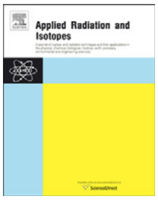
Applied Radiation and Isotopes 70 (2012) 1784–1791

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso



Airborne spectrometry: Extraction of low energy γ-rays using two or three spectral windows

Nicolas Martin-Burtart [a], Ludovic Guillot [a,*], Abdel-Mjid Nourreddine [b]

[a] CEA, DAM, DIF, F-91297 Arpajon, France
[b] UMR 7178 UdS CNRS-In2p3, 23 rue du Loess, BP 28, F-67037 Strasbourg Cedex, France

ARTICLE INFO

Article history:
Received 3 March 2011
Received in revised form
7 March 2012
Accepted 13 March 2012
Available online 21 March 2012

Keywords:
Airborne γ-rays spectrometry
Low energy
Windows method
NaI(Tl)
Algorithms

ABSTRACT

Airborne γ-ray spectrometry with NaI(Tl) is a recognized tool for emergency mapping. The maps produced usually look for natural isotopes (^{40}K, ^{238}U, ^{232}Th) and ^{137}Cs due to the Chernobyl accident. Nowadays a new thematic emerges as nuclear materials tracking. Such materials emitting at low energies require new algorithms and a new method is presented here based on counts observed in two or three spectral windows. Since altitude is an important factor to be taken into account, an improvement is proposed to follow flight altitude changes. An extension to medium energies is proposed and compared to windows methods and to peak detection.

1. Introduction

Airborne gamma spectrometry using NaI(Tl) is a powerful tool for post-accidental mapping. Aircraft can quickly cover a large area and provide a preliminary emergency map. Several methods exist for data processing. Full absorption peak detection (Guillot, 2001), windows methods (International Atomic Energy Agency, 1991, 2003) allow us to access spectral contributions of isotopes of interest (for example: ^{40}K, ^{238}U, ^{232}Th, ^{137}Cs, etc.). Other methods, such as noise adjusted singular value decomposition (NASVD) (Aage et al., 1999) generates synthetic spectra for processing, and deviation display (Kock et al., 2010) presents relative changes in spectral data over energy and time, can be used.

Full absorption peak detection and windows methods work well over 400 keV, when the spectrum is quite flat so the background estimation is possible. Below (for example ^{131}I at 364 keV), the spectrum slope increases the difficulty. NASVD and deviation display using NaI(Tl) in airborne spectrometry do not specially address low energy extraction, and the scattering background at these energies is widely changing. This can lead to false extraction. Principal component methods (Dickson, 2004) require a very large number of spectral measurements and so are unsuitable in short surveys. Furthermore, they increase post-processing time, so cannot be used if delay in reporting results is an issue. The filtered differential analysis (Cresswell and Sanderson, 2009) is a method of visualizing changing radiation environments. This involves the calculation of a difference spectrum by the subtraction of a local background from each recorded spectrum. This local background is calculated from a rolling average of recent spectra, using a filter to exclude spectra that show signals significantly different than would be expected for slowly varying radiation fields. In Cresswell and Sanderson (2009), it is noted that ground clearance is an important parameter. In lower parts of the spectrum, a small altitude variation can lead to a big change in scattering background. Even if all these methods have not been shown to be unsuitable, an algorithm dedicated to low energy extraction, considering the scattering background, is necessary.

Today, a new problem emerges for airborne γ-ray spectrometry: detecting and tracking nuclear materials. These materials generally have their full absorption peaks below 400 keV, where the scattering background is too intense for the techniques mentioned earlier, and new algorithms are needed for isotope extraction. ^{241}Am as the γ tracker in case of Pu release has its principal full absorption peak at 59 keV. Furthermore, detection of a located γ-ray source is complicated by a widely varying terrestrial background, because these variations frequently look like signals from well situated sources. Sanderson et al. (1997) successfully located a x-ray machine source, using ratios of radiation fluence between 100–220 keV and 200–300 keV to that in the 300–450 keV. This produced two anomalies in the survey, indicating that these spectra need a more specific study. This method did not extract the rays causing the anomaly, but indicated that an anomaly is present. Hendricks (1975) introduced two new methods, called 2-windows and 3-windows (hereafter

---

[*] Corresponding author. Tel.: +33 1 69 26 45 86.
E-mail addresses: nicolas.martin-burtart@cea.fr (N. Martin-Burtart), ludovic.guillot@cea.fr (L. Guillot).

0969-8043/$ - see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.apradiso.2012.03.019

referred to, respectively, as 2W and 3W), designed to extract low-energy γ-rays in NaI(Tl) spectrometry.

2. 2W and 3W methods

2.1. General overview

While high levels of man-made activity can sometimes be identified by gross-count rate activity, lower levels of man-made activity tend to be masked by a widely varying natural background. It has been observed that in typical natural background areas, the ratios of counts in one spectral window to the counts in another spectral window are nearly constant, providing none of the windows correspond to strong emissions from particular radionuclides (Bristow, 1978). The 2W and 3W methods compare the counting variations in 2 or 3 windows, optimized for a particular isotope. In Hendricks (1975), the choice of windows is not discussed. A methodology for the choice is presented here with relevant criteria.

