Detector Efficiency Calibration for Extended Gamma-Ray Sources

Roberto M. dos Santos, Frederico A. Genezini, and Guilherme S. Zahn

Instituto de Pesquisas Energéticas e Nucleares – IPEN-CNEN/SP
Av. Lineu Prestes, 2242, Cidade Universitária, São Paulo-SP.

Abstract. A new method for the efficiency calibration of Ge detectors efficiency in measurements with large sources is proposed. To check the reliability of the method, a standard large source was produced and the results are compared to the ones obtained using the proposed method. The preliminary results point to the needs of increasing statistical measurements to allow for a more accurate evaluation of the method.

Keywords: Large sources, efficiency calibration.
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INTRODUCTION

Several gamma spectroscopy applications like environmental radioactivity measurements or neutron activation analysis that requires the precise activity determination need accurate photopeak efficiency calibration for the usual energy range of these techniques. The geometry of the sources, especially in the first-mentioned application, can be not punctual sources due to low specific activity that require a higher sample mass and small source-detector distance [1,2]. The first consequence of having an extense source instead of point sources is the effect of self-absorption mainly for low energy photons. Another effect to take into account is the geometrical nature of the measurement because the detector crystal dimensions become comparable with the source dimensions [1]. Due to these facts an appropriate treatment for the efficiency measurement must be done.

Three treatments are most often used for this purpose, namely the relative method, Monte Carlo method and semi–empirical method. The first method reproduces the measurement conditions as well as possible, producing a comparative standard source with the same material and geometry of the sample to be measured. This method is the most accurate of them, however the need for liquid standard sources add handling difficulties or, worse, loss in the accuracy of the activity value. In addition, the availability of standard material for different source geometries is also an important restriction [3]. The second method, based in numerical simulation where the measurement geometry and the physics of photon interaction are modelled, try to predict if the photon is absorbed or leave the detector. Nowadays, the computational time is not an important restriction, but the lack of precise information of detector's internal geometry and the requirement of an accurate sample chemical composition presents a limit to this method [4]. The last method employs a hybrid of experimental

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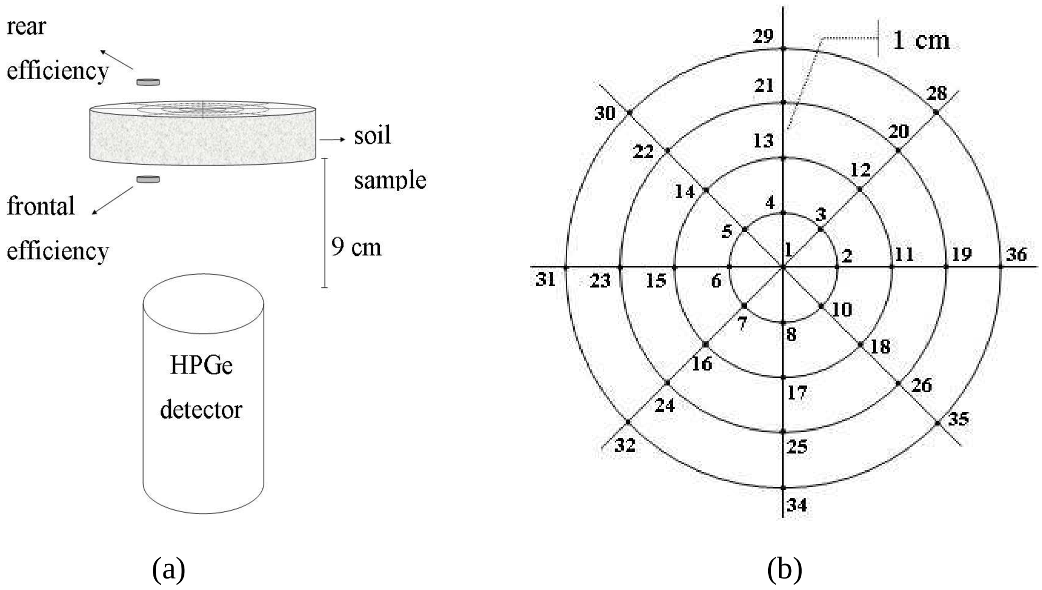

FIGURE 1. The experimental setup (a) and the grid of points (b).

measurements and the theoretical aspects of photon-sample interactions and detector response. Complex geometries, such as those with no symmetry axis, and the need of the same information as in the Monte Carlo method are the limitations of this method.

In this work, an alternative method to the calibration of a germanium detector when large sources are used is proposed, based in standard point-source efficiency measurements in a grid of points in the space above and below a large sample.

EXPERIMENTAL METHODS

In this method the sample studied must have a cylindrical shape. Two experimental setups were considered, one in which the calibration source is positioned in the frontal surface of the sample, and the second where the calibration source is positioned in the rear surface of the sample (Fig. 1a). In each setup the efficiencies were measured in a grid composed by 40 points (Fig. 1b) and the average of these points gives the efficiency of the frontal (ε_f) and rear (ε_r) positions. Finally, to reach an effective efficiency value (ε_{ls}) as a function of the energy (E) the geometric average of these two efficiencies is calculated:

$$\varepsilon_{ls}(E) = \sqrt{\varepsilon_f(E) \, . \, \varepsilon_r(E)} \qquad (1)$$

Efficiency Measurements

This method was tested for a sample of soil inside a polyethylene holder of cylindrical shape with 10 cm in diameter and 3 cm height. The holder was filled with 189.48 g of soil which was previously analyzed by neutron activation analysis (with

