Romanian Reports in Physics, Vol. 67, No. 2, P. 460–464, 2015

ATOMIC AND NUCLEAR PHYSICS

MONTE CARLO SIMULATIONS FOR THE EFFICIENCY OF TWO HPGE DETECTORS IN CLOSE GEOMETRY

A. OLACEL[1,2], C. BORCEA[1], A. NEGRET[1], O. SIMA[2]

[1]Horia Hulubei National Institute for Physics and Nuclear Engineering, Reactorului 30, 077125, Bucharest-Măgurele, Romania
E-mail: aolacel@tandem.nipne.ro
[2]University of Bucharest, Faculty of Physics, Atomistilor 405, 077125, Bucharest-Măgurele, Romania

Received July 4, 2013

Abstract. An activation measurement was recently performed at the TANDEM accelerator of Horia Hulubei National Institute for Physics and Nuclear Engineering in order to determine subbarrier cross sections for the fusion of ^{6}Li and ^{194}Pt. The irradiated targets were measured using two HPGe detectors in very close geometry. Extensive Monte Carlo simulations were performed for the determination of the efficiency of the setup. MCNP5 [1] was employed to interpolate and extrapolate the experimental efficiencies at the gamma energies of interest while GESPECOR [2] was used to determine the summing correction factors. We describe in detail the two simulations of the setup and give examples of simulated and experimental efficiencies with and without summing corrections.

Key words: Monte Carlo methode, efficiency simulations, close geometry.

PACS: 29.85.Fj, 29.30.Kv

1. INTRODUCTION

Recently, reactions with slightly bound projectiles that have a pronounced cluster structure were intensively studied. These nuclei behave differently from stable solidly bound nuclei. When approaching another nucleus it is possible that the Coulomb field becomes strong enough to break them apart and in this case we have to account for the complex interaction of at least three nuclei [3]. The result can be a classical complete fusion but also an incomplete fusion with only a part of the projectile nucleus.

The experiment for which we determined the efficiency was conducted at the TANDEM accelerator operated by the Department of Nuclear Physics of the Horia Hulubei National Institute for Physics and Nuclear Engineering.

For the determination of the detection efficiency we used Monte Carlo simulations. MCNP5 [1] software was used for the interpolation/extrapolation of the experimental efficiency obtained with a ^{152}Eu source, and for the determination of the summing correction factors we used the GESPECOR code [2].

2. EXPERIMENTAL SETUP

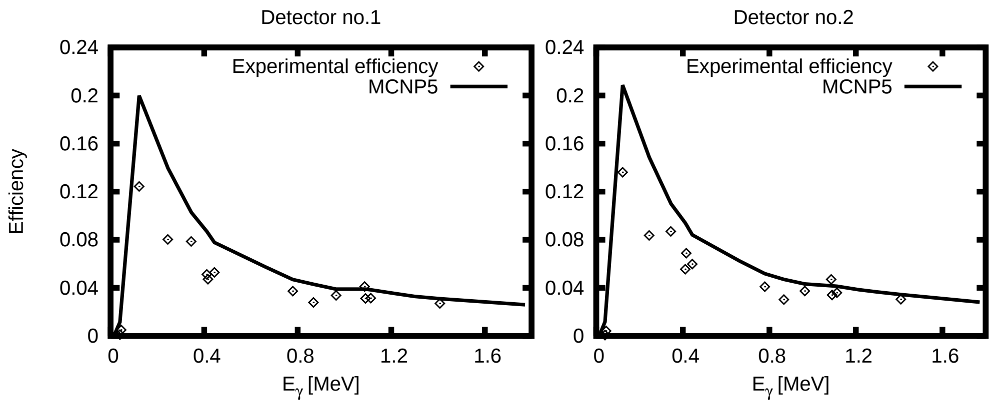

Fig. 1 – The comparison between the MCNP5 simulated and the experimental efficiency; the experimental calculated efficiencies are represented by symbols while the MCNP5 simulated efficiencies are represented by solid lines

