

Application of the airborne radiometric method in radiation protection applications

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ABSTRACT

The airborne radiometric method has been extensively applied to uranium exploration and geological mapping problems since the 1940s, taking advantage of the natural variations in radioelement concentrations in the upper part of the earth's crust and the information which can be deduced from these regarding surface geology and potentially economic mineralisation. In the process, a number of conventional practices have been adopted, largely regarding calibration and its supporting assumptions.

The science of radiation protection looks at the quantification of radiological exposure to human beings, the assessment of the health impacts of these exposures and the development of strategies to minimise these exposures. As a result, the underlying methodologies and supporting assumptions differ, in some cases greatly, from those made in geophysical surveying, potentially resulting in misunderstandings between experts in the two fields.

Airborne surveying on its own cannot generally directly quantify the radiological dose to human beings on the ground, although it can be used, given certain assumptions, to estimate ground level exposure rates. It can, however, play a vital role in the location, identification and, to some extent the characterisation of ground sources of radioactivity which could lead to increased radiological doses to the public. The extensive aerial coverage provided by the airborne survey method also offers a unique opportunity for the mapping of potentially radiologically significant sources.

While it has traditionally been applied to the mapping of naturally occurring radioactive materials, modern multi-channel airborne spectrometers may also be applied to the search for and mapping of sources containing artificial radionuclides.

Key words: radioactivity, airborne radiometric method, radiation protection, calibration.

INTRODUCTION

Airborne radiometric surveys have been flown since the 1940s (Cook, 1952) in the search for uranium, initially for military applications and later also for the generation of nuclear power. While early surveys were flown with Geiger-Müller detectors, thallium activated sodium iodide (NaI(Tl)) detectors have been used almost exclusively since the early 1960s (Moxham, 1960), with multichannel analysers allowing the discrimination of gamma radiation from a range of radionuclides (Grasty, 1975; Pitkin and Duval, 1980; International Atomic Energy Agency, 1991). Modern spectrometric systems record the gamma ray spectrum using a large number (typically >256) narrow spectral channels, allowing the discrimination of natural and anthropogenic gamma ray emitters.

Radiation protection is the branch of science concerned with the protection of workers, members of the public

and the environment from the harmful effects of ionising radiation or radioisotopes (International Commission on Radiological Protection, 1990). Principal among the tools available to the radiation protection practitioner is the 'effective dose'. This is a way of putting a numerical value to the potential risk an individual is at from being exposed to a particular level of radioactivity.

METHOD

Airborne radiometric surveying

Airborne surveys, generally flown in conjunction with the magnetic method involve the repeated spectrometric measurement of the gamma ray flux striking one or more large detectors mounted in a moving aircraft. Data are corrected for variations in altitude, atmospheric radon and cosmic background radiation and processed to produce results expressed as the concentrations of potassium, uranium and thorium

based on calibration data collected over sources of known potassium, uranium and thorium concentrations and test flights over areas of known ground concentrations and radiation levels. Two key assumptions are made in this process:

- That the uranium and thorium decay series are in secular equilibrium (as activity measurements are made using ^{214}Bi in the ^{238}U decay series and ^{208}Tl in the ^{232}Th decay series) and
- That the sources on the ground are homogenous and of effectively infinite extent (in practice this means a radius of up to a few hundred metres around the measurement point).

For the transposition of the method to a radiation protection application, it is important to remember that these assumptions are used only in the calculation of the ground concentrations of radionuclide concentrations and have absolutely no bearing on the collection of spectral data, which may be calibrated and processed in various ways to extract other spectral information. Furthermore, the activities of individual gamma-emitting radionuclides may also be calculated from the recorded gamma ray spectra.

In recent years, full spectrum analytical methods have been developed, primarily to reduce noise in survey data (Green et al., 1988; Hovgaard and Grasty, 1997; Dickson and Taylor, 1998). These methods break recorded spectra down into a number of orthogonal components and then reconstruct the original spectra after discarding those components deemed to contain noise. In the case of the Noise Adjusted Singular Value Decomposition (NASVD) method developed by Hovgaard (1997) physical significance can be attached to the spectral components extracted. These components may be used to identify the location of anthropogenic radionuclides on the ground (Hovgaard, 1997; Coetzee, 2008), as well as locating radiation related to uranium contamination under conditions of extreme secular disequilibrium (Coetzee, 2008). In both of these cases, conventional calibration methods are not applicable and alternative methods need to be employed or the radiometric method used simply to identify anomalous areas for further ground-based follow-up and assessment.