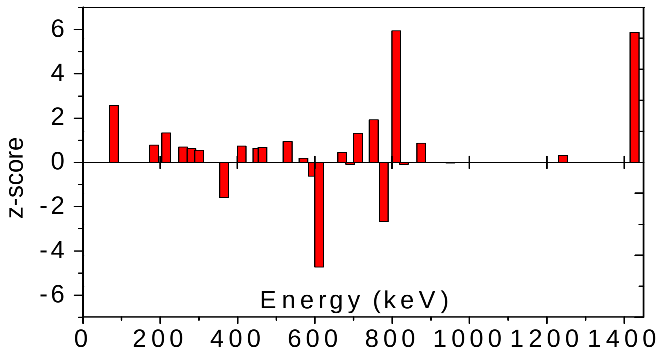

FIGURE 2. Z-scores calculated with efficiency by new method and standard source.

iron as the dominant element). This sample was positioned at 9 cm from detector face, and a standard point-like (the deposition area of radioactive material is less than 0.4 cm) source of ^{166m}Ho (24.41 kBq) was used to scan the grid. For the two experimental setups necessary for this method (one to obtain the frontal efficiency with the source in front of the sample and the second one to measure the efficiency with the source in the back of the sample) the acquisition time was 5 min per source position.
In order to validate the methodology, the efficiency curve obtained was compared with another efficiency curve which comes from a measurement using ^{166m}Ho (1 kBq)) standard liquid source diluted in the soil sample. The source was made by dripping aliquots of liquid source on the soil more evenly as possible. After the addition of the liquid source to the soil, it was submitted to a homogenization process and heated in a stove (50 ^{o}C) for drying. Finally the same polyethylene holder used previously was filled with the soil plus the diluted source. The acquisition time was 240 min. All the measurements were done using a 20% extended range HPGe detector.

Data Analysis

The z-scores for the efficiency obtained with this method and with the relative method (standard large source) were calculated for each recommended energy value of ^{166m}Ho [5]. Most of the z-score values were in the -1<z<1 range, as shown in Fig. 2.

Another way to test this method was the fit of an efficiency function, where an equation with 5 fit parameters was used [6]:

$$\varepsilon(E) = (p_1.e^{p_2.E} + p_3.e^{p_4.E}).e^{p_5.\mu} \tag{2}$$

Where ε is the efficiency, E the energy, p_i the fitted parameters and μ the mass attenuation coefficient.

To check the reliability of the method, 7 values were chosen and covariant interpolations were done whit the two efficiency fits. Table 1 shows the interpolated efficiency values and the relative errors and Fig. 3 shows the fitted curves.

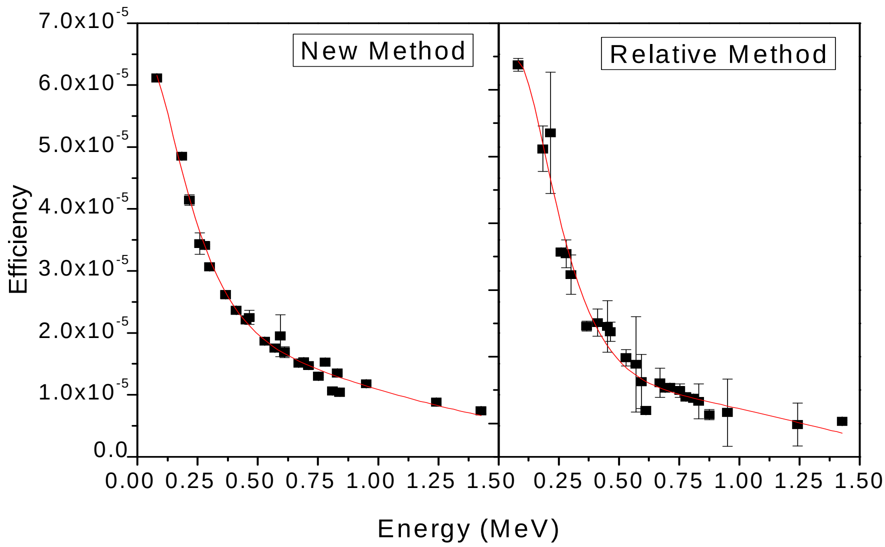

FIGURE 3. Efficiency function fitted curve for both the proposed method (left) and the standard large source method (right).

TABLE 1. Interpolated efficiency values from this method compared to the standard large source.

Energy(keV)	*effic.New method*	*effic.Relative Method*	Δ (%)
90	6.15(3)	6.35(10)	3.3
100	6.10 (3)	6.28 (13)	2.9
200	4.558 (15)	4.56 (12)	0.07
300	3.219 (13)	3.12 (5)	3.5
400	2.423 (11)	2.26 (3)	7.5
500	1.952 (9)	1.85 (4)	5.8
1022	0.921 (12)	1.141 (20)	19.2

FINAL CONSIDERATIONS

The results from these preliminary measurements show that this method is suitable for obtaining the efficiency calibration for extended gamma ray sources using standard point-like sources. New experimental data for ^{166m}Ho with 10 min for each point for the proposed method and 600 min for the standard large source method will be acquired in order to enhance statistics. Also, tests with ^{109}Cd (88.0 keV) and ^{60}Co (1173.2 and 1332.5 keV) shall be performed.

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