SIMULATION OF THE TOTAL EFFICIENCY OF CYLINDRICAL SCINTILLATION GAMMA-RAY DETECTORS FOR DISK SOURCES

by

Shakeel U. REHMAN, Sikander M. MIRZA, and Nasir M. MIRZA*

Department of Physics & Applied Mathematics, Pakistan Institute of Engineering & Applied Sciences, Islamabad, Pakistan

Scientific paper
UDC: 621.387.46:519.245
DOI: 10.2298/NTRP1002085R

The total efficiency of cylindrical scintillation γ-ray detectors has been determined using a novel, primary interaction based Monte Carlo algorithm. With the use of biasing in these simulations, this approach has been made computationally efficient, yielding converged results with standard errors less than a fraction of a percent for about 10^4 histories which is about two orders of magnitude smaller than the conventional stochastic techniques. This methodology has been implemented in a MATLAB based computer program, DSEMC. For thin disk sources of various radii having coaxial configurations, the predictions of the DSEMC code have been found in excellent agreement with the corresponding results obtained by using the direct analytical technique. Similar agreement has also been found in the DSEMC calculated values of total efficiency and the corresponding results obtained by the direct analytical technique for coaxial thin disk sources of various radii over a wide range of γ-energies.

The DSEMC program has been used for the determination of total detection efficiency for off-axial configurations. As the disk source radius increases, results show a gradual decreasing trend in total efficiency. For these configurations, energy dependency of the total efficiency is found to follow the variation of the corresponding total attenuation coefficient which is consistent with the expected behavior. For coaxial thin disk sources, the total detection efficiency has been found to approach a corresponding maximum value as length is increased in the 1-20 cm range for various values of radii of disk sources and -ray energy, while keeping the diameter of the detector fixed at 7.62 cm. A similar behavior is observed when the radius of the detector is increased from 1-20 cm, while keeping the length of the detector fixed at 7.62 cm for various values of radii of disk sources and γ-ray energy.

Key words: gamma-ray detector, total efficiency, disk source, Monte Carlo simulation

INTRODUCTION

Due to their high value of detection efficiency and room temperature operation, NaI(Tl) detectors are commonly used for the identification and quantification of radioactivity; particularly for low-level radioactive sources [1]. For absolute measurements of the strength of radioactive materials and the calibration of detectors, knowledge of efficiency is essential [2]. Extended gamma-ray sources, particularly disk sources, have attracted a lot of attention due to their wide use in a variety of practical situations. Research efforts carried out in the past concerning disk sources can be classified into two categories: direct and stochastic. Among such early efforts, Grosjean developed an expression involving a complicated triple integral as a power series of the disk radius R by elementary formula exact up to R^2-terms only, as it entailed extensive calculations [3]. Then Nakamura used the Monte Carlo method for the estimation of the total efficiency of NaI(Tl) for axially aligned disk sources of Cu, Fe, Mn, and In [4]. A fast, primary interaction based Monte Carlo method has been proposed by Rehman *et al.* [5] for total efficiency calculations of scintillation detectors. He found good agreement between the predicted values and the corresponding experimental measurements. However, his work was focused on thick disk sources of relatively low γ-energies. This work was extended to include higher energy photons by Belluscio *et al.* for thick disk sources [6].

Later, a semi-empirical technique based on experimental measurements was developed by Moens *et al*. which required no mathematical model simplifica-

* Corresponding author; e-mails: nasirmm@yahoo.com
nmm@pieas.edu.pk

tion and no Monte Carlo calculations [7]. But due to its semi-empirical nature, its range of applicability is limited. Selim *et al.* developed an analytical expression for the determination of γ-ray efficiency of scintillation detectors for coaxial small-diameter disk sources [8]. It was later extended to include coaxially placed larger-diameter circular disk sources [9]. They have reported the agreement between their calculated values of total efficiency and the corresponding published data. However, their analytical expressions are limited to specific geometrical arrangements. Any deviation from these source-detector arrangements entails complicated calculations. As a result, the extendibility of the technique is limited. An analytical treatment of the total efficiency for off-axial disk sources has not been carried out so far. Recently, Abbas has applied an analytical approach for scintillation and other well-type detectors used for *in-situ* measurements, but it also lacks easy extendibility to wider variations of geometrical arrangements [10, 11].

In view of the above-mentioned limitations, a primary interaction based methodology has been developed in this work which is applicable to both point and thin circular disk sources for coaxial and off-axial geometries. A biasing technique has been used for accelerating the convergence rate of total efficiency values. This methodology has been implemented in a Matlab-based computer program: disk source total efficiency estimation using the Monte Carlo method (DSEMC). Details of the geometry and simulation procedure, including the mathematical framework and structure of Monte Carlo simulations, are given in the next section. Comparisons of predictions of the DSEMC program with the corresponding results for co-axially located disk sources available in literature are presented latter on. New results on the variation of detector efficiency for off-axially located disk sources with the radii of the disks, various values of off-axial distance, various γ-ray energies, length and diameter variations of scintillation detectors are also given in this section.

