Araştırma Makalesi / Research Article

Investigation of the Collimator Effect on the 3″x3″ NaI(Tl) Detector System by the FLUKA code

Zehra Nur KULUÖZTÜRK[1*], Nilgün DEMİR[2]

[1]*Bitlis Eren University, Vocational School of Health Services, Bitlis, Turkey*
[2]*Bursa Uludağ University, Physics Department, Bursa, Turkey*
(ORCID:0000-0003-0929-5987)(ORCID:0000-0003-2245-8461)

Abstract
The efficiency of the 3″x3″ NaI(Tl) detector and gamma attenuation calculations were investigated under the different collimation parameters. In this purpose, photon beams with 511 and 1332 keV energy were collimated by using Pb collimator with different diameters. This system was defined by the FLUKA Monte Carlo code; the detector efficiency and gamma attenuation coefficients were simulated.

Keywords: 3″x3″ NaI(Tl) Detector, Collimator simulations, FLUKA.

FLUKA kodu ile 3″x3″ NaI(Tl) Detektör Sistemine Kolimatör Etkisinin İncelenmesi

Öz
3″x3″ NaI(Tl) detektörünün verimliliği ve gama zayıflatma hesaplamaları farklı kolimasyon parametreleri altında incelenmiştir. Bu amaçla, 511 ve 1332 keV enerjili foton demetleri, farklı çaplarda Pb kolimatörü kullanılarak kolime edildi. Bu sistem FLUKA Monte Carlo kodu ile tanımlandı; detektör verimliliği ve gama zayıflama katsayıları simüle edildi.

Anahtar kelimeler: 3″x3″ NaI(Tl) detektörü, Kolimatör simülasyonları, FLUKA.

1. Introduction

Investigation of the absorption of gamma rays on material, that is to know the gamma absorption coefficient of the material, is essential not only for radiation physics studies but also for studies in medicine, industry, and biology. Gamma attenuation coefficient calculations have been reported in numerous studies using experimental and theoretical methods [1-7]. The gamma attenuation coefficient depends on the characteristics of the absorber and the energy of the gamma source. In order to avoid significant differences between the gamma attenuation coefficients obtained from different methods, the most appropriate parameters should be determined when making measurements and calculations. One of the most critical parameters taken into consideration for this is the suitable collimation and transport of the beam. Since the gamma sources used in the gamma attenuation coefficient measurements have an isotropic distribution, the beam must be collected correctly and reached to the absorbent material and the detector. When the transmitted beam is collected correctly, and a narrow beam is obtained, a large number of scattered photons are prevented from reaching the detector. The studies related to beam collimation have been presented using various absorber materials and detector systems at different energies [8-11].

The scintillation detectors, which are based on the principle that the gamma rays entering the detector are transformed into visible light photons by the so-called scintillator crystal, are often preferred in radiation investigations because of their high efficiency of measurement and ability to operate at room

*Sorumlu yazar: znkuluozturk@beu.edu.tr
Geliş Tarihi: 07.11.2019, Kabul Tarihi: 20.12

temperature. For this purpose, 3″x3″ NaI(Tl) detector was modeled to investigate the effect of beam collimation in this study. The effect of photon beam collimation on the gamma attenuation coefficient and the full energy peak efficiency of the 3″x3″ NaI(Tl) detector system was theoretically calculated depending on the collimator diameter and the energy of the photon beam. The beam properties, geometry system, physical quantities, formulations, and approaches required for calculations were modeled using FLUKA code.

2. Material and Method

2.1. Theory

In this section, some theoretical formulations are described for the efficiency of the 3″x3″ NaI(Tl) detector and the mass attenuation coefficients determined using this detector. For the quantitative evaluation of the simulation model, the full energy peak efficiency was calculated by the following equation [12];

$$E_{\text{full-energy peak}} = \frac{N_{FEP}}{N} \qquad (1)$$

where N_{FEP} and N represent the net count in the full-energy peak corresponding to energy and the number of photons emitted by the source of energy, respectively.

The mass attenuation coefficient which determines the probability of interaction of the photon with the material have been calculated for investigated samples by the following equation based on the Beer-Lambert law;

$$I = I_0 e^{-\mu x} \qquad (2)$$

I_0, I and x are the attenuated photon intensity, incident photon intensity and the thickness of the material (cm), respectively.

