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RELATIVE EFFICIENCY CALCULATION OF A HPGe DETECTOR USING MCNPX CODE

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ABSTRACT

High-purity germanium detectors (HPGe) are mandatory tools for spectrometry because of their excellent energy resolution. The efficiency of such detectors, quoted in the list of specifications by the manufacturer, frequently refers to the relative full-energy peak efficiency, related to the absolute full-energy peak efficiency of a 7.6 cm x 7.6 cm (diameter x height) NaI(Tl) crystal, based on the 1.33 MeV peak of a ^{60}Co source positioned 25 cm from the detector. In this study, we used MCNPX code to simulate a HPGe detector (Canberra GC3020), from Real-Time Neutrongraphy Laboratory of UFRJ, to survey the spectrum of a ^{60}Co source located 25 cm from the detector in order to calculate and confirm the efficiency declared by the manufacturer. Agreement between experimental and simulated data was achieved. The model under development will be used for calculating and comparison purposes with the detector calibration curve from software Genie2000™, also serving as a reference for future studies.

1. INTRODUCTION

Gamma spectrometry is a direct technique for the analysis of radionuclides, capable of identifying and quantifying gamma emitters present in samples, without the need of any previous chemical treatment [1]. The method's versatility allows this technique to be applied in several fields of study, such as industries, research centers and area monitoring, amongst others [2]. One of the main advantages of this technique is the amount of information obtained in one single analysis. Besides, it is a fast, multi elemental and non-destructive analysis procedure.

The most commonly used types of detectors in gamma spectrometry are the inorganic scintillators and semiconductors. These detectors can provide qualitative and quantitative information on the levels of ionizing radiation to witch matter is exposed. With such measurements, it is possible to calculate the concentration of radionuclides present in a sample, further estimating the radioprotection parameters responsible for guaranteeing the

ALARA principle that establishes the necessary conditions to protect men from the harmful effects caused by ionizing radiation [3].

Among the essential parameters that guarantee a good performance of radiation detectors, and also an increased reliability of the results, one can mention the need for a good calibration of the measuring system, high photopeak resolution, low MDA (minimum detectable activity), the use of certified standard gamma sources and good counting efficiency per photon energy [4].

Counting efficiency, in its wide sense, is a measure of a detectors' capability of registering a radioactive emission. It is usual to classify the efficiency as *total* or *peak* efficiency, both being still subdivided in *intrinsic*, *absolute* or *relative* efficiencies. The *absolute total efficiency* is the probability that a gamma ray emitted by a specific source is registered by the detector. The *relative efficiency* takes as comparison reference that obtained by a thallium-activated sodium iodide (NaI(Tl)) detector, in standardized conditions [5]. The counting efficiency of a gamma detector, whether it's a scintillator or a solid-state detector, depends on the energy of the photons to be counted, on the geometry of the source-detector system and on the physical characteristics of the detector. Fig. 1 shows a typical efficiency curve for a Hyper-Pure Germanium detector (HPGe).

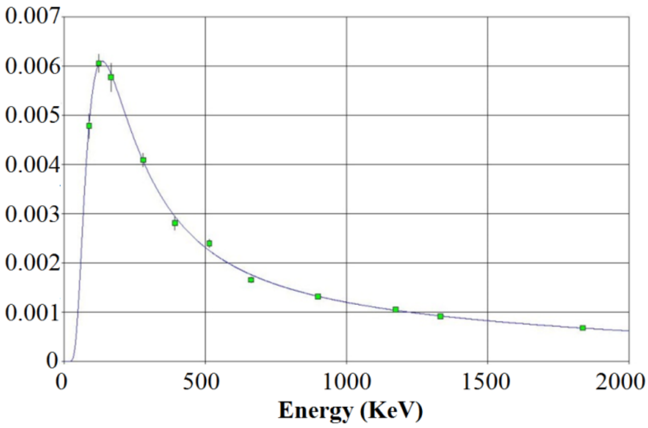

Figure 1: Typical efficiency curve of a HPGe detector, obtained on Genie™ 2K software.

The efficiency stated by the manufacturers of HPGe detectors is a relative efficiency, obtained by the ratio between the *absolute full-energy peak efficiency* (for the 1.33 MeV peak) for a point source of ^{60}Co positioned 25 cm from the Germanium detector, and the correspondent efficiency obtained by a NaI(Tl) scintillator detector with 7.6 cm of diameter x 7.6 cm high, in the same conditions. The absolute full-energy peak efficiency is defined by equation (1) [5]:

$$Absolute\ full\text{–}energy\ peak\ efficiency = \frac{total\ number\ of\ counts\ under\ the\ peak}{number\ of\ photons\ emitted\ by\ the\ source} \qquad (1)$$

The main purpose of this study was to use a code based on the Monte Carlo method to reproduce the necessary conditions to calculate the relative efficiency of a HPGe detector and compare the reference value stated in the manufacturer's manual with the value obtained through the computational model. Further, we intend to use the same modeling to obtain efficiency curves within a virtual environment.