MONTE CARLO SIMULATION STRUCTURE

We consider a cylindrical NaI(Tl) detector of radius R and length L along with a circular thin disk source of radius ω, as shown in fig. 1. The disk source is located at distance ρ from the origin in the z = 0 plane. The center of the front-face of the detector is at distance D from the origin in the z = 0 plane, with its axis parallel to the z-axis. As shown in fig. 1, for a randomly selected source point $Q(x_s, y_s, z_s)$ on the disk source, the dynamically adjusted biasing limits for both polar and azimuthal angles are: $\theta \quad [\theta_{\min}, \theta_{\max}]$, $\varphi \quad [\varphi_{\min}, \varphi_{\max}]$. Clearly, when ρ = = 0, co-axial geometry is obtained. Since the results

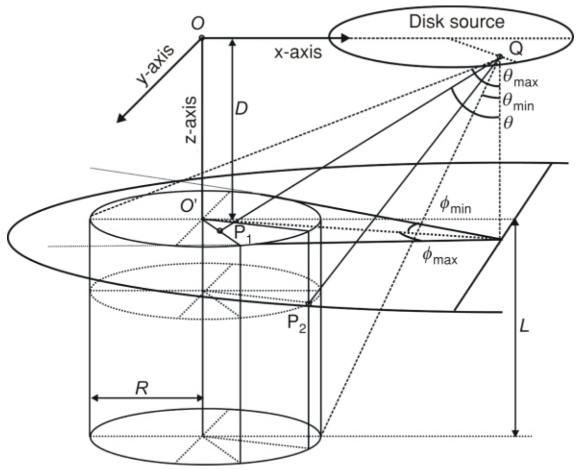

Figure 1. Details of the geometry of a cylindrical scintillation -ray detector and disk source at an off-axial location

need to be compared with data available in literature, these studies are also based on assuming no scattering from surroundings. Furthermore, the attenuation of incident photons in the entrance "window" is also neglected.

Mathematical foundation

The first step in the simulation is the random selection of co-ordinates of the source point Q(x_s, y_s, z_s) on the disk. This is carried out by random sampling of disk polar co-ordinates (r_s, θ_s) using the following relations

$$r_s \quad \omega\sqrt{n} \tag{1}$$

$$\theta_s \quad 2\pi n \tag{2}$$

where, n is a random number such that $n \quad [0, 1]$. For the disk source located at ρ off-axial distance, the co-ordinates of the random source point are

$$x_s \quad \rho \quad r_s \cos\theta_s \tag{3}$$

$$y_s \quad r_s \sin\theta_s \tag{4}$$

$$z_s = 0 \tag{5}$$

Now, a γ-ray photon is emitted in random direction (θ, φ), having energy E. Cosine-sampling has been used for the polar angle $\theta \quad [\theta_{\min}, \theta_{\max}]$ and uniform sampling for the azimuthal angle $\varphi \quad [\varphi_{\min}, \varphi_{\max}]$ range

$$\theta \quad \cos^{1}[(1 \quad n)\cos\theta_{\min} \quad n\cos\theta_{\max}] \tag{6}$$

$$\varphi \quad [(1 \quad n)\varphi_{\min} \quad n\varphi_{\max}] \tag{7}$$

where $n \quad [0, 1]$ is a random number and, as shown in fig. 1, the limits of polar and azimuthal angles are

$$\theta_{\min} = \begin{cases} \tan^{-1}\dfrac{\sqrt{x_s^2+y_s^2}-R}{D+L}, & \text{if } \sqrt{x_s^2+y_s^2} \geq R \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

$$\theta_{\max} = \tan^{-1}\frac{\sqrt{x_s^2+y_s^2}+R}{D} \tag{9}$$

and

$$\varphi_{\min} = \begin{cases} \tan^{-1}\dfrac{y_s}{x_s} - \sin^{-1}\dfrac{R}{\rho} & \text{if } \rho \geq R \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

$$\varphi_{\min} = \begin{cases} \tan^{-1}\dfrac{y_s}{x_s} + \sin^{-1}\dfrac{R}{\rho} & \text{if } \rho \geq R \\ 2\pi & \text{otherwise} \end{cases} \tag{11}$$

