Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Optimization of high resolution pinhole collimator for radioactive waste monitor using gamma camera

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1. Introduction

Decommissioning should be proceeded safely. It is important to evaluate the radiological characterization at all stages including installation, pre-operation, operation, transition phase after final shutdown before initiation of dismantling, dismantling, and final status for site release. The hot spot, effective dose, and discrimination of radionuclides must investigate in order to determine the radiological characterization. It is widely known how the radiological characterization evaluates at each stages [1]. The radioactive waste is roughly divided into high-level, intermediate-level, and low-level. Most of the waste is typically stored in drum for deep disposal. The importance of decontamination is emphasized because the site of disposal require a large land. The scintillation detector is widely used for radioactive waste monitor. Many scintillation detectors are needed to identify the position of the radioactive contamination although it widely used for dose measurement. Large-area detectors are also needed to inspect wide field-of-view (FOV). There is, therefore, a limitation to detect the hot spot accurately. This problem can overcome by gamma camera which detects and visualizes of the radioactive sources emitting the gamma ray. Therefore, using the gamma camera, the contamination distribution of the radioactive waste can be visualized and evaluated. The high resolution gamma camera is essential for effective decontamination and cost reduction.

The purpose of this study is to optimize the high resolution pinhole collimator for radioactive waste monitor. The spatial resolution, collimator efficiency, and angle-dependent efficiency were investigated a using Monte Carlo N-Particle Transport code, version 6.

2. Materials and methods

2.1 Geometry for Monte Carlo Simulation

Many collimators including pinhole, parallel hole, converging, diverging, and coded mask have been developed. It is know that the pinhole collimator has higher spatial resolution than others [2]. There are two types of pinhole collimator; knife-edge type and channel-height type. The channel-height structure has a higher spatial resolution than the knife-edge structure because of a lower penetration and scatter contributions significantly diminishes at non-perpendicular incident in spite of a lower efficiency [2, 3]. The spatial resolution, one of the main performance indicators of the gamma camera, is determined by the height and diameter of the collimator.

A geometry which was composed of the channel-height collimator and scintillation detector for simulation are shown in Figure 1. A con-shaped pinhole collimator was divided into tungsten aperture and lead septa. For shielding environmental radiations, the thickness of tungsten and the width of septa were set to 31.1 mm and 30 mm, respectively. The point sources including ^{99m}Tc, ^{137}Cs, ^{60}Co, and ^{40}K were located 70 cm above the center of tungsten aperture. The acceptance angle was around 37 degree and field-of-view was 46.8 × 46.8 cm^2. The focal length, which defined as the distance between the center of tungsten aperture and scintillation detector, was set to 15 cm. The scintillation detector was considered as NaI (Tl) which has a dimensions of 10 cm × 10 cm × 1 cm.

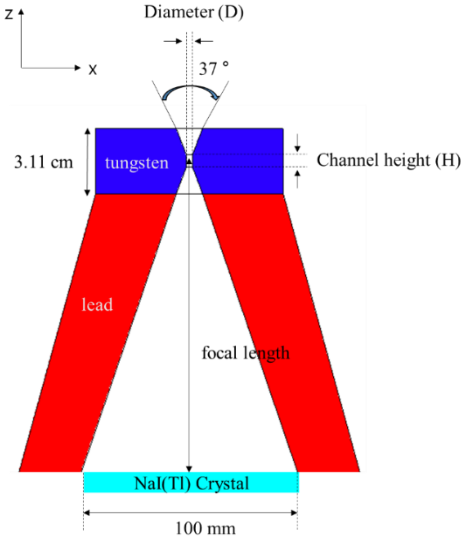


Figure 1. Geometry of pinhole collimator used in the simulation

2.2 Optimization of Pinhole Diameter and Channel Height

The longer the height of the pinhole collimator, the higher the system has spatial resolution. However, if the height is too long, there is a disadvantage of a long time detection. It is necessary to optimize the height and diameter of the pinhole collimator through trade-off curves expressed by the spatial resolution and the collimator efficiency. The optimal range of height and diameter of pinhole collimator were estimated by trade-off curves using Monte Carlo N-Particle Transport code, version 6.

The collimator resolution (R_C) is determined by the distance from source to the collimator, focal lengh, pinhole diameter, and channel height.

$$R_C \approx \frac{d_e(l+b)}{l}$$

where b is the distance from the source to the collimator, l is focal length, and d_e is the effective diameter. Collimator resolution (R_C) is evaluated as the full width at half maximum (FWHM) of the profile which is called the point-spread function (PSF) or line-spread function (LSF) [2].

