30 and 50 liters of NaI detectors with 4 or 8 liters of shielded detectors for monitoring variations in atmospheric radioactivity.

Modern spectrometers record at least 256 channels of spectral data in the range 0 – 3 MeV. They also record three additional windows to monitor ^{40}K gamma–rays at 1460 keV, ^{214}Bi gamma–rays at 1760 keV from the uranium decay series, and ^{208}Tl gamma–rays at 2615 keV from the thorium decay series. A total count window is also recorded to monitor overall radioactivity levels. A cosmic ray window which records all incident particles above 3 MeV is used to monitor cosmic ray increase with aircraft altitude above sea-level. All modern spectrometers are energy stabilized so that gamma rays of the same energy always fall into the same channel. This is achieved by continuously monitoring one of the prominent gamma-ray peaks from either potassium or thorium.

Standardized procedures for converting the airborne gamma-ray measurements to ground concentrations of potassium, uranium and thorium were developed in the late 1970's mainly through large government uranium exploration programs such as those carried out in the United States and Canada. These procedures were developed because many aircraft with different detector volumes were involved in these national programs. The International Atomic Energy Agency (IAEA) has long been involved in the gamma ray spectrometer methods and has published a number of technical reports on various aspects of the subject. The calibration and processing procedures for airborne gamma ray surveys are comprehensively dealt with in IAEA (1991). More recently, the Australian Geological Survey Organisation (AGSO) published a guide to the technical specifications for airborne gamma ray surveys (Grasty and Minty, 1995). This AGSO report provides a more detailed explanation for the specifications and the consequences of not abiding by them.

Large concrete calibration pads, typically 8 m across and with known concentrations of the three radioactive elements were used to establish the mutual interferences (stripping ratios) between the three radio-element windows. Nowadays, these stripping ratios are determined using small concrete pads, 30 cm x 30 cm x 1m which are located in most parts of the world. Airborne sensitivities are determined from flights at different altitude over a calibration range whose ground concentrations are measured with a calibrated portable gamma-ray spectrometer. These flights are also used to derive exponential factors to correct for changes in the airborne count rate with aircraft altitude.

In this extended abstract, some of the issues in relation to the use of an airborne calibration range are discussed. These include the effect of variations in the gamma ray signal caused by soil moisture fluctuations and the applicability of the height attenuation coefficients in areas of high topographic relief. Finally, a section is devoted to a new procedure for reducing statistical noise in the airborne measurements that makes use of up to 256 channels of the spectrum.

CALIBRATION RANGES

Calibration ranges are used to calculate height attenuation coefficients for each window and to calculate the sensitivity of the airborne system (counts per second per unit concentration of K, U and Th) for any particular survey altitude. A series of flights at different altitudes over the calibration range are used to determine the height attenuation coefficients while the system sensitivities are determined from the measured ground concentrations of the calibration range.

There are several reasons why the ground concentrations of a calibration range should be measured with a calibrated portable spectrometer rather than by the geochemical analyses of soil samples. For example, variations in soil moisture affect the gamma radiation from the ground but not the geochemical analyses. For instance, a ten percent increase in soil