This photon can now enter NaI(Tl) crystal either through the side curved face or the top-flat face. To find the intersection point $P(x_p, y_p, z_p)$ of the photon path with the side curved face, we consider a straight line from $Q(x_s, y_s, z_s)$ to $P(x_p, y_p, z_p)$

$$\begin{aligned} x_p &= x_s + \lambda\sin\theta\cos\varphi \\ y_p &= y_s + \lambda\sin\theta\sin\varphi \\ z_p &= z_s + \lambda\cos\theta \end{aligned} \tag{12}$$

where λ is the distance between P and Q points. This system of equations is subjected to the condition for cylindrical NaI(Tl) detector's curved face

$$x_p^2 + y_p^2 = R^2 \tag{13}$$

and this quadratic equation yields two possible values of λ: λ_1, λ_2 as roots. If both λ_1 and λ_2 are such that the corresponding values of z_p satisfy the $D \leq z_p \leq D+L$ condition and the intersection with the top-flat surface of the detector has been ruled out, then the point of intersection with the side curved face of the detector is found by using

$$\lambda = \min(\lambda_1, \lambda_2) \tag{14}$$

For the intersection of the incident photon path with the top-flat face of the detector, the following relation is satisfied

$$\lambda = \frac{D - z_s}{\cos\theta} \tag{15}$$

therefore, the set of eqs. 12 becomes

$$\begin{aligned} x_p &= x_s + (D - z_s)\tan\theta\cos\varphi \\ y_p &= y_s + (D - z_s)\tan\theta\sin\varphi \end{aligned} \tag{16}$$

Clearly, if $(x_p^2 + y_p^2)^{1/2} \leq R$ is satisfied, then the photon enters the NaI(Tl) detector through the top flat face at $P(x_p, y_p, z_p)$ with x_p, y_p values given by eqs. 16.

After determining the co-ordinates of the point of entry $P(x_p, y_p, z_p)$ of the photon into the NaI(Tl) detector, the free-flight distance ξ traveled by the photon before interaction is found by using

$$\xi = -\frac{1}{\mu}\ln n \tag{17}$$

where μ is the linear attenuation coefficient of the NaI(Tl) detector at energy E and n – the random number in the [0, 1] range. Then, the co-ordinates of the primary interaction point $T(x_p, y_p, z_p)$ are computed using

$$\begin{aligned} x_d &= x_p + \xi\sin\theta\cos\varphi \\ y_d &= y_p + \xi\sin\theta\sin\varphi \\ z_d &= z_p + \xi\cos\theta \end{aligned} \tag{18}$$

Point $T(x_d, y_d, z_d)$ is inside the detector if $(x_d^2 + y_d^2)^{1/2} \leq R$ and $D \leq z_d \leq D + L$. For this condition, the photon counting *score* is incremented by $F_\theta F_\varphi$

$$score = score + F_\theta F_\varphi \tag{19}$$

where F_θ and F_φ are polar and azimuthal biasing factors, respectively, and have values

$$F_\theta = \frac{\cos\theta_{\min} - \cos\theta_{\max}}{2} \tag{20}$$

$$F_\varphi = \frac{\varphi_{\max} - \varphi_{\min}}{2\pi} \tag{21}$$

Product $F_\theta F_\varphi$ represents the fraction of the total solid angle that couples the radiation source and the detector.

This procedure of starting a photon history from a random point on the disk source till its primary interaction is repeated for N number of photons where N is 10^4. Details of the primary interaction Monte Carlo algorithm are given in fig. 2.

The total efficiency $\varepsilon_{tot}(E)$ of the NaI(Tl) detector is found by using

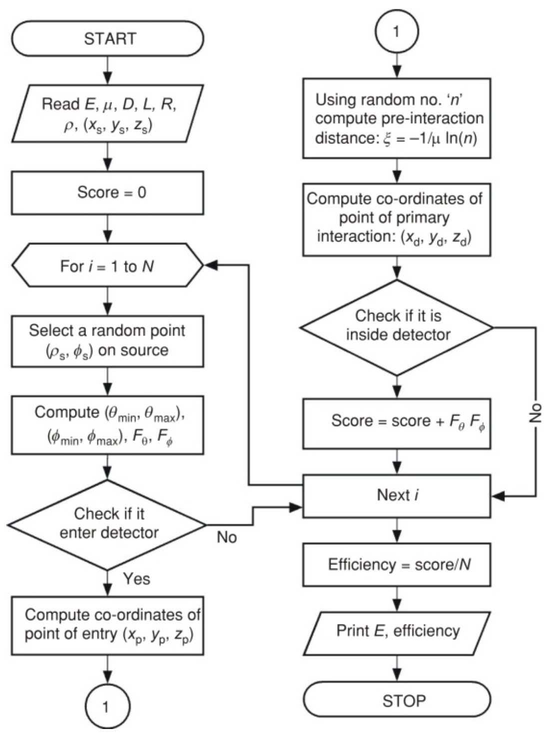

Figure 2. Flowchart of the biased primary interaction Monte Carlo algorithm for disk sources

$$\varepsilon_{\text{tot}}(E) \quad \frac{score}{N} \tag{22}$$

In these simulations, the data for the incoherent total linear attenuation coefficient μ at various values of γ-ray energies for the NaI(Tl) detector were obtained using the XCOM software by Berger *et al*. [12].

