EFFICIENCY EVALUATION OF A HIGH RESOLUTION, LOW BACKGROUND GAMMA SPECTROMETER WITH GEANT4

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În lucrare prezentăm câteva rezultate privind evaluarea eficienţei la fotopic a unui spectrometru gama de mare rezoluţie, bazat pe un detector de GeHP ce lucrează în anticoincidenţă cu un sistem de monitorizare cu un scintilator. Folosind un model simplificat şi o simulare in Geant4, am evaluat eficacitatea sistemului pentru surse punctuale şi de volum, pentru energii de la 0,2MeV la 2,0MeV.

We present some results on photopeak efficiency evaluation of a high resolution gamma spectrometer for gamma detection based on an HPGe detector working in anticoincidence with a scintillator gamma monitoring system. Using a simplified model and a Geant4 simulation, we have evaluated the efficiency of the system for point and volume sources, for incident gamma energy from 0.2MeV to 2.0MeV.

Keywords: efficiency, Monte-Carlo simulation, Geant4, gamma detector.

1. Introduction

Active shielding in the low-background gamma spectrometry is a strongly developing technique in the last decade [1]. An “ideal” low background, high resolution, high efficiency HPGe (hiperpur germanium) spectrometer would completely embed the gamma source (as in a deep “well” detector) inside the Ge crystal which is surrounded close to a 4π geometry by a scintillator crystal [2], the so-called “anticompton” (AC) detector. By operating the HPGe and AC detectors in a fast anticoincidence regime (tens of nanoseconds time resolution) can be obtained a significant reduction of the Compton background in the high resolution spectra [3]. Commercially available scintillation crystals cover more than 80% of the 4π solid angle and are made from materials as NaI(Tl) and BGO [4]. The specific problems of such systems, related with the summing peaks [5] can be nowadays overcomed by employing of the digital techniques of the pulse shape analysis [6].

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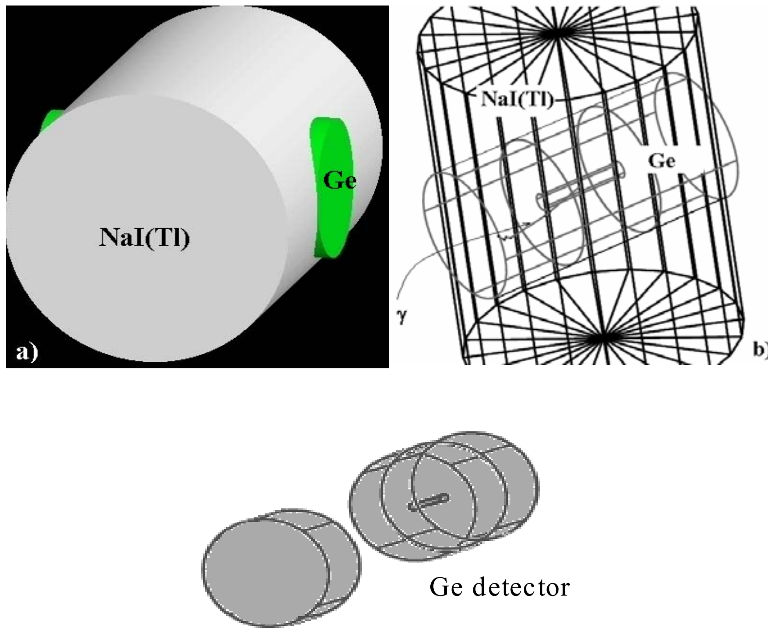
Low activity radioactive sources, suitable to be measured by such spectrometers are generally volumic sources (environment or biological samples). Therefore the process of efficiency calibration is strongly relying on the numerical simulations [7]. It is the goal of this work to presents a preliminary evaluation of the photopeak efficiency of such a detection system based on a NaI(Tl) AC detector by using a Monte Carlo method. The passage of the particles through the matter was performed with a widely used simulation package Geant4[8]. Developed by RD44 project (with first production release in 1998), Geant4 is a « toolkit » based on object-oriented methodology and C++ language, with high modularity and flexibility properties. The user has full freedom to develop an own simulation program. He must implement several mandatory classes to describe the detector geometry, the primary particle generator and a class to describe the relevant particles and physics processes. Other non-mandatory classes must be created to resolve proper objectives. Created for applications in High Energy Physics (HEP), the toolkit has been used also in other fields, as in applications in space engineering and medical physics.

