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Rapid Communication

Investigation of Collimator Effect on Full-Width at Half-Maximum of NaI(Tl) Detector

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Abstract : The interaction process of gamma rays in various media results in complete absorption, elastic scattering and inelastic scattering of incident photons. Photon interactions are due to photoelectric effect, Compton scattering and pair production processes. There are higher-orders processes occur due to large number of secondary radiation produced in the first encounter and are known as multiply Compton scattered radiations. Collimator dimension and interaction probability of radiation play important role on Compton scattered radiation counts. In this study the Monte Carlo simulation used for generation of theoretical data. Therefore, at the first the system geometry has been defined by Monte Carlo simulation. Two ^{137}Cs gamma apart sources and a NaI(Tl) detector with 2" diameter used to study collimator effect on FWHM (full-width at half-Maximum). Theoretical results show, the FWHM is function of geometrical arrangement radioactive sources and detector, collimator dimension. The present study depicted optimum thickness for lead collimator with a 3mm diameter bore radius (circular section parallel holed) is 2cm. these results have been obtained by 2" NaI(Tl) detector. There are different approaches to account for the multiply scattering of gamma rays in a material. It is difficult to determine collimator dimensions due to complicated nature of the scattering process and differing geometrical constraints. Monte Carlo methods can be used to determine different parameters such as bore radius of collimator and distance of detector from source. In order to obtain optimize FWHM on a detector type the proper bore radius must be defined for each collimator thickness.

Key words : Monte Carlo, Collimator, NaI(Tl) detector, Scintillator, FWHM, Gamma.

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Introduction

Studies have been performed in order to optimize the collimator dimensions. The performance of a photon emission imaging system is determined more by the collimator than any other single component. Therefore, the collimator plays an important role on determining image quality in a medical gamma camera as well as nuclear survey system. The need for a collimator arises from the fact that photons with energies in the range of interest cannot be focused in the optical sense and information transfer must be accomplished by assuming a directional correspondence between the points of emission and detection.

In the energy range from 10 keV to 10 MeV, most of the gamma ray interactions are due to photoelectric effect, Compton scattering and pair production processes. Out of these three processes, higher-order processes occur due to large number of secondary radiation produced in the first encounter and are known as multiply Compton scattered radiations. In gamma ray interaction study, these radiations

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may also reach the detector along with singly scattered radiation and get counted. Therefore, multiply Compton scattering is one of the principle difficulties for interpreting data, which is present within the same energy range as the single scattering (Singh *et al.*, 2006).

In previous studies, multiple scattering has been evaluated by both analytical and numerical methods. But due to complicated nature of gamma scattering there isn't experimental data about collimator effect on 2"×2" NaI(Tl) detector. One of the methods that used to adjust Compton scattering is to use collimator. Using of collimators plays pivotal role in different fields such as gamma cameras and application to determination of the ^{235}U enrichment with NaI detectors (Mortreau and Berndt, 2005; Marel and Cederwall, 2001).

Resolution of NaI(Tl) detector defined as FWHM. Therefore, the FWHM has important role on gamma spectroscopy. As the FWHM is reduced, peaks of energy spectrum became sharp (Nicholas, 1983). According to Wilderman et al. report, energy-depend of FWHM given by:

$$FHWM = 2.6132 \times e^{0.4414} \quad \text{........ (1)}$$

This parameter can be improved by using suitable collimator (Wilderman *et al.*, 1999). Material of collimator and its pinhole radius affect on optimization of FWHM.

The material of collimator acts as absorber and its pinhole guides scattered photons in to detector.

Therefore, investigation of collimator dimension and thickness of absorber material at the same time leads to optimize FWHM parameter (Lee and Cho, 2002; Giokarisa *et al.*, 2004; Sidhu *et al.*, 1999).

The effect of collimator on detector resolution has been evaluated by both analytical and numerical methods.

In this work, this effect has been theoretically and experimentally verified for NaI(Tl) scintillator detector with 2"×2" dimension. The MCNP4C code (Monte Carlo N-Particle transport code) has been used to achieve theoretical results and two similar ^{137}Cs gamma sources have been applied to obtain experimental data.