moisture will change the gamma ray emissions from ^{40}K and ^{208}Tl by a similar amount. However, the effect of moisture on the measurement of ^{214}Bi is more complicated due to changes in the near surface concentration of the gas ^{222}Rn.
^{214}Bi is a decay product of ^{222}Rn. In a soil, a certain fraction of ^{222}Rn (a decay product of ^{226}Ra) escapes from the soil particles into the soil pores. For a soil, this emanating fraction typically varies from 20 to 40 percent, but can exceed 50 percent. Since ^{222}Rn is a gas it can diffuse through the ground. Furthermore it has a relatively long half-life of 3.8 days, and can therefore diffuse considerable distances through the ground and subsequently into the atmosphere. Consequently laboratory measurements of ^{214}Bi or ^{226}Rain may not represent the field situation.
Another reason why geochemical sampling is not recommended for measuring the ground concentrations of a calibration range relates to the response of an airborne spectrometer. For both airborne and ground spectrometers, sources near the surface have a greater influence on the airborne measurement than sources at depth. However, the radioactivity of soils can vary with depth. Unless this depth variation is taken into consideration, soil sampling will not provide reliable estimates for the ground concentration of an airborne calibration range as viewed by the airborne system.
For airborne surveys carried out in areas with significant topographic relief, many airborne survey contractors have run into problems in using attenuation coefficients derived from flights over a calibration range. This problem is frequently believed to be due to the limited range of the exponential height attenuation corrections. Figure 3 shows the background corrected thorium window count rates from a series of flights taken at different altitudes over a large island in Lake Ontario, Canada. The figure shows that the exponential correction can be applied over this range of altitudes, from 50 m to 620m.
The results shown in Figure 3 were taken over an area with little topographic variation. For airborne surveys carried out over such areas, the aircraft altitude would not deviate significantly from the nominal survey altitude. Consequently any corrections due to height variations would be minimal. It is in areas of steep topography that the aircraft would vary significantly from the planned survey altitude and height corrections would become important.
The fact that the standard exponential height correction procedure frequently fails in mountainous areas can be explained by differences between the response of the radar altimeter and the airborne spectrometer. When flying over a valley, the radar altimeter will register the altitude of the aircraft above the valley floor. However, if the valley has steep sides and is also narrow, a significant proportion of the radiation received by the spectrometer can originate from the valley sides. This source of radiation can be much closer to the detector than indicated by the radar altimeter. Consequently, the height correction factor based on the radar altimeter reading will be too high. This will increase the corrected count rates from their true value .
Conversely, when flying over a steep ridge, there are similar problems with the height correction procedure. However, in this case the source of radiation will be on average farther away than indicated by the radar altimeter. The height corrected count rates will therefore be less than the true value. In practice, in mountainous terrain the survey aircraft spends more time over valleys than over ridges. Consequently, unless topographic effects are considered, airborne data generally shows a higher ground concentration than really exists. Schwarz et al (1992) attempted to correct for these topographic problems theoretically using a digital terrain model. Most survey companies take a more practical approach by correlating the measured count rates with the aircraft altimeter reading. However, there is the danger that the process will tend to remove any geological features that relate to topography.
It is also interesting to note that at high altitudes such as exist in the Andes, air density can be half the value at sea level. Consequently, gamma radiation can travel twice as far as at sea level. Therefore, airborne gamma ray data which would normally be rejected at aircraft altitudes above 300m can be useful up to altitudes as high as 600m. This also means that radiation from the sides of valleys can be detected at quite large distances.

REDUCTION OF STATISTICAL NOISE

One of the main limitations of the airborne gamma ray spectrometric method has been due to the statistical nature of the gamma ray counting process. Figure 4 shows a profile of the uranium window counts rates over the Geological Survey of Canada (GSC) calibration range. An analysis of the data shows that the standard deviation of the individual measurements is approximately 5 counts. This is also the value calculated theoretically from the square root of the mean count (25). The agreement between the calculated and measured variation shows that for uranium, the GSC calibration range is relatively uniform. This variation of 20 percent in the raw uranium window counts is increased significantly to around 55 percent after the uranium window has been stripped and background corrected.
Recently there have been major advances in reducing the statistical errors particularly in the measurements of uranium and thorium. The technique uses up to 256 channels of data from the entire survey data set to identify all statistically significant spectral shapes which are then used to reconstruct new potassium, uranium and thorium windows. After this reconstruction, the new windows are found to have significantly less noise than the original raw windows. Since the procedure makes use of all the counts in the spectrum as well as the correlation between potassium, uranium and thorium, the reduction in statistical noise is found to be significantly greater than for multi-channel spectral fitting. An analysis of both simulated and measured survey data has shown that for uranium and thorium the reduction in statistical noise is equivalent to increasing the detector volume by a factor typically between 3 and 4 (Hovgaard and Grasty, 1997). More recently, Minty and MacFadden (1998) have improved the technique even further by first sorting the data into clusters on the basis of similarity in spectral shape. This was found to typically reduce the statistical noise by a further factor of two.
Compared to the multi-channel spectral fitting procedure, the technique has the advantage that following this pre-processing procedure, the standard 3-window analysis can be carried out as recommended by the International Atomic Energy Agency (1991). An additional advantage over multi-spectral fitting is that no model experiments are required to derive the potassium, uranium and thorium spectra at different heights. This technique can be applied not only to airborne gamma ray survey data but also to any series of gamma ray measurements.
The procedure is a modified version of the Principal Component Analysis (PCA) techniques and gives the spectral components as well as the amplitude of the components at each individual measurement point. In airborne data where

