

Radioactive Source-Detector System: Design and Monte Carlo Opinion

Zainab kareem Ali \bigcirc , Ali N. Mohammed *

Department of Physics, College of Education, Mustansiriyah University, Baghdad, Iraq. *Corresponding Author.

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Abstract

In the current research, a computer simulation program was designed and written according to the Monte Carlo method to serve as a virtual practical system instead of a real one. The program has been statistically, geometrically and numerically tested for virtual radioactive source-detector setup. The simulation program is carried out for NaI(Tl) detector, and once for Gieger-Muller counter, for a range of energy up to 10 MeV. The Law of Large Numbers and the Central Limit Theorem were used to test the accuracy and precision of the program's workflow and an indication of how the results are close to their averages and, statistically, how they tend to a normal distribution. Generally, results of a number of detector efficiency types showed a high agreement with published experimental and several global codes results within a percentage error of ~ 0.02-5% (i.e. the accuracy ~ 95-99.98%) and the significance level reflects the precise of the algorithm of simulation. The accurate and precise estimation of the current simulation gives it the desired reliability. The current simulation program also showed flexibility and effectiveness in designing any nuclear sourcedetector system and providing the relevant workers or experimenters with indicators that help in the optimal design of a system in terms of equipment and geometrical configuration with the least time. It may take a few seconds to a few minutes of execution time for a personal computer with normal specifications. Unlike laboratory experiments which may take from several minutes to several hours. In addition, it provides an ideal work environment that is completely free of radiation hazards. Also, the current simulation provides a deep understanding of the interactions that occur in a real physical practical system.

Keywords: Central limit theorem, Large numbers law, Monte Carlo simulation, NaI(Tl) detector efficiency, Radiation counting statistics.

Introduction

Designing and testing a particular detection system usually brings some financial costs and time considerations¹. Numerical Simulation can be an effective and economical alternative tool. Monte Carlo simulation is a numerical simulation method that mimics physical phenomena and can be thought of as an 'experiment' carried out on a personal computer. Since Monte Carlo is a simulation of stochastic processes^{2,3}, therefore, it can be used for designing and analyzing radiation detectors. This is because detector responses are derivable from Measurable quantities such as particle flux or current densities, that can be interpreted as expected of a statistical system.

In nuclear and radiation physics, one of the main reasons to implement Monte Carlo simulation is that, in many practical cases, it is difficult to provide calibrated radioactive-sources that cover all energy ranges; furthermore, these sources are obviously limited regarding to their dimensions and compositions. With, by Monte Carlo technique, one

can reproduce, flexibly, any experimental circumstances, whatever complicated⁴. Another clear advantage of this approach is the short computation time.

As can be done by experimental^{5,6} or theoretical^{7,8} approaches, Monte Carlo technique has been used in gamma detection techniques which have a fundamental role in the field of gamma-rays spectroscopy^{9,10} applied in nuclear physics, radiation measurement of environmental samples radiation dosimetry¹¹⁻¹⁵, medical radiography¹⁶, neutron

Materials and Methods

The proposed configuration for the current simulation is shown in Fig. 1 including, a 'virtual', radioactive source and detector (for example type of NaI(Tl)), in the coordinates system. The source lies within the fixed dimensions system with Cartesian coordinate axes $(x,y,z)^{20}$ to determine the position of the source with respect to the axial z-axis.



Figure 1. The suggested design for the present source-detector systems simulation, the trajectory t represents a propagating "beam" of γ -ray that passes through point r in many of random directions.



activation analysis¹⁷, well logging¹⁸, and study of cosmic rays¹⁹.

Monte Carlo simulation computer program, as a virtual setup, was designed and written to be used instead of a real experimental system. The achievements concerning time assumption and flexibility versus the complicated were verified. A number of statistical, geometrical and characteristic parameters concerning the detection system have been estimated.

(a) Fixed dimensions system and, (b) Reference dimensions system. Where, (b1) The Cartesian coordinate system (x, y, z) and, (b2) The Spherical coordinate system (r, θ, φ) , where *r* is the radial distance from the origin, θ with the range $0 \le \theta \le \pi$ is the polar (or zenith) angle and φ with range $0 \le \varphi \le 2\pi$ is the azimuthal angle.

