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A detailed procedure to simulate an HPGe detector with MCNP5

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ABSTRACT

Due to its high resolution, HPGe detectors are widely used for analysis of gamma emitters radioisotopes. The determination of the response curves for this type of detector is not easy and demands a large number of gamma emitters in order to account for the energy range of interest. For volumetric geometries, a standard solution of a mix of radionuclides is commonly used, but requires one standard solution for each counting geometry of interest. The Monte Carlo method can be used to determine the detector's response curves, making it easier and cheaper. This work presents a detailed description of the procedure to simulate and calibrate co-axial HPGe detectors. It also presents a complete input file for the MCNP5 computer code. The comparison of the simulated and the experimental data showed very good agreement and the discrepancies are mainly due to the uncorrected peak sum effect of the experimental data.

1. Introduction

With the increasing use of nuclear and radioactive material, it becomes of great importance the environmental monitoring in order to prevent possible ways of contamination. Worldwide people are getting more and more aware of the impact that radiation can cause to humans and biota alike.

Due to the high penetration of photons, gamma spectrometry is of great importance for sample analysis; it does not require chemical separation and can be measured in bulk form. Both qualitative and quantitative analysis is performed in a single measurement.

HPGe detectors are widely used for gamma spectrometry, mainly because of its high resolution, which enables discrimination between photons of very close energies.

Nevertheless, the experimental determination of the response function of HPGe detectors presents some difficulties. It demands the availability of standards sources of a mix of radionuclide in the same counting geometry that the samples will be measured.

Another difficulty is the peak sum effect, which is the occurrence of two or more photons interacting within the detector's crystal simultaneously. These events are common for isotopes that emit multiple gamma rays in a single event, especially when the radiation source is placed close to the detector. These events affect the activity results and need to be taken into account. This effect is not dependent on the activity of the source.

Another way to determine the detector's response function is by the Monte Carlo method.

The Monte Carlo method is broadly used for photons and particles transport (Jacob et al., 1987; Moreira et al., 2010; Salgado et al., 2006). It became a powerful tool, very flexible and enables the analysis of a wide energy range. When applied together with a gamma spectrometry system, provides means to determine the detector's response function, optimizing both time and financial resources.

The MCNP5 – Monte Carlo N-Particle Code, developed by the Los Alamos National Laboratory (X-5 Monte Carlo Team, 2003a, 2003b), has been widely used for all kinds of purposes involving radiation transport.

This work establishes a methodology and presents a detailed procedure for modeling a semiconductor HPGe co-axial detector using the MCNP5 Monte Carlo computer code. It has been tested by comparison between the measured and the simulated response functions for a spatial and a volumetric counting geometries.

2. Materials and methods

2.1. Experimental efficiency curves

Experimental measurements were carried out with an HPGe co-axial gamma-X detector, manufactured by Canberra, with relative efficiency of 45%. The detector's crystal dimensions given by the manufacturer are: 6.4 cm diameter, 63.5 cm high and 0.5 cm from the top of the detector's crystal to the entrance window.

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The detector's response curves were determined experimentally by counting standard gamma ray sources, in a given counting geometry, covering the energy range of interest. The efficiency curves were determined for two different counting geometries: filter and pot.

The two gamma sources used for the experimental efficiency curves determination consisted of several radionuclides covering the 46 keV–1332 keV energy range. The sources were prepared by the Brazilian Ionizing Radiation Metrological Laboratory (LNMRI), at the Institute for Radioprotection and Dosimetry (IRD), Brazil. The radionuclides and activities for both sources are listed in Table 1.

2.2. Detector's simulation

Some of the data required for the detector's simulation are found in its certificate provided by the manufacturer, which describes its characteristics and dimension. Nevertheless, some other data need to be determined by either direct measurement with a pachymeter, like the external diameter, or experimental determination, like the dead layer and inner electrical contact.

A schematic representation of the 45% HPGe detector is presented in Fig. 1. The detector's axis coincides with the *x* axis and the center of the base of the crystal was positioned at 0,0,0 (*x*,*y*,*z*). The simulation process will be described in details in order to properly present de procedure used.

2.2.1. Germanium crystal

The detector's crystal is a critical step for the simulation process because it is the region where de energy deposition will be accounted for and, the most important, some of the necessary data are not available and need to be determined.

Fig. 2 presents a cross section of the geometrical volume and the surfaces used for the simulation of the germanium crystal. The mathematical description is composed of one torus (surface 9), one sphere (surface 8), four planes (surfaces1, 2, 3 and 4) and three cylinders (surfaces 5, 6 and 7) blended together.