The collimator efficiency defined as the fraction of gamma rays passing through the collimator per gamma ray emitted by the source [2]. This is shown in the following equation [4].

$$\varepsilon_{col} \approx \frac{C_{source}}{A \times \varepsilon_{int}}$$

where C_{source} is the count rate of the source, A is the source activity, and ε_{int} is the intrinsic efficiency which defined as the number of pulse recorded per the number of radiation quanta incident in detector [4].

2.3 Angle-Dependent Efficiency

The collimator efficiency decrease when the source moves from the center of the aperture to the side in the useful FOV range [5, 6]. It is called as angle-dependent efficiency. This is more pronounced in the channel height collimator than in the knife edge collimator because more amounts of gamma rays are detected due to penetration effect of the edge of tungsten aperture. Angle-dependent efficiency will be simulated by shifting the ^{40}K point source from the center of the pinhole aperture to the side at intervals of 5 cm in the useful FOV range.

3. Results

3.1 Optimization of Pinhole Diameter and Channel Height

The tradeoff curves of the spatial resolution and the collimator efficiency by changing the channel height form 0 mm to 6 mm when the pinhole diameters were 1 mm, 1.5 mm, 2 mm, 2.5 mm, and 4 mm were shown in Figure 2. The spatial resolution and the collimator efficiency were evaluated by the FWHM of the point spread function and the fraction of gamma rays passing through the collimator per gamma ray emitted by the source.

The FWHM should be less than 2.62 mm to satisfy 1° spatial resolution. We assume that the count rate of source was 1000 per second when the ^{137}Cs source of 40 μCi in the around 100 cm distance from detector was measured. The limit value of the collimator efficiency for obtaining meaningful image from the background image was calculated by above equation as 6.76×10^{-7}.

The optimal ranges of pinhole diameter and channel height were determined to be 1 mm and 4 mm with a resonable collimator efficiency for this study. Figure 3 shows an images and profiles at two different positions.

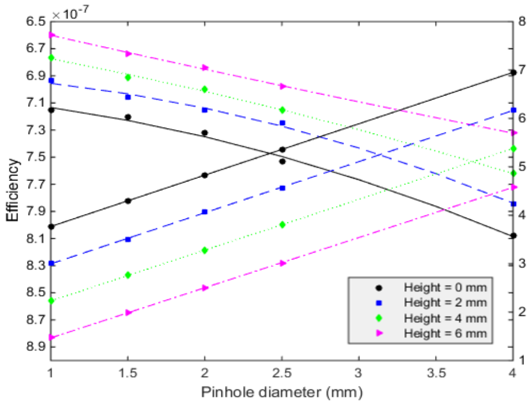
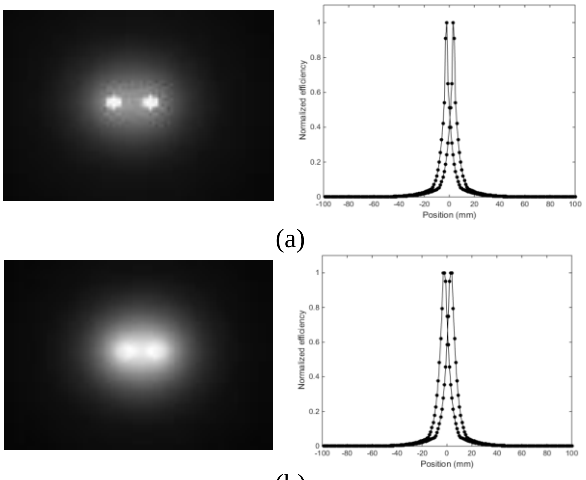


Figure 2. Tradeoff curves of the spatial resolution and the collimator efficiency relationship.



(a)

(b)

Figure 3. Images and profiles at two different positions when the pinhole diameter was fixed as 1 mm: (a) Height = 4 mm, good resolution (b) Height = 0 mm, Knife edge, poor resolution.

3.2 Angle-Dependent Efficiency

The results of angle-dependent efficiency will be presented at poster presentation.

4. Conclusions

The pinhole collimator for high resolution and high energy gamma ray imaging was introduced and its characteristics were evaluated by Monte Carlo simulation. The optimal range of pinhole diameter and channel height were estimated by a tradeoff curves expressed as the spatial resolution and the collimator efficiency. Spatial resolution and collimator efficiency were investigated for simulation study. The optimal values of pinhole diameter and channel height were determined to be 1 mm and 4 mm with a resonable the collimator efficiency.

Until now, the simulation study was performed to optimize the parameters of pinhole collimator for high resolution and high energy gamma ray imaging. After that, the pinhole collimator will be manufactured based on the simulation results and evaluated the performances.

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