While the space outside of the source volume towards the detector lies within the reference dimensions system with spherical coordinate axes $(r,\theta,\varphi)^{20}$ to follow the random geometric projections of emitted photons from the source on the planes of the detector and to determine the random probabilities of whether or not a photons they were to fall and be detected. The distance between the source and the detector can change. Based on the suggested configuration, a Fortran95 program for Monte Carlo simulation has been developed. It was designed and written to depict the interaction processes that occurred when the photon beam came into the detector, the results of which are that only the photons that are incident within a solid angle covered by the detector are to be impinging with the front face of the detector. These photons, later, are to be registered (counted) after satisfying a number of concern conditions as will be explained. These registered events allowed us to study "virtually" the the experimental characteristics of system concerning geometrical characteristics of a system. The present program is executed by Compaq Visual Fortran Professional edition 6.6.0, 2000 compiler package under windows 10.

The attenuation in the material of the radioactive source and in the air between the source and detector are neglected. The particles are transferred using the eq. 1^{21} :

$$\vec{x} = \vec{x_o} + \vec{u}s \cdots \cdots 1$$

where: $\vec{x_o}$ is initial position, \vec{x} is a new position with \vec{u} direction and *s* is the distance that the particle travels before it intersects with a plane of a specific region.

In calculating particle transport in Monte Carlo as well as ray-tracing algorithms, a common problem is finding the distance a particle must travel in order to intersect a particular surface. Therefore the distribution function method can be used to sample the distributed photon path length. The probability function is given by Eq. 2^{22} :

$$p(x) = \mu_l \exp(-\mu_l x) \cdots 2$$

where: μ_l is the linear attenuation coefficient for a certain medium.

Briefly, the history of photons can be illustrated in the following algorithm:

- 1. Based on simple linear congruential generators $(LCG)^{21}$, generate two random numbers Rn_1 and Rn_2 into the interval (0, 1).
- 2. In fixed coordinates, using Eq. 1 to determine the random gamma emitting position from a radioactive source, with r_s Radius, $(x_s, y_s, z_s)^{22}$:

$$x_{s} = r_{nx} + r_{s} \cos \theta_{o} \cdots \cdots 3a$$
$$y_{s} = r_{s} \sin \theta_{o} \cdots \cdots 3b$$
$$z_{s} = 0 \cdots \cdots 3c$$

where r_{nx} is off-axial location of source. Then a certain counter called emitting photon is increasing.

- 3. As in step 1, generate two random numbers Rn_3 and Rn_4 within range [0,1].
- 4. By using cosine sampling²¹, Forced formulas have estimated the values of incident angles of photons on the front face of the detector²²,

$$\theta_i = \cos^{-1} \left(\left((1 - Rn_3) \cos \theta_{min} \right) + (Rn_3 \cos \theta_{max}) \right) \dots \dots 4a$$

$$\varphi_i = \left(\left((1 - Rn_4)\varphi_{min} \right) + (Rn_4\varphi_{max}) \right) \qquad \dots \dots 4b$$

^{5.} In the reference dimensions system, Fig. 1 b2 sampling Eq. 1 in spherical coordinates to locate the intersection point of random gamma photon



path with the front face of the detector $(x_s^{df}, y_s^{df}, z_s^{df})$,²²

$$x_s^{df} = x_s + t_s^{df} \sin \theta_i \cos \varphi_i \cdots 5a$$

$$y_s^{df} = y_s + t_s^{df} \sin \theta_i \sin \varphi_i \cdots 5b$$

$$z_s^{df} = z_s + t_s^{df} \cos \theta_i \cdots 5c$$

6. Calculate the spherical projection radius of a gamma-ray on the front detector face r_{df} , where:

$$r_{df} = \left(x_s^{df} + y_s^{df}\right)^{1/2} \cdots \cdots 6$$

- 7. If $r_{df} > r_d$, this means that the radius of the spherical projection of the photon is greater than the radius of the front face of the detector. Then the photon was rejected, a certain counter called non -incident is increasing, and come back to step 1, else a certain counter called incident photon is increasing, then continue.
- 8. Generate one random number $Rn_5: 0 \le Rn_5 \le 1$
- 9. Solve the probability function²², Eq. 2, to determine the free path-length of gamma photon within/not the active medium of detector gives:

$$l_{f.p.} = \frac{1}{\mu_l} \ln(1 - Rn_5) \cdots \cdots 7$$

10. From steps (5 and 9), estimate the photon interaction position location within the detector, that is, (x_d^w, y_d^w, z_d^w) , then²²:

