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Study of Zone Importance for γ-Rays in Germanium Detectors by Monte Carlo Simulation

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Abstract: A computer simulation code based on the Monte Carlo method has been developed to study the response of a cylindrical germanium detector to incident gamma rays of various energies as a function of depth along the detector axis. The code first generates a reference spectrum for the whole volume of the detector. The detector is then sliced into a series of cylindrical cells. The contribution of each individual cell is evaluated by comparing the reference spectrum with the spectrum generated from the detector's response function that excludes the contribution of the cell being considered. When the difference between these two spectra is plotted as a function of depth along the detector axis, a curve is obtained that shows how the importance of a given cell varies as a function of its position in the detector volume. Such a curve has a maximum that is deeper inside the detector volume and is more pronounced for higher energies. Moreover, the results of this study indicate that the relative importance of the response function of each cell is determined by the full energy peak, while the compton continuum has little effect on it.

Key words: Monte Carlo, spectrum, detector response, transport, zone importance

INTRODUCTION

Simulation based on Monte Carlo[1,2] algorithms provides a powerful tool to investigate most complex radiation measurement systems and allows the prediction of their responses. More than that, the method can achieve results that are beyond the reach of experimentation. It is essential that measurement applications, especially those complex ones, be accompanied by computational design tool to perform the necessary analysis and calibrations. One goal of this study is to show that Monte Carlo method, when properly used, offers the necessary means to do an analysis of the spectrum importance associated with different zones of a solid detector.

Now a days, with the development of computers capabilities, Monte Carlo is becoming affordable on small computers. It is therefore possible to tailor codes, based on the method, that can simulate the physics of radiation-matter interactions using microscopic data.

Typical Monte Carlo codes used in radiation transport have a modular structure[3]. Each module describes a particular aspect of the problem, such as geometry and tracking of the particle history through different zones, particle-collision physics, detector's response function, variance reduction, *etc.*

In our code the microscopic data pertinent to the problem beforehand has been used in its form provided by the XCOM[4] library.

In this study, Monte Carlo method has been used to simulate the detector response to a gamma ray source. It is understood that the spectrum obtained is a global contribution of the detector as a whole unit. Evaluation of the detailed contribution of each cell of the detector gives more insight to knowing the most sensitive part of detectors. The challenge is thus to assign the proper importance weight to each zone. Perturbed and unperturbed detector responses are determined and used to model zone importance.

MATERIALS AND METHODS

Model: The model consists into imagining a solid detector made up of a set of cells. These cells are fictive, their borders do not exist really. In practice, a zone is defined by its boundaries which are represented by two parallel planes chosen to be perpendicular to the z-axis which coincides with the cylindrical detector axis. Hence the detector can be viewed as a collection of non interfering cells. As far as the detector response is concerned, each cell contributes, therefore has a weight which means a spectral importance. The question to be addressed is as

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follows: will all the cells contribute equally? To evaluate the contribution or the importance of a zone, one would set a Monte Carlo experiment in which the detector response is determined while ignoring the contribution of the considered zone. That is one performs a perturbation by neutralizing a zone within the detector active zone and look at its effect by calculating a perturbed spectrum. The approach adopted is as follows:

On one hand, we run a numerical experiment for each zone. The obtained detector response is seen as the contribution of the entire active zone except the one cell that is being neutralized in the sense that the deposited energy, by the photon and it's by-products in that part of the detector, is not included in the determination of the final spectrum. The dimensions of the neutralized zone should be chosen as small as possible bearing in mind the fact that the use of a too small cell thickness would result into erroneous statistics. Moreover the number of numerical experiments will increase as the inverse of the cell thickness and so is the computing time.

On the other hand, for a given source and a series of numerical experiments associated with different neutral zones, a reference spectrum is calculated, that means the determination of the detector response without any neutral zone being considered. The difference between the non perturbed spectrum and the perturbed one could be seen as the contribution of the cell to the total spectrum. This would set a basis for the importance characterization of each detector cell.

RESULTS AND DISCUSSION

In order to carry out the evaluation of the detector zone importance, a specific-purpose Monte Carlo code[5] that simulates the gamma ray transport in solid detectors has been developed. It is essentially devoted to calculate the response of a cylindrical detector to an external point source. Its original version treated the whole detector as one active zone. The problem specificity lead us to modify it so that it can deal with multi-zones detectors (shielding, dead layer, etc.).

