Calibration of lanthanum bromide scintillation detectors

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Abstract

A new analytical method of efficiency calibration is proposed for cylindrical lanthanum bromide ($LaBr_3$:Ce) scintillation detectors. The cerium-doped lanthanum halide crystals have gained special interest due to their high density and atomic number, which results in excellent scintillation properties and higher detection efficiencies in comparison to NaI(Tl). The comparisons with the experimental and Monte Carlo method data reported in the literature indicate that the present method is useful in the efficiency calibration of the cylindrical lanthanum bromide scintillation detectors.

Introduction

Much current research is directed to the development of $LaBr_3$:Ce detectors as practical instruments for the simultaneous measurement and discrimination of gamma radiation. The present work is mainly concerned with introducing a new straightforward theoretical approach to calibrate cylindrical lanthanum bromide ($LaBr_3$:Ce) scintillation detectors for isotropic radiating gamma-ray (point and plane) sources. This approach is based on the direct mathematical method reported by Selim and Abbas and has been used successfully before to calibrate point, plane and volumetric sources with cylindrical, well-type, parallelepiped, borehole, and 4π NaI(Tl) detectors.

Methods

1. The case of a non-axial point source

In the following, direct analytical expression for the absolute efficiency of a cylindrical detector is derived using an isotropic radiating non-axial point source. For each photon emitted from the isotropic point source, there are two cases to be considered to find the photon path length d through the cylindrical detector medium, as shown in Fig. 1.

