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Airborne gamma-ray spectrometry- How to settle Rn atmospheric correction

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ABSTRACT

In the workflow of airborne gamma-ray spectrometry processing, background correction is the most substantial component. The major part of this correction requires knowing the contribution of atmospheric ^{222}Rn and its daughter products within airborne recorded spectra. To evaluate the atmospheric Rn component, specific calibration flights are needed.
Two types of techniques are commonly used: i) upward looking detector technique, ii) spectral ratio technique. For both, the issue lies first in the ability to get the spectra of **atmospheric radon** and the spectra of **uranium from ground.** This ability is strongly dependent on local conditions. Two local conditions have to be satisfied: (i) presence in the vicinity of the survey of a wide water surface, (ii) presence of high radon content in the air during calibration flights.
BRGM, the French Geological survey, has designed, quality controlled and processed a wide variety of surveys. The experience gained assisted in the monitor atmospheric Rn spectra depending on local condition. Examples from BRGM experience in Tropical forest and temperate climate zones are presented. Constraints and limitations of atmospheric background correction techniques are debated.

Key words: airborne gamma-ray spectrometry; background corrections; atmospheric Rn.

INTRODUCTION

Airborne gamma ray spectrometry is widely used for geological mapping dedicated to mineral exploration (Shives et al. 2000, Tourlière et al, 2003) and landscape management weathering and erosion analysis (Wilford et al., 1997, Carrier et al, 2005). Since the 90', 256 or 512-channel gamma-ray spectrometers associated with efficient NaI detectors sampling at 1 second interval, allow mapping very slight changes in radioelement concentrations.
BRGM, the French geological survey, uses airborne gamma-ray within national geological programs as well as in international activities. Even if this public organisation doesn't operate its own airborne system, it has designed, supervised and processed more than 1.5 million line km. All these surveys have been flown in much contrasted areas, from desertic to tropical environment (Martelet et al, 2006).
Airborne gamma-ray spectrometric data need careful processing based on three main corrections: (i) background correction, (ii) height correction and (iii) Compton stripping. In the workflow of processing, background correction is the most substantial and the most difficult to evaluate. Three main sources contribute to background radiation: radioactivity from the aircraft (constant), radiation of cosmic origin (recorded in a cosmic window with energy above 3 Mev) and radon background. In this paper, authors will focus on atmospheric radon (^{222}Rn) corrections.

METHODS

Radon originates from Uranium disintegration series; as an inert gas, Rn is very mobile and escapes easily from soil into the atmosphere due to pumping action of changing temperature and pressure. Rn concentration in the air depends on meteorological conditions and can be strongly variable during a survey.
In airborne radiometric data, atmospheric Rn signal is superimposed on ground-uranium signal. Gamma-ray emitting isotopes are mainly the same for ^{222}Rn and its daughter products in aerosols or soil uranium source, in equilibrium with its progeny. Both source emissions give similar gamma-ray spectra.
Background induced by atmospheric Rn can increase up to 100% counts rates recorded in the U energy window. Continuous background radiation monitoring is crucial in airborne surveys, nevertheless large errors

are introduced for U content estimation. Differentiation of signal source within the spectra remains a challenge for precise Rn contribution estimation.

- ***Upward looking detector technique***

Grasty (1988) and the IAEA (1991) have described a procedure to remove radon by recording gamma-ray spectra using an upward looking detector partly shielded from ground radiation. Rn contribution in U window (downward looking detector) is reduced from count rates recorded by the upward looking detector.

- ***Spectral ratio technique***

Alternatively, Minty (1992, 1997) has developed spectral ratio and full-spectrum methods for radon removal. Spectral ratio method is based on the observation that on atmospheric Rn spectra, ratio between low energy ^{214}Bi photopeak at 0,609 MeV and high energy ^{214}Bi peak at 1,76 MeV is greater than equivalent ratio on ground U spectra. Rn monitoring relies on unexpected count rate variations in the low energy ^{214}Bi peak above the Compton continuum.

Both techniques are robust, operate successfully and can be easily implemented by contractors. Nevertheless they need dedicated calibration procedures and suffer some limitations.

