PHOTOPEAK EFFICIENCY OF Ge DETECTORS STUDIED WITH THE CODE MCNP

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One of the prerequisites of experimental nuclear physics is a precise understanding of the response of the detectors used in experiments. While high purity Ge detectors are the standard piece of equipment for the detection of gamma radiation, the complexity of the new detector arrays and of their component detectors is constantly increasing. Computer modeling of the detector response has proven to be a useful, and sometimes indispensable, tool for extracting information on quantum observables out of measured quantities.

Our aim is to model a mini-array composed of three clover-, one 80%- and one 120% coaxial HPGe detectors, which has been used in one of the last experiments performed at NSCL before the shutdown [1]. The first step, described in this progress report, was to study the photopeak efficiency of the simpler 80% and 120% detectors using the computer code MCNP [2] (Monte-Carlo N-particle transport code).

The code provides a convenient way of specifying the geometry of the problem using simple surfaces which define so-called cells. The material of each cell can be specified, either as isotopically pure or "natural composition" for simple cases, or by specifying the different components and their percentages for composite materials. There are several built-in geometries of sources, as well as distributions of the particles they emit (in energy, direction, time and position). The code can be used to monitor the transport of neutrons, photons and electrons. For our specific aim, the transport of photons (primary, i.e. emitted from the source, as well as secondary) and secondary electrons has to be studied. The fundamental processes involved in the interaction of electromagnetic radiation with substance are well studied. They are input to the computer modeling in the shape of tabulated cross-sections involving different materials and $\gamma-$ray energies. The electron transport can be treated either by actually monitoring each of the electrons, or by taking into account the secondary photons they produce using a thick-target bremsstrahlung model. Since the electron transport is dominated by the long-range Coulomb force, resulting in a large number of interactions with small energy transfer, the first option is very computer-time consuming. We opted for the second one and checked in a few cases that the results are not very sensitive to the method used to describe the energy deposition/photon production by secondary electrons. The Monte Carlo technique is employed in following each particle from the source, throughout its "life" in the specified system, until its "death" in some terminal category (absorbtion, escape, etc.). Probability distributions for different possible processes are randomly sampled to determine the outcome at each step (interaction) of the particle's life. Different aspects of the average behavior of the particles (tallies) can be recorded as specified by the user. We used the so-called "pulse-height distribution" to monitor the detector response to $\gamma-$rays emitted by a monoenergetic source.

The absolute photopeak efficiency is defined as the ratio of the number of counts in the full-energy photopeak to the total number of gamma rays emitted from a source. This definition includes the effect of the solid angle subtended by the detector and thus the photopeak efficiency depends on the spatial extension of the source (usually negligible for standard calibration sources) and the distance between the source and the detector. Furthermore, the efficiency depends on the energy of the gamma ray. For the detector-source geometries used in the experimental setup, we determined that a source extension corresponding to a disk of radius 5 mm does not influence the photopeak efficiency by more than 1%. We used in the following tests a monoenergetic point source with isotropic distribution. No time-dependence was taken into account. We used the pulse-height distribution tally to monitor how many $\gamma-$rays fell into given energy bins, and normalized them to the total number of photons emitted by the source. Three energy bins were used: one between 0 and 10^{-2} keV in which the photons which entered the detector but did not produce any interaction were counted, one between 10^{-2} keV and the energy of the monoenergetic source minus 5 keV, in which the Compton scattered photons were counted, and one centered around the energy of the monoenergetic source and of width 10 keV. The photons with energy within $\pm$5 keV of the full peak energy were considered to belong to the photopeak, and the corresponding normalized number was equated to the photopeak efficiency. We note that a too fine binning (for example equidistant intervals of 10 keV each) tended to produce erroneous results unless a very large number of particles was tracked.