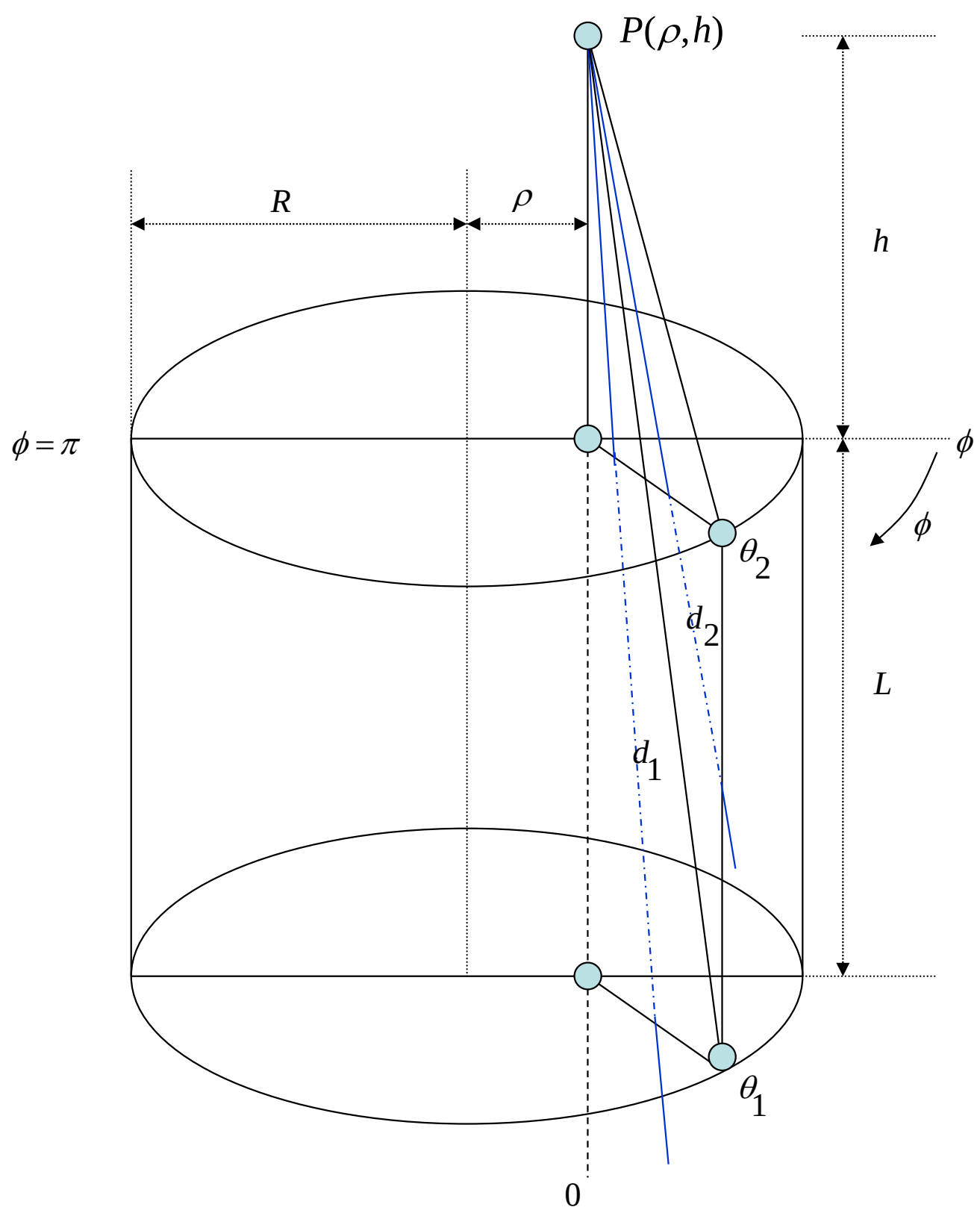

Fig. (1) Schematic view of all the possible path lengths through the active volume of a cylindrical (*2RxL*) detector irradiated by photons of an isotropic radiating non-axial point source *P(ρ,h).* The source-to-detector distance is *h.*

The incident photon may enter the cylindrical detector upper surface and emerge from:

a- the detector crystal base:

$$d_1 = \frac{L}{\cos\theta}$$

b- the detector crystal side:

$$d_2 = \frac{M(\phi)}{\sin\theta} - \frac{h}{\cos\theta}$$

The distance $M(\varphi)$, is given as follows: $M(\phi) = -\rho\cos\phi + \sqrt{R^2 - \rho^2\sin^2\phi}$

The total efficiency of a cylindrical detector for a photon incident, with energy *Eγ*, from an isotropic radiating non-axial point source *P(ρ,h)* is derived as:

$$\varepsilon_{Point} = \frac{1}{2\pi}\int_0^{\pi}\left(\int_0^{\theta_1} f_1 d\theta + \int_{\theta_1}^{\theta_2} f_2 d\theta\right) d\phi$$

The polar angle takes the steps $\theta_1 = \tan^{-1}\left(\frac{M(\phi)}{h+L}\right)$ $\theta_2 = \tan^{-1}\left(\frac{M(\phi)}{h}\right)$

$$f_i = f_{att}(1 - e^{-\mu . d_i})\sin\theta, \quad i = 1, 2$$

The meaning of the geometrical factors (R, L, h and *ρ*) is deducible from Fig. 1.

Finally, the factor f_{att} accounts for the attenuation of gamma rays by the source itself and by any other materials between the source and the detector active volume, this factor is expressed as:

$$f_{att} = e^{-\sum_j \mu_j . \delta_j}$$

where, μ_j is the attenuation coefficient of the jth absorber for gamma-ray energy, and $\delta_j = t_j / \cos\theta$ is the actual path length of the gamma-ray through the jth absorber and t_j its thickness.

2. The case of a concentric coaxial plane (disk) source

The absolute efficiency of a closed-end coaxial HPGe detector arising from a radiating isotropic and coaxial circular disk source, with radius S < R, is given by:

$$\langle\varepsilon\rangle_d = \frac{2}{S^2}\int_0^S \varepsilon\,\rho\,d\rho$$

where, ε is the absolute efficiency of an off-axis radiating point.

Results

The absolute total efficiencies are calculated using the present work, and compared with those obtained by experimental measurement and Monte Carlo simulation for cylindrical $LaBr_3$(Ce) scintillation detector using point and circular disk sources. The 2.54 x 2.54 cm^2 $LaBr_3$(Ce) crystal is housed in 0.05 cm aluminum casing. Fig. 2 shows the absolute total efficiency (present work) is plotted as a function of the gamma-ray energy in the energy range between 150 and 1332 keV. Finally in Fig. 3 we compare our theoretical total efficiency with the simulated values taken from Kumar et al. for cylindrical $LaBr_3$(Ce) scintillation detector in the energy range from 662 keV to 5 MeV, for source to detector distance h = 10 cm.

