2007 International Nuclear Atlantic Conference - INAC 2007
Santos, SP, Brazil, September 30 to October 5, 2007
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: 978-85-99141-02-1

CALIBRATION DETECTOR MEASUREMENT FOR LARGE SOURCES

Frederico A. Genezini[1], Emerson E. G. de Farias[1], Juan Y. Zevallos-Chávez[2] and Manoel Tiago F. da Cruz[3]

[1] Centro Regional de Ciências Nucleares (CRCN/CNEN-PE)
Av. Professor Luiz Freire, 200
50740-540 Recife,PE
fredzini@cnen.gov.br

[2] Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN- SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
juanyury@gmail.com

[3] Instituto de Física da Universidade de São Paulo (IFUSP-SP)
Rua do Matão, Travessa R, 187
05508-090 São Paulo, SP
tiago@if.usp.br

ABSTRACT

Environmental samples used in gamma ray spectroscopy are in general not point sources, actually large sources are needed which have in general very low specific activities determining in the most cases the use of short detector-source distances. As a consequence, effects of self absorption appear mainly for low energy photons, and the crystal detector dimensions become comparable with the source dimensions.
In this work, an alternative method to obtain the detection efficiency for large sources in gamma spectroscopy measurements is proposed, in which solid point sources together with a matrix of sand are used in order to determine the detection efficiency when large sources are involved. Monte Carlo simulations were also done in order to explain effects like absorption of photons due to a matrix of sand used in the experiment.

1. INTRODUCTION

In some specific applications of gamma spectroscopy the efficiency measurement of the detector is easily obtained if the activity of the source is low (< μ Ci) and point sources are considered. The detector-source distance is also another parameter to take into account. Studies involving environmental samples, which are in general not point sources and have very low specific activities, short detector-source distances must be used [1,2]. The first consequence of having an extended 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 crystal detector dimensions become comparable with the source dimensions [3]. Due to these facts an appropriated treatment for the efficiency measurement must be done.
One simple method consists in using standard sources with the same dimension and matrix composition of the environmental samples. Otherwise, frequently, the standard sources must be liquid, adding difficulties of handling or worse, the loss in the precision activity. In this

work we show an alternative method to perform the calibration of a germanium detector when large sources are used, based in the distribution of standard point sources on a matrix simulating an environmental source. Finally, Monte Carlo calculations were done in order to elucidate effects of absorption and backscattering of photons in the used matrix.

2. THE METHOD

In this method we suppose that the sample studied has a cylindrical shape where the most important dimension is its radius. This cylinder is positioned with one of the faces looking the frontal face of the germanium detector. See figure 1.

One way to take into account, in an efficiency measurement, the spatial distribution of a large source, specially its area and thickness, is the simultaneous measurement of the calibration standard source together with the sample of interest. For this study two experimental setups were considered, one in which the calibration source is positioned in the frontal surface of the sample, and the second the calibration source is positioned in the rear surface of the sample. Actually we have a distribution for the position of the calibration sources, which consists of seventeen geometrical points. (See figure 2). This distribution was used for determining the efficiency on the detector for the two configurations, frontal and rear positions. Finally, combining the measurements of both setups, a combined efficiency is obtained.