RESULTS AND DISCUSSION

In this work, a primary interaction based Monte Carlo simulation with a biasing DSEMC program has been developed for the determination of the total detection efficiency of cylindrical NaI(Tl) detectors for both axially and off-axially located thin disk γ-ray sources. In the DSEMC program, fast convergence is achieved by utilizing a dynamic biasing technique yielding a fraction of a percent standard deviation for typical values of total efficiency in about 10^4 histories, many orders of magnitude smaller than the number of histories generally required by standard Monte Carlo techniques.

For 0.5 MeV -rays, the variation of the total detection efficiency of a 3" 3" (7.62 cm 7.62 cm) NaI(Tl) detector with the radius of a co-axially placed circular disk source in the 0-7 cm range has been studied for various source-to-detector distances D, ranging from 0-50 cm range. For this purpose, the DSEMC program has been used and the predicted values have been compared with the corresponding results obtained by direct analytical calculations [8, 9], shown in fig. 3. As can be seen, the predictions of the DSEMC program are in good agreement with values obtained by the direct analytical technique.

The DSEMC program has been used for the analysis of the energy dependence of the total efficiency for various radii of circular thin disk sources ranging from 0-2 cm. As shown in fig. 4, the DSEMC-predicted variation of the total detection efficiency ε_{tot} with $E_\gamma \in$ [0.1, 20] in the MeV range is in good agreement with the corresponding results obtained by direct analytical calculations. The total efficiency of NaI(Tl) detectors for off-axially located thin disk sources has also been studied by using the primary interaction based Monte Carlo approach. This is indicative of the fact that the proposed approach is flexible and can easily be extended to other geometries, while remaining computationally efficient. The variation of the total efficiency for a 3" 3" NaI(Tl) detector with disk sources of different radii in the 0-7 cm range for D = 1 cm, ρ = 1 cm, and E_γ in the range of 0.05-20 MeV has been studied using the DSEMC program and the corresponding results are shown in fig. 5. An increase in the radius of the disk is followed by a decreasing trend in the values of total efficiency. As seen in fig. 5, as γ-ray energy increases, total efficiency first decreases and then, after passing through a minimum value, subsequently increases. This is consistent

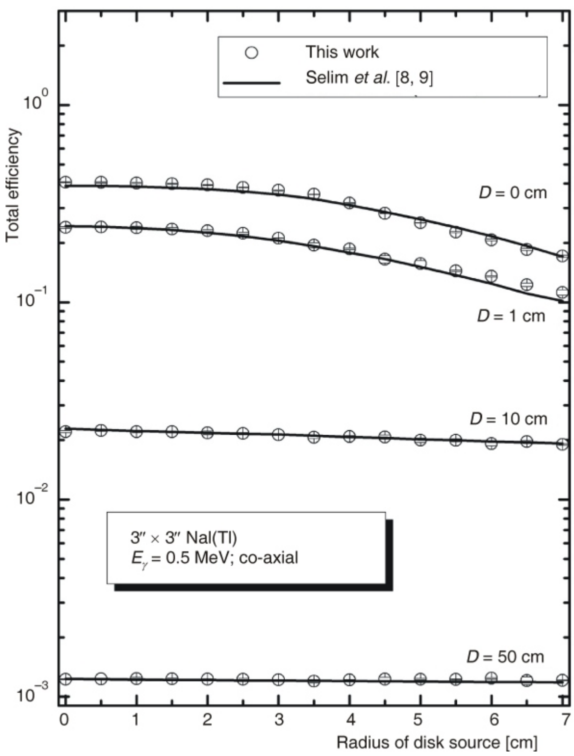

Figure 3. Comparison of the disk source radius dependent total detection efficiency for a 3 3 NaI(Tl) detector of 0.5 MeV γ-rays with corresponding results using the direct method for various indicated values of axial source-to-detector distances