$$x_d^w = x_s + (l_{f.p.} + t_s^{df}) \sin \theta_i \cos \varphi_i \cdots \otimes 8a$$

$$y_d^w = y_s + (l_{f.p.} + t_s^{df}) \sin \theta_i \sin \varphi_i \cdots \otimes 8b$$

$$z_d^w = z_s + (l_{f.p.} + t_s^{df}) \cos \theta_i \cdots \otimes 8c$$

11. Calculate the spherical projection radius of a gamma-ray on the detector planes, r_{dw} . Where:

$$r_{dw} = (x_d^w + y_d^w)^{1/2} \cdots \cdots 9$$

- 12. With exception when $r_{dw} < r_d$ and $d_{sd} < z_d^w < (d_{sd} + h_d)$, the photon must be rejected and a certain counter called unregistered photons are increasing, then come back to step 1, otherwise a certain counter called registered photons are increasing, then continue.
- 13. Classification of the registered photon according to the type of interaction (photo-electric,



Compton scattering or pair production) depending on the probability of occurrence of that interaction.

- 14. Repeat the above steps of the algorithm by the number of emitted photons from the radioactive source.
- 15. Ordering the results in particular files.

The total efficiency of the detector was estimated by comparing the number of registered photons and those that were emitted from the source. While, the intrinsic efficiency was estimated by the ratio of registered photons number to those that hit the front face of the detector. The geometric efficiency was estimated by comparing the number of photons that hit the front face of the detector and those that were emitted from the source.

The values of mass attenuation coefficients for the active medium of detector were calculated using the XCOM program²³.

For more Accurate validation, GM-counter system (type ABG, CAT: PA1885-020-030) as shown in Fig. 2 was used to validate, experimentally, some findings of the present simulation.



Figure 2. Uncovered (to illustration) ¹³⁷Cs radioactive source- GM counter configuration.

Results and Discussion

The random nature of radiation interaction with matter must be explained and interpreted according to probabilistic terms. Two of the main results in probability: are the Law of Large Numbers (LLN)²⁴ and the Central Limit Theorem (CLT)²⁴. Both are related to sums of independent random varibles⁶ that are included in the above algorithm. So, to complete the calculations with an accurate estimation of the value to be calculated, it must be re-implemented for a suitable large number of photon histories based on the LLN. Fig. 3. Exhibits a smaller number of trials for 10, 10^2 and 10^3 do not effectively estimate value conformity with a standard or observed value (one of values of Hoang²⁵). While, the result of 10⁴ and 10⁵ trials produce a values are close to observed value. Concern 10⁶ trials, the resultant are the closest with the smallest percentage error rate and highest accuracy.



Figure 3. A clarification of the law of large numbers using a particular run of the simulation.

These accuracy values refer to how Monte Carlo values get closer to the observed values up to 99.9%. However this test is insufficient to assess the performance of present simulation, because these values are based, in their calculation, on independent

random variables. Consequently, besides the LLN, the CLT is considerably useful in precisely predicting the characteristics of these random variables and how they are distributed.

The experimental curve in Fig. 4 is the result of statistical repetitions of series of one hundred 1 minute counts of a Cs-137 source made with G-M laboratory counter set up which is shown in Fig. 2.



Figure 4. Experimental and simulated frequency distrbution curves.

While, the simulated curves in Fig.4 are the result of a series of one hundred 10, 10^2 and 10^6 history of photons for 662 keV that was executed to mimic the experimental setup that is shown in Fig. 2. The distribution curve of 10 history of photons is not normal, right another hump is formed. As for the curve of 100 history of photons is not precise enough to be normal. While the identical is clear between the experimental and simulated 10⁶ history of photons curves and the variation between them is, axiomatically, due to random error introduced by radionuclide decay that is a randomly varying quantity. Therefore, repetition of more measurements, the measurements tend to be a normal distribution, as stated in the central limit theorem. Thats is, the values close to the expected value are more frequent than values that are far from them.

The average value for the results of series of 1 minute counts of a Cs-137 source made with G-M counter was 1940 C/1mint. with 40.4 of standard deviation and chi square (χ^2) 24.43. It took about 1.5 hours. Whereas for a series of one hundred 10⁶ history of photons for 662 keV, the average was 250196 count with 449.5 of standard deviation and chi square 79.942. It took about 5 minutes. From the table of χ^2



values, the experimental and simulated significance level was 0.706 and 0.77 respectively. This indicates that the results reflect feasible instrument operation and the precision of the performance of the measurement system and the algorithm of simulation. The accurate and precise estimation of the current simulation gives it the desired reliability.