there are only natural radioactive elements, it is generally found that 8 spectral components are sufficient to explain the real spectral shapes present in the data. From the amplitudes and the first eight spectral components, it is then possible to reconstruct the measured spectra at each measurement point. In reconstructing the spectrum in this manner the noise components are largely removed and the reconstructed spectrum is much less noisy.
Figure 5 shows the high energy part of a measured and reconstructed airborne spectra calculated from a series of flights over the GSC calibration range. The potassium, uranium and thorium windows were then recalculated from the reconstructed spectra. Figure 6 shows the stripped and background corrected uranium profile flown over the GSC calibration range before and after the filtering technique has been applied to the data. The errors in the stripped uranium counts are reduced from approximately 56 percent to 16 percent. In terms of the reduction in statistical noise, this is equivalent to flying with a detector volume 12 times greater $(56/16)^2$.

CONCLUSIONS

Recent studies have shown the relationship between soil moisture, the radon emanation coefficeint of the soil and airborne measurements of uranium. For soils with high emanation coefficient, the airborne uranium counts can increase with increasing soil moisture due to a build-up of radon in the near surface. These radon studies have shown that the ground concentrations of an airborne calibration range should be measured with a portable gamma ray spectrometer rather than by taking geochemical samples. Flights over an airborne calibration range have shown that the airborne count rates vary exponentially with height up to altitudes as high as 600 meters. However, due to differences in the response of the radar altimeter and the airborne system, these coefficients cannot be applied in areas of high topographic relief. Recently there have been major advances in reducing statistical noise in the airborne measurements. This has been accomplished through a spectral component analysis technique that uses up to 256 channels of spectral information.

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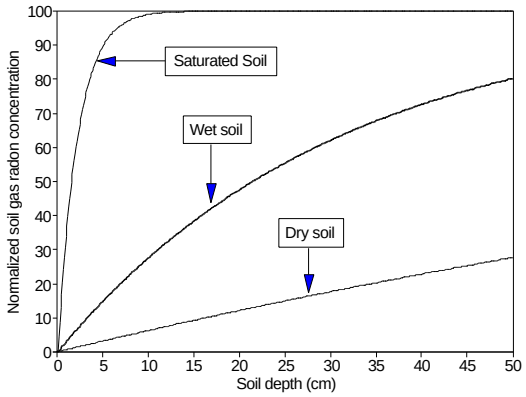

Figure 1. The variation in soil gas radon cocentration with depth for soils under three different soil moisture conditions.

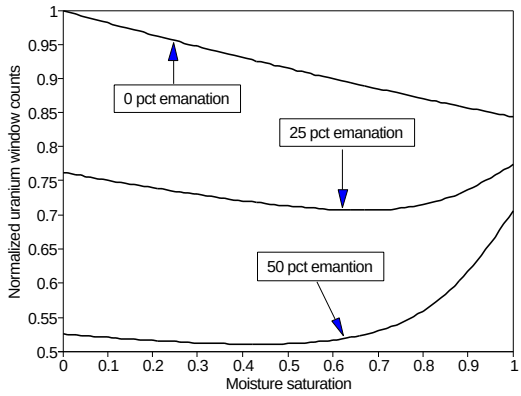

Figure 2. The variation in the uranium window count rate with moisture saturation for a soil with the same radium concentration but with different radon emanation coefficients.