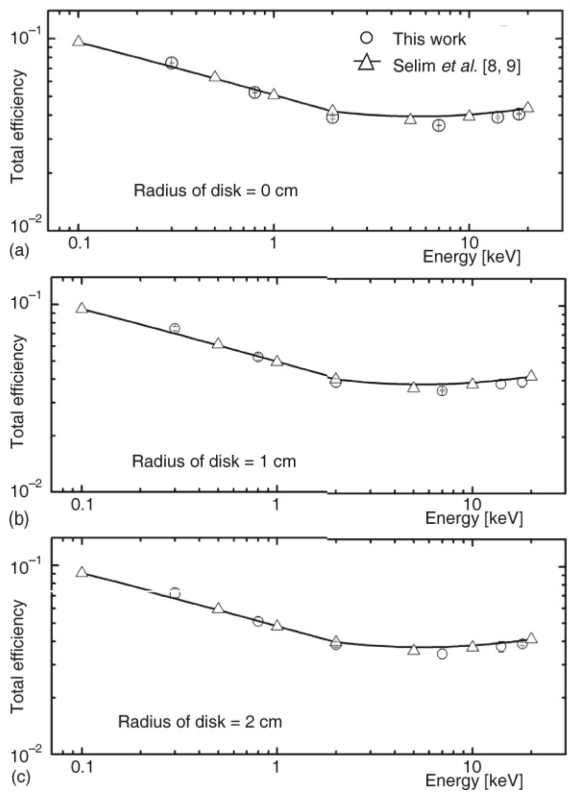

Figure 4. Variation of the total detection efficiency of a 3 3 NaI(Tl) detector with the γ-ray energy for various indicated values of radii of the disk sources

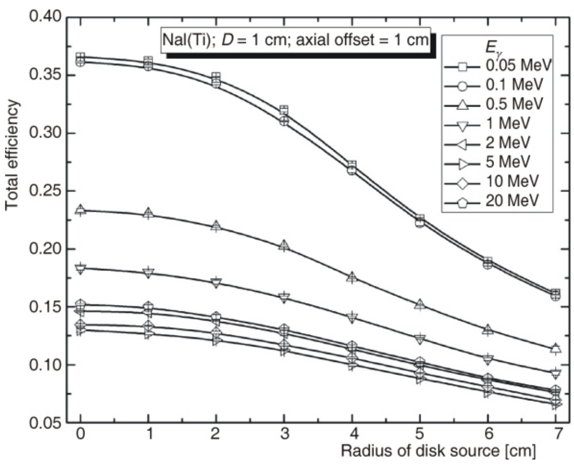

Figure 5. Variation of the total detection efficiency of a 3 3 NaI(Tl) detector with the radius of the disk source for various indicated values of γ-ray energies

with the expected behavior, since the energy dependence of the corresponding attenuation coefficient μ of the detector dominates the energy dependence of the total efficiency and μ is known to exhibit this type of energy dependence. For the same γ-ray energy, total efficiency reduces with the increase in the radius of the disk source. These trends are consistent with the expected behavior. As the -ray energy increases, the value of linear attenuation coefficient decreases, thereby reducing total efficiency. Similarly, in cases of fixed γ-ray energy, as the radius of the disk source is increased, the points near the outer periphery, further away from the detector, will have a smaller subtended solid angle and, therefore, a smaller contribution to the total efficiency which, in turn, tends to reduce total efficiency.

Tables 1-3 give the numerical values of the total efficiency for a 3" 3" NaI(Tl) detector for off-axial disk sources of different radii, ranging from 0-7 cm, with ρ = 1, 5, and 10 cm and -ray energies in the 0.05-20 MeV range. Typically, the values of total efficiency exhibit a decreasing trend with the increase in the radius of the disk source which is consistent with the expected behavior. Because, as explained above, the points near the outer periphery of the thin disk source at a larger distance from the detector have smaller values of subtended solid angles, as a result, their contribution to the total efficiency is smaller. The same decreasing behavior is seen in the values of total efficiency as off-axial distance is increased which is, again, consistent with the expected variation, due to the reduction of the solid angle.

Table 1. Values of total efficiency of a 3" 3" cylindrical NaI(Tl) detector at ρ = 1 cm for various γ-ray energies at indicated values of circular thin disk source radii ω

ω [cm]	E_γ [MeV]							
	0.05	0.1	0.5	1	2	5	10	20
0	3.6576E-01	3.6139E-01	2.3322E-01	1.8340E-01	1.4619E-01	1.2999E-01	1.3456E-01	1.5195E-01
1	3.6240E-01	3.5793E-01	2.3049E-01	1.7985E-01	1.4547E-01	1.2703E-01	1.3363E-01	1.4992E-01
2	3.4867E-01	3.4285E-01	2.1934E-01	1.7127E-01	1.3799E-01	1.2135E-01	1.2782E-01	1.4130E-01
3	3.1985E-01	3.1038E-01	2.0274E-01	1.5816E-01	1.2745E-01	1.1259E-01	1.1710E-01	1.3079E-01
4	2.7229E-01	2.6774E-01	1.7511E-01	1.4108E-01	1.1337E-01	9.9855E-02	1.0601E-01	1.1599E-01
5	2.2588E-01	2.2221E-01	1.5141E-01	1.2251E-01	9.9604E-02	8.8264E-02	9.2775E-02	1.0242E-01
6	1.8915E-01	1.8643E-01	1.2958E-01	1.0485E-01	8.6753E-02	7.6505E-02	8.0969E-02	8.8156E-02
7	1.6160E-01	1.5916E-01	1.1331E-01	9.2837E-02	7.6054E-02	6.5893E-02	6.9539E-02	7.7940E-02

