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On the Total Intrinsic Efficiencies of a Scintillation Counter

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Abstract :

Analytical expressions for the total intrinsic efficiency of a cylindrical scintillation detector arising from a radiating coaxial - point, -narrow disk and - right cylinders, are deduced. Theoretical results are compared with measurements.

Introduction

Through their extensive calculations for evaluating radiation fields from distributed sources Hubbell (1963); Hubbell et al. (1961) have given mathematical expressions of the solid angle subtended at a non-axial point detector by radiating - circular and - rectangular shaped sources.

Independently, through spherical trigonometry mathematical expressions of the solid angle subtended by a radiating point to nominally any planer or curved surface could be obtained, Selim and Abbas (1994). From such calculations, the geometrical efficiency for a coaxial radiating - point, circular disk or right circular cylinder isotropic sources to a circular detector are easily computed. Numerical values for the three cases are shown in figure (1).

For gamma - rays detection, measurements are often met with scintillation counters. Here, beside the geometrical efficiency there arises the interaction efficiency of the detector. The total intrinsic efficiency of a scintillation counter is the product of these two efficiencies.

Interaction Efficiency :

Detector intrinsic efficiency as a function of energy, for NaI (Tl) scintillation detectors has been treated for special cases. Miller et al. (1961), Zerby et al. (1962) and Seltzer et al. (1971) used Monte Carlo calculations for isotropic axial - point sources. By the same method Beam et al. (1978) considered the case of an off-axis point sources.

The detection efficiency of an emitted gamma-ray of energy E_o from the off - axis radiating point source P entering the scintillation detector traversing a distance d in the NaI (Tl) crystal say, figure (2-a), is derived as :

$$\in(E_o) = 1 - e^{-\mu(E_o).d} \tag{1}$$

Where $\mu(E_o)$ is the attenuation coefficient of the scintillator's material at the corresponding energy. The effective traversed distance d depends upon the polar angle θ and azimuthal angle Φ. For the case shown in Figure (2-a):

$$d = \frac{y}{\sin\theta} - \frac{h}{\cos\theta} \tag{2}$$

with

$$y = \rho \ \cos\phi + \sqrt{R^2 - \rho^2 \sin^2 \phi} \tag{3}$$

Detection efficiency for a photon to be registered from a point source is given by :

$$\in_{i=} \int \in(E_0). d\Omega / \int d\Omega \tag{4}$$

Where :

$$\int d\Omega = \int \int d\phi . \sin\theta \ d\theta \tag{5}$$

In the case of ρ <R, see figure (2-b):

$$\int d\phi = 2\pi \qquad \text{, for zone I} \tag{6}$$

$$= 2\phi_{max} \qquad \text{, for zone II}$$

Where

$$\phi_{max} = \cos^{-1} \frac{\rho^2 - R^2 + h^2 \tan^2 \theta}{2h\rho \tan\theta} \tag{7}$$

The total intrinsic efficiency becomes $\frac{\Omega \in_i}{4\pi}$ which leads to a direct mathematical expression, very easily to be computed, Abbas (1995). Figure (3) shows the variation of the total intrinsic efficiency of a 3"×3" NaI (Tl) detector with energy arising from radiating coaxial - point, circular disk and right cylindrical isotropic sources at different heights. For a radiating coaxial - point source the numerical values coincide well with the values reproduced by Tait (1980). The numerical values of the attenuation coefficients were derived from the tables given by Berger and Hubbell (1993).

Experimental:

A Sodium-22 liquid source was subjected to a 3"×3" NaI (Tl) scintillation detector. Two distinct gamma lines were considered for measurements, namely 0.511 MeV and 1.275 MeV. The sources have cylindrical shapes with an effective base radius S=1.06 cm and of different heights. In each case the activity was measured at different separation distances from the detector. The calculated and experimental data are shown in figure (4). A good agreement is shown.

Conclusion :

In this paper, the solid angle subtended at a circular cylindrical source radiating by a circular cylindrical detector was calculated by the use of compact analytical expressions. In addition, the scintillation detector total intrinsic efficiency was obtained in mathematical forms.

Data obtained from the theoretical model was found to be in good agreement with those obtained from the experimental measurements and the rather time consuming Monte Carlo calculation. For wider sources ($\rho > R$) calculations could be performed, taking into consideration the contribution arising from the rays penetrating through the curved side of the cylindrical detector Selim and Abbas (1996).

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Figure Captions

Fig. (1): Geometrical efficiency for coaxial cylinder, coaxial disk and axial - point. h distance of source's mid point to detector.

Fig. (2): Point source location above NaI (Tl) detector.

Fig (3): Total intrinsic efficiency of 3"×3" NaI (Tl) detector for coaxial right cylinder, coaxial disk and axial - point sources at different heights.

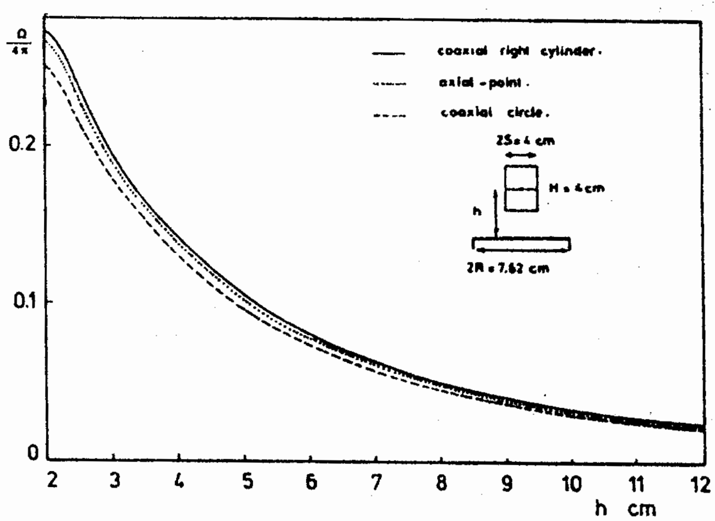
Fig (4): Total intrinsic efficiency of 3"×3" NaI (Tl) with a cylinder source.

circles: experimental measurements

curve : theoretical calculations

a) for 1.275 MeV peak.

b) for 0.511 MeV peak.