2.2. Simulation details

The FLUKA code, written in the Fortran programming language and used in the Linux operating system, was developed to calculate particle transport and the interaction of particles with matter [13]. The FLUKA code can simulate electromagnetic and hadronic interactions and particle transport in any target material for 60 different particles. The code is often used in current studies of nuclear physics such as detector design, target design, dose, and shielding calculations.

The details of the 3″x3″ NaI(Tl) detector that modeled by FLUKA code are given in Figure 1. The geometry was modeled with a cylindrical scintillation crystal of 7.62 cm x 7.62 cm with a case of 0.5 mm of aluminum. The space between the case and the crystal was filled with MgO of 0.185 cm thickness. The SiO_2 layer after the crystal is 0.3 cm thick. The detector geometry has been taken from previously reported detector efficiency study [14].

In the simulation, monoenergetic point sources with 511 keV and 1332 keV energy were placed 8 cm away from the detector using BEAM and BEAMPOS cards. The collimator is designed as a lead metal with a cylindrical geometry of 4 cm thickness. The detector layers and their contents are defined in the input file by using MATERIAL, COMPOUND, and ASSIGNMA commands, respectively.

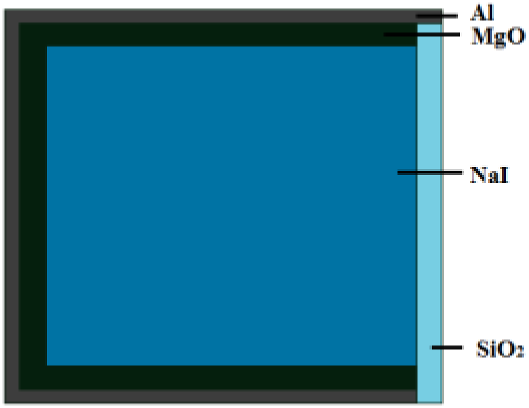

Figure 1. Geometry of 3″x3″ NaI(Tl) detector

The geometry in Figure 2 was modeled and displayed from the geometry editor in the FLAIR interface to calculate the detector efficiency [15]. Figure 2 (a) and Figure 2 (b) show the geometries of the largest (10 mm) and smallest (3 mm) diameter collimators used for this study, respectively. Figure 3 is setup for simulation of the gamma absorption coefficient consisting of an isotropic point source, Pb collimator, absorber material and NaI(Tl) detector. In this study, Aluminum (Al) metal has been chosen as the absorber material. DETECT scoring card was used to investigate the effect of beam collimation. In the FLUKA code, the DETECT card calculates the amount of deposited energy in the detection bin. In addition, the USRBIN card was used for photon fluence calculations in the simulation environment and in the NaI(Tl) detector. All simulation results were obtained by running 10 cycles of 10^5 particles.

