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SIMULATION OF GAMMA-RAY SPECTRA FOR COMPLEX MEASUREMENT SYSTEMS USING GEANT 3.21*

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Abstract. HPGe detectors are commonly used in gamma-ray spectrometry measurement systems where nuclide identification and also quantification are desired. For quantification, an efficiency calibration must be performed. This task becomes increasingly difficult and expensive as the sources become large and complex. This work relates to the study and characterization of the response function of two gamma-ray spectrometry systems: ISOCART (Ortec) and Segmented Gamma Scanner WS1100 (Canberra) used for measuring especially large sources. To this purpose the Monte Carlo code GEANT 3.21 was applied and the spectra expected in the photon energy range from 50 to 2000 keV for high volume sources measured with ISOCART and SGS-WS1100 were simulated. The full energy peak efficiency as well as the total efficiency were also evaluated.

Key words: Gamma-ray spectrometry, Monte Carlo simulation, efficiency calibration

1. INTRODUCTION

The experimental calibration of germanium detectors used in gamma-ray spectrometry [1] is difficult especially in the case of measurement of samples that cannot be approximated as point sources. In the context of the task to analyse different samples, with various geometries and matrices, the dependence of the detection efficiency on sample geometry and matrix (composition and density) would require a large number of calibration measurements using many different standards. The situation is more difficult in the case when the samples are measured with high efficiency detectors and the sample is placed near to detector, because in this case most radionuclides will give rise to important coincidence summing effects [2]. As a consequence the detection efficiency for a given energy depends not only on energy and experimental set up, but also on the radionuclide.

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Therefore a comprehensive experimental calibration would require the measurement of an enlarged number of standards, one for each geometry and matrix of interest, containing certified activities for each radionuclide that is present in the real samples. This task is almost impossible for the majority of the matrices and radionuclides. A better solution for determining the detection efficiency is the application of specific methods of calculation. Various methods, extending from approximate procedures, that offer a rough estimate of the efficiency, to rigorous and sophisticated methods, capable to reproduce all the experimental details and to take into account every physical process that is important, have been developed. The most precise methods are based on Monte Carlo simulation [3, 4, 5] of radiation transport from the moment of emission through the final signal that is build in the detector. Besides direct application to the computation of the efficiency, Monte Carlo simulation can be used also for the computation of the efficiency transfer factor [6]. In fact, due to its relative insensitivity to the uncertainties of the detector data and of the calculation model, the method of efficiency transfer, based either on Monte Carlo simulation or on semiempirical methods [7, 8, 9], is increasingly applied to the computation of the efficiency in the case when direct experimental calibration is not available [10].

In this work we report the application of Monte Carlo simulation to the study and characterization of the response function of two gamma-ray spectrometry systems, ISOCART from Ortec and Segmented Gamma Scanner WS1100 from Canberra, used for measuring large sources. Specifically we consider a 220 l radioactive waste drum as the volume source. This drum is typically used for conditioning of radioactive waste in Romania and has been the subject of several previous studies [11, 12, 13]. However this is the first study in which the complete spectrum is simulated and used for the evaluation of the efficiencies.

2. EXPERIMENTAL SETUP

In this work we evaluated the detection efficiency for two detector systems. The first is a p-type Ortec detector with a relative efficiency of 25%; resolution 1.85 keV at 1332 keV (^{60}Co) and 0.82 keV at 122 keV (^{57}Co). The diameter of the germanium crystal is 57.4 mm and the length 52.2 mm. The thickness of the dead layer is 0.7 mm on top and sides. A central hole is drilled into the bottom side of the crystal with 34 mm length and 9 mm diameter. The crystal is encased in aluminium housing with thickness equal to 1.27 mm on top and sides. The distance from end cap to crystal is 3 mm. In the measurement of waste drums this detector is shielded with a lead collimator of 203 mm length, 16 mm thickness and 110 mm inner diameter of the collimator. The distance from the front of the collimator to the front of the detector is 20 mm.

The second detector is a p-type Canberra detector with a relative efficiency of 44.4%, resolution 1.92 keV at 1332 keV (^{60}Co) and 1.08 keV at 122 keV (^{57}Co). The diameter of the crystal is 61 mm and the length 64 mm. The germanium dead layer has a thickness of 0.62 mm on top and 0.645 mm on sides. The central hole has 40 mm length and 10 mm diameter. The crystal is encased in aluminium housing with 1.268 mm thickness on the entrance window and 1.5 mm on the side surfaces. The distance from end cap to crystal is 5 mm. In typical measurements of waste drums this installation also uses a lead collimator. The total length of the collimator is 365 mm. The first part, located in front of the detector, with a length of 140 mm, has a rectangular opening with the dimensions 30×60 mm (height and width). The median part, surrounding the detector, has the length of 155 mm, the inner diameter of 138 mm and the thickness of 69 mm. The bottom side of the collimator has 70 mm length, the thickness of 105 mm and the inner diameter equal with 28 mm.

