Nuclear Instruments and Methods in Physics Research A 609 (2009) 183–186

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Efficiency calibration and simulation of a $LaBr_3$(Ce) detector in close-geometry

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ARTICLE INFO

Article history:
Received 8 June 2009
Received in revised form
1 August 2009
Accepted 10 August 2009
Available online 18 August 2009

Keywords:
Efficiency calibration
Close-geometry
Coincidence summing
GEANT4

ABSTRACT

Close-geometry efficiency calibration has been performed for a 25.4 mm × 25.4 mm cylindrical $LaBr_3$(Ce) detector using calibrated point sources of ^{137}Cs and ^{60}Co placed on the top of the detector surface. The absolute total detection efficiency and the absolute photo-peak efficiency, obtained with ^{60}Co, are corrected for coincidence-summing effect. The measured efficiency for ^{137}Cs and the corrected efficiencies for ^{60}Co are reproduced by GEANT4 simulations, considering the detector in a realistic geometry. In addition, the simulations also faithfully reproduce the entire measured spectra for both the sources.

1. Introduction

The cerium-doped lanthanum halide crystals have gained special interest due to their excellent scintillation properties. Of these, $LaBr_3$(Ce) is the most promising material with a light output of about 61 photons/keV, a fast decay time of about 16 ns, a density of 5.08 gm/cm^3 and an emission wavelength of 380 nm. The very high light yield results in an energy resolution of about 3% (FWHM) at 662 keV. This is, by far, the best for any scintillator. The fast decay time with no intense slow components and afterglow provides a time resolution of about 300 ps. The high density of $LaBr_3$(Ce) and high atomic number of Lanthanum result in higher detection efficiencies in comparison to NaI(Tl) [1–7]. Another very attractive feature of these crystals is their negligible variation of light output within the temperature range −20 to +60 °C [8]. All these properties open up a very wide usage of these scintillators in nuclear spectroscopy, geological applications, medical imaging, astronomical applications, [9–13] etc.

A flurry of activities are currently underway to fully understand the overall performance of the $LaBr_3$(Ce) detector. The present work aims to determine the absolute efficiencies of a 1 inch × 1 inch cylindrical $LaBr_3$(Ce) detector for close source-to-detector geometry. The experimental determination of efficiency calibration of $LaBr_3$(Ce) scintillators for close source-to-detector geometry is useful in gamma-ray spectroscopy [14,15]. The main advantage of point-source efficiency measurements in close-geometry lies in the large solid angle subtended by the detector at the source; resulting in higher efficiencies, both total and photo-peak, and shorter measurement times required to obtain a certain statistical accuracy of the results. The major problem in this geometry is due to true coincidence summing. The effect of coincidence summing of gamma radiation occurs when two or more gamma rays are emitted in coincidence from the decay of the same radio-nuclide, and are recorded simultaneously within the resolving time of a detector. The coincidence-summing effect greatly depends on the decay scheme of the radio-nuclide and the solid angle subtended by the detector at the source [16,17]. For close geometries, point sources will exhibit larger coincidence-summing effects than the extended sources as reported by Debertin and Schotzig [18]. The coincidence summing of gamma-rays leads to the loss of counts from under the individual photo-peaks, while incrementing the counts under the sum peak. Therefore, the determination of true efficiencies for the individual gamma-rays demands an accurate and careful correction [19]. The determination of energy dependence of efficiencies requires considerable number of mono-energetic gamma-ray sources. Since, most of the gamma-ray emitters in the range of few hundred keV to few MeV emit multiple gamma-rays, it is necessary to carry out coincidence-summing corrections for determining the true efficiencies. Several methods to circumvent the problem of coincidence summing have been proposed in the literature [20,21]. Recently, Vidmar et al. [22] have developed a new method for the determination of efficiencies, both total and photo-peak, in close-geometry with point radioactive sources that decay with a two-step cascade. This method has been proved to be successful in determining the absolute total efficiencies

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doi:10.1016/j.nima.2009.08.045

simultaneously with absolute photo-peak efficiencies from the photo-peak areas in the recorded spectra.

In the present work, for the first time, we report the absolute total efficiency and the absolute photo-peak efficiency of a 25.4 mm × 25.4 mm cylindrical $LaBr_3$(Ce) detector measured using calibrated point sources of ^{137}Cs and ^{60}Co placed on the top of the detector surface. Monte Carlo simulations of the efficiencies for the above sources have been carried out using the radioactive-decay module available in GEANT4 simulation toolkit (version 9.1) [23–25] considering the detector in a realistic geometry. The measured and simulated efficiencies, both total and photo-peak, obtained for ^{60}Co have been corrected for coincidence summing. The angular correlation between gamma-rays has been neglected in the present work by positioning the sources on the top of the detector.

Experimental details are given in Section 2. Simulation details are presented in Section 3. Experimental and simulated results are presented, compared and discussed in Section 4. Section 5 presents important conclusions.