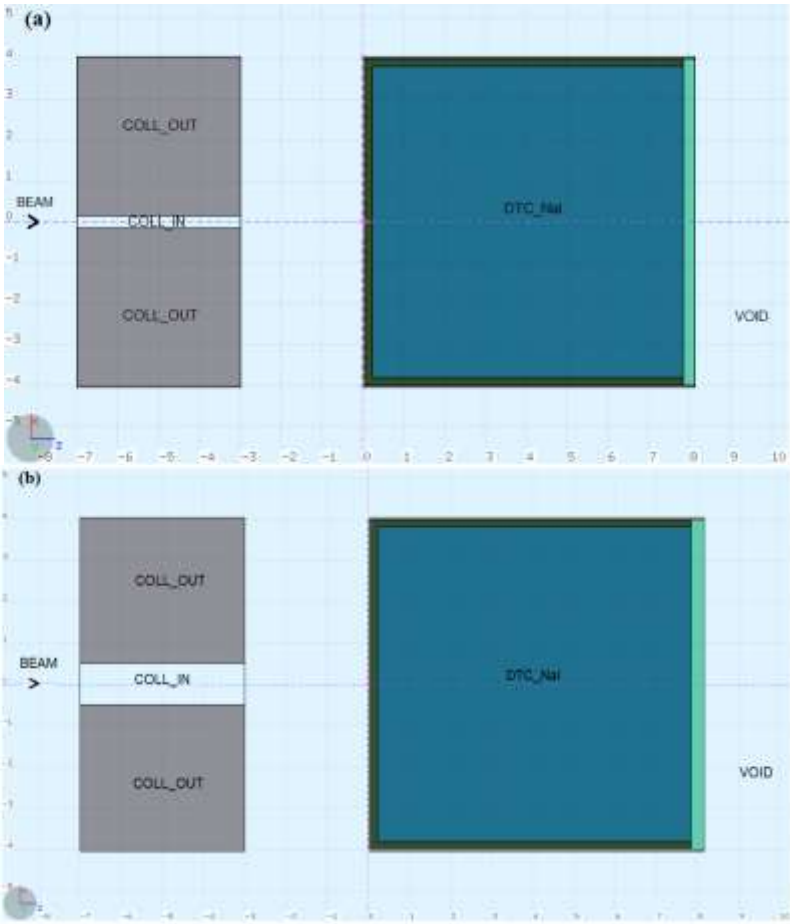

Figure 2. FLUKA geometry with (a) 3 mm and (b) 10 mm diameter collimator for efficiency calculation

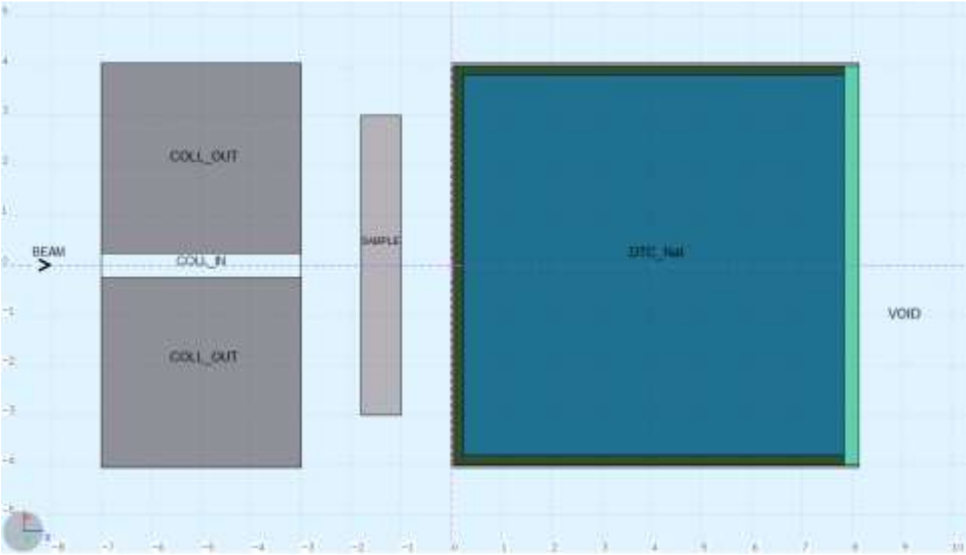

Figure 3. FLUKA geometry with 5 mm diameter collimator for gamma attenuation coefficient calculation

3. Results and Discussion

3.1. Investigation of collimator effect on detector efficiency

In order to investigate the effect of collimator on efficiency in NaI(Tl) detector system, 511 keV and 1332 keV gamma energies and collimators of 3 mm, 5 mm, 7 mm, and 10 mm diameter were used. The variation of the full energy peak efficiency of the detector as a function of the collimator diameter is shown in figure 4 for 511 keV and 1332 keV gamma energy. As the diameter of the collimator increases, the number of photons entering the collimator increases. Therefore, full energy peak efficiency increased due to equation 1. Detector efficiency decreases when the energy increases in the efficiency curve of the NaI(Tl) detector [16]. However, when the beam collimation is performed, as shown in Figure 4, the number under the full energy peak at 1332 keV is higher than 511 keV. Only the highest diameter 10 mm diameter collimator yields almost the same efficiency values in two energies.