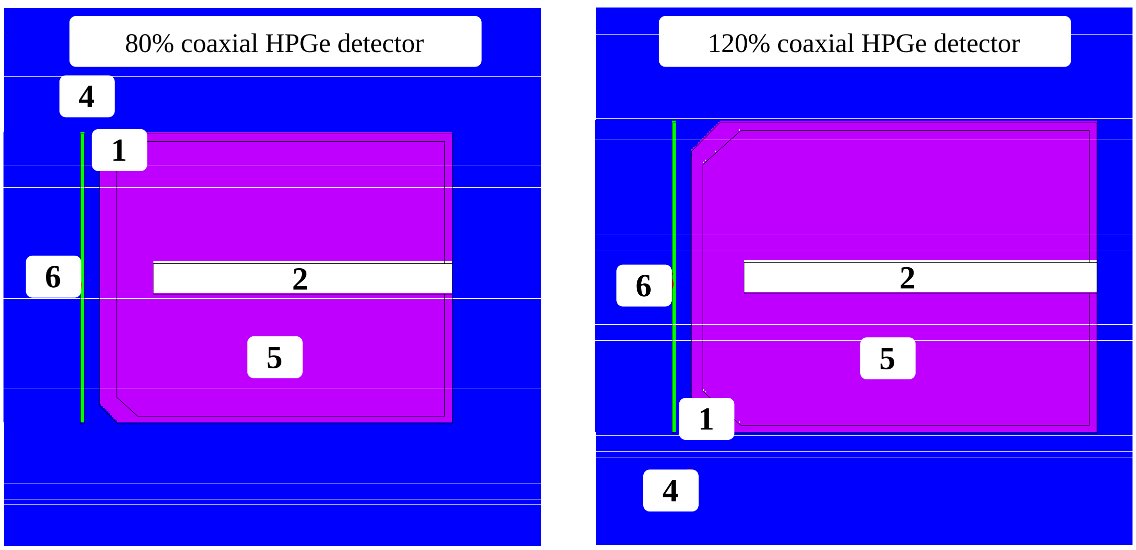

Figure 1: Geometries used in the modeling of the 80% and 120% coaxial HPGe detectors. The figures are produced with the plot option of the MCNP code. The cells shown on the figure are: 1. dead layer of Ge; 2. bore for the inner contact and cooling finger; 4. sphere of air; 5. active Ge; 6. Al cap. Cell 3 (not shown) represents the rest of the world. The dimensions are as given in Table 1.

The experimental photopeak efficiencies we aim to reproduce were deduced from data taken with a ^{228}Th source (activity 0.5 μC) and a mixed ^{154,155}Eu, ^{125}Sb source (SRM-4275C) at the foil position in the setup described in Ref. [3] (experiment 97004 at NSCL). The distance between the source and the Al end-cap was 15mm for the 80% and 45mm for the 120% Ge detector, and the same source-detector geometry has been used in the simulation. The dimensions we used for the two detectors were the ones specified in the quality assurance data sheet provided by ORTEC, as given in Table 1. The amount of material lost by cutting the corners of the detectors (bullet shape) was not specified, and the specified thickness of the dead layer on the exterior of the (p-type) detectors was taken only as a starting point. We have varied slightly the geometries to allow for different amounts of bulletization and thickness of the dead layer. The geometries which allowed for the best description of the experimental photopeak efficiency curves are shown in Fig. 1. We note that the dead layer (specification 0.7 mm for both detectors) had to be increased to 4.5mm and 3 mm for the 80% and 120% detector, respectively. The rather large thickness used for the MCNP simulation might partially be due to the effects of the inhomogenous electric field between the inner and the outer contact in the forward direction. Such effects will mostly influence the

Ge	crystal diameter	crystal length	end cap to crystal	Al layer	Inactive layer	hole diameter	hole length
80%	75.5	92.0	4	1.0	0.7	8.0	78.0
120%	80.8	105.8	4	1.0	0.7	8.0	92.0

Table 1: Dimensions of the 80% and 120% coaxial HPGe detectors, specified by ORTEC. All dimensions are in mm.

detection of low-energy gamma rays, which mainly interact with the first few cm of detector material.

