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Design of Multi-absorber Detection System for Double-scattering Compton Camera to Improve Imaging Sensitivity

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1. Introduction

The Compton camera, which has, in principle, many advantages wherein positional information of a gamma source can be determined three-dimensionally without mechanical collimator, has gained interest in nuclear medicine and industrial applications [1–3]. Obviously, high imaging sensitivity and good imaging resolution are the desired properties for these applications. For practical use of the Compton camera, our group has developed double-scattering-type Compton camera, called DOCI [4]. The main purpose of the DOCI is to improve imaging resolution by determining the trajectory of the scattered gamma ray with high accuracy using two sets of high spatial resolution scatterer detectors. In the previous study, DOCI achieved an imaging resolution of ~5 mm FWHM for a point-like ^{22}Na gamma source (1275 keV) [5]; however, the imaging sensitivity was rather low compared with the single-scattering-type Compton camera. To be utilized in the practical applications, enhancing the imaging sensitivity is crucial. To this end, the DOCI with additional absorbers around the scatterer detectors was designed. In the present study, the optimal thickness of the CsI(Tl) absorber detectors was determined by Geant4 Monte Carlo simulations [6,7].

2. Methods

The DOCI consists of three gamma-ray detectors: two sets of double sided silicon strip detectors (5 cm × 5 cm × 0.15 cm) which have 16 orthogonal strips on each side as scatterer detector and an cylindrical NaI(Tl) scintillation detector (3" × 3") as absorber detector. The distance between the first and second scatterer detector was set at 5 cm. The absorber detector was placed 0.1 cm behind the second scatterer detector. In the DOCI, for effective events, primary photon should be Compton scattered in each scatterer detector and fully absorbed in absorber detector. To increase the absorption probability of the double-scattered photon, four CsI(Tl) scintillation detectors whose dimension of 5 cm × 5 cm × 5 cm were added around scatterer detectors as side absorber (see Fig. 1).

To determine the optimal thickness of the side absorber, energy distribution absorbed in the side absorber was calculated. A point-like gamma source simulated was located at 3.7 cm in front of the camera and emitting 1332 keV photons isotropically. With the calculated energy distribution deposited in the side absorber, optimal thickness of the side absorber was determined as follows:

$$\text{Thickness} = -\ln\frac{I_{0.05}}{I_0}\Big/\mu \qquad (1)$$

where I_0 is the intensity of the incident photon, $I_{0.05}$ is the penetrated intensity which is not absorbed in CsI(Tl) detectors, and μ is linear attenuation coefficient. The ratio $I_{0.05}/I_0$ equals to 0.05 which represents that 95% of incident photon is attenuated in the side absorber. The performance of the side absorbers for the DOCI was determined in terms of the imaging sensitivity as a function of the gamma energies, that is, ^{131}I (364 keV), ^{137}Cs (662 keV), and ^{60}Co (1173 keV, and 1332 keV).

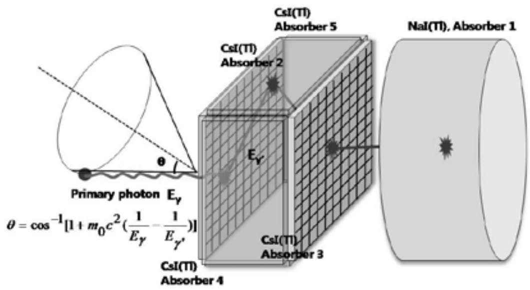

Fig. 1. Double-scattering Compton camera with side absorbers.

3. Results and discussion

Thanks to the side absorber, a number of effective events were increased up to 91.8%. Fig. 2 shows the energy distribution absorbed in the side absorbers. The most probable energy absorbed in the side absorber was determined with Gaussian fitting to the acquired energy distribution. In the each side absorber detector, the most probable energy was 250 keV for a 1332 keV source. With the most probable energy, the optimal thickness of the side absorber was determined to be 2.5 cm according to Eq. 1.

Fig. 3 shows the imaging sensitivities as a function of the side absorber thickness. With increasing the thickness of the side absorber, the imaging sensitivity was improved; however, above the thickness of 2.5 cm, the imaging sensitivity was saturated. This results shows that 2.5 cm thickness of the side absorber is enough for practical applications considering that the most gamma source used in medical and industrial applications emits a gamma-ray below 1332 keV.

Fig. 4 shows the performance of the side absorber detector. Compared with the imaging sensitivity of the DOCI without side absorbers, that of the DOCI with side absorbers was increased 59%, 68%, 80%, and 86% for source energy of 364 keV, 662 keV, 1173 keV, and 1332 keV, respectively. The effect of the side absorber was increased when the source energy increases, because the higher-energy photon tends to scatter more times between the side absorbers before being fully absorbed.

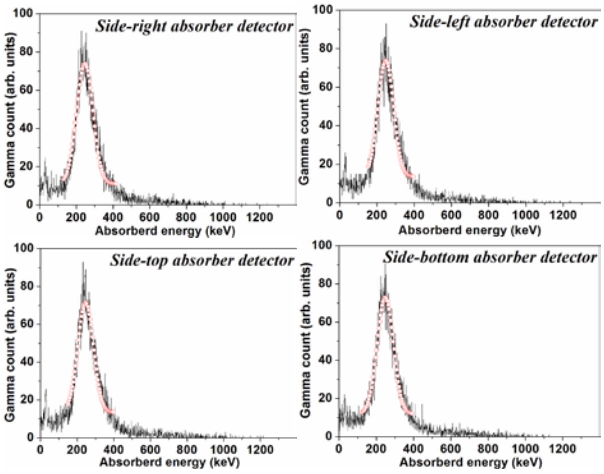

Fig. 2. Energy distributions deposited in side absorbers.

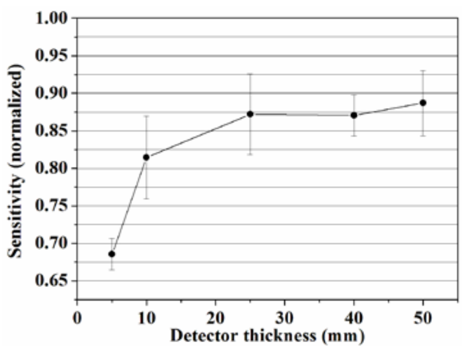

Fig. 3. Imaging sensitivities as a function of thickness of the side absorber.

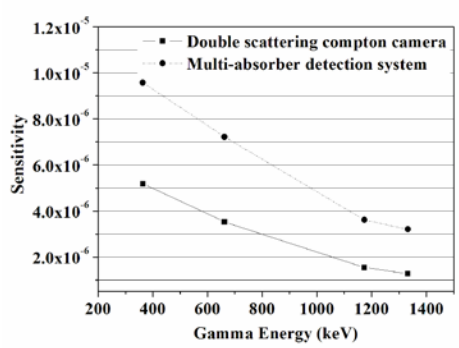

Fig. 4. Imaging sensitivities of DOCI as a function of the photon energy with and without side absorbers.

4. Conclusion

The multi-absorber detection system was designed and evaluated its performance in terms of the imaging sensitivity of the double-scattering Compton camera (DOCI). The optimal thickness of the side absorber was determined to be 2.5 cm. Compared with the imaging sensitivity of the DOCI without side absorbers, that of the DOCI with side absorbers was increased 59%, 68%, 80%, and 86% for source energy of 364 keV, 662 keV, 1173 keV, and 1332 keV, respectively.

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