In both cases the radioactive source considered was a 220 l waste container. This source is a cylinder with dimensions of 880 mm length and 570 mm diameter, encased in an iron container with walls having the thickness equal to 1.25 mm. The source matrix considered was concrete with standard composition. The axis of the detector is perpendicular on the axis of the cylinder. The distance from the centre of the coordinate system associated to the detector to the centre of the cylinder was 500 mm for both geometries. We denote by Geom1 the complete experimental setup based on the Ortec detector and by Geom2 the similar setup based on the Canberra detector.

3. SPECTRUM SIMULATION WITH GEANT 3.21

GEANT 3.21 [14] is a system of detector description and simulation tools that help in designing and optimizing the detectors, developing and testing the reconstruction and analysis program, and interpreting the experimental data. The GEANT code simulates the passage of elementary particles through the matter. Originally designed for high energy physics experiments, it has found today applications also outside this domain in areas such as medical and biological sciences, radioprotection and astronautics. A major advantage of GEANT is the flexibility for describing accurately various experimental systems, including in our case a detailed characterization of the detector, collimator system and the complex, high volume, source.

In principle, the application of the Monte Carlo method for the calculation of detection efficiency for big samples, e.g. the waste drum, is almost the same as in the case of small samples. From the practical point of view, especially with respect to calculation time, there appears a big difference. In the case of big samples, in which the majority of emission points are located far away from the detector, the fraction from the number of emitted photons that contributes to the detector signal is very small. Consequently, the number of photons that should be followed until a statistically significant number of signals will be reached should be very large, resulting in a long computation time. In our study about 7 10^{10} photons were simulated.

All the details of the source (dimensions, composition), measurement geometry (source position, detector position, collimator characteristics) and detector were implemented in GEANT 3.21.

In principle the simulation was carried out as follows. Emission points were selected at random from a uniform distribution in the volume of the source. The directions of the emitted photons were randomly generated from isotropic distributions. The history of each source photon, as well as each secondary photon and electron resulting from interactions in the source, detector and the environment was followed until the energy of the particle became low enough to be considered locally absorbed. The energy deposition in the detector for each source photon was evaluated. Then the energy deposition was distorted according to a Gaussian distribution closely matching detector resolution. The inclusion of detector resolution in simulation is important for obtaining realistic spectra, similar to the experimental data. This enables the application of the same analysis procedure both to the simulated and to the experimental spectra, an important point in the analysis of the results in the case of volume sources, especially at low energies.

The simulations have been done for the main gamma photons (12 energies) emitted by ^{152}Eu. In the case of Geom1 3×10^9 photons were followed for each energy. In the case of Geom 2 slightly less photons were simulated.

Individual spectra were recorded in separate files. In the end all spectra were combined with weights according to the emission probability of each gamma ray [15]. The resulting spectra are presented in Fig. 1.

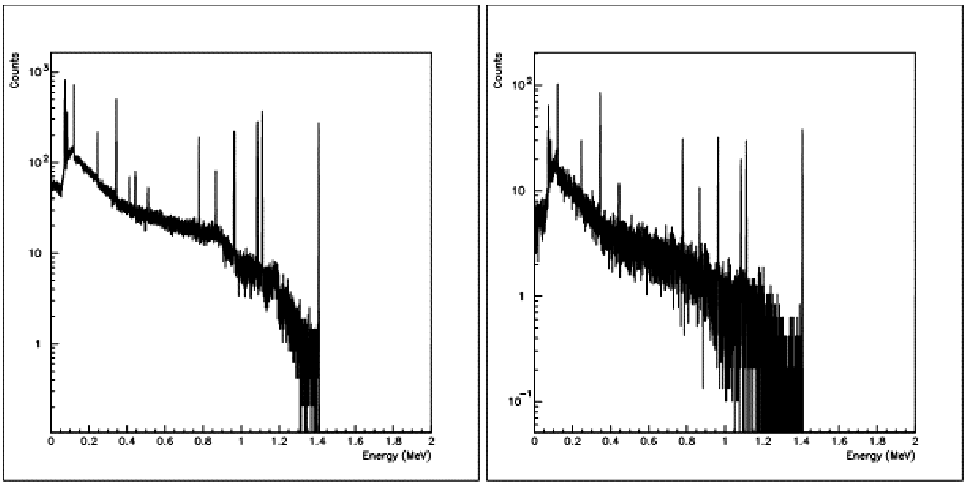

Fig. 1 – Spectrum simulated with GEANT 3.21 for a source of ^{152}Eu uniformly distributed in the waste drum; Geom 1 – left panel, Geom 2 – right panel.