Materials and Methods

In order to simulate interactions between radiations and materials the MCNP4C code, which can be used for neutron, photon, electron, or coupled neutron/photon/electron transport has been used (Briesmeister, 2000). Its input file has been accomplished as configuration shown in Fig.1. As seen in Fig.1 two separated ^{137}Cs sources have been located at the front of NaI(Tl) detector that covered by lead collimator. Gamma rays may reach the detector directly or after having scattered in the media as secondary photon production. There is an exponential attenuation for gamma rays that interact with medium (Eq. (2)) (Lee *et al.*, 2007).

$$I = I_0 B(t, E_\gamma) e^{-(\mu/\rho)\rho t} \quad \text{........ (2)}$$

Where I is the intensity of radiation; I_0 is the intensity of radiation before attenuation; B is the buildup factor; μ/ρ is the mass attenuation coefficient of medium; r is the density of medium; t is the thickness of medium; and Eã is the energy of gamma ray.

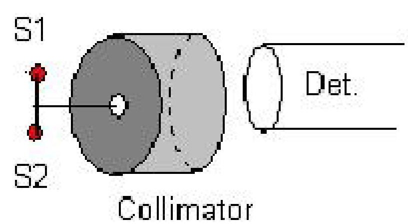

Fig. 1: Input geometry for MCNP simulation

Whereas the mass attenuation coefficient of lead is suitable to attenuate of gamma ray, the lead was used as medium in this work.

The lead thickness of 20 mm is sufficient to absorb photons that have energy less than 1.4MeV. Therefore, the effect of lead collimator dimensions has been verified by counting average numbering of photons that deposit their energy in NaI(Tl) detector during a definite time.

By increasing 1cm lead thickness in each case, photon counts were obtained for different distance from center of sources distance to detector.

As seen in Fig.2, in the experimental method two ^{137}Cs sources with 5 ìCi activity were applied. The pinhole radius of collimator was 0.15cm. These sources with 2cm apart were placed on different distance from center of detector to count gamma rate.

Fig. 2: Photograph of set-up used to obtain experimental data

A new parameter, signal-to-noise ratio, has been applied to detect the minimum detector sensitivity. Signal-to-noise ratio that named contrast given by

$$S = \frac{C_{source} - C_{bkg}}{C_{bkg}} \times 100 \qquad \text{........ (2)}$$

Where, S is the Signal-to-noise ratio C_{source} is the count rate of the sources plus background, and C_{bkg} is the count rate of the background without the sources.

Monte Carlo Simulation

However, tracing of photons and investigation of their interactions with material are difficult but it is possible by MCNP4C code. To simulate Fig.1, the input file of MCNP4C code was accomplished. It is assumed that two point ^{137}Cs sources were put in front of NaI(Tl) detector with 2"*2" dimension that covered by lead collimator. Two lead collimators (with 0.15 cm and 0.5 cm pinhole radiuses) were used on theoretical calculations. The calculations have been iterated on different locations and ten million photons that emitted from two ^{137}Cs sources have been traced by MCNP4C code. Figs. 3 and 4 show output data of MCNP4C code for different collimator thickness. In these Figs. S-S, S-D, Pb and rc are sources apart, distance from S-S center to detector, lead thickness and pinhole radius respectively.

Experimental details

$$S = \frac{C_{source} - C_{bkg}}{C_{bkg}} \times 100$$

The experimental arrangement for present measurements is given in Fig.1. Gamma rays of 662keV photon energy were obtained from two radioactive point sources of ^{137}Cs housed in aluminum container with an activity about 5µCi (Hosseini-Ashrafi, 1998). For detection and counting of the gamma rays a 2"×2" NaI(Tl) detector was used. The detector, gamma sources and other instruments were made by Germany LYBOLD Co. Keeping the pinhole radius fixed at 0.15cm, the lead absorber thickness was increased stepwise. To show collimator effect clearly, the whole experiment was repeated for only two S-D distances (2cm and 5cm). Variations of signal-to-noise ratio (contrast) vs. distance from center of sources for different thicknesses of lead collimators has been plotted in Figs. 5 and 6. It is seen that because of presence of collimator two sources can be separately recognized by detector.