2. Experimental

The efficiency measurements have been made for a cylindrical 1 inch × 1 inch $LaBr_3$(Ce) detector procured from Saint Gobain Inc. The crystals are housed in 0.5 mm aluminum casing and fitted with glass light guides for coupling the photo tubes. We have used a 3 inch BURLE S83021E PMT (equivalent to Hamamatsu R1911-01) having a bialkali photo cathode (with maximum quantum efficiencies in the wavelength range 320–420 nm) suitable for $LaBr_3$(Ce) crystal with maximum emission around 380 nm. The PMT has been coupled to the crystal using DOW CORNING clear, white, silicone liquid. We have used two weak point sources of ^{137}Cs and ^{60}Co having activities 2.08 and 1.41 μCi, respectively, to minimise dead time and pileup effect. The uncertainty of the source activities was 5% as provided by the manufacturer. The dead times could be maintained below 2% using these sources. The energy spectra for ^{137}Cs and ^{60}Co have been recorded for time durations 600 and 1800 s, respectively, by placing them on the detector surface. The determination of the absolute efficiencies demands a careful subtraction of the background. The background spectrum was recorded without the sources for the same duration of time. A preamplifier and a spectroscopic amplifier with a shaping time of 1 μs have been used to shape the anode signal. The energy spectra were recorded in a multi-channel analyzer-based personal computer.

The experimental efficiency extraction for ^{137}Cs is rather simple. The absolute detection efficiency is given by [26]

$$\varepsilon_{abs} = \frac{N_{det}}{Atp} C_d \tag{1}$$

where N_{det} denotes the total number gamma-rays detected, A the activity of the radioactive source, t the duration of measurement, p the photon emission probability and C_d the correction factor due to dead time. The absolute photo-peak efficiency is given by

$$\varepsilon_{peak} = \frac{N_{peak}}{Atp} C_d \tag{2}$$

where N_{peak} denotes the number of net counts in the photo-peak. The uncertainties associated with the measured values of ε_{abs} and ε_{peak} have been calculated by using the method given in Ref. [27]. However, the efficiency extraction for radioactive sources with two-step cascade decay requires both careful and complicated procedures. For example, ^{60}Co emits two gamma-rays simultaneously, which generate two full-energy peaks and the sum peak. The determination of the full-energy peak efficiencies is not straightforward due to coincidence loss. The corrected absolute total efficiencies ε_{t1} and ε_{t2} and the corrected absolute photo-peak efficiencies ε_{p1} and ε_{p2} for the two gamma-rays corresponding to the energies E_1 and E_2 were then obtained using the method developed by Vidmar et al. [22]. The uncertainties in the corrected efficiencies have been calculated using Eqs. (16), (19) and (20) given in Ref. [22]. The coincidence-summing correction factors corresponding to the gamma-ray energies E_1 and E_2 have been calculated using the equations

$$C_1 = \frac{N'_1}{A\varepsilon_{p1}} \tag{3}$$

$$C_2 = \frac{N'_2}{A\varepsilon_{p2}} \tag{4}$$

where N'_1 and N'_2 denote the count rates in the peaks corresponding to the energies E_1 and E_2, respectively.

3. Simulations

In the present work, the GEANT4 has been implemented as the Monte Carlo simulation package of choice. The toolkit has been developed at CERN for high-energy physics experiments and simulates all relevant physical processes taking place in matter along the passage of elementary particles from the source to the detector of any configuration. The geometrical information, as provided by the manufacturer, describing the $LaBr_3$(Ce) crystal was incorporated in the detector construction class. The gamma-rays from the source lose part of their energy in the aluminum casing of the crystal before they hit the crystal. Therefore, to simulate the response of the detector to gamma-rays, the space coordinates of the crystal and aluminum casing have been incorporated in the simulation. Fig. 1(a) shows the two-dimensional cross-section of the cylindrical $LaBr_3$(Ce) detector supplied by the manufacturer. Fig. 1(b) presents the GEANT4 simulated three-dimensional view with the exact specifications provided by the manufacturer. For each event, the energy deposited in the detector has been calculated and the output files in ASCII format were generated for each simulation. The general particle source (GPS) module has been used as particle generator [28]. The simulations were carried out for large number

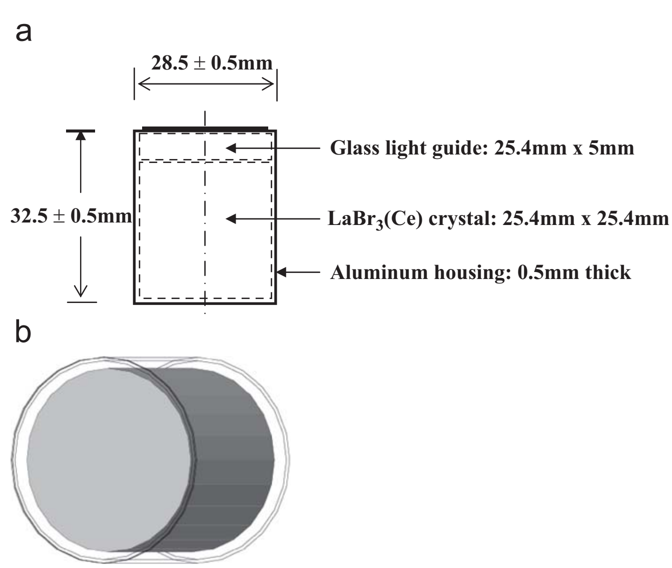

Fig. 1. (a) Two-dimensional cross-section of the cylindrical $LaBr_3$(Ce) detector supplied by the manufacturer. (b) GEANT4 simulated three-dimensional view of the detector with the exact specifications provided by the manufacturer.