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Coincidence summing corrections for a clover detector

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ABSTRACT

The true coincidence summing effect on the full energy peak efficiency calibration of a clover HPGe detector for point sources has been determined as a function of sample-to-detector distance using mono-energetic and multi-energetic gamma ray sources. The coincidence summing effect has been observed to increase at closer distances with the correction factors as high as 1.25 at closest distance studied. The correction factors for the total and the photopeak efficiencies have been obtained using the analytical method. The clover detector response has been simulated using MCNP code, taking care of the bevels and the flat surfaces of the clover detector. The geometry of the clover detector has been optimized to match the experimental and the theoretical efficiencies. The true coincidence summing correction factors (k_{TCS}) have also been experimentally obtained by taking the ratio of corresponding mono-energetic extrapolated efficiencies to multi-energetic efficiencies. The k_{TCS} obtained from analytical method has been found to match with the experimental k_{TCS} with the simulated values within 1–5%.

1. Introduction

In gamma ray spectrometry, true coincidence summing takes place when two or more cascade gamma rays (or a gamma ray and an X-ray) emitted by a radionuclide, are detected within the resolving time of the detector. This gives inaccurate peak areas leading to erroneous results in quantitative estimation of radionuclide activity. The extent of coincidence summing depends upon the probability that two gamma rays emitted from an excited nucleus will be detected simultaneously in a radiation detector [1,2]. Therefore, these effects are independent of count rate of the source and depend solely on the emission probabilities and detection efficiencies of the cascade gamma rays. The magnitudes of these corrections become significant for detectors having high intrinsic efficiency, particularly at close distances owing to greater probability of two gamma rays reaching the detector simultaneously. Corrections due to coincidence summing effect become important for gamma-spectrometric determination of low level activity when use of high efficiency detector and counting at closer distance becomes necessary. The high efficiency coupled with high resolution can be achieved by building HPGe detectors with large crystal volumes. The latter is limited by the practically achievable crystal volume (300 cm^3) and also by the poor timing characteristics. The problem has been circumvented with the advent of composite detectors like Clover detector which is made up of four HPGe n-type crystals placed closely in the same cryostat. Thus a large active crystal volume (>470 cm^3) is achieved, with timing characteristics preserved [3]. Due to the high efficiency of these detectors, the true coincidence summing corrections are very important to get reliable results.

Coincidence correction factors (k_{TCS}) can be obtained by an analytical method [4,5] using the equation:

$$k_{TCS} = \frac{1}{1-\sum_{i=1}^{i=n} p_i \varepsilon_{ti} \overline{W_i}} \quad (1)$$

where n is the total number of gamma rays in coincidence with gamma ray of interest, p_i represents the probability of simultaneous emission of ith gamma and the gamma ray of interest, ε_{ti} represents the total efficiency of ith gamma ray and $\overline{W_i}$ represents the angular correlation of the two gamma rays averaged over the solid angle of the detector. This method has been improved and applied by many authors [6–14]. The method has been given in detail in the appendix of this paper. In order to calculate k_{TCS} by this method, the probability p_i is calculated by taking into account the nuclear decay characteristics such as the mode of parent nuclide decay, energies of γ-transitions, γ-ray emission probabilities, K-capture probabilities (in electron capture decay), mean energy of K X-rays, fluorescence yield, total and K

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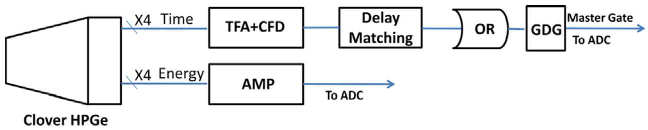

Fig. 1. Energy and timing signal processing of a clover detector.

Table 1
Clover detector parameters provided by manufacturer and optimized by MCNP code.

Detector parameters	Manufacturer provided dimensions (cm)	Optimized dimensions (cm)
Crystal radius	2.50	2.25
Crystal length	7.00	7.00
Front Ge dead layer thickness	0.00005	0.05
Inner hole radius	0.50	0.50
Inner hole depth	5.50	5.50
Al end cap thickness	0.15	0.20
Al end cap to crystal distance	0.35	2.30

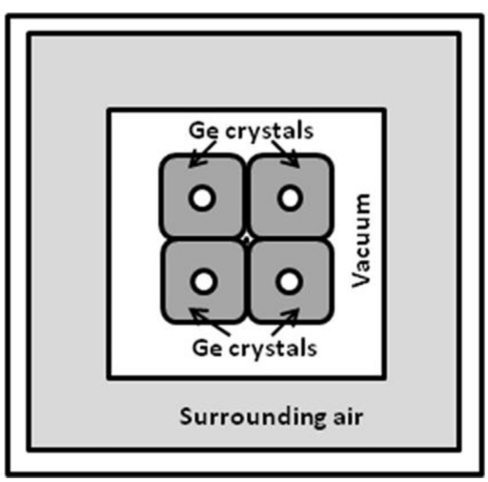

Fig. 2. Geometry of the clover detector used for Monte Carlo simulation.