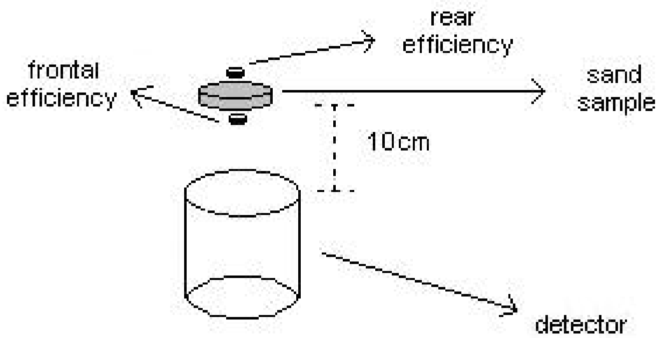

Figure 1. Experimental setup

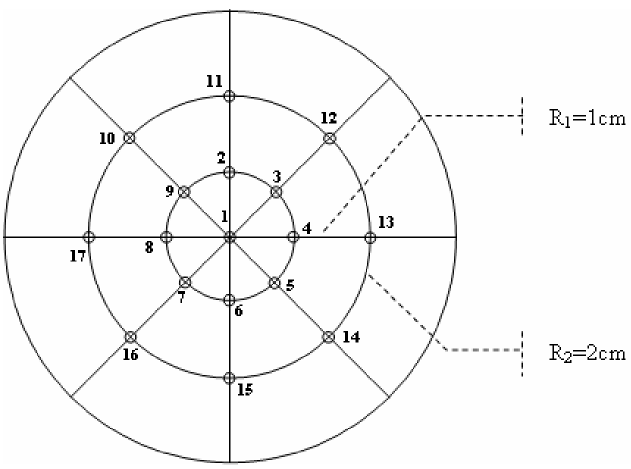

Figure 2. Source point distribution.

2.1. Efficiency measurements

It was considered a sample of sand, inside of a polyethylene holder of cylindrical shape of 47 mm in diameter and 0.6 mm of height. The holder was filled of 16.7 g of sand previously sieved. A calibration standard source of ^{152}Eu with an activity of 19.1 kBq was used, the detector-source distance was 10 cm. Two experimental setups were considered, one to obtain the frontal efficiency (source in front of the sample) and the second one to measure the rear efficiency (source in the back of the sample). See Figs. 1 and 2. The acquisition time was 10 min per source position, summing an overall time of 17x10=170 min.
In order to validate our methodology, the efficiency curve obtained was compared with another efficiency curve which comes from a measurement using a standard liquid source of ^{152}Eu, which has been referred as the standard efficiency $\varepsilon_{standard}$. This last measurement considers a sample composed by the same sand but doped with ^{152}Eu liquid source. The specific activity was 42.7 Bq.ml^{-1}, resulting in 187 Bq. After the addition of the liquid source to the sand, it was submitted to a homogenizing process and heating in a stove (50 ^{o}C) for drying. Finally the sand was positioned in the same polyethylene holder in order to perform the measurements. Acquisition time was 60 min. All the measurements were done using a Ge detector of 40% efficiency associated with conventional electronics.

2.2. Efficiency fitting

The two setups produce two efficiency curves which can be fitted using the following analytic functions:

$$\varepsilon_{frontal}(E) = \sum_i A_i \exp(-a_i E) \tag{1}$$

$$\varepsilon_{rear}(E) = \left(\sum_i B_i \exp(-b_i E) \right) \exp[-\mu(E)\, \Delta x] \tag{2}$$

The parameters A_i, B_i, a_i, b_i and Δx must be fitted in the equations 1. The mass attenuation coefficient $\mu(E)$ and the effective thickness attenuation Δx, appears in equation 2. The thickness attenuation Δx was considered due to the effect of photon absorption in the sample.
Fitting was done in the following way:

a) fit $\varepsilon_{frontal}(E)$ according to equation 1;
b) fit $\varepsilon_{rear}(E)$ using the A_i and the a_i values as initial values of B_i and b_i, respectively and keep them invariant in order to fit only the value of Δx;
c) finally fit all the parameters B_i , b_i and Δx, simultaneously.

2.3. Combining the Efficiencies

Now, it is possible to create a combined efficiency $\varepsilon_{largesource}$ calculating the geometric average of the two efficiencies:

$$\varepsilon_{l\arg esource}(E) = \sqrt{\varepsilon_{frontal}(E)\, \varepsilon_{rear}(E)} \tag{3}$$

The geometric average is equivalent to the efficiency from the half-thickness layer of the sample, being an effective efficiency for the system.

If the coefficients fitted were similar (taking into account their standard deviations) $A_i \approx B_i$ and $a_i \approx b_i$, either one of the following expressions can be used:

$$\varepsilon_{l\arg esource}(E) = \varepsilon_{frontal}(E)\sqrt{\exp[-\mu(E)\,\Delta x]} \qquad (4)$$

or

$$\varepsilon_{l\arg esource}(E) = \varepsilon_{frontal}(E)\,\exp[-\mu(E)\Delta x/2] \qquad (5)$$

3. MONTE CARLO SIMULATIONS

In this work, the overall experiment was simulated using the MCNP code [4]. The germanium detector geometry was modeled according to its specification sheet [5] and the geometry of the sample follows the descriptions of the section 2. The source of photons was isotropic and followed the position distribution of the figure 2. In addition, for the source was used the energy spectrum emission of a ^{152}Eu taking into account the photon probability emission. The number of histories for each setup (three for the simulations) was $N=1x10^8$ lasting around 140 min computational time. The spectrum was generated using the MCNP score function F8[4].