An activation experiment took place at the TANDEM accelerator. The experimental goal was to measure the fusion evaporation cross section for ^{6}Li on ^{194}Pt with the aim of comparing the results with those obtained using a ^{6}He projectile [4]. 6 targets of ^{194}Pt were irradiated at incident energies ranging from 22 to 33 MeV with a beam of ^{6}Li for 2-4 hours depending on the lifetime of the nuclide of interest. The current was integrated with a Faraday cup. To detect the gamma rays we used 2 face-to-face HPGe detectors with 0.5 cm distance between them and 50% relative efficiency. The detectors were shielded with 0.3 cm Al, 0.3 cm Cu and 10 cm Pb to decrease the background level. The natural background counting rate decreased from 300 counts/s to 40 counts/s due to the shielding. For the acquisition system we used TNT2 digitizers running at 100 MHz which are flash analog to digital converters that record samples of the input signal with a high repetition rate and transfer them for signal processing [5]. In order to determine the detection efficiency an ^{152}Eu calibration source was used. The ^{152}Eu spectrum was analyzed, the peaks were integrated, and the experimental efficiency was computed as:

$$\epsilon = \frac{R}{\Lambda * I} = \frac{\frac{A}{t}}{\Lambda * I} = \frac{A}{t * \Lambda * I}$$

where R represents the counting rate, A the peak area, t is the acquisition time, Λ the activity of the source and I the intensity of the γ rays.

The symbols in Fig. 1 are the experimental results. One notes that the experimental points are affected by coincidence summing effects.

3. MCNP5 SIMULATION

The MCNP5 simulations were performed in order to understand the setup, and then to extrapolate/interpolate the experimental efficiency at energies of interest.

MCNP is a general-purpose Monte Carlo N-Particle code used for photon, neutron, electron, or coupled photon/neutron/electron transport. For photons, the code accounts for coherent and incoherent scattering, the possibility of fluorescent emission after photoelectric absorption, and absorption in electron-positron pair production. The photon energy regime is from 1 keV to 100 GeV [1]. To determine the efficiency, using the MCNP5 software, we built the experimental geometry using the data from Table 1.

In Fig. 1 the results of the MCNP5 simulation are displayed with solid lines. The overlap between the simulated and experimental efficiency is poor because our MCNP5 simulation disregards the coincidence summing effects.

4. GESPECOR SIMULATIONS

GESPECOR simulations were performed to determine the coincidence summing correction factors and calculate the real experimental efficiency. The coincidence summing effects occur in the case when the nuclides decay through emission of fast cascading radiations and are peak dependent. Ref. [2] presents a complete description of the computation of coincidence summing correction factors by GESPECOR.

The initial purpose of GESPECOR was to provide a set of procedures for the computation of self-attenuation and of coincidence-summing corrections required in gamma-ray spectrometry with germanium detectors. Now, GESPECOR is used for the determination of the self-attenuation corrections, the coincidence-summing corrections, the full energy peak efficiency and the total efficiency. In order to determine the summing correction factors we build a model of the geometry of the detectors and source, accounting for the composition of the source and the levels scheme of ^{152}Eu. Table 2 displays the simulated correction factors with the uncertainties. The simulated corrections factors were applied to the experimental points in order to calculate the experimental efficiencies. The comparison between these new calculated efficiencies and the MCNP5 simulated efficiencies is displayed in Fig. 2.

Table 1

The elements of the detectors geometry used as input in MCNP5 simulations

Elements	Detector 1	Detector 2
distances from the origin to the det. cap (cm)	0.25	0.25
angle of the axis of detector and ox (beam) (degrees)	180	0
angle of the axis of detector and oy (horiz) (degrees)	90	90
angle of the axis of detector and oz (vertical) (degrees)	90	90
radius of the well (cm)	0.465	0.44
radius of the crystal (cm)	3.175	3.295
thickness of the region between end cap crystal and the well (cm)	1.34	1.34
front gap between Al cap and crystal (cm)	0.4	0.4
length of the crystal (cm)	8.35	7.35
length of the cap (cm)	11	11
front of detector crystal dead layer (cm)	0.07	0.07
front external corner dead layer (cm)	0.07	0.07
dead layer at the bottom of well (cm)	0	0
inside (well) corner dead layer (cm)	0	0
end plane of the crystal dead layer (cm)	0	0
external dead layer of the crystal (cm)	0.07	0.07
dead layer on the wall of the well (cm)	0.5	0.5
front cap thickness (cm)	0.1	0.1
cap external radius (cm)	4.375	4.375
cap internal radius (cm)	4.275	4.275
crystal front edge rounding passage to cylinder (cm)	0.8	0.8
crystal bottom of well passage to cylinder (cm)	0.5	0.5
absorber thickness (cm)	0	0