Fig. 5 depicts an additional representation of the total and partial attenuation coefficients for γ -rays, which were obtained through the current simulation of a 3"×3" NaI(Tl) detector at specific energies of a radioactive source. The attenuation coefficient, in probabilistic terms, describes how radiation interacts with matter. As a function of energy, Fig. 5 and Fig. 6 are identical.



Figure 5. Comparing the number of detected photons that interact by photoelectric, Compton scattering and pair production effects at particular energy.



Figure 6. Total and partial mass attenuation coefficients of NaI(Tl) detector material.

Fig.7 shows the dependence of the registered count by detector versus the distance between the radioactive source and detector face (D_{sd}) for varied volume values of NaI(Tl) detector. When D_{sd} increases, the registered count decreases, and after passing through minimum, then it increases again. Since mean free path length of gamma rays is the inverse of the total attenuation coefficient as shown in Fig. 8. Therefore, as a function of geometry, Fig. 7 is upside down to Fig. 8 and vice versa. Similar results have been reported by Hoang ²⁵, Urkiye ²⁶, Ogundare ²⁷ and Jehouani ²⁸.



Figure 7. Variation of the registered count rate of different size of NaI(Tl) detectors as a function of source to detector distance for 662 keV of gamma rays.





Figure 8. Mean free path length of various volume NaI(Tl) detectors as a function of Source-to-Detector distance at 662 keV of gamma rays.

Varying types of efficiency, as numerical factors, were mimicked to validate the present simulation. The outcomes, tabulated compared with published results ²⁶ for For $2'' \times 2''$ of NaI(Tl) detector at particular distances 0.001, 5,10 and 15 cm for different energies 150-3000 keV as shown in Table 1. The comparison exhibits high agreement within a percentage error of ~ 0.02-5%. For further distances between the source and detector, the program has been implemented as it showed a clear match whether with the experimental or calculated results as shown in Table 2.

				partic	cular d	istance	es for d	ifferen	t energ	jies.				
	D	compa	Energ	gy (keV))									
	(cm)	rison	150	200	300	400	500	600	661	800	1000	1332	2000	3000
		ref.25	0.49 88	0.48 42	0.41 92	0.36 58	0.33 18	0.30 74	0.29 4	0.27 38	0.25 09	0.22 95	0.19 64	0.17 93
	0.001	present M.C.	0.49 87	0.48 35	0.41 9	0.36 65	0.33 127	0.30 91	0.29 7	0.27 68	0.25 3	0.22 43	0.18 61	0.17 7
Tat		error %	0.02	0.14	0.05	0.19	0.16	0.55	1.02	1.10	0.84	2.27	5.24	1.28
al		ref.25	0.04 76	0.04 35	0.03 63	0.03 15	0.02 85	0.02 67	0.02 55	0.02 38	0.02 19	0.02	0.01 74	0.01 57
cien	5	present M.C.	0.04 78	0.04 34	0.03 635	0.03 17	0.02 87	0.02 68	0.02 59	0.02 41	0.02 21	0.01 973	0.01 637	0.01 564
су		error %	0.42	0.23	0.14	0.63	0.70	0.37	1.57	1.26	0.91	1.35	5.92	0.38
	10	ref.25	0.01 41	0.01 33	0.01 17	0.01 04	0.00 96	0.00 88	0.00 86	0.00 81	0.00 74	0.00 67	0.00 59	0.00 54
	10	present M.C.	0.01 43	0.01 34	0.01 172	0.01 044	0.00 956	0.00 899	0.00 868	0.00 811	0.00 749	0.00 67	0.00 56	0.00 534

Table 1. For 2"×2" of NaI(Tl) detector, Total, intrinsic and geometric efficiency comparison at particular distances for different energies.