Table 2. Values of total efficiency of a 3" 3" cylindrical NaI(Tl) detector at ρ = 5 cm for various γ-ray energies at indicated values of circular thin disk source radii ω.

ω [cm]	E_γ [MeV]							
	0.05	0.1	0.5	1	2	5	10	20
0	6.9298E-02	6.8196E-02	4.9750E-02	4.0099E-02	3.4098E-02	2.9929E-02	3.1769E-02	3.4862E-02
1	6.9636E-02	6.8890E-02	4.9717E-02	4.0939E-02	3.3522E-02	2.9263E-02	3.1371E-02	2.4672E-02
2	6.7953E-02	6.7294E-02	4.8696E-02	3.9812E-02	3.3113E-02	2.9002E-02	3.0678E-02	3.3322E-02
3	6.6728E-02	6.5967E-02	4.7089E-02	3.8447E-02	3.0911E-02	2.7975E-02	2.9612E-02	3.2795E-02
4	6.5073E-02	6.4165E-02	4.6534E-02	3.7399E-02	3.0765E-02	2.8096E-02	2.8794E-02	3.1806E-02
5	6.4579E-02	6.3213E-02	4.4384E-02	3.5794E-02	2.9931E-02	2.7252E-02	2.7552E-02	3.0704E-02
6	6.2326E-02	6.1457E-02	4.3237E-02	3.5195E-02	2.8972E-02	2.6088E-02	2.6824E-02	2.9899E-02
7	5.9280E-02	5.7907E-02	4.2337E-02	3.3620E-02	2.7825E-02	2.4764E-02	2.5782E-02	2.8718E-02

Table 3. Values of total efficiency of a 3 3 cylindrical NaI(Tl) detector at ρ = 10 cm for varius γ-ray energies at indicated values of circular thin disk source radii ω

ω [cm]	E_γ [MeV]							
	0.05	0.1	0.5	1	2	5	10	20
0	2.3466E-02	2.3370E-02	1.6592E-02	1.3852E-02	1.1664E-02	1.0189E-02	1.0434E-02	1.2088E-02
1	2.2929E-02	2.2802E-02	1.6955E-02	1.3697E-02	1.1102E-02	1.0333E-02	1.0463E-02	1.1729E-02
2	2.3606E-02	2.2657E-02	1.7076E-02	1.3987E-02	1.1115E-02	1.0030E-02	1.0931E-02	1.1836E-02
3	2.3357E-02	2.2921E-02	1.6831E-02	1.3428E-02	1.1356E-02	1.0111E-02	1.0633E-02	1.1680E-02
4	2.3277E-02	2.2854E-02	1.6704E-02	1.3853E-02	1.1166E-02	1.0352E-02	1.0611E-02	1.1578E-02
5	2.2751E-02	2.2807E-02	1.6568E-02	1.3279E-02	1.1422E-02	1.0288E-02	1.0540E-02	1.1385E-02
6	2.2731E-02	2.3345E-02	1.6610E-02	1.3379E-02	1.1197E-02	9.8820E-03	1.0446E-02	1.1773E-02
7	2.2426E-02	2.2273E-02	1.6541E-02	1.3127E-02	1.0760E-02	1.0008E-02	1.0457E-02	1.1033E-02

These tables also show a decreasing trend followed by a rising trend in the values of ε_{tot} as the energy of incident γ-rays is increased. This behavior matches the corresponding variation of the total attenuation coefficient μ with energy. Since detector efficiency is directly related with the energy dependent attenuation properties of the NaI(Tl) crystal, the observed variation of ε_{tot} is consistent with the expected behavior.

Lastly, the DSEMC program has been used for the study of the dependence of ε_{tot} on the dimensions of the cylindrical NaI(Tl) detector for various thin circular disk sources of different radii. Figures 6 and 7 show the corresponding dependence on detector length and radius, respectively. Figure 6 shows detector total efficiency approaching maximum limiting values as the detector length increases in the 1-20 cm range. This is due to the fact that a dominant fraction of incident photons have a primary interaction within a few mean free paths from the entry point, while only a small fraction penetrates greater depths of the detector. Therefore, the incremental gain in the total efficiency decreases with increasing values of detector length L and, as a result, total efficiency approaches the corresponding maximum value.

