A detailed study of the volume dependence of the performance of $LaBr_3$:Ce detector

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Introduction

The recent invention of Lanthanum Halide detectors, namely, Lanthanum Bromide ($LaBr_3$:Ce) and Lanthanum Chloride ($LaCl_3$:Ce) marks a major development in the field of scintillator detectors. The significantly superior properties of these detectors have generated wide interests to understand the potentials and limitations of these crystals. The excellent energy resolution of $LaBr_3$:Ce, ∼3% at 662 keV, is better than any other commercially available scintillator detector. The fast decay time of 35 ns, with no intense slow component and afterglow, leads to a time resolution of about a few hundred picoseconds. The high density of $LaBr_3$:Ce (5.08 gm/cm^2) and the high Z of Lanthanum result in higher detection efficiency than NaI(Tl). These highly attractive properties of $LaBr_3$:Ce make it ideal for both low and high energy gamma-rays spectroscopy.

The measurements

Over the last several years we have been pursuing a systematic study of the properties of Lanthanum Bromide ($LaBr_3$:Ce) detectors [1–3]. The primary motivation has been to have in-depth understanding of the applicability of these detectors for both low (few hundred kev to few Mev) and high energy (up to 40-50 MeV) γ-ray spectroscopy. The various properties studied by us include, energy and timing resolutions, linearity of response, response to both γ-rays and neutrons, uniformity of the crystals, internal activity of $LaBr_3$:Ce etc. We have been studying both cylindrical and square bars of $LaBr_3$:Ce with volumes ranging from 12.8 cm^3 [1] to 946 cm^3 [3]. This rather wide range in volume provides us the opportunity to carry out a systematic study of the volume dependence of the performance of these crystals. Here we report about the results of our recent studies. We have studied the energy resolutions, timing resolutions and photo-peak efficiencies of four different sizes, namely, 1"X1", 2"X2", 3.5"X6" cylinders and square bars of dimensions 2"X2"X8". The energy resolutions and photo-peak efficiencies have been studied at four different energies from 59 kev to 4.43 MeV using radioactive sources of ^{241}Am, ^{137}Cs, ^{60}Co and AmBe. The timing resolutions have been measured at ^{60}Co energies of 1173 and 1332 kev. The 2"X2" and 3.5"X6" crystals are integral assemblies while for both the 1"X1" and 2"X2"X8" crystals we have used two different types of PMTs. We have determined the best operating voltages for all the PMTs providing linear response over the entire region of energy under study. The variation of the measured energy resolutions for all the four crystals at four different energies are shown in Figure 1. A clear pattern that emerges is an initial improvement in resolution followed by a deterioration with increase in volume. This dependence is maximum for the lowest energy of 59 keV (upper most curve) and decreases with increase in energy of the γ-rays. This behaviour is obviously due to the internal loss of the scintillation photons before they enter the photomultiplier tube. For the lowest energy the full energy deposition happens very near the entrance window of the detector in contrast to higher energy photons. The loss of the scintillation

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photons in the medium before reaching the photo tube increases with volume resulting in poorer energy and timing resolutions.

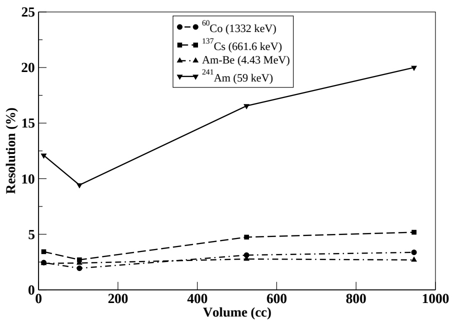

FIG. 1: The variation of measured energy resolutions with volume for four different energies. The lines joining the data points are for guiding the eye.

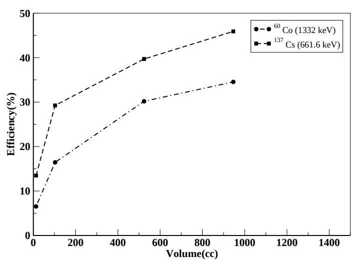

FIG. 2: The variation of measured absolute photo-peak efficiencies with volume at 662 and 1332 kev. The lines joining the data points are for guiding the eye.

The photo-peak efficiencies were studied using calibrated sources kept at a distance of 30 cm from the face of the detectors. The counts under the photo-peaks were obtained after subtracting the background counts due to both internal activities of the detector and external activities. Figure 2 shows the variation of photo-peak efficiencies with energy for all the four crystals. As expected, the efficiency increases with volume for a given energy and decreases with energy for a given volume. We have carried out realistic GEANT4 simulations to obtain the absolute photo-peak efficiencies for the different energies and detectors. The measured efficiencies match nicely with the GEANT4 results. The timing resolutions were measured for three different volumes, namely, 1"X1", 2"X2" and 2"X2"X8" by measuring the coincidence spectra using ^{60}Co source. The timing resolution is found to vary from around 300 ps for the smallest crystal to about 770 ps for the largest volume. Our measurements provide a comprehensive study of the volume dependence of the performance of $LaBr_3$:Ce detectors.

References

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