Typical numerical experiments were conducted on a Germanium detector with cylindrical geometry whose dimensions are: a 15 cm radius, a 3.6 cm thickness and the source detector distance was set to 4 cm. To show the effect of the surrounding material, the experiments were performed with shielded and unshielded detectors.

A set of three mono-energetic sources was used to estimate the effect of the source energy on zone importance. The reference and the perturbed spectrums for a given cell position are illustrated in Fig. 1. Both of the response functions show coinciding flat regions and different photo-peak heights. The flat region corresponds to the Compton continuum. The major difference happens

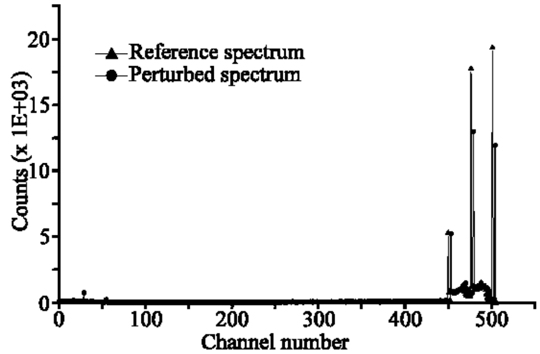

Fig. 1: Reference and perturbed detector responses

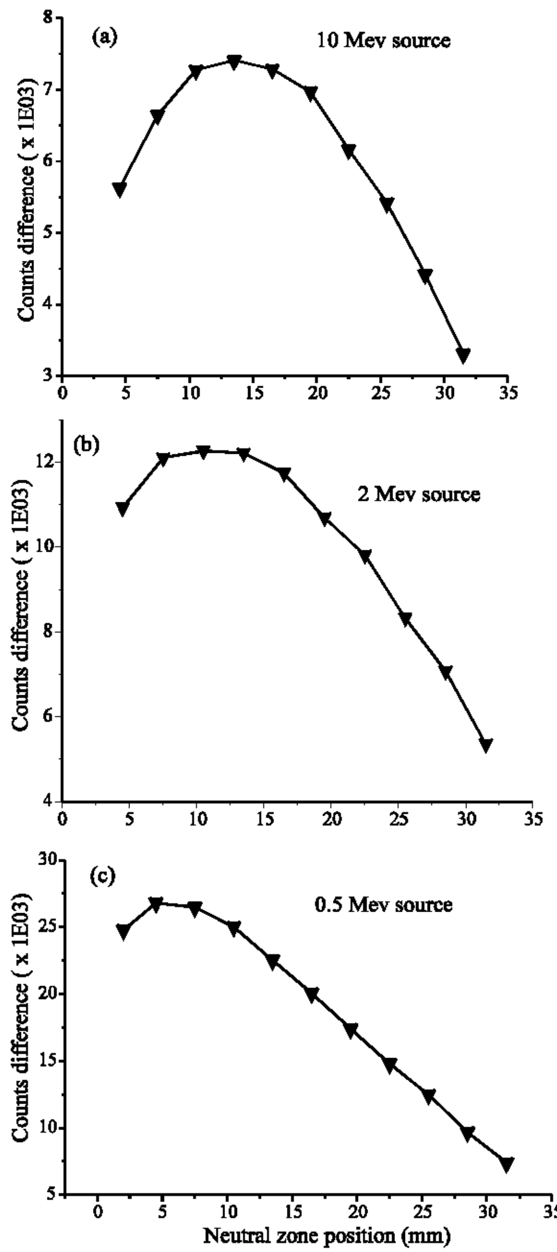

Fig. 2(a-c): Zone importance for unshielded detector

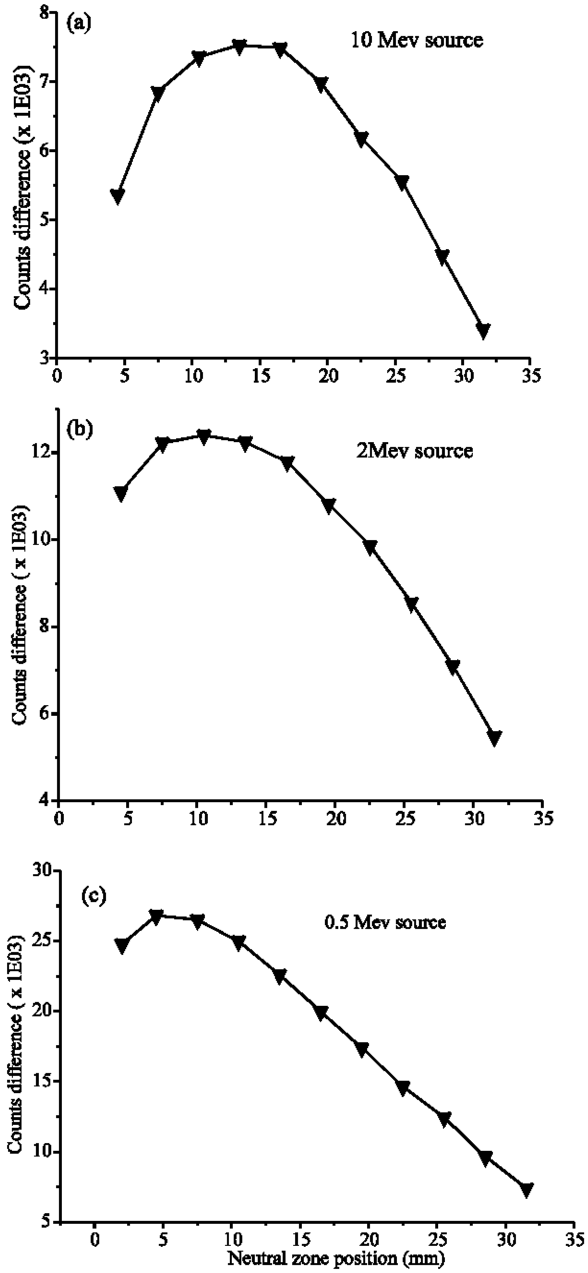

Fig. 3(a-c): Zone importance for shielded detector

to be at the photo-peak energy. If one compares the flat regions, one observes no discrepancy between these two spectrums. However, at the photo-peak energy, large variations are observed when going from one cell position to another. It is therefore clear that, in the context of this problem, the most interesting part of the spectrum is that one which is in the neighborhood of the photo-peak energy. A study which will look at the variation of the importance of the cells at that particular energy is worth undertaking.

The results that will be presented illustrate the effect of the neutralized cell position on the zone importance distribution for a given photo-peak energy. Two study cases are considered, the first one uses an unshielded detector, the second one concerns a lead shielded detector. For each case a set of three mono-energetic sources is used.