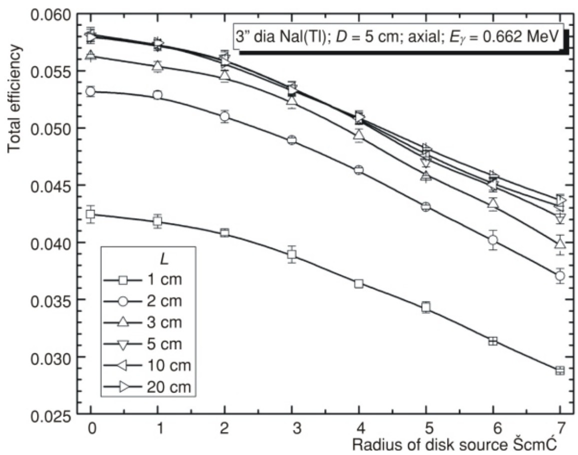

Figure 6. Variation of the total detection efficiency of a cylindrical NaI(Tl) detector with a 3 diameter and the radius of the disk source for indicated values of detector length *L*

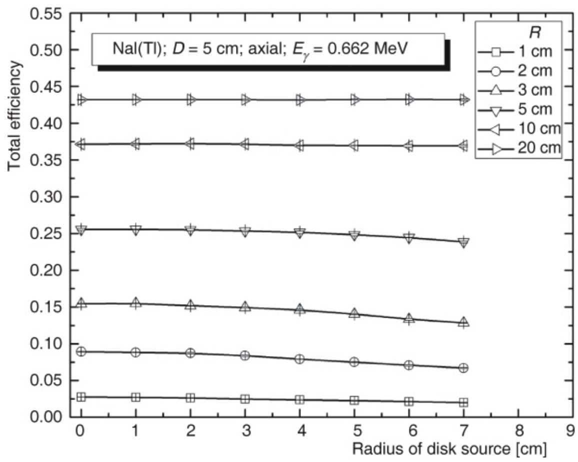

Figure 7. Variation of the total detection efficiency of a cylindrical NaI(Tl) detector with a 3 length and the radius of the disk source for indicated values of detector radii

A similar trend of approaching maximum values of ε_{tot} is found as the detector radius increases within the 1-20 cm range. This behavior has been observed for various thin disk sources with radii in the 0-7 cm range and corresponding results are shown in fig. 7. This is consistent with the expected approach to the maximum value of ε_{tot} following the increase in the solid angle caused by the increase in the detector radius.

CONCLUSIONS

The novel, primary interaction based Monte Carlo methodology has been found effective for the determination of the total efficiency of NaI(Tl) detectors for thin circular disk sources. This methodology has been implemented in a Matlab based computer program, the DSEMC. Fast convergence has been attained by utilizing a dynamic biasing technique which yields a fraction of a percent standard deviation in about 10^4 histories, two orders of magnitude smaller than the conventional Monte Carlo technique.

When total efficiency is concerned, the predictions of the DSEMC program and the results of direct analytical calculations have been found to be in excellent agreement for an axially located thin disk source for various values of source-to-detector distances in both the 0-20 cm range and various radii of disk sources in the 0-2 cm range. The DSEMC program has been used to study the variations of ε_{tot} with the radius of the disk source for off-axial configuration having ρ in the 1-10 cm range and photon energy E_γ in the 0.05-20 MeV range. This program has also been used for studying the dependence of ε_{tot} on the radius and length of the NaI(Tl) scintillator for various values of disk source radii in the 0-7 cm range and E_γ = 0.662 MeV. Observed behavior matched expected variations in each case.

ACKNOWLEDGEMENT

Shakeel-ur-Rehman gratefully acknowledges the financial support of the Higher Education Commission (HEC), Pakistan, for the Ph. D. (Indigenous) fellowship under scholarship No. 17-5-I(P-160)/HEC/Sch/2004.