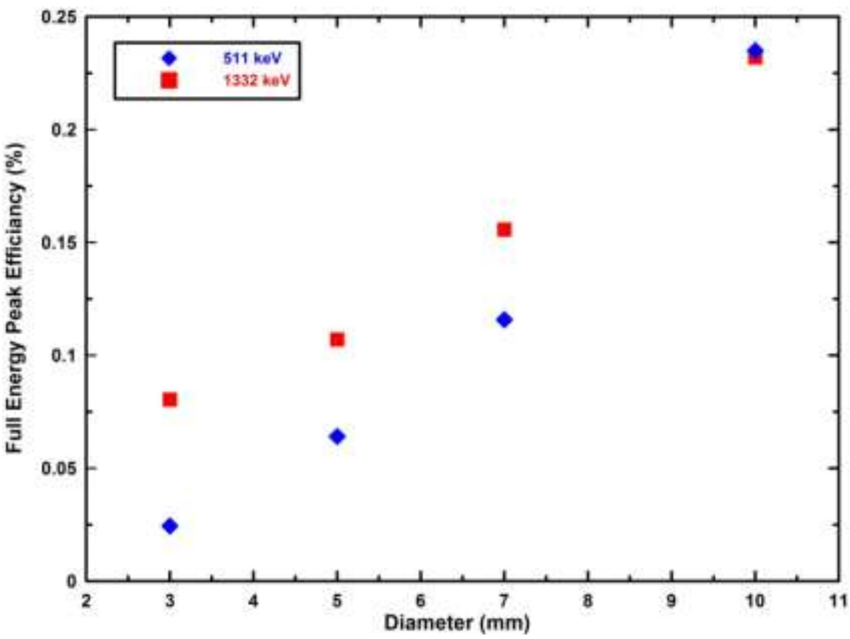

Figure 4. Full energy peak efficiencies calculated by FLUKA code as a function of collimator diameter for 511 keV and 1332 keV gamma energies

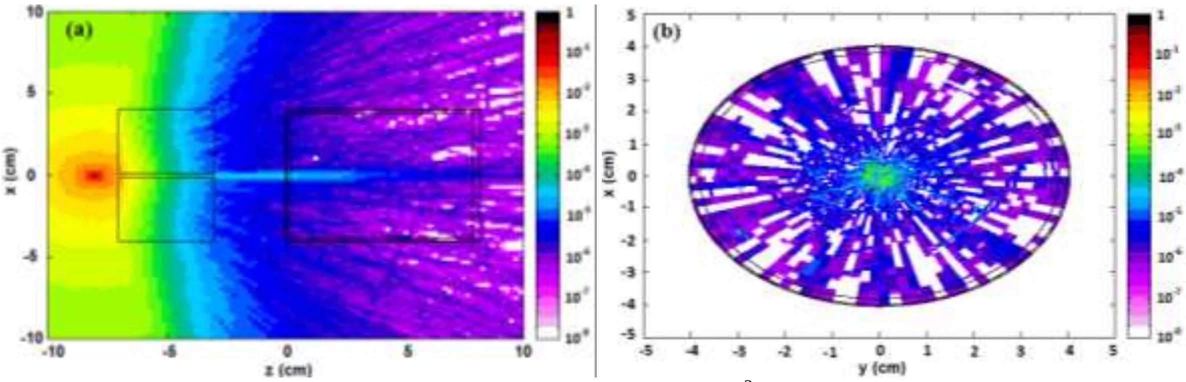

Figure 5. Two-dimensional drawing of photon fluence (photon/cm^2/primary photon) (a) in the simulation volume and (b) in the NaI(Tl) detector for 511 keV photon beam and the collimator with 3 mm diameter

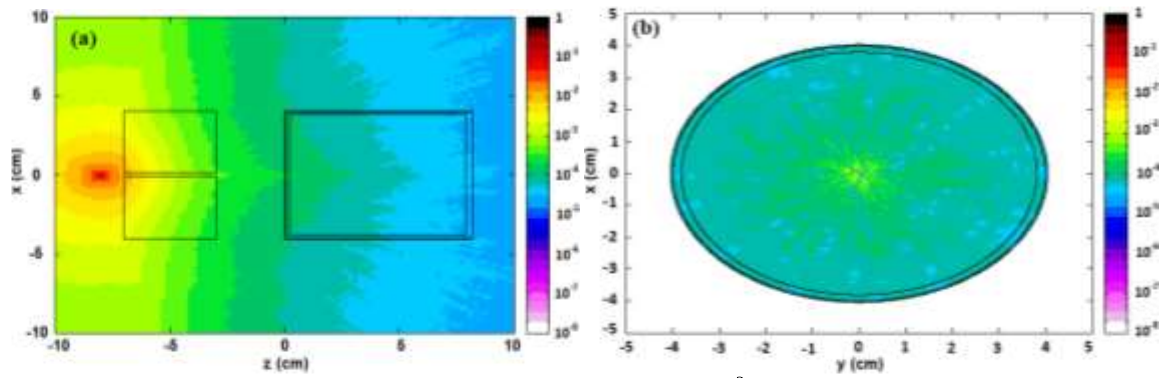

Figure 6. Two-dimensional drawing of photon fluence (photon/cm^2/primary photon) (a) in the simulation volume and (b) in the NaI(Tl) detector for 1332 keV photon beam and the collimator with 3 mm diameter