In Fig. 2(a-c) every point represents the zone importance of a given cell within the detector active zone at that cell position and for a specified energy, which is the photo-peak energy. The shapes of the obtained curves are similar. An increasing then a decreasing importance with a maximum that is sliding towards smaller cell position values as energy is increased. The importance maximum for a 10 MeV source happen to be at 13.5 mm compared to 4.5 mm for a 0.5 MeV source. We also observe increasing values of the importance maximum as energy decreases, from 7000 for 10 MeV to 26000 for 0.5 MeV.

Figures 3(a-c) concern the second case study with lead shielded detectors. Except for a small shift towards higher values of the importance weight, on the overall, what have been said on the unshielded detector applies to this case.

The shift of the importance maximum towards smaller cell position values can be justified by the fact that energetic gamma rays penetrate deeper into the medium. Larger importance values associated with smaller source energy, at all cell positions, are due to the fact that the escape probability of energetic photons is larger compared with that of less energetic ones resulting into more photons leaving the detector.

A specific purpose Monte Carlo code was developed to evaluate detector response functions. It was then adapted and used to model detector zone importance as a function of the penetration distance of gamma ray photons. We have discussed the effect of the source energy on the importance maximum as well as that of the shield. The focus of the study was restricted to a single energy, namely the photo-peak energy. The same analysis could be extended to other features of the spectrum mainly first and second escape peaks. As for the Compton continuum energy region, little variation in the importance is observed

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