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Temperature peak-shift correction methods for NaI(Tl) and $LaBr_3$(Ce) gamma-ray spectrum stabilisation

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HIGHLIGHTS

- ► NaI(Tl) and $LaBr_3$(Ce) scintillation detectors are used for gamma-ray spectrometry.
- ► Environmental temperature changes result in a peak shift and spectral distortion.
- ► Two methods are proposed to stabilise the measured spectra.
- ► These methods are applied using a software algorithm, without adjusting the gain.
- ► Both methods are tested in the laboratory under controlled temperature conditions.

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ABSTRACT

NaI(Tl) and $LaBr_3$(Ce) detectors are frequently operated under unstable temperature conditions when used in an open environment. These temperature changes result in a peak shift and spectral distortion during measurement. Two methods are proposed to stabilise the measured spectra; they are applied using a software algorithm, without the necessity of adjusting the gain. Both methods are based on the experimental observation that the relative channel displacement due to temperature changes is approximately the same for all channels. The first method corrects the spectrum using experimental data obtained under controlled conditions in the laboratory, and thus it only depends on the detector temperature. The second method uses one known peak in the spectrum to correct all of the channels: the NORM ^{40}K peak for the NaI(Tl) detector, the internal contaminant peak of ^{138}La for the $LaBr_3$(Ce), or an external source when these two cannot be easily identified.

1. Introduction

The calibration methodology for NaI(Tl) and $LaBr_3$(Ce) scintillation detectors in the laboratory is well known (Casanovas et al., 2012). However, when used in an open environment, the detectors frequently operate under unstable temperature conditions. This affects the performance of the detectors either in the crystal itself, such as their light yield or decay time constants (Ianakiev et al., 2009; Moszyński et al., 2006), or the electronics (ICRU 53, 1994). For environmental monitoring, where the main interest is focused on isotope identification rather than exact activity determination, it is important to account for the effect of temperature on electronics. It is known that temperature changes may lead to gain instabilities and result in a peak shift and spectral distortion during measurement (ICRU 53, 1994). This can lead to the misidentification of some isotopes.

Several methods are commonly used to stabilise the gain, and thus the gamma-ray spectra. Some examples of this are as follows: using an electronic reference pulse that produces a known equivalent energy in the spectrum (Shepard et al., 1997), attaching an external radioactive source to the detector (Shepard et al., 1997; Pausch et al., 2005), using isotopes from the natural background (Pausch et al., 2005), using the temperature dependence of the light pulse decay time (Pausch et al., 2005) and using LEDs as reference light sources (Pausch et al., 2005; Saucke et al., 2005). However, all of these methods are based on automatically adjusting the gain. Therefore, they are not valid for systems with an analogue gain control.

In this study, we present two methods to correct the peak shift without continuously adjusting the gain. The spectra are corrected by a software implementation of an algorithm that compensates for

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gain drifts due to temperature variations. The methods were tested in the laboratory under controlled temperature conditions. The results indicate that the methods are valid approaches to peak shift corrections in the gamma-ray spectra produced by temperature changes.

2. Materials and methods

2.1. Experimental set-up

The detectors used in this study were a 2" × 2" NaI(Tl) and a 2" × 2" $LaBr_3$(Ce) scintillation detectors. The NaI(Tl) detector was an ORTEC® Model 905-3, and the $LaBr_3$(Ce) detector was a BrilLanCe™380 from Saint-Gobain Crystals. Both detectors were coupled to a preamplifier (ORTEC® Model 276) and an amplifier (ORTEC® Model 575A) with shaping time constants adjusted to 1.5 μs, which were connected to a Multi-Channel pulse-height Analyser (MCA) ORTEC® TRUMP™-PCI-2k. The spectrum analysis software that we used was ScintiVision™ from ORTEC®. A refrigerator and an oven were used to control the temperature changes, and all of the temperatures were measured using a temperature probe (Brodersen Controls Model PXT-10/11). The experimental data were obtained using four radioactive sources: ^{152}Eu, ^{241}Am, ^{137}Cs and ^{60}Co. These sources emit gamma-rays over a range of energies up to 1408 keV.

2.2. Data collection

To validate the methods, we collected two sets of 18 spectra for each detector (72 spectra) in the approximate temperature range of 0 °C to 50 °C, which is the manufacturer's recommended operating range. The first set of spectra was collected using the ^{152}Eu source and the second set using a combined source containing ^{241}Am, ^{137}Cs and ^{60}Co. Each spectrum was collected after thermal stability was achieved (at least 1 h of constant temperature), and the corresponding temperature was noted.