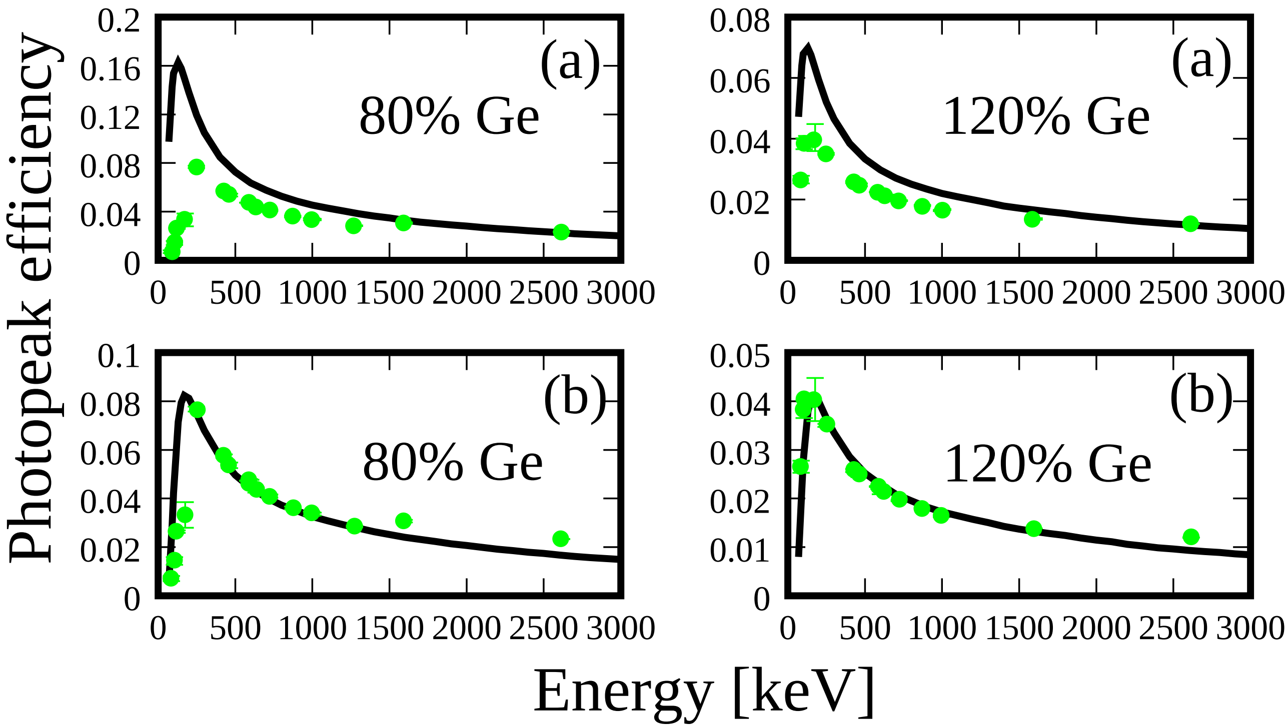

Figure 2: Experimental (filled circles) and calculated photopeak efficiencies from MCNP (solid line) for the 80% and 120% coaxial HPGe detectors. The distances end cap – source are 15mm for the 80% and 45mm for the 120% Ge detector. (a) A simple geometry (cylinder with a bore and thin Ge dead layer) has been considered for the two detectors. (b) A more realistic geometry including a bullet shape and a thicker dead layer substantially improves the agreement with the experimental data.

In order to illustrate the above point, we show in Fig. 2 (a) the calculated efficiencies compared to the experimental ones, using a simple geometry for the computer simulation. In this approach, each Ge detector was described as a cylinder with a bore (both of actual dimensions) and a dead layer of 0.7mm at the external surface. The large discrepancy at low energies might indicate that too little absorbing material is present at the front of the detector in the simulation. As mentioned, the reduced experimental efficiency at low energies could also be the effect of field inhomogenities. Nevertheless, the discrepancy is still present at higher energies, showing that the active area of the detector, as considered in the MCNP simulation, is too large. We therefore corrected the geometry both by increasing the thickness of the dead layer in the front of the detector, and by cutting the edges with a right cone placed in front of the detector at a distance roughly given by d=r-3mm (r is the radius of the detector in mm). The experimental and calculated (MCNP) photopeak efficiencies using the improved geometry are shown in Fig. 2 (b). For each of the simulated points we used a monoenergetic isotropic source of the corresponding energy and followed 500000 photons emitted by the source. The error bars due to the convergence of the calculation are in the range of 2% or smaller. No systematic errors are included.

The overall agreement with the data when we use the more realistic geometry is good, and clearly proves the applicability of the method. The MCNP approach fully accounts for the main features of the efficiency curves, and the agreement might be further improved by taking into account all the different materials present in the experimental setup (for example, Al cup, cryostat, etc). Once the simple detectors have been fully understood, we will use the MCNP simulation to the study of the more complex clover detectors. Since the radioactive beam used in the experiment [1] was implanted in a double-sided silicon strip detector and illuminated most of the full 4cm x 4cm surface, we also have to develop a more realistic description of the extended source.

References

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