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Efficiency Determination of a HPGe Detector by Monte Carlo Simulations Using the GEANT Package*

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Abstract: Monte Carlo model was developed using the GEANT 3 code for calculation of the full energy peak efficiency of the HPGe detector operating in the Slovak Institute of Metrology. The model will be used for determination of radon activity concentrations in secondary radon standards by its decay products. The detector model was validated by comparison of simulated efficiencies with measured experimental values for point sources in different geometries. A reasonable 5% agreement between simulated and experimental results was achieved in the range of 100 to 2000 keV.

1. Introduction

Germanium detectors proved to be excellent tools for gamma spectrometry in last decades. High purity germanium (HPGe) detectors are widely used for analysis of radionuclides in all kind of samples, where high efficiency, superior energy resolution and low background are needed. To supress the radiation from outside of the detector, like cosmic rays, ^{222}Rn daughters and radionuclides in the close neighbourhood, the HPGe detector is surrounded by shielding materials, e.g. by low activity lead, copper and iron. For identification of the registered gamma rays, energy calibration is needed, and for the determination of activity concentrations of investigated radionuclides, full energy peak efficiency calibration is needed. In general, detector efficiency can be defined as a ratio of the registered gamma rays to number of gamma rays emitted from the source.

There are several methods for determination of detector efficiency for current radionuclides present in specified samples. The used method is usually determined by the energy of emitted gamma ray and by the geometry of the sample. The simplest method is to use a calibration radioactive source of the same radionuclide, as will be determined, with known activity and the same geometry as the investigated sample [1]. There is no need for further corrections, and we get directly the detector efficiency from the experimental measurement, however this method requires the standard with the same geometry and the same radionuclide for each sample geometry, which is not always possible (because of a compli-

*Dedicated to Professor Peter Prešnajder on the occasion of his 70th birthday cated shape of the sample, unknown composition, etc.). Therefore, semi-empirical methods are commonly used for determination of detection efficiency for gamma rays of other energies, then energies of gammas emitted from the standard [2]. This requires the knowledge of the mathematical description of the detector response function, which is usually different for each geometry of the sample.

A more sophisticated option is to use Monte Carlo methods for simulation of generation, transport and registration of the gamma rays in the Ge detector [3–5]. Nowadays, there are several packages enabling tracking the gamma rays from the source to the detector. Most commonly used simulation methods for Ge detector efficiency determination are based on MCNPX (developed in Los Alamos National Laboratory [6]) or on GEANT (developed in CERN [7]).

The Department of Ionizing Radiation in the Slovak Institute of Metrology operates a coaxial HPGe detector (Canberra, model GC3020), that is planned to be used for determination of ^{222}Rn in secondary national standard by measuring the radon decay products. For these measurements, the use of non-standard geometry of Marinelli beaker is planned and therefore efficiency calibration of the detection system is needed. The aim of this study is development of the GEANT code for Monte Carlo simulation of the detector response and determination of counting efficiency.

2. Methods

GEANT toolkit was developed for high-energy physics in CERN, but nowadays its successful applications include also other fields of science, like nuclear and accelerator physics, as well as medical and space sciences. It includes wide range of functionality from event tracking, geometry, and different physics models for registration of the hits [7]. Currently it is available free in the GEANT4 version, however in this paper the previous version GEANT 3.21 has been used.

A Monte Carlo model of the HPGe detector with a relative efficiency of 30% and an energy resolution of 2.0 keV at the 1332.5 keV gamma rays of ^{60}Co has been developed. The detector is placed inside a cylindrical shield made dominantly from 15 cm of lead. The cross sections of the shielding and the detector geometry are shown in Fig. 1.

