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Validation of new mathematical formulae for calculating well-type gamma-ray detector efficiencies

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Abstract

In this study, direct mathematical formulae are found for measuring the full-energy peak efficiency of an HPGe well-type detector, and the values of the measured efficiencies are compared with published studies on the old experimental and theoretical methods with good agreement. In this new approach, the path length $d(\theta, \varphi)$ is derived as a function of the polar angle θ and the azimuthal angle φ, which will reduce the mathematical formulae to a simple and compact shape.
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Keywords: HPGe well-type detectors; Full-energy peak efficiency; Path length; Azimuthal angle; Polar angle

1. Introduction

Well-type HPGe and NaI (Tl) detectors are a suitable choice when low gamma activity samples need to be measured with a good energy resolution. Previously, gamma detector efficiencies were measured [1–20] using the spherical trigonometry technique. Recently, Abbas [21,22] introduced a new approach involving the determination of the path length $d(\theta,\varphi)$ covered by a photon inside the detector's active volume and the geometrical solid angle Ω. In this new approach, the path length $d(\theta,\varphi)$ is derived as a function of the polar angle θ and the azimuthal angle φ. This procedure will reduce the mathematical formulae to a simple and compact shape, and the integration over the azimuthal angle φ will always be from 0 to 2π [23,24]. Most importantly, it calculates the well-type detector efficiencies without the need for standard sources, as is the case for experimental methods, or optimisation of the detector parameters, as required for simulation methods. The study describes below involves the use of a new direct analytical expression to calculate the efficiencies of the well-type detector. Thus, we will measure the well-type HPGe detector efficiencies using this new method for a non-axial point and extended circular disc and compare the results with the previous work (old method).

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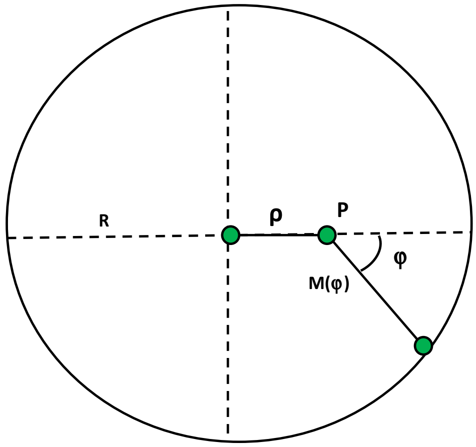

Fig. 1. Distance $M(\varphi)$.

2. Mathematical method

The basic formula of the efficiency with respect to the point source can be expressed as follows:

$$\varepsilon = \frac{1}{4\pi}\int_{\theta}\int_{\varphi} f_{att}(1-e^{-\mu d})\sin\theta d\varphi d\theta \tag{1}$$

where μ is the attenuation coefficient of the detector material; and d is the path length travelled by a photon through the detector active medium. f_{att} is the attenuation factor that determines the photon attenuation by the source container and the detector end cap materials, which can be expressed as follows:

$$f_{att} = e^{-\sum_j \mu_j \delta_j} \tag{2}$$

where μ_j is the attenuation coefficient of the jth absorber for a gamma-ray photon [17]; and δ_j is the path length of the gamma photon through the jth absorber. The f_{att} factor is applicable to the full-energy peak efficiency or photo peak efficiency, which is the efficiency for producing only full energy peak pulses instead of a pulse of any size for the gamma ray, but not to the total efficiency (the ratio of the total number of counts in the spectrum to the number of photons with energy emitted by the source).

The circular disc efficiency can be given by the equation as follows:

$$\varepsilon^{disk} = \frac{2}{S^2}\int_0^S \varepsilon\rho d\rho \tag{3}$$

where S is the disc radius; and ε is the point source efficiency.

Fig. 1 introduces the distance $M(\varphi)$, which is the distance between the projection of the non-axial point source and any point lying on the circumferences of the inner circle $M_i(\varphi)$ and the outer circle $M_o(\varphi)$ of the well-type detector, where $M(\varphi)$ is given by $M(\varphi) = -\rho\cos\varphi + \sqrt{R^2-\rho^2\sin^2\varphi}$.

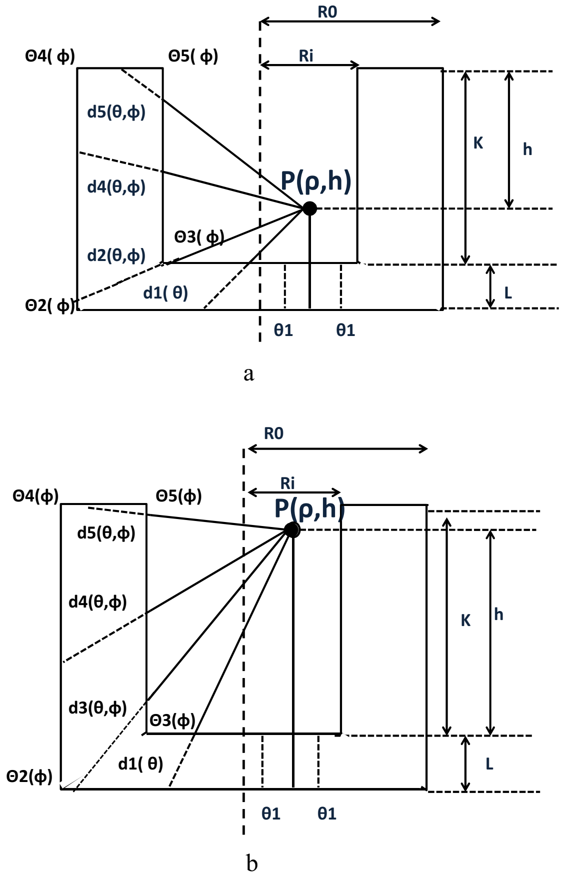

Fig. 2. Dimensions of the detector and the path of the photons from the source to the detector surface.

The source is located inside the detector at a position h, and the non-axial point efficiency can be calculated based on five different path length covering distances (d_i, i = 1, 2, 3, 4 and 5) considering the gamma ray emitted from the source and entering the detector, as indicated in Fig. 2, as follows:

$$d_1(\theta) = \frac{L}{COS\theta} \tag{4}$$

$$d_2(\theta,\varphi) = \frac{Mo(\varphi)}{Sin\theta} - \frac{h'}{COS\theta} \tag{5}$$

$$d_3(\theta,\varphi) = \frac{L+h'}{COS\theta} - \frac{Mi(\varphi)}{Sin\theta} \tag{6}$$

$$d_4(\theta,\varphi) = \frac{Mo(\varphi)-Mi(\varphi)}{Sin\theta} \tag{7}$$

$$d_5(\theta,\varphi) = \frac{-K+h'}{COS\theta} - \frac{Mi(\varphi)}{Sin\theta} \tag{8}$$

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