REFERENCES

[1] Perez-Andujar, A., Pibida, L., Performance of CdTe, HpGe and NaI(Tl) Detectors for Radioactivity Measurements, *Applied Radiation and Isotopes, 60* (2004), 1, pp. 41-47
[2] Abbas, M. I., Analytical Calculation of the Solid Angles Subtended by a Well-Type Detector at Point and Extended Circular Sources, *Applied Radiation and Isotopes, 64* (2006), 9, pp. 1048-1056
[3] Grosjean, C., On the Absolute Detection Efficiency of a Cylindrical Scintillation Phosphor in the Case of an Extended Plane γ-Ray Source, *Nucl. Instr. and Meth., 17* (1962), 3, pp. 289-309
[4] Nakamura, T., Monte Carlo Calculation of Efficiencies and Response Functions of NaI(Tl) Crystals for Thick Disk Gamma-Ray Source and its Application to Ge(Li) Detectors, *Nucl. Instr. and Meth., 105* (1972), 1, pp. 77-89
[5] Rehman, S., Mirza, S. M., Mirza, N. M., A Fast, Primary-Interaction Monte Carlo Methodology for Determination of Total Efficiency of Cylindrical Scintillation Detectors, *Nuclear Technology & Radiation Protection, 24* (2009), 3, pp, 195-203
DOI: 10.2298/NTRP0903195R
[6] Belluscio, M., De Leo, R., Pantaleo, A., Vox, A., Efficiencies and Response Functions of NaI(Tl) Crystals for Gamma-Rays from Thick Disk Sources, *Nucl. Instr. and Meth., 118* (1974), 2, pp. 553-563
[7] Moens, L., De Donder, J., Xilei, L., De Corte, F., De Wispelaere, A., Simonits, A., Hoste, J., Calculation of the Absolute Peak Efficiency of Gamma-Ray Detectors for Different Counting Geometries, *Nucl. Instr. and Meth., 187* (1981), 2-3, pp. 451-472
[8] Selim, Y., S., Abbas, M. I., Fawzy, M. A., Analytical Calculation of the Efficiencies of Gamma Scintillators, Part I: Total Efficiency for Coaxial Disk Sources, *Radiation Physics and Chemistry, 53* (1998), 6, pp. 589-592
[9] Selim, Y., S., Abbas, M. I., Analytical Calculation of Gamma Scintillators Efficiencies-II. Total Efficiency for Wide Coaxial Circular Disk Sources, *Radiation Physics &. Chemistry, 58* (2000), 1, pp. 15-19
[10] Abbas, M. I., Analytical Formulae for Well-Type NaI(Tl) and HPGe Detectors Efficiency Computation, *Applied Radiation and Isotopes, 55* (2001), 2, pp. 245-252
[11] Abbas, M. I., Analytical Calculations of the Solid Angles Subtended by a Well-Type Detector at Point and Extended Circular Sources, *Applied Radiation and Isotopes, 64* (2006), 9, pp. 1048-1056
[12] Berger, M. J., Hubbell, J. H., XCOM Version 3.1 NIST Standard Reference Database, 1999 http://www.physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html.

Received on March 31, 2010
Accepted on August 13, 2010

Шакил У. РЕХМАН, Сикандер М. МИРЗА, Насир М. МИРЗА

СИМУЛАЦИЈА УКУПНЕ ЕФИКАСНОСТИ ЦИЛИНДРИЧНИХ СЦИНТИЛАЦИОНИХ ГАМА ДЕТЕКТОРА ЗА ИЗВОРЕ У ОБЛИКУ ДИСКА

Одређена је укупна ефикасност цилиндричних сцинтилационих гама детектора употребом новог Монте Карло алгоритма заснованог на примарној интеракцији. Коришћењем редукције варијансе у симулацијама, овај поступак убрзава прорачун конвергирајући решењима са стандардном грешком мањом од дела једног процента при 10^4 историја – што је око два реда величине ниже од конвенционалних стохастичких техника. Методологија је имплементирана у компјутерски програм DSEMC, са МАТЛАБ основом. За изворе у виду танког диска различитих полупречника и коаксијалних конфигурација, показало се да су предвиђања DSEMC програма изванредно сагласна са одговарајућим резултатима добијеним директним аналитичким поступком. За коаксијалне изворе промењљивог полупречника, и у широком подручју гама енергија, потврђена је слична сагласност између израчунатих вредности укупне ефикасности помоћу програма DSEMC и одговарајућих резултата добијених непосредним аналитичким поступком.

Програм DSEMC коришћен је такође за одређивање укупне ефикасности детекције за неаксијалне конфигурације. Са увећањем полупречника диска извора зрачења, резултати показују постепено слабљење укупне ефикасности. За ове конфигурације, енергетска зависност укупне ефикасности прати промену одговарајућег укупног коефицијента слабљења, што се могло очекивати. За изворе у облику коаксијалног танког диска, укупна ефикасност детекције приближава се одговарајућој максималној вредности како се дужина детектора увећава од 1 cm до 20 cm, за различите вредности полупречника диска и различите енергије гама зрачења, а за стални пречник детектора од 7,62 cm. Слично понашање је примећено када се полупречник детектора увећава од 1 cm до 20 cm, а задржава дужина детектора од 7,62 cm, за различите вредности полупречника диска и различите енергије гама зрачења.

Кључне речи: гама детектор, укупна ефикасност, извор у облику диска, Монте Карло симулација