The segment of the source code for the MCNP5 input relative to the surfaces definitions to describe the detector's crystal is:

```
1 px 0
2 px (height*0.8142)
3 px (height − 1)
4 px height
5 cx radius
6 cx (radius − 1)
7 cx 0.7
8 sx (height*0.8142−1.27) 1.45
9 tx (height − 1) 0 0 (radius − 1) 1 1
```

Where "height" is the height or length of the crystal and "radius" is its radius. These data are given by the manufacturer and can be found in the detector's certificate. The length unit is cm.

Table 1
The radionuclides and activities of the sources used for evaluation of the HPGe detector response.

Sources	Energy (keV)	Activity (Bq)	
		Filter	Pot
^{54}Mn	834.82	–	308.7
^{57}Co	122.66	1986.7	2098.9
^{60}Co	1173.22 1332.49	1031.0	1965.5
^{109}Cd	88.03	4126.4	3716.7
^{137}Cs	661.65	302.9	422.2
^{210}Pb	46.54	–	2571.7
^{241}Am	59.54	360.2	457.3

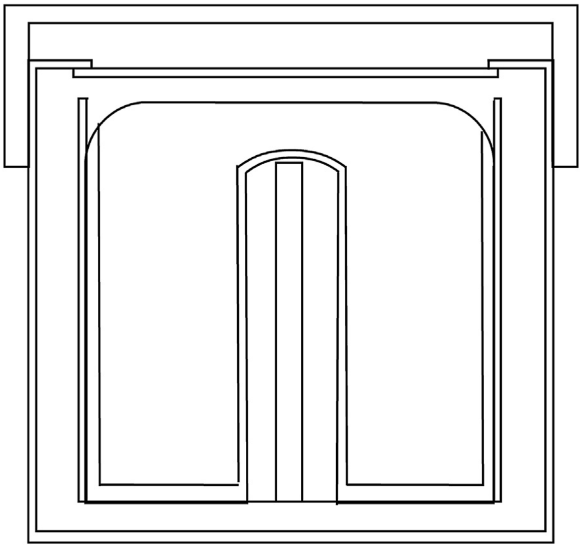

Fig. 1. Output of the MCNP5 computer code relative to the described geometry used as input. The detector was described along the *x* axis and the center of the base of the crystal was positioned at 0,0,0 (*x*,*y*,*z*).

In addition to that, it is also necessary to include the dead layer, which is the region responsible for the electrical contact, and a transition layer, in which the electrons released by the photons interactions are not completely collected due to the fact that the electric field is not up to the working level, contributing, in this way, to the Compton continuum. The sum of the thickness of both layers will be referred, from now on, as "dead layer".

The extension of the dead layer depends on the detector's size and operating voltage. Therefore, its thickness must be determined for each individual detector to be simulated. Due to the high atomic number of germanium, there is great probability of photons interacting in this region, especially for low energy photons; hence, the dead layer must be precisely determined. (Santo et al., 2012; Conti et al., 1999; Clouvas et al., 1998; Sánches et al., 1991; Burns et al., 1990; Nakamura, 1983).

Fig. 3 shows the crystal's dead layer and the surfaces needed for the simulation.

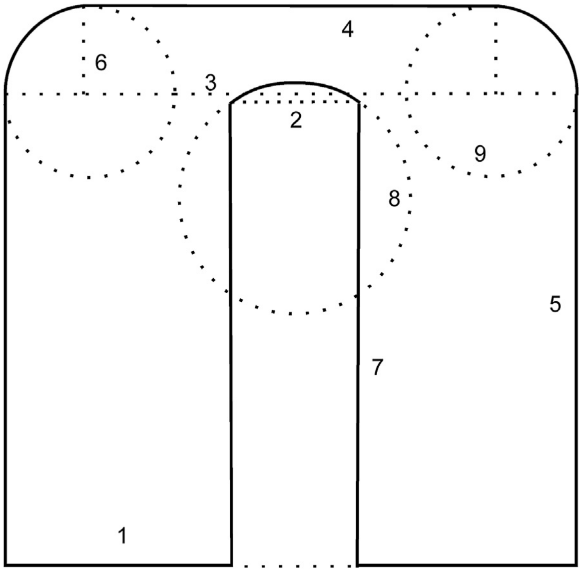

Fig. 2. Schematic representation of the geometrical forms to describe the detector's crystal.