4. RESULTS AND DISCUSSION

4.1. Experimental

In the figure below we show the $\varepsilon_{largesource}$ together with the $\varepsilon_{standard}$. It is clear that the first efficiency is systematically smaller than the second. The main discrepancy appears in the low energy photon region where the effect of absorption is more important.

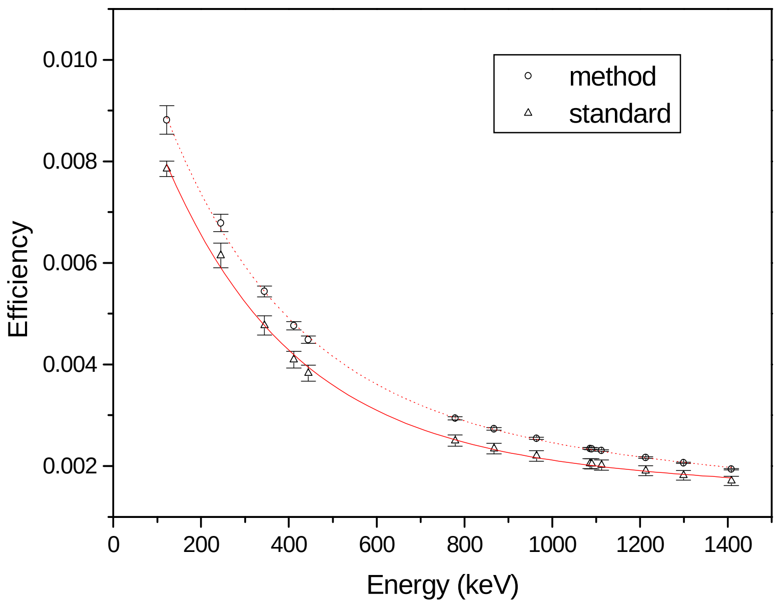

Figure 3. Comparison between efficiencies: $\varepsilon_{largesource}$ and $\varepsilon_{standard}$.

4.2. Numerical simulation

Monte Carlo simulation, see figure 4, shows ^{152}Eu spectra, collected in the detector for the frontal and rear efficiencies and a setup in which there is no sand matrix.

