Efficiency Calibration of Scintillation Detector using Compact Compton Coincidence Technique : GEANT4 simulations

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Introduction

Efficiency calibration of a radiation detector is crucial for precise cross section measurement experiments. Standard γ-ray sources such as ^{137}Cs, ^{60}Co, ^{22}Na, ^{241}Am-^{9}Be, etc., are used for such calibration. However, these γ-ray sources can provide only a limited amount of data for obtaining energy dependent efficiency calibration curve, which leads to uncertainty in efficiency of the detector for unknown energies. Not many laboratory γ-ray sources are available in nature for accurate efficiency calibration. This highlights the need of having a technique for accurate efficiency calibration curve using limited number of available γ-ray sources.

In our recent publication we have used compact Compton Coincidence Technique (CCT) to find intrinsic energy resolution of $CeBr_3$ detector [1]. CCT was developed by Valentine and Rooney for studying non-proportional response of scintillation detectors to γ-rays [2]. The technique consists of one test detector whose intrinsic resolution is to be measured and one reference detector which is used for energy gating [3]. It has been observed that energy resolution can be obtained for many gamma energies using single mono-energetic γ-ray source. This motivated us to explore the possibility of using compact CCT to generate more data for efficiency calibration curve using a mono-energetic γ-ray source.

In CCT, events are selected on the basis of energy deposited in reference detector. For example, if 662 keV γ-ray from ^{137}Cs is incident on reference detector and the energy gating window is centered at 477.65 keV, then, according to Compton scattering formula, the angle of scattered gamma ray will be restricted around 180°. The scattered γ-ray will trace back the same path passing through the location of actual γ-ray source and fall on the front surface of test detector. This will create a virtual "Compton γ-ray source" emitting γ-rays of 184.35 keV energy.

The standard γ-ray sources used in laboratories are point sources in general and emit γ-rays isotropically. It is desirable that the Compton γ-ray source is also a point isotropic γ-emitter. Events which correspond to scattering of primary γ-ray around 180° have been selected to ensure point-like nature of Compton γ-ray source. In this case, the scattered γ-rays will appear to be originating from same point where actual source is placed. It is to be noted that the energy gating width in reference detector will determine the variation in angle of scattering. Large variation in angle of scattering will lead to an extended source instead of a point source. A point isotropic source requires all the γ-rays to be scattered at exactly 180°. This corresponds to selection of events in which primary γ-ray deposits precisely 477.65 keV energy. However, precise selection of such events is not possible experimentally because of finite energy resolution of reference detector.

This prompted us to study the effect of finite energy gating window in reference detector on efficiency of test detector. A quantity called gating width dependent efficiency, ε_g is hereby defined as follows:

$$\varepsilon_g = \frac{N_t}{N_r}$$

where, N_t is the number of γ-rays which deposited full energy in the test detector after depositing partial energy in the reference detector within the gating window and N_r is the

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Incident energy (keV)	Energy gating window (keV)	ε_g (%)	Mono-energetic efficiency(%)
662.0	477.65-477.45	65.79	66.00
834.0	638.40-638.00	63.20	63.52
1115.0	907.13-906.53	59.74	60.37
279.0	145.63-145.55	74.02	81.14

TABLE I: Comparison of ε_g with intrinsic full energy peak efficiency for incident γ-rays of different energies.

number of γ-rays which deposited partial energy in the reference detector within the gating window. In this paper we report results of GEANT4 simulations on efficiency ε_g of a scintillation detector using the Compton γ-ray source.

Simulation details

Monte Carlo simulations were carried out using GEANT4 simulation toolkit. Two cylindrical 1″×1″ $LaBr_3$:Ce were placed opposite to each other with 6 cm distance between them. Mono-energetic γ-rays of energy 662 keV(^{137}Cs), 834.85 keV (^{54}Mn), 1115.54 keV (^{65}Zn) and 279.2 keV (^{203}Hg) were generated from mid point of both detectors using *particleGun* class. Events corresponding to deposition of energy within a specific energy window by the incident γ-rays in the reference detector were selected to obtain N_r. Energy window has been chosen in such a way that γ-rays are scattered close to 180° and form the Compton γ-ray source. The number of scattered γ-rays which deposited full energy in test detector (N_t) was obtained. A mono-energetic γ-ray source emitting γ-rays of energy corresponding to scattered γ-rays was also simulated to obtain the intrinsic full energy peak efficiency of test detector. Moreover, simulations were also carried out to study the behaviour of ε_g with decreasing width of gating window. The simulations were done for 10^7 events.

Results and Discussion

Table I shows the energy of γ-ray incident on the reference detector, energy gating window in the reference detector and efficiency ε_g of the test detector. The efficiency ε_g obtained using Compton γ-ray source is compared with intrinsic full energy peak efficiency

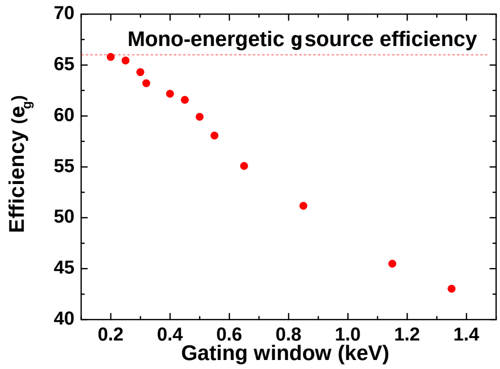

FIG. 1: Variation of ε_g with respect to Gating window(keV).

obtained using mono-energetic γ-ray source. A good agreement was found between ε_g and efficiency using mono-energetic γ-ray source. Figure 1 shows the variation of ε_g with respect to the gating window for 662 keV γ-ray incident on reference detector. Gating window of decreasing width is applied around 477.65 keV in the reference detector. It is evident from the figure that when energy gating window is decreased, ε_g gets closer to intrinsic efficiency for mono-energetic 184.35 keV isotropic γ-ray source. Large variation in ε_g with respect to small changes in gating width is consequence of angle of scattering being very sensitive to energy deposited by primary γ-ray in the reference detector. Work is in progress to carry out experimental measurements for comparison.

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References

[3] V. Ranga *et al.*, IEEE Trans. on Nucl. Sci., 65 (2018) 616-620
[3] J.D. Valentine, B.D. Rooney, NIM A, 353 (1994) 37-40
[3] L. Swiderski *et al.*, IEEE Trans. Nucl. Sci., 57 (2010) 1697-1701