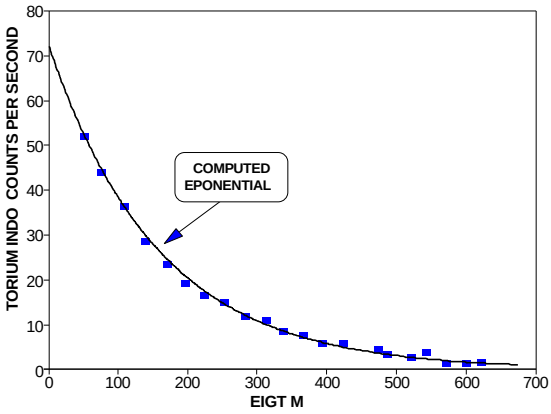

Figure 3. The variation of the thorium window with aircraft altitude.

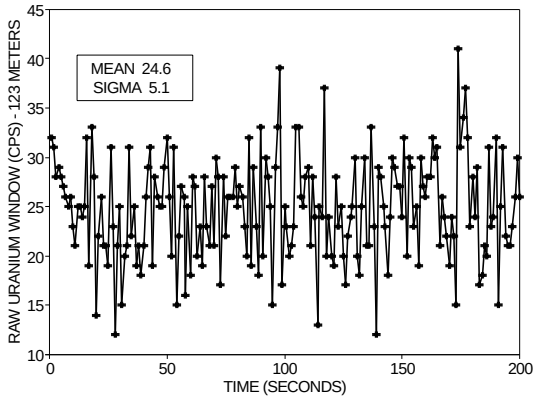

Figure 4. A raw uranium window profile over the GSC airborne calibration range.

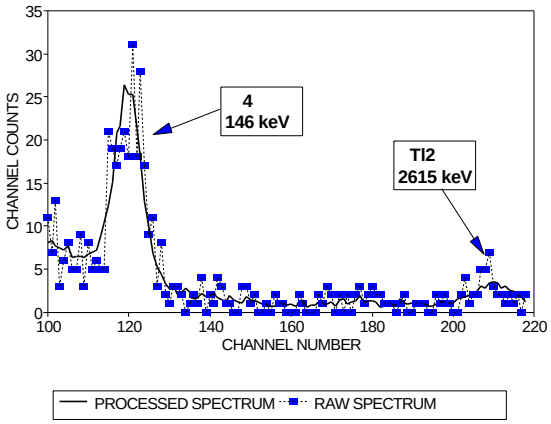

Figure 5. A raw and reconstructed airborne spectrum showing the high energy channels.

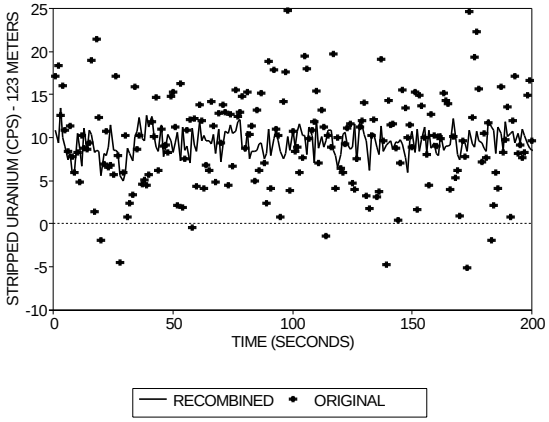

Figure 6. A standard and filtered background corrected and stripped uranium profile over the GSC airborne calibration range.