		error %	1.42	0.75	0.17	0.38	0.42	2.16	0.93	0.12	1.22	0.03	5.08	1.11
Intr insi		ref.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	present	0.00	0.00	0.00	0.00	40 0.00	0.00	42 0.00	4 0.00	0.00	0.00	0.00	0.00
		M.C. error	657	628	561	508	468	441	428	402	372	334	281	268
		%	1.08	1.88	0.18	0.45	1.74	0.23	1.90	0.50	0.54	1.21	3.10	0.70
	0.001	ref.25	0.99 8	0.96 88	0.85 87	0.75 18	0.00 39	0.61 5	0.38 82	0.34 77	0.30 19	0.43 91	0.39 3	0.33 87
		present M.C.	0.99 74	0.96 72	0.83 81	0.73 31	0.66 25	0.61 83	0.59 53	0.55 36	0.50 7	0.44 87	0.37 23	0.35 4
		error	0.06	0.17	0.07	0.18	0.21	0.54	1.21	1.08	1.02	2.27	5.27	1.31
		ref.25	0.88	0.79	0.66	0.58	0.52	0.49	0.46	0.43	0.40	0.36	0.31	0.29
	5	present	0.87	99 0.79	75 0.66	0.58	9 0.52	08 0.49	99 0.47	0.42	24 0.40	95 0.36	0.30	0.28
		M.C. error	62 0 40	69 0 38	63 0 15	23 0.12	66 0.45	29 0.43	52 1 13	1 20	69 1 1 2	23 1 90	1 5.61	76
c effi		%	0.92	0.86	0.75	0.67	0.61	0.57	0.55	0.51	0.47	0.44	0.38	0.35
cien cy		ref.25	33	56	3	47	58	47	5	89	93	15	29	14
	10	M.C.	0.92 12	0.86 44	0.75 45	0.67 3	0.61 64	0.57 98	0.56	0.52 37	0.48 42	0.43 32	0.36 26	0.34 58
		error %	0.23	0.14	0.20	0.25	0.10	0.89	0.90	0.93	1.02	1.88	5.30	1.59
	15	ref.25	0.94 51	0.90	0.80 56	0.72 28	0.66 38	0.62 7	0.59 95	0.56 62	0.52 19	0.48 03	0.41 74	0.38 43
		present	0.94 28	0.90	0.80 29	0.72 37	0.66 62	, 0.62 72	0.60 81	0.57	0.52 75	0.47 41	0.39 79	0.38
		error	0.24	0.43	2)	57	02	72	01		15	71	1)	02
		A (U.24	0.42	0.34	0.12	0.36	0.03	1.43	0.67	1.07	1.29	4.67	1.07
		%	0.24 0.49	0.4 2 0.49	0.34 0.49	0.12 0.49	0.36 0.49	0.03 0.49	1.43 0.49	0.67 0.49	1.07 0.49	1.29 0.49	4.67 0.49	1.07 0.49
		% ref.25	0.24 0.49 98 0.49	0.42 0.49 98 0.49	0.34 0.49 98 0.49	0.12 0.49 98 0.49	0.36 0.49 98 0.49	0.03 0.49 98 0.49	1.43 0.49 98 0.49	0.67 0.49 98 0.49	1.07 0.49 98 0.40	1.29 0.49 98 0.49	4.67 0.49 98 0.49	1.07 0.49 98 0.49
	0.001	% ref.25 present M.C.	0.49 98 0.49 999	0.42 0.49 98 0.49 999	0.34 0.49 98 0.49 999	0.12 0.49 98 0.49 999	0.36 0.49 98 0.49 999	0.03 0.49 98 0.49 999	1.43 0.49 98 0.49 999	0.67 0.49 98 0.49 999	1.07 0.49 98 0.49 999	1.29 0.49 98 0.49 999	4.67 0.49 98 0.49 999	1.07 0.49 98 0.49 999
	0.001	%ref.25presentM.C.error%	0.24 0.49 98 0.49 999 0.03 8	0.42 0.49 98 0.49 999 0.03 8	0.34 0.49 98 0.49 999 0.03 8	0.12 0.49 98 0.49 999 0.03 8	0.36 0.49 98 0.49 999 0.03 8	0.03 0.49 98 0.49 999 0.03 8	 1.43 0.49 98 0.49 999 0.03 8 	0.67 0.49 98 0.49 999 0.03 8	1.07 0.49 98 0.49 999 0.03 8	 1.29 0.49 98 0.49 999 0.03 8 	 4.67 0.49 98 0.49 999 0.03 8 	1.07 0.49 98 0.49 999 0.03 8
	0.001	% ref.25 present M.C. error % ref.25	0.24 0.49 98 0.49 999 0.03 8 0.05 41	0.42 0.49 98 0.49 999 0.03 8 0.05 44	0.34 0.49 98 0.49 999 0.03 8 0.05 43	0.12 0.49 98 0.49 999 0.03 8 0.05 42	0.36 0.49 98 0.49 999 0.03 8 0.05 39	0.03 0.49 98 0.49 999 0.03 8 0.05 43	1.43 0.49 98 0.49 999 0.03 8 0.05 42	0.67 0.49 98 0.49 999 0.03 8 0.05 42	1.07 0.49 98 0.49 999 0.03 8 0.05 44	1.29 0.49 98 0.49 999 0.03 8 0.05 43	4.67 0.49 98 0.49 999 0.03 8 0.05 45	1.07 0.49 98 0.49 999 0.03 8 0.05 42
Geo	0.001	% ref.25 present M.C. error % ref.25 present	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 43	1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448	1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446	4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44
Geo met	0.001	% ref.25 present M.C. error % ref.25 present M.C. error	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.37	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453 0.61	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.37	1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 	 4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.18 	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37
Geo met ric effi	0.001	%ref.25presentM.C.error%ref.25presentM.C.error%ref.25	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74 0.01	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18 0.01	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.37 0.01	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453 0.61 0.01	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11 0.01	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.37 0.01	 1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15 0.01	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 0.01 	 4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.18 0.01 	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37 0.01
Geo met ric effi cien cy	0.001	%ref.25presentM.C.error%ref.25presentM.C.error%ref.25present	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74 0.01 53 0.01	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18 0.01 54 0.01	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 43 0.05 45 0.37 0.01 55 0.01	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453 0.61 0.01 54 0.01	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11 0.01 56 0.01	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 43 0.05 45 0.37 0.01 53 0.01	1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 55 0.01	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 55 0.01	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15 0.01 54 0.01	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 0.01 53 0.01 	4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.18 0.01 54 0.01	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37 0.01 53 0.01