2. Monte Carlo simulation

2.1. Geometry of the system

The gamma-ray detector is made of a Ge cylinder with a central cylindrical cavity, where is positioned the gamma source. The Ge detector is surrounded by a NaI(Tl) cylindrical scintillator crystal with photomultipliers attached. As can see in figure 1, the Ge cylinder is oriented perpendicular on the scintillator cylinder long length[3]. The detection system of germanium crystal works in anticoincidence with photomultipliers, trying to eliminate a part of Compton electrons generated by gamma rays which are not absorbed by photoelectric effect in germanium.

[3] Dimensions used in simulation : radius of NaI cylinder = 75mm, length of NaI cylinder = 200mm, Ge cylinder radius = 35mm, Ge cylinder length = 150mm, length source cylinder = 50mm, source cylinder radius = 2.5mm.



c)

Fig. 1. Detector geometry: a) Ray Tracer image of the detector system; b) Volumes created in CSG representation with one gamma event; c) Detail of HPGe sensor.

The geometry was built in *DetectorConstruction* class using CSG (Constructive Solid Geometry) by assembling some solid Tubes, also using Boolean subtraction. For materials definition we have used the Geant4 material database.

2.2. Method for efficiency evaluation

Photopeak efficiency was calculated as ratio between the number of detected photons which were absorbed in germanium by photoelectric effect and the number of photons emitted from the source,

$$\varepsilon = \frac{N_d^f}{N_0} , \tag{1}$$

where N_d^f represents the number of photons absorbed in germanium by photoelectric effect and were registered, N_0 is the total number of photons emitted from source.

We suppose that detection efficiency for charges generated in germanium is 1, so that N_d^f will be the difference between the number of photons absorbed by photoelectric effect in germanium and the number of pulses from scintillator which eliminate by anticoincidence photons registered in germanium, $N_d^f = N^f - N_{NaI}^f$. The number of pulses from scintilator which eliminate photons registered in germanium, N_{NaI}^f, was approximate evaluated with the supposition that pulses are distributed uniforms in time. If N_{NaI} is the total number of pulses in scintillator, N^C is the number of Compton electrons created in germanium, and N^f is the number of photoelectrons created in germanium, then

$$N_{NaI}^f = \frac{N_{NaI}}{N^C + N^f} N^f \ . \tag{2}$$

The photopeak efficiency will be

$$\varepsilon = \left(1 - \eta \frac{N_{NaI}}{N^C + N^f}\right) \frac{N^f}{N_0} \ , \tag{3}$$

where η is scintillator efficiency to convert gamma-ray interactions in registered pulses.

2.3. Program implementation

We have written ten user classes: three user mandatory classes and some user action classes. Physics processes defined in *PhysicsList* are low-energy electromagnetic processes with valid energy range down to 250eV. This variant is based on the use of experimental data parameterizations using databases developed by Lawrence Livermore National Laboratory: EPDL97 (Evaluated Photon Data Library), EEDL (Evaluated Electron Data Library) and EADL (Evaluated Atomic Data Library) [9]. Photon interactions include photoelectric effect, Compton scattering, pair production, Rayleigh scattering, and electrons interactions include bremsstrahlung, multiple scattering and ionization. Atomic effects after photoelectric effect, as X-rays emission and Auger effect are included. So it is possible to have a vertex from photoelectric effect as in figure 2.