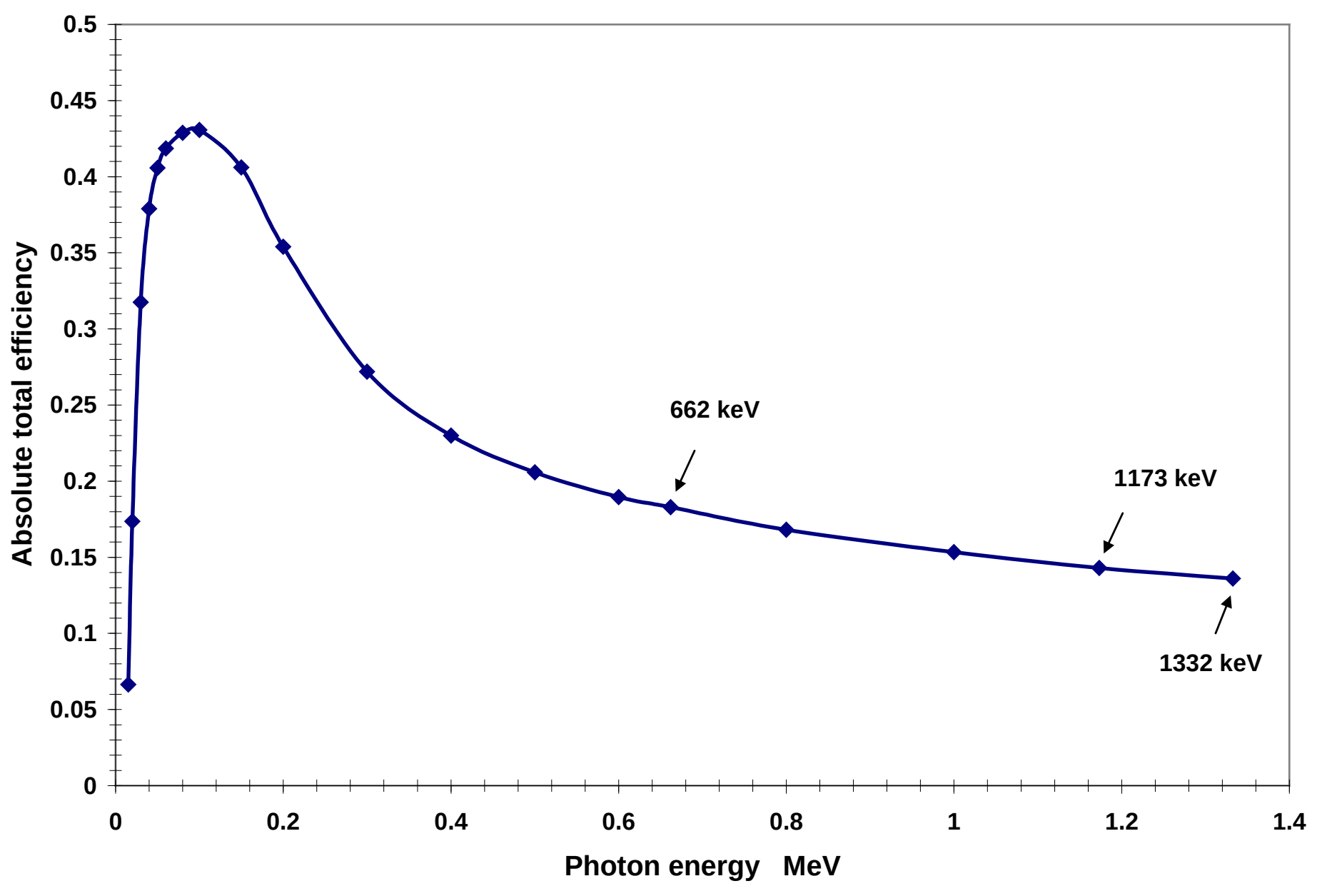

Fig. (2)