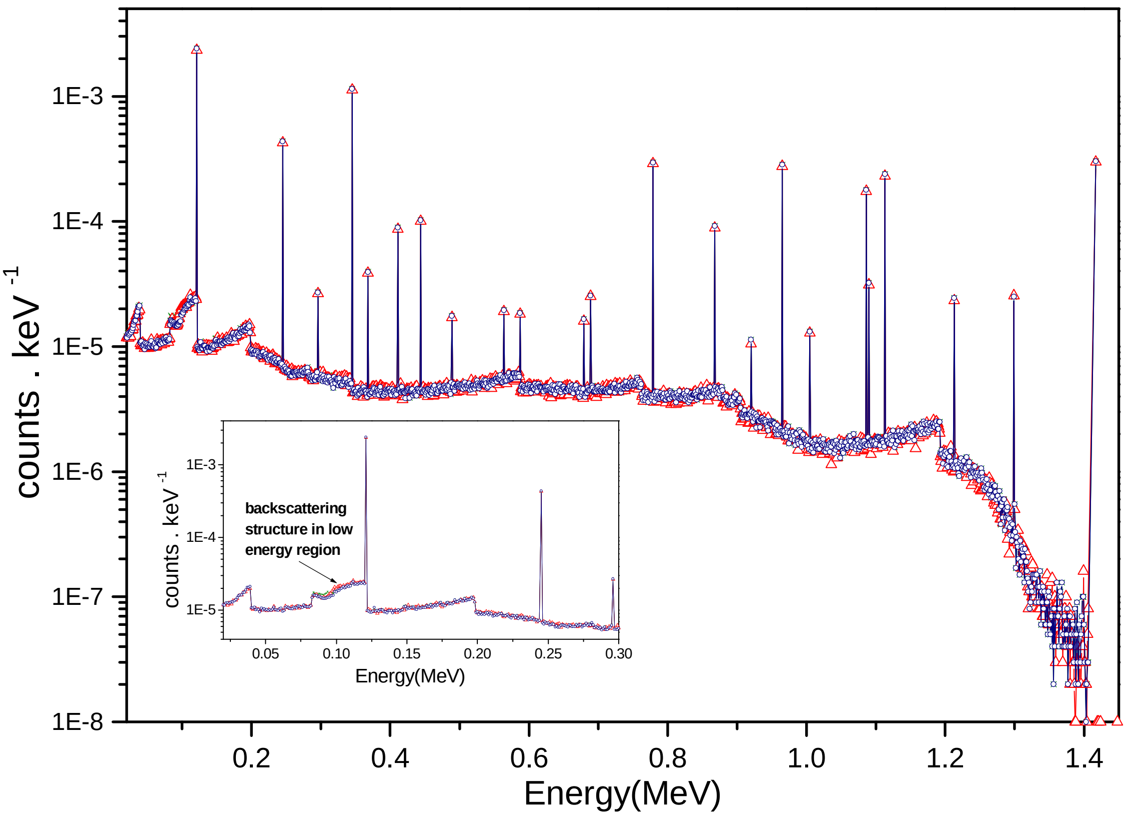

Figure 4. Spectra of ^{152}Eu using Monte Carlo simulation. The crosses and the triangles are for the $\varepsilon_{frontal}$ and ε_{rear} ,respectively, and the circles are for the setup without the sand matrix.

The effect of using a matrix for the total absorption photopeak is not so relevant. On the other hand if a low probability transition photon is of interest and has a photon emission energy in the low energy range of the spectrum, its analysis will be difficult because the backscattering continuous shape will be more intense. In addition, the backscattering events for the three setups are almost the same, considering their standard deviations (see detail of the figure 4).
The simulations show that the attenuation effect due to the matrix is not relevant, because of the small thickness of the matrix (0.6 mm). See figure 4.
This information gives us a way to plan the dimensions of the matrix sand to perform the calibration detector measurements in order to diminish effects of backscattering and absorption of photons.

5. CONCLUSIONS

Reliability tests of the method were successfully performed using the ^{152}Eu standard source. A small difference was observed between the efficiency obtained by the method $\varepsilon_{largesource}$

and the efficiency using the doped sample $\varepsilon_{standard}$. Two factors can be the origin of this difference:

a) We suspect that the efficiency obtained by the method is overestimated, because the punctual standard source was not positioned in the more extreme area (with radii ranging from 2 cm up to 2.3 cm, see figure 2). Not only the Monte Carlo simulations showed the effects of backscattering and attenuation of photons due to the matrix but in future simulations the contributions of the different regions of the matrix to the efficiency curve will be studied.

b) The standard efficiency $\varepsilon_{standard}$ is a little underestimated due to a probable loss of activity during the doping process. In order to have more precision for the activity value a method based in the mass variation will be used.

REFERENCES

1. C. A. Papachristodoulou, P.A. Assimakopoulos, N.E. Patronis, K.G. Ioannides, Use of HPGe γ-ray spectrometry to assess the isotopic composition of uranium in solis, *Journal of Environmental Radioactivity*, **64**, pp. 195-203 (2003).
2. D.J. Karangelos, M.J. Anagnostikis, E.P. Hinis, S.E. Simopoulos, Z.S. Zunic, Determination of Depleted uranium in environmental samples by gamma-spectroscopy techniques, *Journal of Environmental Radioactivity*, **76**, pp. 295-310 (2004).
3. J.P. Bolivar, R. García-Tenorio, M. García-León, A method for the determination of counting efficiencies in γ spectrometric measurements with HPGe detectors, *Nuclear Instruments & Methods in Physics Research*, **A382**, pp. 495-502 (1996)
4. J.D. Briesmeister, MCNP- *A general Monte Carlo N-particle transport code*. Version 4C, LA-13709 M (2000)
5. Camberra, Germanium detector chamber typical Cross-Sectional View (2000).