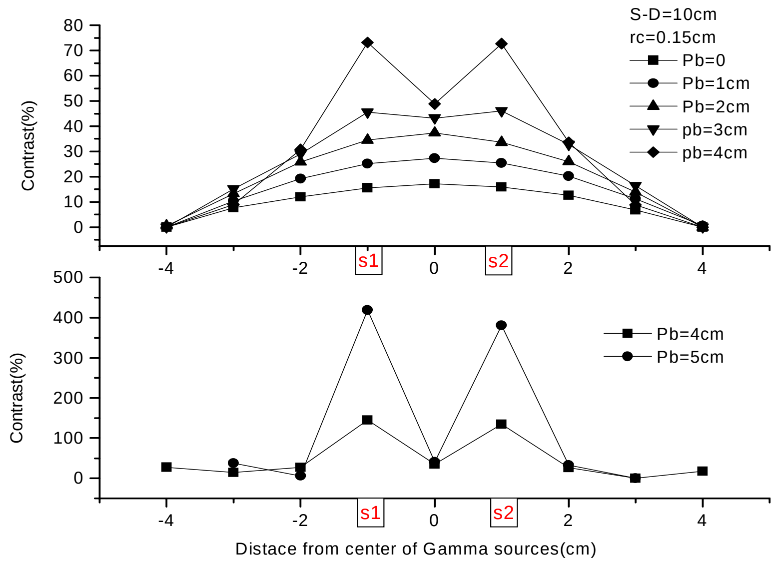

Fig. 3: Variation of signal-to-noise ratio (contrast) vs. distance from center of sources for different thicknesses of lead collimators (MCNP outputs). Distance between sources center and detector (S-D) is 10cm and pinhole radius is 0.15cm. To compare the thickness effect on detector resolution, the curve of 4cm thickness has been repeated.

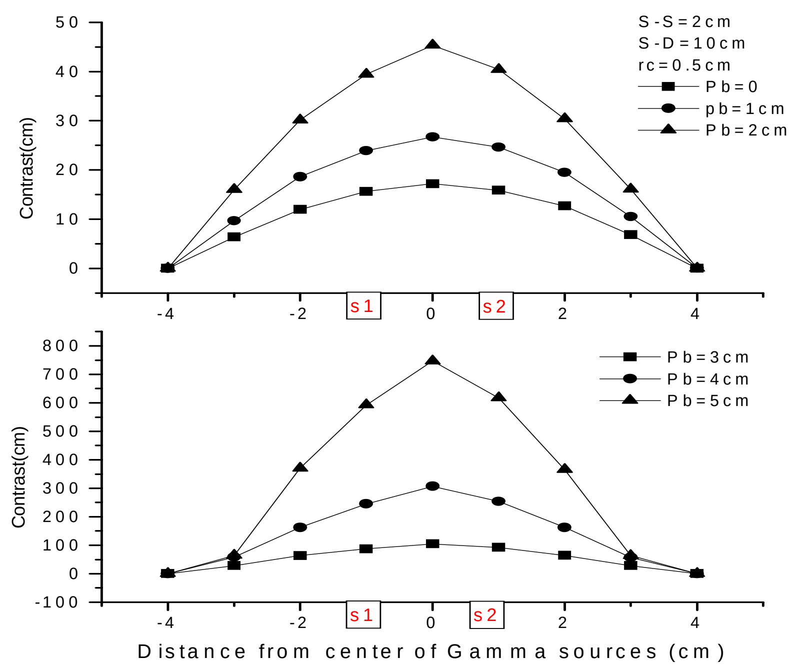

Fig. 4: Variation of signal-to-noise ratio (contrast) vs. distance from center of sources for different thicknesses of lead collimators (MCNP outputs). Distance between sources center and detector (S-D) is 10cm and pinhole radius is 0.15cm.

