Studies on angular correlation of gamma rays using GEANT4

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Introduction

Radioactive sources that emit gamma rays in two-step cascade are widely used in gamma spectrometry for the purpose of energy calibration. This type of sources are also widely used for the purpose of efficiency calibration as very few mono-energetic gamma sources are available in the laboratory. However, if the time difference between these two gamma rays is small compared to the resolving time of detector, then the deposition of energy of two gamma rays results in a sum peak in the energy spectrum. Consequently, the counts from individual full energy peaks are lost in sum-peak. It is well known that if counts in sum-peak are large enough then the efficiency calibration done using individual full energy peaks will not be accurate. Therefore, the coincidence summing effect needs to be corrected in order to obtain accurate efficiency calibration of the detector. In addition, in double gamma emitters, two gamma rays are angularly correlated i.e. emission of second gamma ray is not isotropic. For example, in case of ^{60}Co, the probability that the second gamma ray emitted in the same direction, parallel or anti-parallel, as first gamma ray is about 17% higher than emitted at an angle of 90°.

In order to understand the extent to which coincidence summing and angular correlation effects the number of counts under individual gamma ray peaks and sum peak, it is necessary to carry out Monte Carlo simulations. Many theoretical and experimental studies have been done on this phenomenon [1, 2]. Courtine *et al.*, [3] have studied the angular correlation between gamma rays emitted from ^{60}Co for well type HPGe detector and reported that the sum peak is not biased by the angular correlation for a source inserted in a well inside the detector crystal. On the other hand, when the source is placed outside, near the detector, the sum peak is significantly affected by the angular correlation and this effect is enhanced with increasing distance. Not many groups have reported studies using simulations that can provide new information about this phenomenon with scintillation detectors. In the present work, we aim to study the effect of coincidence summing and angular correlation between gamma rays by Monte Carlo simulations using using $LaBr_3$:Ce.

Simulations

Monte Carlo simulations were carried out using GEANT4 toolkit [4] in order to understand whether the angular correlation would result in peak areas different from those obtained by considering random emissions of coincident gamma rays. For this purpose, we have used decay schemes of different double gamma emitters, namely, ^{60}Co, ^{46}Sc and ^{94}Nb. The detector used was a cylindrical $3.56'' \times 6''$ $LaBr_3$:Ce detector. In the simulations, we have considered standard electromagnetic package for physics process class. The range cut was selected in such a way that when the energy of the particle is less than 100 eV, the particle has been considered to be entirely absorbed within the active volume of the detector. The number of events was selected to be 10^7 in order to neglect the statistical uncertainties associated with counts in photo-peaks and sum-peak due to the Monte Carlo nature of the simulations. Simulations

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were also carried out using individual monoenergetic gamma rays, for comparison.

TABLE I: Corrected photo-peak efficiencies with and without angular correlation

Distance (cm)	Single Energy Source	Without angular correlation	With angular correlation
10	0.129	0.133	0.128
	0.123	0.122	0.122
12	0.099	0.094	0.099
	0.093	0.097	0.094
15	0.074	0.075	0.073
	0.069	0.077	0.070
20	0.051	0.049	0.051
	0.047	0.048	0.047

The effect of angular correlation was incorporated in the simulations as follows. Two coincident gamma rays were generated using particlegun class. The first gamma was assumed to be emitted randomly and the second gamma was emitted with correlation relation:

$$W(\theta) = 1 + acos^2\theta + bcos^4\theta$$

where θ is the angle between directions of gamma rays. It can be verified that W(0°) = W(180°) = 1, whereas W(90°) = W(270°) = 1.17. As GEANT4 toolkit does not have the functionality to take into account the effect of angular correlation, the probability of both gamma rays being emitted at a certain angle with respect to right angle was incorporated into the code. An array of angles was made with frequency of a particular angle stored in it being governed by the probability of that angle. That probability was determined by the above given formula. During the simulation, a random angle was chosen from this array. Simulations were done for a source located on the detector front surface and also for different values of source-detector separation. The correction for coincidence summing was done by the method explained in Ref. [5].

Results and Discussion

Table-I shows the simulated absolute photopeak efficiencies of $LaBr_3$:Ce detector considering ^{60}Co source and after correcting for coincidence summing. In each cell of the table, two efficiency values correspond to gamma energies of 1173 keV and 1332 keV. The efficiencies were simulated with and without incorporating the effect of angular correlation. The corrected efficiencies are compared with those obtained using monoenergetic gamma sources. Clearly, with increase in source-detector separation, the efficiencies obtained using angular correlation are better agreement with those obtained using monoenergetic gamma rays of similar energies. Experimental measurements are in progress for validating the simulated results.

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