2. MATERIALS AND METHODS

2.1. HPGe detector

The detector used in this study was a Canberra HPGe, model GC3020 with 30% of relative efficiency declared by the manufacturer, which belongs to the Real Time Neutrongraphy Laboratory (LNRTR) of the Federal University of Rio de Janeiro (UFRJ). Its main characteristics are available in the specification sheet accompanying the product upon acquisition, which were considered to be a faithful representation of the true aspects of the equipment. Fig. 2 shows some data provided by the manufacturer and used in this study to create the computer model for the detector. Some measurements not declared in the specification sheet were estimated. Data on the internal electronics of the detector are not available.

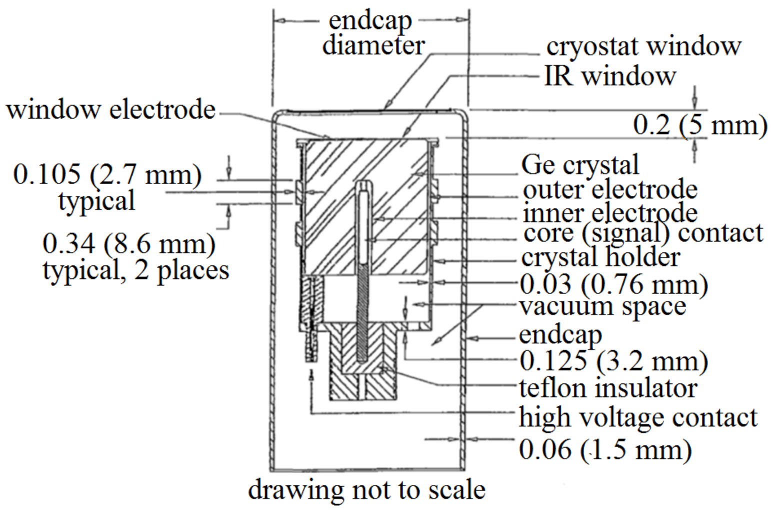

Figure 2. Germanium detector chamber cross-sectional view.

2.2. Simulation using MCNPX

The MCNPX [6] code was used to create the computational model in this study. Data on the geometry and on detector materials were obtained in the specifications sheet. The chemical composition of the materials present in the model were obtained from the literature [7]. Fig. 3 shows the system in a 3D image and a sectional view generated by the interface software Vised [8] that accompanies the MCNPX code, where the germanium crystal (active volume) and the main internal components can be identified. Since the equipment is reasonably new, kept almost constantly under low temperatures, it was assumed that there wasn’t any variations in the original dead layer stated by the manufacturer.

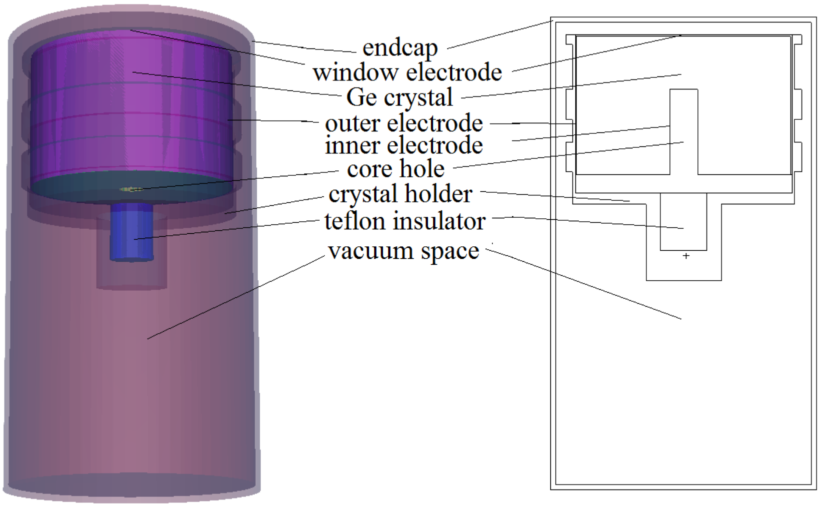

Figure 3: 3D and cross-sectional view of the HPGe computer model.

The F8 tally (*pulse height tally*) was used to obtain the spectrum shown in Fig. 4. It was used 8186 energy channels, divided in a way to reproduce the standard spectrometry methodology used in LNRTR, which uses the Genie™ 2K software. The *Gaussian Energy Broadening* (GEB) function was also used in the computational model to reproduce the experimental resolution of the detector. This function allows modifying the pulses obtained per channel through a Gaussian function.

