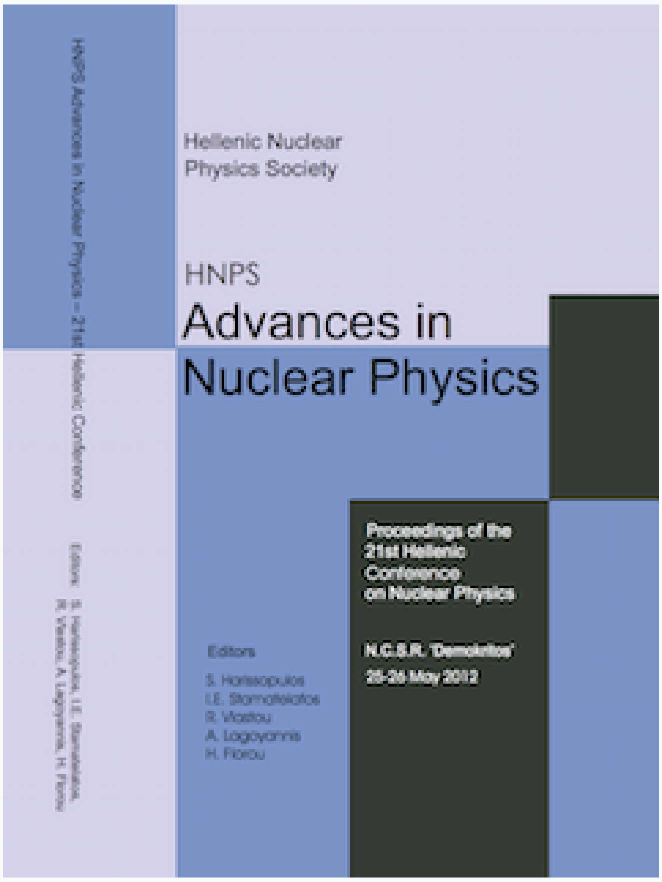
Annual Symposium of the Hellenic Nuclear Physics Society

Τόμ. 20 (2012)

HNPS2012



Monte Carlo MCNP modeling of a HPGe detector and its efficiency for extended sample geometry

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doi: 10.12681/hnps.2498

Monte Carlo MCNP modeling of a HPGe detector and its efficiency for extended sample geometry

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Abstract

The activity of an extended ^{241}Am sample with complex shielding and geometry has been measured by an 80% HPGe detector, after its irradiation by a neutron beam at 10.4 MeV, in order to determine the cross section of the reaction ^{241}Am(n,2n)^{240}Am. Due to the complexity of sample's geometry, the estimation of the detector's efficiency has been achieved by MCNP5 Monte Carlo simulations. The simulations have been gradually evolved in order to define the detector model, the experimental setup geometry (geometry definition), the sample's density and finally the detector's efficiency for the irradiated ^{241}Am sample.

1. Introduction

The absolute detection efficiency of HPGe detectors in gamma-ray spectroscopy is of particular importance for cross section measurements. In the cases of samples of various types with extended geometry, the determination of detection efficiency using Monte Carlo techniques is inevitable, since calibration sources cannot be produced for all types of samples. In order to achieve accurate results, the effect of precise modeling of the detector itself is of vital importance and can be verified by comparing the simulations with experimental results taken with calibration sources. More precisely, the effect of the detector design and geometry as well as the rounded edges and the dead layer of the Ge crystal, has been investigated [1-3] and found to considerably affect the results. The dead layer at the Ge surface can act not only as an absorber for the gamma rays but also as an inactive part which reduces the active volume of the detector. The various unknown parameters can be optimized by reproducing point source efficiencies and then used to simulate detection efficiencies for other more complex geometries [4,5].

2. The Experimental Problem

In the present work, in order to measure the cross section of the ^{241}Am(n,2n)^{240}Am reaction, the induced activity of an extended ^{241}Am sample with complex shielding and geometry has been measured by an 80% HPGe detector, after its irradiation by a neutron beam at 10.4 MeV. The irradiation with a neutron beam of the ^{241}Am sample was carried out at the tandem accelerator laboratory at NCSR "Demokritos" and lasted for about 3 days. The ^{241}Am sample has been constructed at JRC-IRMM by infiltration of AmO_2 into an Al_2O_3 pellet placed in an Al capsule and covered with a

3mm Pb cylindrical box to shield its high activity 5.11 GBq. A schematic representation of the Am target assembly is shown in Fig. 1.