2.1.1. 2W: windows selection

One window at low energy is chosen which covers only the full absorption peak for the particular isotope of interest. This window is denoted interest window (IW). A second window chosen at higher energy, called high energy window (HEW) contains only background contributions. These two windows are represented in Fig. 1. Two windows algorithms work well when only a single man-made isotope is present or if other man-made nuclides make a small contribution to the count rate.

On a natural background area (NBA), a *stripping ratio* S_{2W} is calculated:

$$S_{2W} = \frac{CR_{IW}}{CR_{HEW}} \tag{1}$$

where CR_{IW} is the counts in the interest window and CR_{HEW} the counts in the high energy window.

This ratio takes into account all the geological characteristics of the site at a mean altitude. Flyovers at this mean value are important. If not, false positive results could occur. This problem is fully discussed and resolved in Section 2.3.

The net counts CR_{2W} is obtained by calculating spectrum by spectrum:

$$CR_{2W} = CR_{IW} - S_{2W} \times CR_{HEW} \tag{2}$$

If the stripping ratio is calculated on an NBA, the mean value $\overline{CR_{2W}}$ will be very close to zero, with a natural background fluctuation $\sigma_{2W,NBA}$.

2.1.2. 3W: windows selection

The algorithm uses relatively narrow windows centered on and to each side of a full absorption peak. The Compton contribution of other nuclides in the central window is interpolated from the two outside windows contributions. When interfering high energy man-made isotopes are present in the spectrum, interpolation of background from the two side windows is generally less subject to Compton interference than background estimated in the 2W process. The windows represented in Fig. 2 are referred to as interest window (IW), low-energy window (LEW) and high-energy window (HEW).

We can calculate, on an NBA, the stripping ratio with the formula

$$S_{3W} = \frac{CR_{IW}}{CR_{LEW} + CR_{HEW}} \tag{3}$$

and the net count CR_{3W} is

$$CR_{3W} = CR_{IW} - S_{3W} \times (CR_{LEW} + CR_{HEW}) \tag{4}$$

If the stripping ratio is calculated on an NBA, the mean value $\overline{CR_{3W}}$ will be very close to zero, with a natural background fluctuation $\sigma_{3W,NBA}$.

2.2. Windows configuration

The most important part of the configuration process is the windows configuration. For low energy γ-ray emitters, the windows are a few channels wide, so the stabilization must be reliable. We note that the use of a digital spectrometer gives a better result than an analog one.

The objectives of the windows configuration are:

1. a good proportion of full absorption (IW),
2. a low sensitivity to natural background variations ($\sigma_{2W,3W,NBA}$ as low as possible),
3. $\overline{CR_{2W}}$ and $\overline{CR_{3W}}$ close to 0 on NBA,
4. low sensitivity to altitude.

2.2.1. Proportion of full absorption peak: example of ^{241}Am

IW has to be centered on the full absorption peak of interest. For example, for ^{241}Am extraction, we center IW on 59 keV. Knowing the FWHM of the detector at this energy and assuming the gaussian peak profile, we can set the width of IW to cover enough of the source signal. For our system, an IW 3 channels wide covers 76% of the signal, 5 channels 95% and 7 channels 99.5%. Covering 95% of the signal if present is sufficient. The calibration was 6 keV/channel, so the 59 keV photopeak was in channel 10.

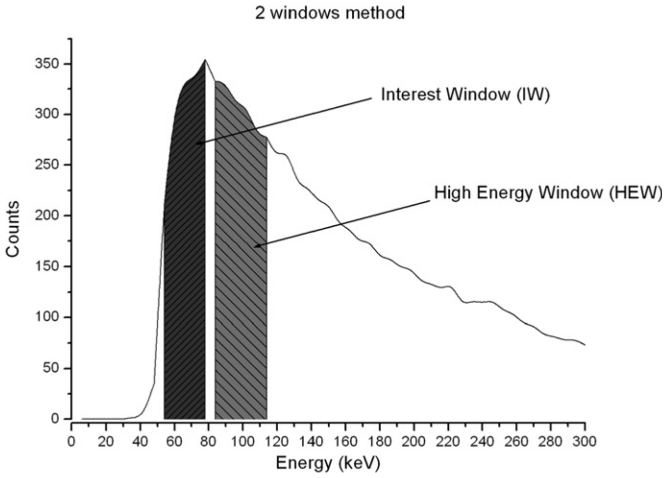


Fig. 1. 2W: Windows configuration.

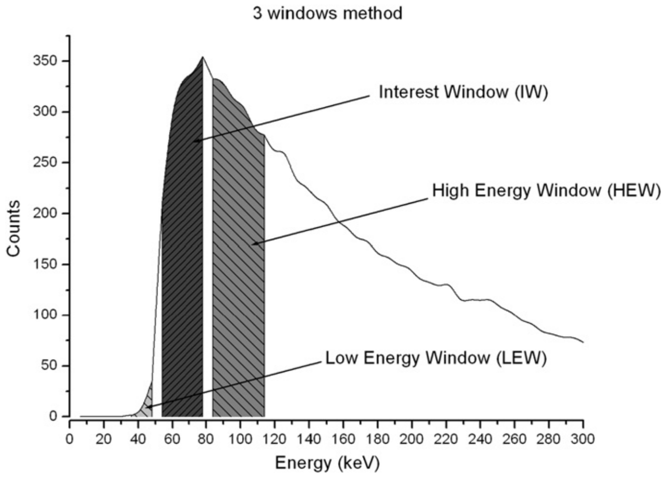


Fig. 2. 3W: Windows configuration.