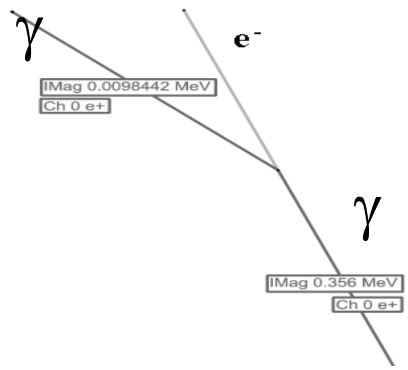


Fig. 2. Vertex resulted from photoelectric effect with primary photon. Secondary photon results from atomic desexcitation. We must do not count photoelectric absorption of this secondary photon.

We have defined two *Sensitive Detector* classes, one for germanium detector and one for NaI scintillator. Registration of interesting processes is made in *SteppingAction* class. For germanium, all electrons generated by photoelectric and Compton processes will be registered. For NaI scintillator we have applied two methods: for gamma-ray with first interaction in scintillator we have applied overall intrinsic efficiency η or we have used this efficiency from an empirical curve. In *RunAction* class we have implemented our simplified algorithm for computing efficiency.

3. Results

We have obtained the efficiency curve for an isotropically point source, placed in the centre of the cylinders (100,000events), and for an isotropically volume source, placed in the small central source cylinder (500,000events), for energy between 0.2MeV and 2.0MeV.

Figure 3 presents simulated photopeak efficiency for a point source using various values for scintillator intrinsic efficiency η (equation (3)). We can see a difference of about 30% between the value without NaI anticoincidence and 100% intrinsic detection efficiency for anticoincidence scintillator, at gamma-ray energy of 2.0MeV.

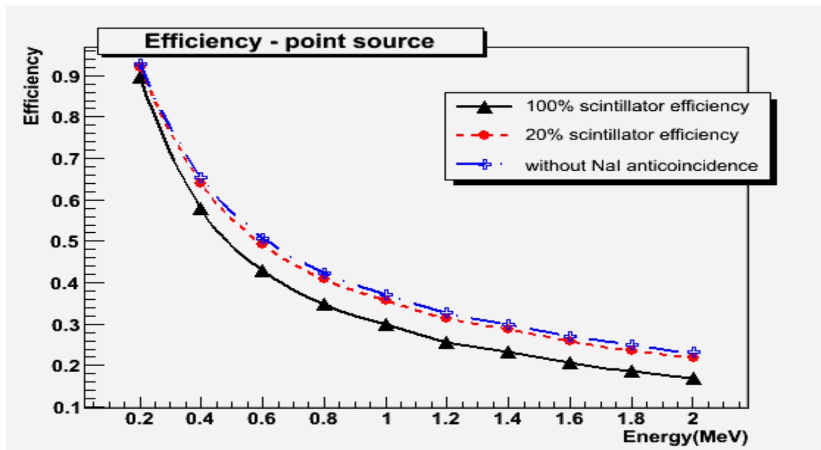


Fig. 3. Efficiency for gamma point source applying various NaI scintillator intrinsic detection efficiencies.

In fig. 4 is shown the efficiency of our system for an isotropically volume source.