2.3. Description of the methods

At a constant reference temperature T_0 (e.g., $T_0 = 25$ °C) of the detector, the position C_{i0} of the i^{th}-channel of the MCA is constant. Thus, the energy calibration is constant. However, temperature changes lead to a channel shift that may invalidate the energy calibration and lead to the misidentification of radionuclides. Thus, the i^{th}-channel position C_{ik} in a gamma-ray spectrum measured at the temperature T_k is displaced with respect to the reference position at T_0, C_{i0}.

If we assume, for a fixed voltage and gain, that the channel positions only depend on the temperature, we can establish a simple relationship between C_{ik} and C_{i0}:

$$C_{ik} = C_{i0} \cdot f_i(T_k) \tag{1}$$

where $f_i(T_k)$ is a function that depends only on the temperature.

Based on experimental evidence (see Section 3.1), we assume that the relative channel displacement due to temperature changes is approximately the same for all of the N channels conforming the spectrum. Thus, the $f_i(T_k)$ functions become:

$$f_1(T_k) \approx f_2(T_k) \approx \ldots \approx f_N(T_k) \equiv f(T_k) \tag{2}$$

To stabilise the spectrum, we displace the C_{ik} channel position to its corrected value $C_{ik}^{\text{corrected}}$, which is the reference position at T_0, i.e., $C_{ik}^{\text{corrected}} \equiv C_{i0}$.

Using the assumption of Equation (2) in Equation (1), the corrected channel position is given by:

$$C_{ik}^{\text{corrected}} = \frac{C_{ik}}{f(T_k)} \tag{3}$$

With the corrected spectrum, the energy calibration obtained at the reference temperature T_0 is still valid. Thus, the objective of the two proposed methods is to find an approximation to $f(T_k)$ that corrects the measured spectrum.

2.3.1. Method 1

Method 1 corrects the measured spectrum using an algorithm based on previous measurements in the laboratory. Thus, no radioactive or pulse reference is needed during the measurements. However, data must be collected in the laboratory under controlled temperature conditions, which is not always possible.

This method assumes a second-order polynomial approximation to the functions $f_i(T_k)$. Thus, Equation (1) becomes:

$$\frac{C_{ik}}{C_{i0}} = \sum_{j=0}^{2} a_{ij} \cdot T_k^j = a_{i0} + a_{i1} \cdot T_k + a_{i2} \cdot T_k^2 \tag{4}$$

The parameters of the second-order polynomial a_{ij} are fit using the 72 spectra (acquired using the different detectors and sources at various temperatures). For each of the main peaks we fit the a_{ij} coefficients. By virtue of Equation (2), we have:

$$a_{1j} \approx a_{2j} \approx \cdots \approx a_{Nj} \equiv a_j \tag{5}$$

where a_j is calculated by averaging the a_{ij} coefficients for the N_p peaks considered:

$$a_j \equiv \frac{\sum_{i=1}^{N_p} a_{ij}}{N_p} \tag{6}$$

Equation (4) becomes:

$$\frac{C_{ik}}{C_{i0}} = \sum_{j=0}^{2} a_j \cdot T_k^j = a_0 + a_1 \cdot T_k + a_2 \cdot T_k^2 \tag{7}$$

The spectrum is corrected using:

$$C_{ik}^{\text{corrected}} \equiv C_{i0} = \frac{C_{ik}}{\sum_{j=0}^{2} a_j \cdot T_k^j} = \frac{C_{ik}}{\left(a_0 + a_1 \cdot T_k + a_2 \cdot T_k^2\right)} \tag{8}$$

2.3.2. Method 2

Method 2 uses a single known peak in the spectrum to correct all of the channels. With this method, no previous measurements in the laboratory are needed, and temperature measurements are not required. However, the known peak should be in all of the spectra, either produced by natural background or by an inner contaminant as for the $LaBr_3$(Ce) detector. If this is not possible, the method requires an external source, which will cause additional undesired counts in the obtained spectra.

This method is based on the assumption made in Equation (2). Thus, it is only necessary to determine $f(T_k)$ for one peak in the spectrum and the spectra can be corrected by following the position of only this one known peak.

Using Equation (3) for the known peak, we have:

$$f(T_k) \equiv \frac{C_{ik}^{\text{known}}}{C_{i0}^{\text{known}}} \tag{9}$$