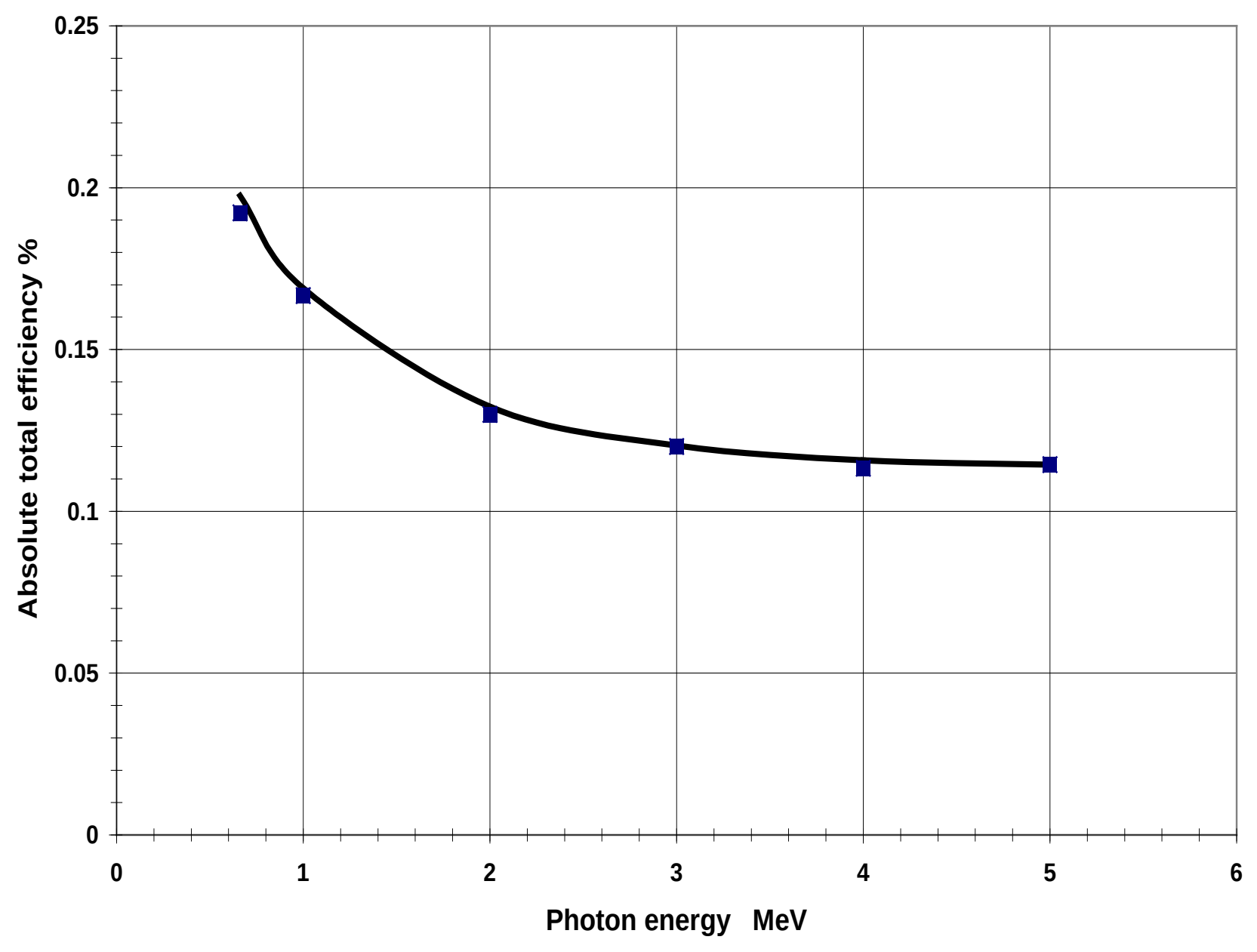

Fig. (3)

Conclusions

The present approach offers straightforward mathematical expressions to calibrate cylindrical lanthanum bromide ($LaBr_3$:Ce) scintillation detectors, over a large energy range without the need for standard sources, as is the case for experimental methods, nor optimization of detector parameters as for other simulation methods. In addition, the attenuation of the photons by the detector housing material is also presented in a simple direct mathematical expression.

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