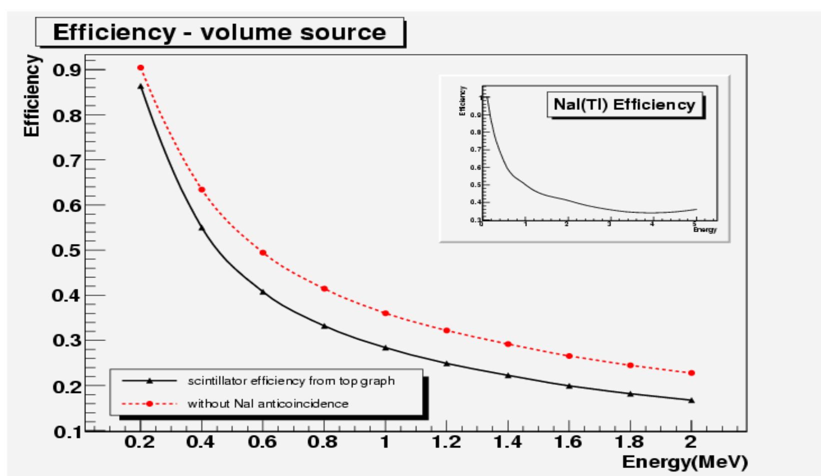


Fig. 4. Efficiency for a volume gamma-ray source with intrinsic detection efficiency of NaI scintilator folded up from top right plot, and without NaI anticoincidence.

Fig. 5 presents dependence of $\ln\varepsilon$ calculated for germanium detector, without anticoincidence from scintillator, as function of $\ln E_\gamma$ (gamma energy in keV), as in [10].

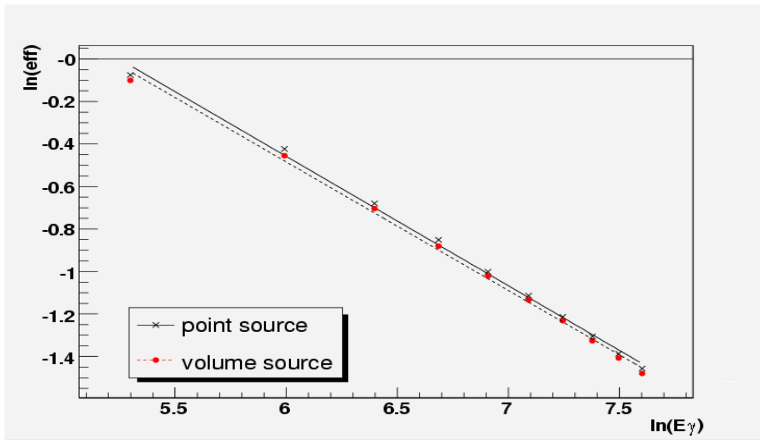


Fig. 5. $\ln \varepsilon$ versus $\ln E_\gamma$ (gamma energy in keV) counting only photoelectrons generated in Ge.

Fitting the points with the line

$$\ln \varepsilon = a_0 + a_1 \ln E_\gamma \quad , \tag{4}$$

we obtain the slope $a_1 = -0{,}609$ for point source ($a_1 = -0{,}605$ for volume source), and the intercept $a_0 = 3.19$ ($a_0 = 3.15$ for volume source).

6. Conclusions

We have obtained the efficiency curve of a 4π HPGe spectrometer for point and volume sources, for gamma-ray energies between 0.2MeV and 2MeV in the frame of a simplified model in order to account for anticoincidence events from NaI monitoring scintillator.

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REFERENCES

[1] *Jong In Bynn et al.,* Appl. Rad. And Isotopes, **vol 58**, 5, 579, 2003
[2] *P. Theodorsson* Measurement of Weak Radioactivity, World Scientific Co. 1996
[3] *G. Gilmore,* Practical Gamma-ray Spectroscopy, Wiley Inc., New York 2008
[4] *R. Nevotny,* Nucl. Instr. And Meth., **A537**, 1-2, 2005, 1
[5] *G. Knoll*, Radiation Detection and Measurement, Wiley Inc., New York 1989
[6] *J. Walter et al.,* Nucl. Instr. And Meth., **A545,** 3, 776, 2005
[7] *A. Andrasi et al.*, Radiat. Prot. Dosimetry, **125,** 456, 2007

[8] *S. Agostineli, et al.,* Nucl. Instr. and Meth. , **A 506,** 250, 2003
[9] *Geant4-UserGuide,* Physics Reference Manual, capIII, December 2007
[10] *S. Kamboj*, *B. Kahn*, Radiation Measurements, v**37**, 1, 2003.