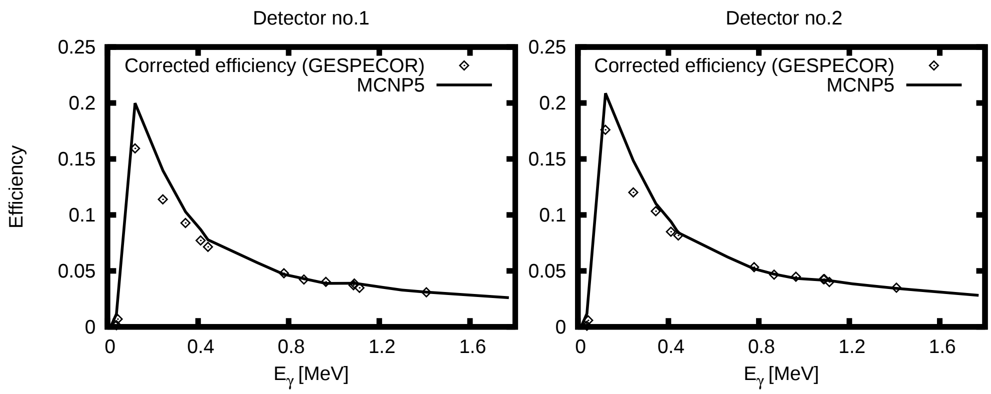

Fig. 2 – The comparison between the MCNP5 simulated and the new experimental efficiency.

Table 2

The simulated correction factors for each energy of interest and the uncertainties.

Energy	F_c Det. 1	Uncertainty (%)	F_c Det. 2	Uncertainty (%)
39.91	0.5856	0.017	0.7173	0.11
45.70	0.7250	0.016	0.7169	0.070
121.78	0.7799	0.004	0.7731	0.044
244.70	0.7040	0.026	0.6961	0.10
344.28	0.8477	0.035	0.8420	0.086
411.12	0.6642	0.035	0.6538	0.14
443.96	0.7403	0.024	0.7321	0.13
778.90	0.7780	0.074	0.7686	0.18
867.38	0.6583	0.039	0.6495	0.13
964.08	0.8409	0.074	0.8368	0.19
1085.84	1.1050	0.034	0.1105	0.31
1089.74	0.8053	0.045	0.7993	0.22
1112.08	0.9005	0.069	0.8981	0.19
1408.01	0.8750	0.088	0.8716	0.18

5. CONCLUSIONS

For the activation experiment of ^{194}Pt with ^{6}Li we determined the HPGe detectors efficiency in close geometry using MCNP5 and GESPECOR. Because of the small distance between the detectors, coincidence summing effects are significant.

MCNP5 was used to simulate the efficiency so we can validate the model, in order to do the interpolation/extrapolation of the experimental efficiency obtained with the ^{152}Eu source.

The summing correction factors were obtained with GESPECOR software and were applied to the experimental points.

The real efficiencies, corrected for summing effects were determined for the ^{152}Eu source.

Acknowledgements. This work was supported by the Romanian Ministry of Education through Contract number PN-II-ID-PCE-2011-3-0370 (UEFISCDI).

REFERENCES

1. https://laws.lanl.gov/vhosts/mcnp.lanl.gov/index.shtml.
2. O. Sima, D. Arnold, C. Dovlete, Journal of Radioanalytical and Nuclear Chemistry **248**, 359–364 (2001).
3. Yu. E. Penionzhkevich *et al.*, Phys. Rev. Lett. **96**, 162701 (2006).
4. N. K. Skobelev *et al.*, Physics of Particles and Nuclei Letters **10**, 248–255 (2013).
5. E. Arnold *et al.*, IEEE Transactions on Nuclear Science **53**, 723–728 (2006).