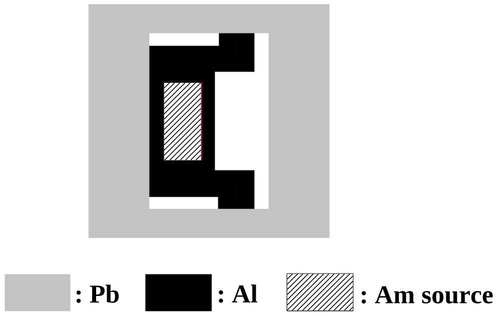

Fig. 1. Schematic diagram of the Am target assembly

The produced nucleus ^{240}Am decays to ^{240}Pu with a half life of 50.8 h, emitting a characteristic gamma ray at 987.8 keV. The results from the analysis of this gamma ray in the spectrum acquired by the HPGe detector, were used for the extraction of the cross section for the ^{241}Am(n,2n)^{240}Am reaction. Another important parameter for the cross section determination is the efficiency of the HPGe detector under the specific geometry including the irradiated ^{241}Am target assembly placed at a distance of about 11cm from the detector window. Since a calibration source with the same complex geometry is not available, the Monte Carlo simulation technique has been used for the determination of the detection efficiency, which also includes the effect of self absorption of the 987.8keV gamma ray in the actual target assembly.

3. MCNP5 Monte Carlo Simulations

As reported in the literature, there is often a mismatch between the simulated and experimental efficiencies because of the sensitivity of the Monte Carlo calculations to the detector geometry specifications. The dimensions provided by the manufacturer correspond to the time of assembly of the detection system at room temperature but there can be changes in the mechanical support of the crystal due to contractions at low temperature. Therefore, there can be uncertainty in various parameters such as the dead layer thickness, the Ge crystal's distance from window etc. In the present work, the MCNP5 code [6] has been used to simulate the HPGe detector response, as will be described bellow.

3.1 Detector Model

The detector used for the measurements is a coaxial one with 80% relative efficiency (Canberra, Model GC8023) and in order to define its geometry, the following procedure has been used. A gamma ray spectrum has been measured for a point ^{152}Eu source (1.23 μCi), which emits gamma rays in a wide energy range, placed at a distance of 11.1 cm from the detector's window. Thereafter, the most intense gamma rays from the ^{152}Eu have been simulated with the MCNP code and the detector’s efficiency has been calculated for every single gamma-ray energy according to the results from MCNP. For MCNP runs, the gamma rays emitted by the ^{152}Eu source have been simulated one by one with 100% intensity and for 10^7 events. In the final results, the correction factors for the real gamma ray intensities have been taken into account, along with the live time of the experimental spectrum and the activity of the

^{152}Eu source. Then, the simulated results have been compared to the experimental ones to optimize the various parameters, while the ^{152}Eu spectrum analysis has been performed by using the SPECTRW software [7].
The detector model has been developed in steps, in order to check the effect of various parameters of the Ge crystal, such as: front dead layer (front DL), side dead layer (side DL), back dead layer (back DL), rounded front edges, crystal's diameter, crystal's length, hole's area and distance from window. The parameters provided by the manufacturer are presented in Table 1, while the dead layer thickness has been defined 1.2 mm for the front DL, 0.6 mm for the side DL and 0.8 mm for the back DL. The Ge crystal's rounded front edges have been modeled using a 1 mm thickness truncated cone. The final model for the HPGe detector (presented in Fig. 2) resulted in good agreement between experimental and simulated detector's efficiency, as shown in Fig. 3.

Description	Nominal value (mm)	Optimized value (mm)
Crystal diameter	74	73
Crystal length	71	70
Distance from window	5	5

Table. 1. Detector parameters provided by the manufacturer and optimized by MCNP simulations

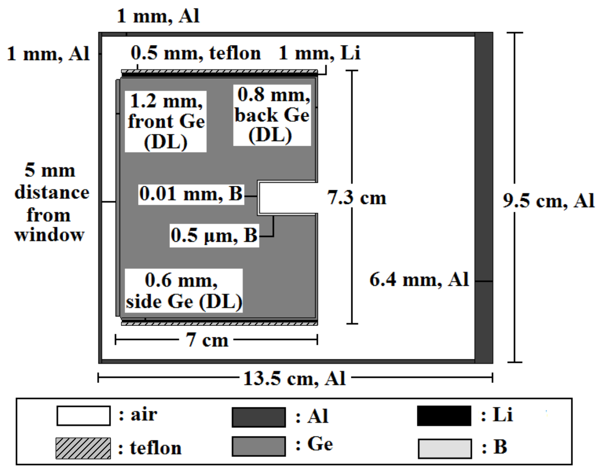

Fig. 2. Schematic diagram of the HPGe detector model

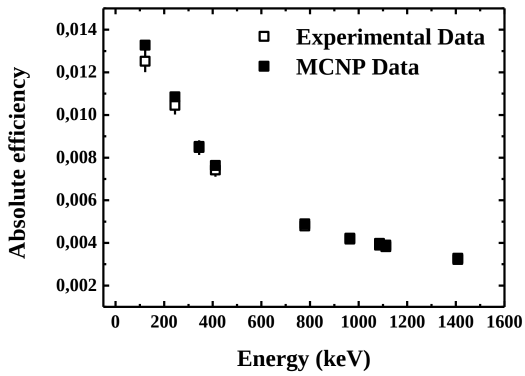

Fig. 3. The experimental results for the detector's efficiency in comparison with the results from MCNP for a point ^{152}Eu source at a distance of 11.1 cm from the detector's window

3.2 Sample Geometry Definition

In order to define the Pb shielding geometry of the Am sample, the experimental efficiency of the detector with the point ^{152}Eu source placed behind the Pb shielding, has been compared with MCNP simulations.