conversion coefficients etc. available from the published decay schemes of the radionuclides. This analytical method also requires full energy peak (FEP) and total efficiencies (including Compton and full energy peak) at each gamma ray energy for a given sample detector geometry. The FEP efficiencies can be obtained by using a set of gamma ray standards of similar geometry. However, the measurement of the total efficiency with multi-gamma sources is more complicated and can be erroneous, since it is not easy to decompose the spectra into well-defined components belonging to gamma rays with distinct energies [15]. Therefore, constructing a total efficiency curve experimentally over full energy range requires several single gamma-ray emitting nuclides, making the process cumbersome and time consuming. The availability and short half lives of these sources are also added constraints. The peak and total efficiencies can also be obtained using Monte Carlo method [16–18]. It is a powerful tool to simulate the detector response and is applicable to a variety of matrices and source geometries [16–18]. The advantage of the method is that it is free of any coincidence summing effects. However, the Monte Carlo method requires knowledge of the internal as well as external components of the detector geometry, which are usually not known accurately. This leads to a mismatch between the experimental and simulated efficiencies. The problem can be dealt with

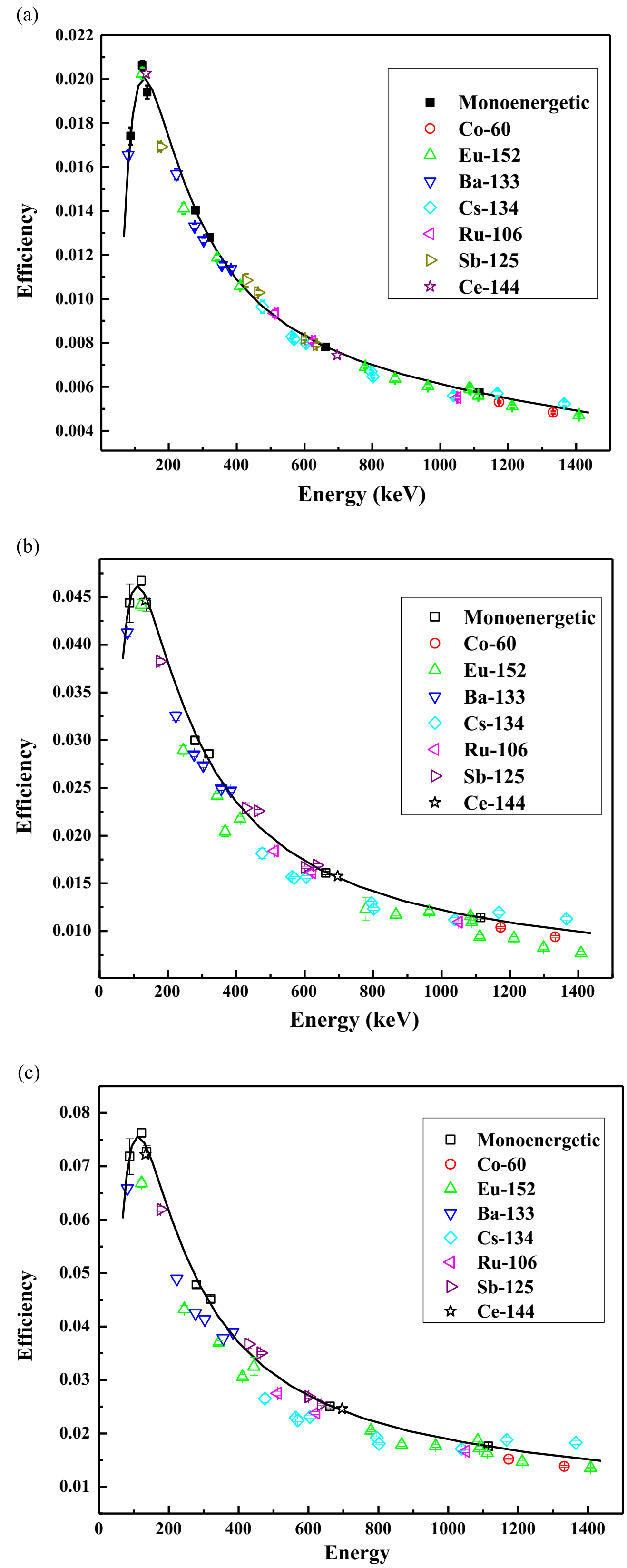

Fig. 3. Efficiencies of a clover detector in addback mode as a function of gamma ray energy for point source geometry at different sample-to-detector distances, $d=$ (a) 10.2 cm, (b) 5.4 cm and (c) 3.2 cm.

by either determining the detector dimensions experimentally [19–22] or by adjusting the detector geometry so as to match the experimental and MCNP efficiencies [23–25].