The variation of photon fluence in the simulation volume of 10x10x10 cm^3 and in the detector is given in Figure 5 and Figure 6 for 511 keV and 1332 keV photon beam, respectively. The color scale on the right side of the drawings shows the change of photon fluence. When the fluence values reaching the detector after passing through the collimator are compared, it is seen that the fluence value of the 511 keV photon beam is less than the 1332 keV photon control fluence value. This shows that the 511 keV photon beam is more likely to be absorbed in the lead collimator. As a result, it is understood that the 1332 keV energy beam reaching the detector by making elastic and inelastic scattering from the 3 mm diameter collimator in Figures 5 and 6 is more likely to interact with the detector crystal. This explains the fact that the detector efficiency of the 1332 keV photon beam is higher than the 511 keV photon beam.

3.2. Effect of beam collimation on gamma attenuation coefficient

The details of the geometry used for the calculation of the linear attenuation coefficient are given in Figure 3. The linear attenuation coefficient was calculated from the slope of the graph of ln (I_0/I) obtained from FLUKA code against different thicknesses of the Al up to 1 cm. Table 1 shows the linear attenuation coefficients calculated for the Al and the 511 keV and 1332 keV energies. Variation of linear attenuation coefficient depending on collimator diameters of 3, 5, 7, and 10 mm was investigated. The reason for comparison with XCOM values is to show that the value range of linear attenuation coefficient calculated by FLUKA code for different collimator diameters is compatible with XCOM [17] which, is a database that calculates the mass attenuation coefficient at 1 keV-1 GeV photon energy.

It is seen from the results in Table 1 that the variation due to the collimator diameter is very small and although not all diameters, the attenuation coefficient is higher in low diameters. In addition, the results are in agreement with the XCOM values. The purpose of beam collimation is to make the isotropic distribution of the gamma source into a narrow beam and to minimize the scattering of photons reaching the detector. However, the change in linear attenuation coefficients is since all photons producing elastic and inelastic scattering are counted below the full energy peak.

Table 1. Linear attenuation coefficients (cm^{-1}) calculated from collimators with diameters of 3, 5, 7 and 10 mm for Al

Absorber material	Energy (keV)	Linear attenuation coefficients, μ (cm^{-1})				
		3 mm	5 mm	7 mm	10 mm	XCOM
Al	511	0.2371	0.2334	0.2749	0.2183	0.2259
	1332	0.1283	0.1382	0.1229	0.1394	0.1437

4. Conclusion and Suggestions

The details of the simulation defined by FLUKA code to examine the effect of beam collimation on the NaI (Tl) detector system are given in Figure 1-3. The effect of collimator diameter on the number below the full energy peak was investigated. It was observed that full energy peak efficiency increased with the increasing diameter of the collimator. It was determined that full energy peak efficiency in small collimator diameters was less than 1332 keV at 511 keV. Linear attenuation coefficients for Al metal and varying collimator diameters were calculated by FLUKA code. Although a narrow beam was obtained, changes in linear attenuation coefficients were observed due to scattering after interacting with the absorber material. As a result, it has been shown that geometric design plays an important role in the studies using NaI(Tl) detector system.

The using of collimator minimizes scattering by making the point source with the isotropic distribution into a pencil beam. However, the radius and length of the collimator used must be carefully selected as this will affect the number of photons entering the detector. Absorption of the low-energy radiation source through the collimator may result in unexpected reductions in detector efficiency. Scattering occurs after the collimated beam and the target material interact. Since these scattered photons are also detected in the detector system, the use of a secondary collimator can prevent this. In addition to this study, in future studies such a system can be constructed with different collimator designs and materials and its effect with the FLUKA code can be investigated.

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