Close-geometry efficiency calibration of $LaCl_3$:Ce detectors: Measurements and Simulations

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Introduction

In gamma spectroscopy, true coincidence summing occurs because of concurrent deposition of energies by gamma rays in the detector active volume within a time less than the resolving time of the detector. This gives rise to a sum peak in the energy spectrum and there is loss of counts from individual peaks. Thus, to estimate the absolute full-energy absorption efficiency and the absolute total detection efficiency of a detector accurately, a correction to this coincidence summing is required. Keeping in view of the fact that there is less availability of mono energetic gamma sources, the coincidence summing correction in a detector using radioactive sources that emit more than one gamma ray in cascade is required to generate efficiency versus gamma energy curve of that detector. Extensive studies were made on coincidence summing correction using different methods such as numerical, Monte Carlo simulations, software, etc. [1-4]. In particular, large amount of literature is available with HPGe detectors. However, not much work has been done on coincidence summing effects in scintillation detectors. This may be due to inferiority of scintillation detectors over HPGe detectors in terms of energy resolution which makes the accurate estimation of counts under individual peak very difficult. We report here experimental measurements and realistic simulations of absolute efficiencies (both photo-peak and total detection) and of coincidence summing correction factors in $LaCl_3$(Ce) scintillation detectors under close-geometry. These detectors have drawn interest owing to their properties superior to that of NaI(Tl) detectors, such as high light yield (46,000 photons/MeV), energy resolution (about 4%), decay time (25 ns), etc.

Theory

Vidmer *et al*. [1] have proposed a method for correcting the coincidence summing in HPGe detector and reported absolute total detection and photo-peak efficiencies by using double gamma emitters ^{60}Co, ^{46}Sc, ^{94}Nb under the close-geometry. The transition probabilities of both gamma rays emitting from these sources is almost 100%. The absolute photo peak efficiency of first gamma ($E_1 < E_2$) after correcting for coincidence summing can be calculated using an equation:

$$\varepsilon_1 = \frac{\varepsilon_{\max} + \varepsilon_{\min}}{2} \quad \text{where,}$$

$$\varepsilon_{\min} = \frac{[(\alpha_1^{app} - \alpha_2^{app}) + ((\alpha_1^{app} - \alpha_2^{app})^2 + 4A\alpha_{12})^{1/2}]}{2A}$$

and

$$\varepsilon_{\max} = \frac{\alpha_1^{app}\alpha_{12}}{A\alpha_2^{app}}$$

Here α_{12} is the count rate under the sum peak, α_1^{app} and α_2^{app} are the apparent count rates under two peaks corresponding to gamma energies E_1 and E_2, A is the activity of the source. From the value of ε_1, calculations of absolute photo-peak efficiency corresponding to gamma of energy E_2 and absolute total detection efficiencies of both gammas can be made.

Experimental Details

In the present work, we have studied coincidence summing in a cylindrical 1"×1" $LaCl_3$(0.9% Ce) scintillation detector (SCIONIX Holland BV), experimentally and also using Monte Carlo simulations, with a calibrated double gamma emitter ^{60}Co. The source was placed on the detector's front surface in order to avoid the effect of angular correlation between two gamma rays emitting in cascade. Figure 1 shows an energy spectrum recorded using $LaCl_3$(Ce) detector.

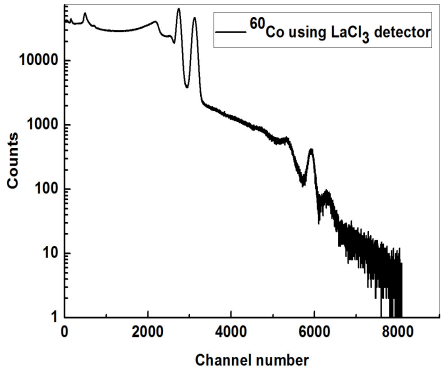

Fig.1. A typical ^{60}Co energy spectrum recorded using $LaCl_3$(Ce) detector at a source-detection separation of 0 cm.

We have made Monte Carlo simulations using GEANT4 toolkit by considering the presence of surroundings of detector and of encasing of scintillation crystal. These simulations were made using double gamma emitters ^{60}Co, ^{46}Sc, ^{94}Nb and ^{24}Na. Standard electromagnetic model was used for physics processes with a range cut of 0.01mm and radioactive decay module was included in the physics list. General Particle Source (GPS) module was used to simulate the same number of events from ^{60}Co as that of strength of calibrated source used in the experiment. We have also generated the gammas of energies 1173 and 1332 keV separately and calculated their absolute efficiencies (both detection and photo-peak) in order to compare with efficiencies obtained after correcting for the coincidence summing.

Results and Discussion

The absolute photo-peak and total detection efficiencies corresponding to two gamma rays emitted by ^{60}Co using $LaCl_3$(Ce) detector, after correcting for coincidence summing are summarized in Table-1 and the coincidence summing correction factors for 1173 and 1332 keV are shown in Table-2. The experimental results are compared with GEANT4 simulations and they are found to be very good agreement with each other.

Table 1: Experimental and simulated efficiencies after correcting for the coincidence summing.

E (keV)	Photo-peak efficiency		Total detection efficiency	
	Exp	GEANT4	Exp	GEANT4
1173	0.86 (0.07)	1.12 (0.16)	15.0 (0.33)	14.0 (0.95)
1332	0.82 (0.06)	0.95 (0.1)	14.5 (0.34)	13.0 (1.1)

Table2: Experimental and simulated coincidence summing correction factors.

E (keV)	coincidence summing correction factors	
	Exp	GEANT4
1173	0.85 (0.2)	0.90 (0.3)
1332	0.84 (0.2)	0.86 (0.3)

The uncertainties in the measured efficiencies were estimated by considering the uncertainty associated with theoretical formalism and statistical uncertainty. The uncertainties associated with the simulated efficiencies were calculated using the uncertainty components associated with the crystal size and thickness of aluminum provided by the manufacturer. The measured and simulated results are in good agreement with each other. The corrected efficiencies were also found to be in good agreement with those simulated using single gamma energies. Also, the corrected efficiencies obtained in simulations using ^{46}Sc, ^{94}Nb and ^{24}Na are in very good agreement with those obtained using single gamma energies. This verifies the validity of method used in coincidence summing correction.

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