Geo met ric effi cien cy	0.001 5 10	%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74 0.01 53 0.01 554	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18 0.01 54 0.01 554	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 43 0.05 45 0.37 0.01 55 0.01 553	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453 0.61 0.01 54 0.01 55	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11 0.01 56 0.01 551	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 43 0.05 45 0.37 0.01 53 0.01 55	1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 55 0.01 55	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 55 0.01 549	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15 0.01 54 0.01 548	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 0.01 53 0.01 546 	4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.18 0.01 54 0.01 543	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37 0.01 53 0.01 543
Geo met ric effi cien cy	0.001 5 10	%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error%	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74 0.01 53 0.01 554 1.57	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18 0.01 54 0.01 554 0.91	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 43 0.05 45 0.37 0.01 55 0.01 553 0.19	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 42 0.05 453 0.61 0.01 54 0.01 55 0.65	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11 0.01 56 0.01 551 0.56	 0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.37 0.01 55 1.31 	 1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 55 0.01 55 0.01 55 0.01 	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 55 0.01 549 0.06	 1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15 0.01 548 0.52 	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 0.01 53 0.01 546 1.05 	 4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.18 0.01 54 0.01 543 0.19 	 1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37 0.01 53 0.01 543 0.85
Geo met ric effi cien cy	0.001 5 10	%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error%ref.25	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74 0.01 53 0.01 554 1.57 0.00 69	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18 0.01 54 0.01 554 0.91 0.00 71	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.01 55 0.01 553 0.19 0.00 7	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453 0.61 0.01 54 0.01 55 0.65 0.00 7	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11 0.01 56 0.01 551 0.56 0.00 69	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 43 0.05 45 0.37 0.01 55 1.31 0.00 71	1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.05 45 0.01 55 0.01 55 0.01 55 0.00 7	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.55 0.01 55 0.01 55 0.01 549 0.06 0.00 7	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15 0.01 54 0.01 54 0.01 548 0.52 0.00 7	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 0.01 53 0.01 546 1.05 0.00 7 	 4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.18 0.01 54 0.01 543 0.19 0.00 7 	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37 0.01 543 0.85 0.00 7
Geo met ric effi cien cy	0.001 5 10	%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74 0.01 53 0.01 554 1.57 0.00 69 0.00	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18 0.01 54 0.01 554 0.91 0.00 71 0.00 602	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.01 55 0.01 553 0.19 0.00 7 0.00 7 0.00	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453 0.61 0.01 54 0.01 55 0.65 0.00 7 0.00 7 0.00	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11 0.01 56 0.01 551 0.56 0.00 69 0.00 202	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.05 45 0.01 55 1.31 0.00 71 0.00 71	1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.05 45 0.01 55 0.01 55 0.01 55 0.00 7 0.00 7	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.05 45 0.01 55 0.01 549 0.06 0.00 7 0.00 7 0.00	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15 0.01 54 0.01 54 0.01 548 0.52 0.00 7 0.00 7 0.00	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 0.01 53 0.01 546 1.05 0.00 7 0.00 700 	 4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.18 0.01 54 0.01 543 0.19 0.00 7 0.00 	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37 0.01 53 0.01 543 0.85 0.00 7 0.00 7
Geo met ric effi cien cy	0.001 5 10 15	%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error%ref.25presentM.C.error	0.24 0.49 98 0.49 999 0.03 8 0.05 41 0.05 45 0.74 0.01 53 0.01 554 1.57 0.00 69 0.00 697 1.01	0.42 0.49 98 0.49 999 0.03 8 0.05 44 0.05 45 0.18 0.01 54 0.01 54 0.01 554 0.91 0.00 71 0.00 698 1.69	0.34 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.37 0.01 55 0.01 553 0.19 0.00 7 0.00 699 0.14	0.12 0.49 98 0.49 999 0.03 8 0.05 42 0.05 453 0.61 0.01 54 0.01 55 0.65 0.00 7 0.00 701 0.20	0.36 0.49 98 0.49 999 0.03 8 0.05 39 0.05 45 1.11 0.01 56 0.01 551 0.56 0.00 69 0.00 703 1.99	0.03 0.49 98 0.49 999 0.03 8 0.05 43 0.05 45 0.05 45 0.37 0.01 55 1.31 0.00 71 0.00 704 0.85	1.43 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.05 45 0.05 45 0.01 55 0.01 55 0.01 55 0.00 7 0.00 7 0.00 705	0.67 0.49 98 0.49 999 0.03 8 0.05 42 0.05 45 0.05 45 0.01 55 0.01 55 0.01 549 0.00 7 0.00 705 0.71	1.07 0.49 98 0.49 999 0.03 8 0.05 44 0.05 448 0.15 0.01 54 0.01 54 0.01 54 0.01 54 0.00 7 0.00 7 0.00 705	 1.29 0.49 98 0.49 999 0.03 8 0.05 43 0.05 446 0.29 0.01 53 0.01 546 1.05 0.00 7 0.00 705 0.71 	 4.67 0.49 98 0.49 999 0.03 8 0.05 45 0.05 44 0.01 54 0.01 54	1.07 0.49 98 0.49 999 0.03 8 0.05 42 0.05 44 0.37 0.01 53 0.01 543 0.85 0.00 7 0.00 705 0.71



