Monte Carlo simulation of a clover detector and its geometry optimization for coincidence summing corrections

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Introduction

In gamma ray spectrometry, the coincidence summing effect becomes a serious problem for high efficiency detectors such as Clover and well type detectors. A general method for computing coincidence correction factors was first demonstrated by Andreev et al [1]. This is an analytical approach which requires intensive use of the decay scheme and needs full energy peak (FEP) efficiency and total efficiency (including Compton and full energy peak) for each gamma ray energy for a given sample detector geometry. Constructing a total efficiency curve over full energy range for all geometries is a cumbersome and time consuming job due to requirement of several single gamma-ray emitting nuclides. The peak and total efficiencies can also be obtained using Monte Carlo method [2]. It is a powerful tool to simulate the detector response and is applicable to a variety of matrices and source geometries [3]. The method requires the knowledge of internal as well as external components of the detector geometry, which are never known accurately. This leads to a mismatch between experimental and simulated efficiencies. The problem can be dealt with by either determining the detector dimensions experimentally or by adjusting the detector geometry so as to match the experimental and calculated values of efficiencies using the MCNP code [4].

In the present work, a clover detector has been simulated using MCNP code with the manufacturer provided dimensions. The efficiencies have been calculated by MCNP at mono-energetic source at different sample-to-detector distances (d=3.2 cm and 25.4 cm). The calculated efficiencies have been found to be very different from the experimental efficiencies at these distances. Optimization of the detector geometry has been carried out to match the experimental and the theoretical efficiencies. The optimized detector parameters have been used for efficiency transfer to other sample-to-detector distances.

Experimental

In this study, a clover detector consisting of four co-axial n-type Ge diodes of 50 mm diameter and 70 mm length mounted in a common cryostat was used. The total active volume of the detector is 470 cm^3 and corresponds to 89% of the original Ge volume [5]. Standard sources of ^{109}Cd, ^{57}Co, ^{203}Hg, ^{51}Cr, ^{137}Cs and ^{65}Zn were counted at different sample-to-detector distances of 3.2, 5.4, 10.2 and 25.4 cm. The efficiencies were obtained at these distances using the following relation:

$$\varepsilon_{\gamma} = \frac{cps}{I_{\gamma}\, x\, dps} \quad (1)$$

where, cps is the count rate at the energy of interest and I_γ is the gamma ray emission probabilities taken from Table of Isotopes [6].

Monte Carlo Simulation

In this work, the version MCNP4c [4] was used to simulate the clover detector response. The efficiency was obtained using F8 tally which is a pulse height tally. Mode P was used. The description of the detector geometry was given in detail in the cell and surface cards of the MCNP input file. All the detector parameters including the absorbing materials (Al end cap, Ge dead layer), were included in the geometry as given in Table 1. The bevels at the front face were successfully reproduced in the calculations as shown in figure 1. In each run ~10^8 particles were sampled to reduce statistical uncertainties.

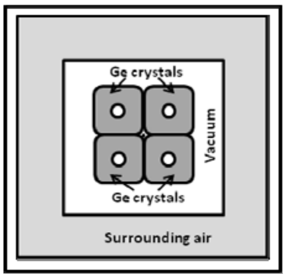

Fig. 1. Geometry of the clover detector used for Monte Carlo simulation.

Results and Discussion

Figure 2 (a) and (b) shows the experimental and the MCNP calculated efficiencies at d = 3.2 cm and 25.4 cm respectively. The MCNP efficiencies were observed to be over-estimated by a factor of 2 at closer distance and 1.4 at farther distance. This is due to inaccuracy of the dimensions provided by the manufacturer.

Table 1: Detector parameters provided by manufacturer and optimized by MCNP code

Detector parameters	Manufacturer provided dimensions (cm)	Optimized Dimensions (cm)
Crystal radius	2.5	2.25
Crystal length	7.0	7.0
Front Ge dead layer thickness	0.00005	0.05
Inner hole radius	0.5	0.5
Inner hole depth	5.5	5.5
Al end cap thickness	0.15	0.2
Al end cap to crystal distance	0.35	2.3

In order to remove this discrepancy, the effect of different detector parameters such as crystal radius, length, end-cap to crystal distance and dead layer thickness on FEP over an energy range of 88-1115 keV was systematically studied. These parameters were optimized to match the MCNP and the experimental efficiencies within 3% at both the distances. The optimized parameters have been given in Table 1. Figure 2 (a) and (b) also shows the MCNP efficiency obtained with the optimized geometrical parameters, which agrees with the experimental efficiencies. The reliability of the optimized geometry was checked by comparing the MCNP simulated efficiencies with experimental efficiencies at two other distances (d=5.4 cm and 10.2 cm). The results were found to agree within 3-5%.

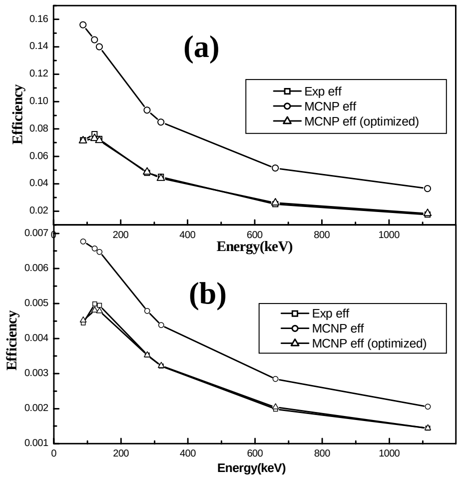

Fig. 2 Efficiency of clover detector as a function of energy at d = (a) 3.2 cm and (b) 25.4 cm.

References

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