For the detection efficiency calculations, the knowledge of inner detector structure and geometry is crucial, however the manufacturer often do not share the know-how of the detector structure and composition, only basic characteristics are available. The known dimensions of the Ge crystal are summarized in the Tab. I. There are also known information about the inner structure of electrodes and crystal position within the detector endcap from the manufacturer [8] and several published papers [9, 10] describing the same or similar detectors. Based on this knowledge, the model of GC3020 detector was constructed and cross section of the used geometry is presented in Fig. 1. The thickness of the dead layers between the electrode contacts and the Ge crystal were approximated to 1 mm. The number of simulated events was chosen in regard to obtain the statistical error of the simulated efficiency below 1%.

The real thicknesses of the dead layers were estimated from comparison of simulated and experimental efficiency calculated from the measurement of point radioactive sources (etalons) with known activity. Three distances of the etalons from the detector

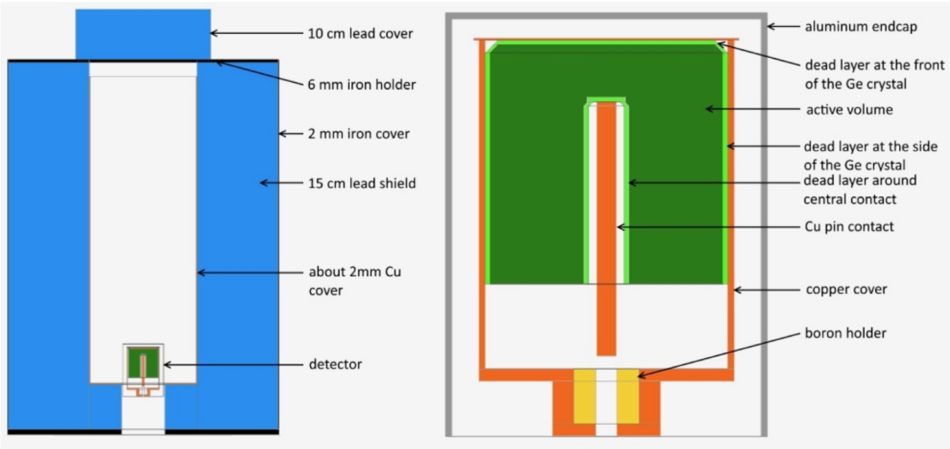

Fig. 1. Schematic view of the lead shield (left) and the modelled HPGe detector (right) with positions and materials.

were used for this estimation. For close geometry, the 7 mm distance was chosen and only monoenergetic etalons (^{241}Am, ^{139}Ce, ^{137}Cs, ^{54}Mn and ^{65}Zn) were considered, to exclude the summing effect of the cascade radionuclides. 16 cm and 31 cm distance of etalons were chosen for distant geometry and efficiencies of ^{129}I, ^{241}Am, ^{133}Ba, ^{57}Co, ^{139}Ce, ^{134}Cs, ^{152}Eu, ^{54}Mn, ^{88}Y, ^{65}Zn, ^{60}Co and ^{22}Na were used for comparison with simulated data. Areas under characteristics energy peaks were used for calculation of the full energy peak efficiencies.

Since the precise thicknesses and compositions of all layers around the detector are unknown, the thickness of the dead layer was used for correction of the efficiency for these unknown layers. The dead layer was divided into three parts – dead layer at the front of the crystal, at the side of the crystal and around the hole for the central contact (see Fig. 1). Each part was optimized separately, because we have expected different layers of unknown materials which could absorb gamma rays in these parts of the detector.

For the optimization of the dead layer at the front of the crystal, low energy gammas were used from 0.7 cm and 16 cm distance. A few dependencies between the simulated efficiency and the thicknesses of the dead layer are presented in Fig. 2. The simulated efficiency for the detector geometry with selected thickness of the dead layer was compared to experimental efficiency calculated for used radionuclides in selected distance of the etalon from the detector.

It can be seen, that even small difference in the thickness of front dead layer result in relatively big difference in the efficiency (i.e. change from 1 mm to 0.5 mm result in 40% increase of the efficiency for 81 keV gammas from 7 mm distance), therefore the thickness interval of the front dead layer is relatively well defined. Final thickness of the front dead layer used in the model was calculated as averaged value of intersections of experimental efficiencies with modelled dependencies.