	TEF			ERROR%				
d(cm)	Present M.C.	Cal. ²²	Exp. ²²	M.C. vs. Cal.	M.C. vs. Exp.			
10	0.020483	0.02004	0.02053	2.16	0.23			
15	0.010478	0.01024	0.01008	2.27	3.80			
20	0.00626	0.0062	0.00594	0.96	5.11			
25	0.00418	0.00415	0.00404	0.72	3.35			
30	0.003004	0.00297	0.00294	1.13	2.13			
35	0.002259	0.00223	0.0022	1.28	2.61			
40	0.001776	0.00174	0.00175	2.03	1.46			
45	0.001418	0.00139	0.00142	1.97	0.14			
50	0.001164	0.00114	0.00124	2.06	6.53			

Table 2. Variation of the total efficiency for a 3"× 3" NaI(Tl) detector respect to point source of 662 keV located at particular distance from the front face and on the symmetric axis of detector.

To demonstrate the effect of the source dimensions, the simulation was carried out for a radiant source with a disk shape. The results were compared with the published results of the international code Geant4 based GATE simulation program²⁹, which clearly showed quite well congruence, see Fig. 9.

Another Validation was implementing the present simulation to scrutinize the detection efficiency versus different 2R_d/H_d ratio of NaI(Tl) detectors, so that the volume of detector remains fixed. The incident monoenergetic energies of γ -rays are 0.662, 1.331 and 4.438 MeV, experimentally, emitted from ⁶⁰Co and ²⁴¹Am radioactive ¹³⁷Cs, sources respectively ³⁰. As shown in Fig. 10, the result reveals that the detector efficiency dependent on the mentioned ratio of the NaI(Tl) detector and the incident energy of γ -photon. At a very low of $2R_d/H_d$, the total detector efficiency increases rapidly and tends to be stable while the intrinsic of which is on the contrary. Anyway, the ratio from 1-2, (i.e. with an average 1.5, matching with ref.30) is an interesting and meaningful point. It is valuable to design detectors for detecting γ -rays that have optimal dimensions.