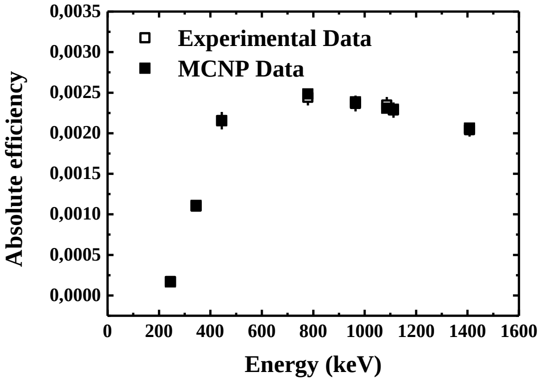

Fig. 4. The experimental results for the detector's efficiency in comparison with the results from MCNP for a point ^{152}Eu source behind the Pb shielding

Then, in order to define the Al capsule's geometry, another simulated efficiency has been compared to the experimental efficiency obtained with the ^{152}Eu source placed behind the Pb shielding, in which the Al container filled with Al_2O_3 compressed powder was enclosed (see Fig. 1).

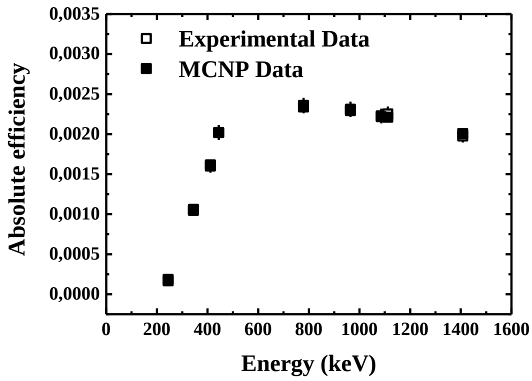

Fig. 5. The experimental results for the detector's efficiency in comparison with the results from MCNP for a point ^{152}Eu source behind the Pb shielding in which the Al container filled with Al_2O_3 compressed powder is enclosed

The simulated results in Figs 4 and 5 are in good agreement with the experimental ones within 6%, thus verifying that the geometry parameters of the target assembly have been optimized and can be safely used for further simulations.

3.2 Am sample's density

The only parameter that remains to be confirmed is the Am sample's density. For this purpose the ^{241}Am natural radioactivity was measured before its irradiation, and compared to the MCNP simulations (shown in Table 2), by fixing the sample's density. The nominal value of the Am sample's density $\rho = 1.716$ g/cm^3 has been tried and finally used since the simulated results agree very well with the experimental ones.

Energy of the photopeak (keV)	Counts in the experimental spectrum	Counts from MCNP simulation	Percentage difference (%)
332.36	3621000	3518600	2.83
335.38	11941400	11872800	0.57
368.59	5758700	5816250	-1.00
376.65	3790400	3779050	0.30
619.01	1753800	1794100	-2.30
688.72	904200	874800	3.25
722.01	5479300	5779300	-5.48

Table 2. The experimental results for the detector's efficiency in comparison with the results from MCNP for the ^{241}Am target assembly.

3.3 Detector's efficiency

Since all the initially unknown parameters have been fixed with MCNP simulations, it has become possible to estimate the detector's efficiency for the actual experimental setup, for every photon energy of interest. Thus the efficiency of the system for the detection of the 987.8 keV transition, arising from the deexcitation of ^{240}Am, has been accurately determined $(3.15 \pm 0.13) \times 10^{-3}$ and subsequently used to define the cross section of the ^{241}Am(n,2n)^{240}Am reaction, implementing the neutron activation method.

4. Summary

The motivation for the simulations presented in this work, is the experimental determination of the ^{241}Am(n,2n)^{240}Am reaction cross section at the tandem accelerator laboratory of NCSR "Demokritos". An extended ^{241}Am sample with complex shielding and geometry has been irradiated by a neutron beam at 10.4 MeV for about 3 days and the induced activity has been measured by an 80% HPGe detector. For the cross section determination the self absorption effect and the efficiency of the HPGe detector under the specific geometry including the irradiated ^{241}Am target assembly placed at a distance of about 11cm from the detector window, have to be determined. For this purpose, Monte Carlo simulation technique with the code MCNP5 has been used and all the parameters involved in the actual measurement have been tested and fixed by comparing the simulated spectra to the experimental ones taken with a point ^{152}Eu source as well as with ^{241}Am sample itself. The implemented methodology has been proved to be successful in cases of gamma ray spectroscopy where calibration sources are not available at the same dimensions and complex geometry as the actual sample under investigation.

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