Similar approach was used for determination of the thicknesses of dead layers at the side of crystal and around the central contact, where simulated efficiencies from different distances and for different energies were compared to experimental value. Calculated thicknesses of dead layers, that were used in the detector model are summarized in Tab. I.

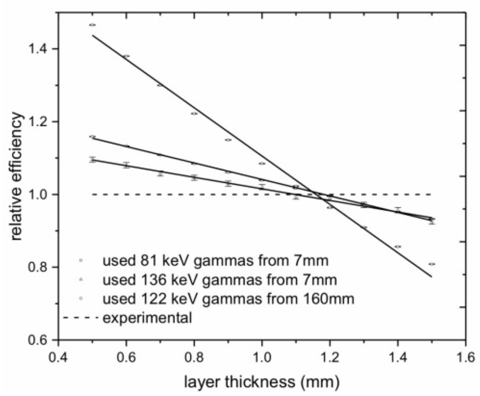

Fig. 2. A comparison of the simulated efficiencies to experimental values for different thicknesses of the dead layer at the front of the Ge crystal.

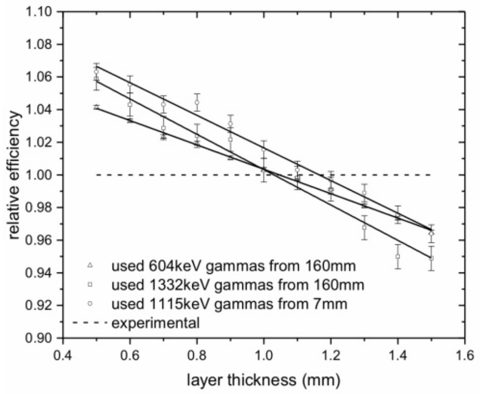

Fig. 3. A comparison of the simulated efficiencies to experimental values for different thicknesses of the dead layer at the side of the Ge crystal.

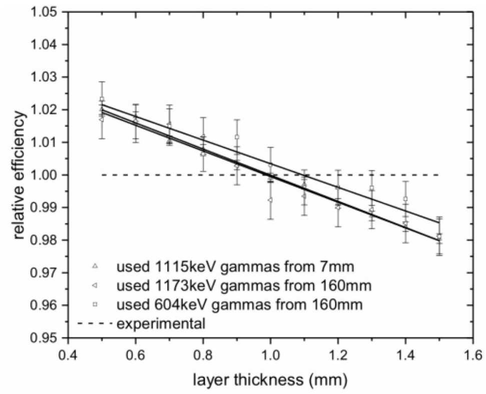

Fig. 4. A comparison of the simulated efficiencies to experimental values for different thicknesses of the dead layer around central contact in the Ge crystal.

Tab. I. Dimensions of the HPGe detector used in the model.

Height of Ge crystal	5.75 cm
Diameter of Ge crystal	5.73 cm
Distance of Ge crystal to front endcap	5 mm
Depth of core in Ge crystal	4.4 cm
Diameter of core in Ge crystal	0.84 cm
Thickness of aluminium endcap	1.5 mm
Diameter of aluminium endcap	7.6 cm
Thickness of copper cover in front of Ge crystal	0.5 mm
Thickness of copper cover on side of Ge crystal	1.5 mm
Thickness of the front dead layer	1.1 mm
Thickness of the side dead layer	1.1 mm
Thickness of the dead layer around the central contact	1.1 mm

Results and discussion

After optimization of the dead layer thickness, the model was used to calculate the detector efficiency for three distances of the point sources. Simulated and experimental full energy peak efficiencies are compared in Figs. 5–7 for distances of 7 mm, 16 cm and 31 cm, respectively. As can be seen from the comparison, the model describes within 5% the efficiency of the GC3020 detector in range from 100 to 2000 keV.