Figure 9. Total efficiency as a function of γ -ray comparison for point and disc radioactive source (p.s. and d.s. respectively).



Figure 10. Intrinsic and total efficiency as a function of diameter to height ratio of $3^{"} \times 3^{"}$ NaI(Tl) detector at different values of γ -ray energy.

Conclusion

For the radioactive source-detector setup, Monte Carlo simulation computer program was designed, written and validated to be used instead of the real experimental system. Subsequently, the current works supplies are better to use provide with useful tool for γ -ray spectroscopy and fashions a good procedure for credible computations in lieu of the routine of laboratory or experimental measurements.

Authors' Declaration

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been

Authors' Contribution Statement

A.N.M and Z. K. A. conceived and designed the study, acquired the data, analyzed and interpreted the results and wrote the manuscript.

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Wherefore, one can sock away time by averting the calibration of practical setup for every geometry concerned. Significantly reducing radiation risks and in less time, the current simulation is a good turn for the experimenter to achieve the best and most suitable geometry of setup. Also, Monte Carlo simulation is a viable tool to design the optimal dimensions of detector for detecting of γ -rays.

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- Ethical Clearance: The project was approved by the local ethical committee in Mustansiriyah University.

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نظام مصدر مشع – كاشف: التصميم و رأي مونت كارلو

زينب كريم علي ، علي نعمة محمد

قسم الفيزياء، كلية التربية، الجامعة المستنصرية، بغداد، العراق.

الخلاصة

تم في البحث الحالي تصميم و كتابة برنامج محاكاة حاسوبي وفقاً لطريقة مونت كارلو ليكون بمثابة نظام عملي إفتراضي بديلاً عن النظام الحقيقي. تم إختبار البرنامج إحصائياً و هندسياً و عددياً لنظام إفتراضي لمصدر مشع- كاشف. تم تنفيذ البرنامج لكاشف آيوديد الصوديوم ولعداد كايكر لمدى من الطاقة يصل إلى 10 MeV. تم استخدام قانون الأعداد الكبيرة (LLN) ونظرية النهاية المركزية (CLT) لاختبار دقة وضبط سير عمل البرنامج والإشارة إلى مدى قرب النتائج من متوسطاتها، وإحصائياً، إلى أي مدى تميل إلى التوزيع الطبيعي. بشكل عام، أظهرت نتائج عدد من أنواع كفاءة الكاشف توافقاً كبيراً مع النتائج التجريبية المنشورة ونتائج عدد من البرامج العالمية ضمن نسبة خطأ 20,0-5% (أي دقة 95-99,90%) و بمستوى دلالة إحصائية يعكس إحكام خوارزمية المحاكاة. إن الترمين الدقيق والمضبوط للمحاكاة الحالية يمنحها الموثوقية المطلوبة. كما أظهر برنامج المحاكاة الحالي مرونة و فعالية عالية في تصميم أي نظام مصدر - كاشف نووي و تزويد العاملين أو المجربين ذات العلاقة بمؤشرات تساعد في التصميم الأمثل للمنظومة من حيث المكونات و هندسية النظام بأقل مدة زمنية. والتي قد تستغرق من بضعة ثواني الى بضعة دقائق لزمن تنفيذ بإستخدام حالي م من المكونات و هندسية النظام بأقل مدة زمنية. والتي قد تستغرق من بضعة ثواني الى بضعة دقائق لزمن تنفيذ باستخدام حاسوب من عمر أي نظام مصدر - كاشف نووي و تزويد العاملين أو المجربين ذات العلاقة بمؤشرات تساعد في التصميم الأمثل للمنظومة من حيث المكونات و هندسية النظام بأقل مدة زمنية. والتي قد تستغرق من بضعة ثواني الى بضعة دقائق لزمن تنفيذ بإستخدام حاسوب منخصي بمواصفات عادية. على عكس التجارب المختبرية التي قد تستغرق من بضعة ثواني الى عدة ساعات. إضافة الى توفير بيئة عمل

ا**لكلمات المفتاحية:** نظرية النهاية المركزية، قانون الأعداد الكبيرة، ، طريقة مونت كارلو، كفاءة كاشف آيوديد الصوديوم المطعّم بالثاليوم (NaI(Tl، احصائيات عد الاشعاع.