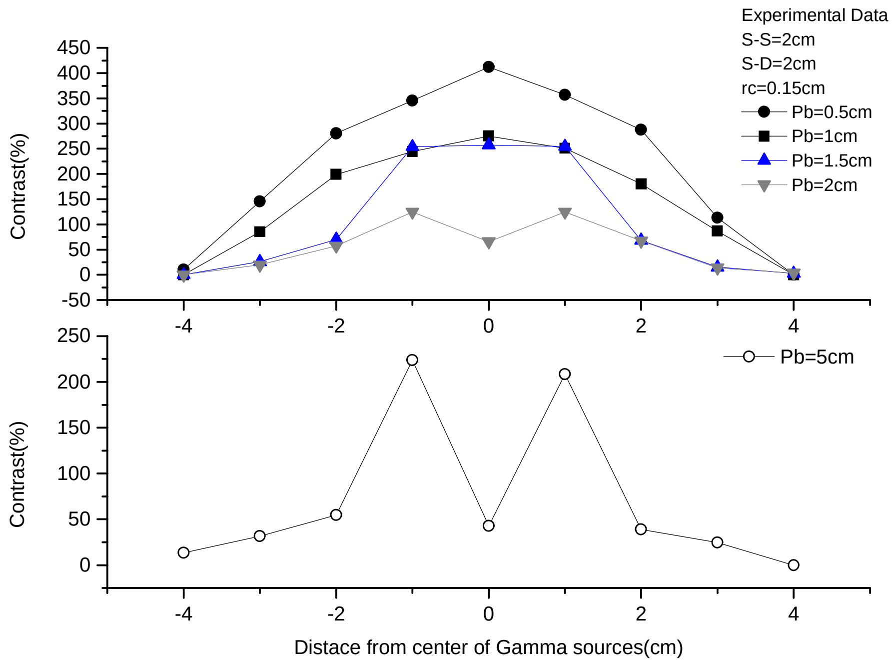

Fig. 5: Variation of signal-to-noise ratio (contrast) vs. distance from center of sources for different thicknesses of lead collimators (Experimental Results for S-D=2cm).

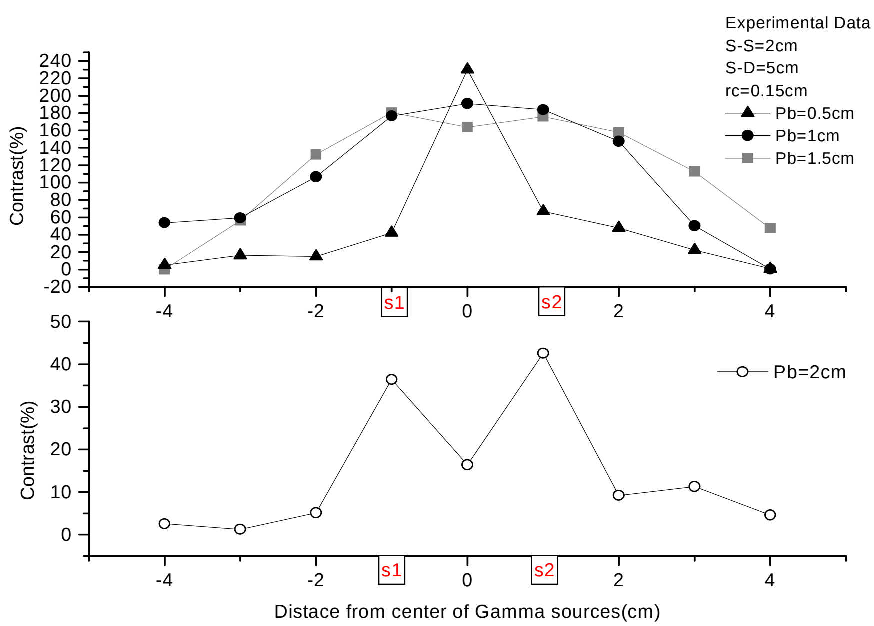

Fig. 6: Variation of signal-to-noise ratio (contrast) vs. distance from center of sources for different thicknesses of lead collimators (Experimental Results for S-D=5cm)

Conclusion

Resolution of the NaI(Tl) scintillator detector severely depend on collimator dimension. In other words, collimator plays an important role to recognize separated sources. In this work, the lead has been used as collimator material. It was found out that the lead thickness, pinhole radius and distance from center of sources to detector affect on resolution of NaI(Tl) detector. The results obtained from this work show a good agreement between experimental and theoretical data. For 2"×2" NaI(Tl) detector the lead collimator, which has a thickness of 5cm and a pinhole radius of 0.15cm, is suitable. It is clear that these optimums will be changed for other detectors with different dimensions.

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