The statistical uncertainty is much lower compared to uncertainty from measured values caused by statistics of the measurement or uncertainty in the activity concentration of the used etalon. The efficiency for energy 39.6 keV of the ^{129}I was excluded from comparison, because the difference was higher than 50%. Applicability of the model below 100 keV is questionable as the differences between simulated and experimental values

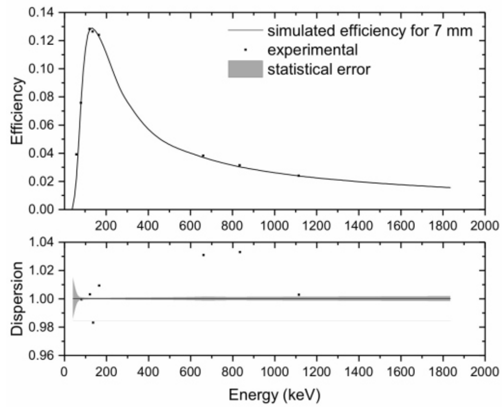

Fig. 5. Comparison of simulated and experimental efficiencies for 7 mm distance to detector.

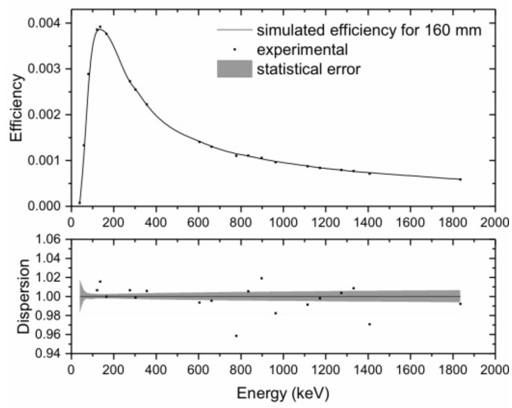

Fig. 6. Comparison of simulated and experimental efficiencies for 16 cm distance to detector.

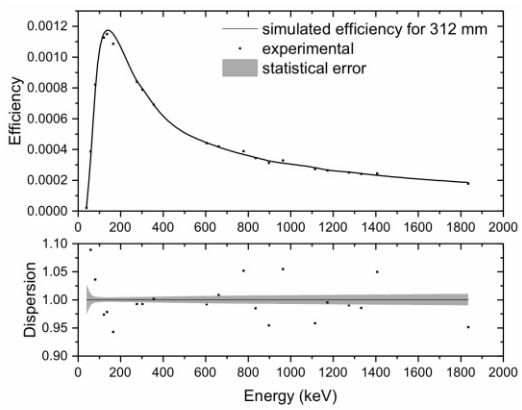

Fig. 7. Comparison of simulated and experimental efficiencies for 31 cm distance to detector.

reach 15% (so high values are out of the range in Fig. 6 for 59.5 keV of the ^{241}Am). The discrepancies between the simulated and experimental efficiencies in this low energy region are probably due to an additional layer (with high Z) in front of the Ge crystal, that absorb low energy gamma rays and modify the response of the model in this region.

The model was validated only by gamma rays coming from the front side (window) of the detector, however, it is planned to be used for Marinelli beaker geometry (surrounding the Ge crystal to enhance the efficiency) as well. In this geometry, the gamma rays enter the crystal also from sides, therefore further optimization is needed for the additional layers of materials surrounding the Ge crystal.

Conclusions

In this work, the GEANT 3 code was used to model the GC3020 HPGe detector efficiency used in the Slovak Institute of Metrology. The detector will be used for measurement of the radon daughters in secondary radon standards and therefore full energy peak efficiency calibration is needed for proper measurement of high-volume samples in a modified Marinelli beaker. The 5% agreement between the simulated and measured efficiencies was achieved in the 100–2000 keV range of gamma rays. For now, this model has been validated only by the point sources in different distances, however, a further validation of Marinelli geometry is needed which will be the aim of further developments.

Acknowledgments

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