CONSTRAINTS

Radon removal techniques require precise calibrations including measurement of reference pure spectra of **atmospheric radon** and for spectral ratio, of **uranium from ground**, preferably with various concentrations.
Since terrestrial radiations are screened by a few meters of water, atmospheric radon spectra are usually obtained from calibration flights over water. Two conditions have to be satisfied: (i) presence in the vicinity of the survey of a sufficiently extended water surface, (ii) presence of high radon content in the air during calibration flights. Achievement of proper radon calibrations may require numerous repeated calibration flights because of winds and changing atmospheric conditions, leading to a time consuming process. Narrow lakes or large rivers do not suit proper calibration as far at nominal survey altitude, gamma-rays originating from the shore require about 500m of air to be almost completely absorbed.

LIMITATIONS

- ***Spectral ratio technique***

This technique requires a dedicated analysis to investigate ^{214}Bi photopeak at 0,609 MeV in the spectrum. Consequently, this method cannot be applied when atomic weapons fallout or nuclear accidents are still contributors in gamma-ray spectra. In these cases, ^{137}Cs contribution occurs at 0,662 MeV in the spectrum, which is very close to targeted ^{214}Bi photopeak, with respect to the resolution of common detectors. This method needs precise determination of effective height of measurement above ground sources.

- ***Upward looking detector technique***

The main disadvantage is the weight penalty from the required extra detector. One or two 4 litres crystal units (25 kg each) are commonly dedicated to radon detection. Smaller sensors are not applicable because of higher statistical noise induced in the signal, even if integration along lines is part of the processing as far as localized radon variations are not expected.

Both techniques have limitations when Rn is not evenly distributed in the lower atmosphere. It can happen in peculiar atmospheric conditions with temperature inversion in which warmer air masses overlay cooler ones. In such cases Rn and its daughter's products are trapped below the cold air. Depending of the height of this phenomenon relative to survey flight altitude, part of the radon will not be seen by an upward looking detector. In case of radon concentration close to the ground, spectral ratio technique also fails in differentiating air background from ground signal. Apart from perturbation of radon emanation from soil by moisture variations (Grasty 1997), surveying should be avoided in case of shower due to sudden put down of aerosols with the rain.
Taking into account all these factors, acquisition design, test flights, and processing flowcharts have to be adapted from one survey to other. Also, generalisation of full spectrum acquisition gives extra flexibility for post survey data processing.

EXAMPLES

The surveys supervised by BRGM, show a great diversity of how to deal with atmospheric Rn background. The discussion is illustrated with surveys performed in Europe (French armorican massif in 1998, Paris sedimentary basin in 2008) and in tropical countries (French Guyana in 1996 and Gabon in 2008).

- ***French Guyana Survey***

This survey is a perfect case study for the application of conventional radon removal methods. The presence of a wide hydro-electric dam (Petit-Saut) within the survey block allowed repeated test flights over water during ferries. Efficiency of the corrections was improved by considering production lines crossing both water and adjacent land. The normalized IAEA upward detector technique was applied successfully.

- ***Gabon Survey***

Gabon survey gives us the opportunity to discuss one limitation of using upward looking detector in a helicopter. Very low count rates were recorded within the upward looking detector due to a small crystal volume combined with low Rn level. The spectral ratio method has been then retained for processing radon background.

- ***Armoricain Massif Survey***

In Europe, the use of spectral ratio technique is not possible considering ^{137}Cs activity. Full spectrum processing of this survey performed at 120 m ground clearance led to produce a ^{137}Cs map. Upward looking technique based on calibration flights over the sea was used for radon removal. The difficulty came out with low atmospheric radon content over the Atlantic ocean, due to dominant marine western winds.

- ***GeoCentre Survey***

In région Centre in France, wide lakes are rare and the sea is far away from the survey area. Flying over water is then difficult for recording atmospheric Rn spectra. We have experimented to monitor a daily atmospheric Rn spectrum by flying every day a 2 minute profile at 600 m STP clearance during ferry flights. Special attention was paid to residual ground contribution in these spectra. Based on this non-conventional calibration approach, satisfying results could be achieved associated to the upward looking procedure.

CONCLUSIONS

Regarding computer performances and advanced techniques developed by scientists, full spectra analysis processing is now commonly applied for airborne gamma-ray spectrometry. The issue for radon atmospheric removal lies first in the ability to get both the spectra of **atmospheric radon** and of **uranium from ground.**

This ability is deeply dependent on local conditions: do we have large water surface in the vicinity of the survey area? Do we expect high atmospheric radon content? Local conditions have to be known before fixing technical procedure: use of an upward looking detector? How to record calibration flights?. This paper gives some recipes based on experience.

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