Data requirements for radiation protection

In the practice of radiation protection there are a number of different measurements that are regularly taken. These include ambient dose, absorbed dose, effective dose and activity concentration. The differing dose types reflect the fact that there are different types of radiation that have differing effects on separate parts of the human body. The two doses that this paper will concentrate on are the ambient dose, a measurement of the dose in a particular area with no consideration

given to the effect on a human body, values nowadays reported in Grays (Gy) or more usually fractions of a Gy. The other dose that will be considered is the effective dose reported as sieverts (Sv), which is a doubly weighted value which indicates the potential harm that a human might come to by having their whole body being exposed to that value of effective dose.

$$E = \sum W_T H_T$$

Where H_T is the equivalent dose in the tissue or organ T, and W_T is the weighting factor for Tissue T.

In relation to the quantities directly measured in an airborne radiometric survey, photons of all energies have a weighting factor $W_R = 1$.

Application of airborne radiometric surveying to radiation protection

On some occasions it is possible to directly measure dose usually the absorbed dose, but in many situations it is easier to measure an activity concentration and using generally accepted conversion factors, calculate an effective dose from those activity concentrations. This then nicely dovetails with the advances in airborne survey techniques whereby it is possible to estimate activity concentrations of specific radioisotopes in the environment, given the assumptions made in radiometric calibration. Combining these values with the accepted conversions and summing the values will then give an indication of absorbed dose.

Airborne radiometric surveys also provide full coverage of the ground area covered by the survey, provided that the flight line spacing is correctly selected to allow the circle of investigation of the spectrometer (Pitkin and Duval, 1980) to overlap with that on the adjacent lines. This provides a unique insight into the distribution of radionuclides on the surface of the earth, which is not biased by the prejudices or preconceptions of the radiation protection practitioner and may identify areas of radiological contamination which would not be expected based on the simplified models of contamination used in site assessments, particularly in their early stages. An example of this is the discovery in the Wonderfontein spruit Catchment west of Johannesburg, using a combination of airborne and ground survey data, linked to field sampling and analysis, that radionuclide contamination levels in sediments downstream of uranium mining operations exceeded levels in ores and wastes, suggesting the existence of chemical concentration processes (Wade et al., 2002).

CONCLUSIONS

The airborne radiometric method has a unique and often underappreciated role to play in the science of radiation protection. Conventional calibration methods used in exploration for radioactive ores and geological mapping are rarely adequate for the requirements of detailed radiation protection studies and novel and often site specific calibrations as well as detailed ground follow-up studies will be required. The method does however allow the full coverage of survey areas and, with the use of multi-channel spectrometers, identification and characterisation of all gamma-emitting sources. It is recommended that the method be applied in cases where contamination with gamma emitters is suspected and where the study areas make conventional ground-based methods prohibitively expensive or logistically difficult.

REFERENCES

- Coetzee, H. (2008) Acquisition, processing and enhancement of multi-channel radiometric data collected with ultralight aircraft mounted detectors. School of Geosciences. Johannesburg, University of the Witwatersrand. PhD Thesis: 357.
- Cook, J. C. (1952) "An analysis of airborne surveying for surface radioactivity." Geophysics **17**(4): pp. 687-706.
- Dickson, B. and Taylor, G. (1998) "Noise Reduction of aerial gamma-ray surveys." Exploration Geophysics **29**: pp. 324-329.
- Grasty, R. L. (1975) "Uranium Measurement by Airborne Gamma-Ray Spectrometry." Geophysics **40**(3): pp. 503-519.
- Green, A. A., Berman, M., Switzer, P. and Craig, M. D. (1988) "A Transformation for Ordering Multispectral Data in Terms of Image Quality with Implications for Noise Removal." IEEE Transactions on Geoscience and Remote Sensing **26**(1): pp. 65-74.
- Hovgaard, J. (1997) A new processing technique for airborne gamma-ray spectrometer data (Noise adjusted singular value decomposition). Am Nucl. Soc. Sixth topical meeting on Emergency Preparedness and Response, San Francisco.
- Hovgaard, J. and Grasty, R. L. (1997) Reducing statistical noise in airborne gamma-ray data through spectral component analysis. Proceedings of Exploration 97: Fourth Decennial Conference on Mineral Exploration, Toronto.
- International Atomic Energy Agency (1991) Airborne gamma ray spectrometer surveying. Vienna, International Atomic Energy Agency.
- International Commission on Radiological Protection (1990) Recommendations of the International Commission on Radiological Protection Oxford and New York, Pergamon Press. **Publication No.60**.
- Moxham, R. M. (1960) "Airborne radioactivity surveys in geologic exploration." Geophysics **25**(2): pp. 408-432.
- Pitkin, J. A. and Duval, J. S. (1980) "Design Parameters for Aerial Gamma-Ray Surveys " Geophysics **45**(9): pp. 1427-1439.
- Wade, P. W., Woodbourne, S., Morris, W. M., Vos, P. and Jarvis, N. V. (2002) Tier 1 risk assessment of radionuclides in selected sediments of the Mooi River., Water Research Commission, WRC-Project K5/1095, Pretoria: 93 p.