4. COMPUTATION OF DETECTION EFFICIENCY

The intrinsic efficiency of a detector usually depends primarily on the detector material, the radiation energy, and the physical thickness of the detector in the direction of the incident radiation. A slight dependence on distance between the source and the detector is presented, because the average path length of the radiation through the detector will change somewhat with this spacing. Counting efficiencies are also categorized by the nature of the event recorded. If all events from the detector are accepted, then the total efficiency is of interest. In this case all interactions, no matter how low in energy, are assumed to be recorded. The peak efficiency assumes that only those interactions that deposit the full energy of the incident radiation are recorded. The number of full energy events can be obtained by integrating the total area under the peak.

In Fig. 2 the peak efficiency curves obtained from the spectra, for both geometries are presented. The fact that the efficiency in Geom2 is smaller than in Geom1 even if the second detector has a higher intrinsic efficiency is explained by the smaller collimator acceptance in the case of Geom2.

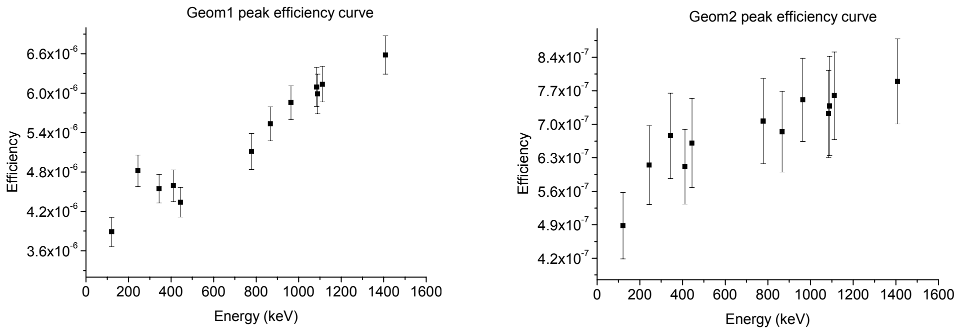

Fig. 2 – The peak efficiencies simulated with GEANT 3.21 for Geom1 (left panel) and Geom2 (right panel).

In Fig. 3 the total efficiency curves obtained also from the simulated spectra, for Geom1 and Geom2 are presented.

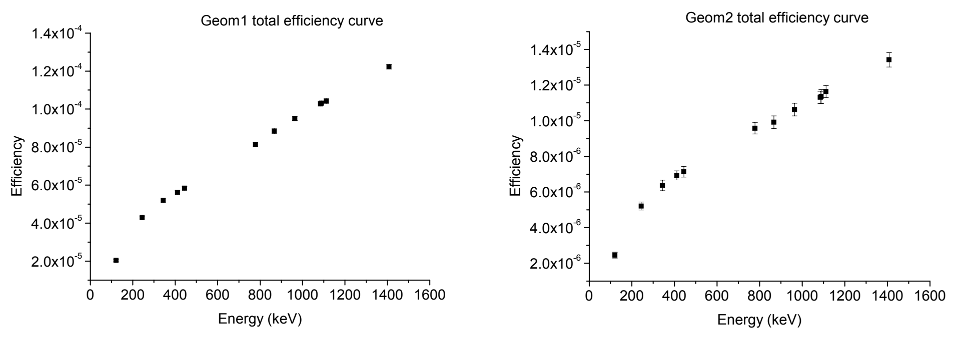

Fig. 3 – The total efficiencies simulated with GEANT 3.21 for Geom1 (left panel) and Geom2 (right panel).

5. CONCLUSIONS

A computation procedure based on Monte Carlo simulation of spectrum and detection efficiencies for two configurations used currently for the measurement of radioactive waste drums was developed. The code applied was GEANT 3.21. Almost 450 individual spectra were simulated and then combined for obtaining the spectrum expected in real measurements. The procedure developed in this work can be used for future studies for other types of sources, with different geometries or compositions.

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