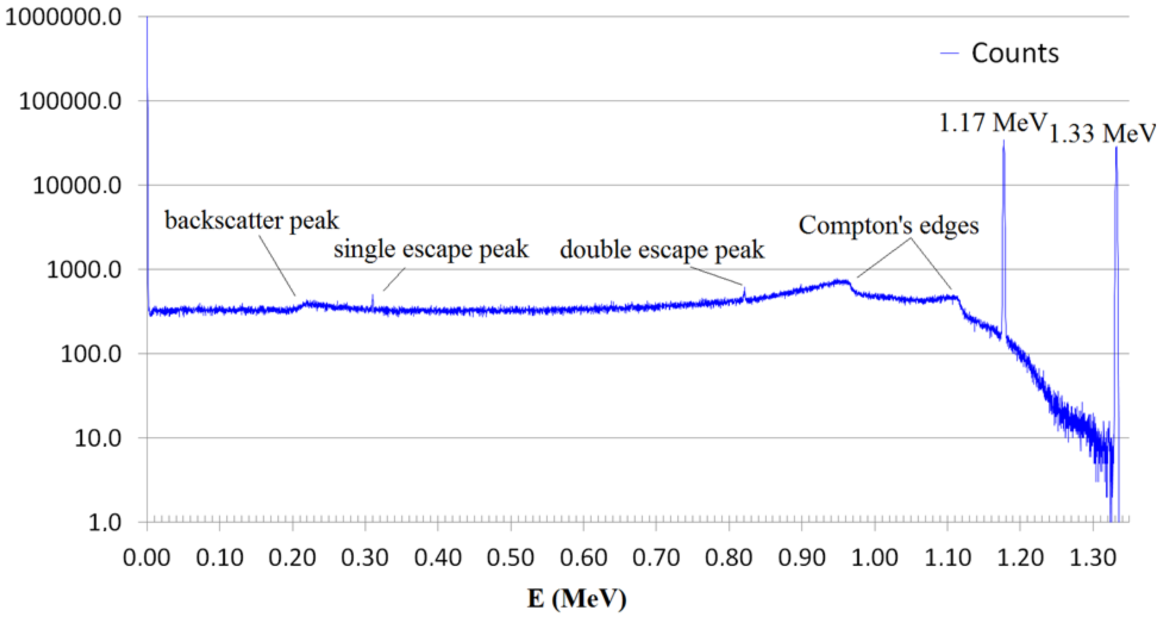

Figure 4: Energy spectrum obtained with the computer model.

The GEB function is defined by equation (2):

$$FWHM = a + b\sqrt{E + cE^2} \tag{2}$$

In equation (2), *FWHM* is the *Full Width at Half Maximum* of a certain photopeak with energy *E* (MeV). The parameters *a*, *b* and *c* were obtained numerically from equation (2) and from the experimental values stated in the equipment datasheet, according to Table 1. The value of FWHM for 1.17 MeV was obtained through linear interpolation between the other two values.

Table1. Performance of the Canberra GC3020 HPGe detector and calculated GEB function parameters.

Energy (KeV)	FWHM (KeV)	GEB function parameters
122	1.066	$a = 9.893.\ 10^{-4}$
1173	1.7105	$b = 4.815.\ 10^{-5}$
1332	1.808	$c = 162.203$

Finally, a point source of ^{60}Co positioned 25 cm from the end cap was modeled, centered in the symmetry axis of the detector. 1.6×10^9 photon emissions by the source were simulated, resulting in uncertainties of less than 5% in all channels. All simulations were performed in a 64 bits 3.2 GHz Intel Core 2 Duo computer.

3. RESULTS, DISCUSSION AND CONCLUSIONS

The spectrum obtained in the computer simulation is presented in Fig. 4, which shows good agreement with spectra available in the literature [9]. From this spectrum, equation 1 was used to calculate the absolute full-energy peak efficiency of the ^{60}Co 1.33 MeV photopeak. The correspondent absolute efficiency that would be obtained in a NaI(Tl) detector, in the same conditions, is available in the literature [5]. The ratio calculated between the efficiency of the computational model and that of the reference value was 34.85%, which corresponds to the efficiency calculated for the present HPGe detector. The resolution obtained experimentally and stated in the specifications sheet is 32.2%. Results are shown in Table 2.

Table 2. Efficiency calculation results

Absolute full-energy peak efficiency (this work)	NaI(Tl) absolute efficiency [5]	HPGe relative efficiency (this work)	Datasheet efficiency (Canberra)	Deviation
4.182E-4	1.2E-3	34.85%	32.2%	8.2%

The difference between the result stated by the manufacturer and that obtained in the computational model of this study can be related to several factors, such as approximations in the detector modeling. The absence of internal circuit geometry in the model and the hypothesis of the original thickness of the detector dead layer are examples of uncertainties that can interfere in the results.

It can be concluded, however, that despite the mentioned uncertainty there was good agreement between the result obtained computationally and the experimental data stated by the manufacturer. In order to adjust even more the efficiency calculated computationally with the experimental data, one can modify the thickness of the dead layer of the germanium crystal until the approximations are considered satisfactory [10]. The dead layer reduces the active volume of the crystal, and its thickness tends to increase over time, requiring periodic recalculations.

In a future stage, we intend to study the adjustment of the total efficiency curves using three different methods: total efficiency from the standard model provided by IRD (*Instituto de Radioproteção e Dosimetria*), total efficiency from the mathematical software LabSOCS, provided by Canberra, and the efficiency from a model simulated in MCNPX. It is intended, hereafter, to make possible an approximation with good reliability of the calculation of activities for complex geometries from the efficiency calculated through the Monte Carlo simulation.

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