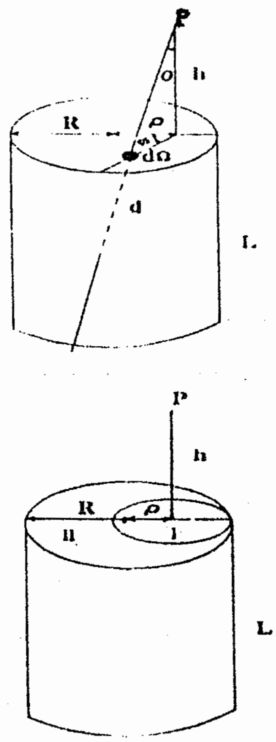


Ω/4π
coaxial right cylinder.
axial-point.
coaxial circle.
2S = 4 cm
H = 4 cm
h
2R = 7.62 cm
0.2
0.1
0
2
3
4
5
6
7
8
9
10
11
12
h cm

Fig (1)

(a)

(b)



P
h
R
ρ
dΩ
d
L
P
h
R
ρ
L

Fig. (2)

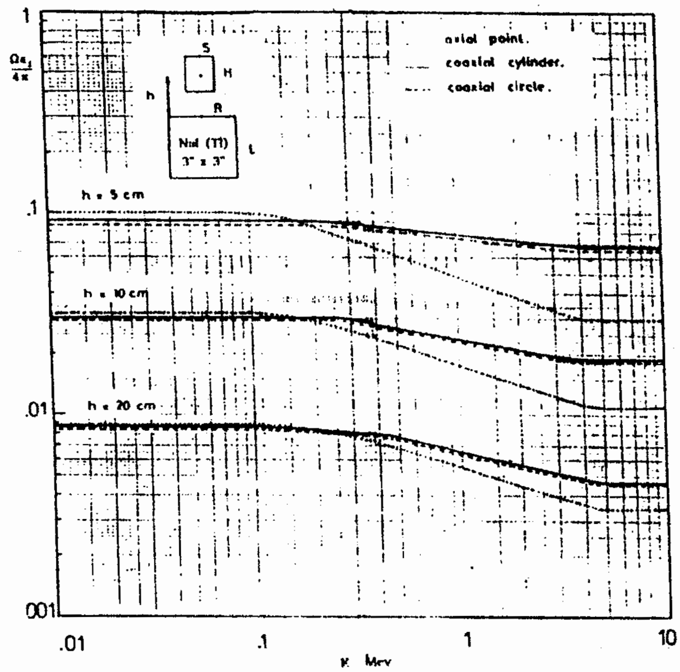

axial point.
coaxial cylinder.
coaxial circle.
NaI (Tl) 3" x 3"
h = 5 cm
h = 10 cm
h = 20 cm
.01
.1
1
10
.001

Fig.(3)

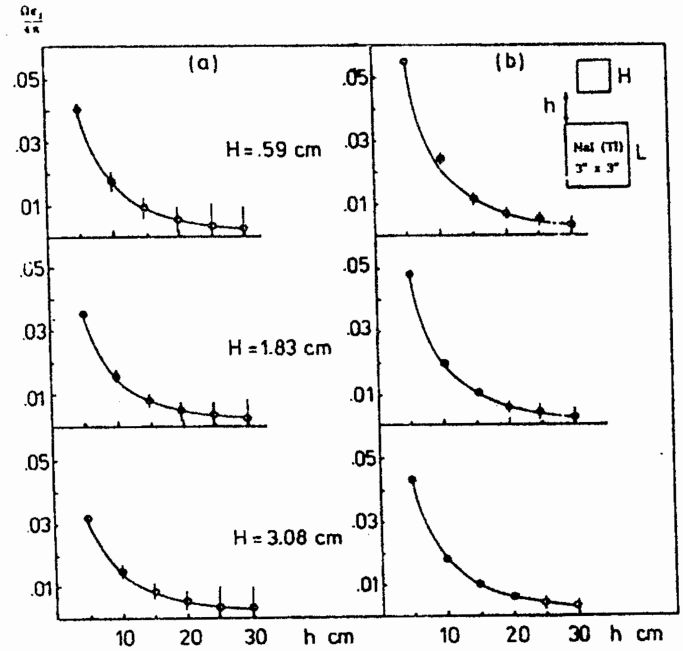

(a)
(b)
H = .59 cm
H = 1.83 cm
H = 3.08 cm
NaI (Tl) 3" x 3"
h cm

Fig.(4)

الكفاءات الكلية للكاشف الوميضى

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ملخص البحث

تم فى هذا البحث الحصول على معادلات تكاملية مطلقة لتعيين الكفاءة الذاتية الكلية لكاشف وميضى أسطوانى الشكل لمصادر أشعاعية تأخذ أشكال عديدة (نقطية – دائرية – أسطوانية)، ووجد تطابق كبير بين الحسابات النظرية والقياسات العملية .