SNM Detection with Coded-aperture Gamma Imager for Nuclear Security

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1. Introduction

Radioactive material is widely used in energy, medicine, and industry [1]. But if it gets into the wrong hands it can cause serious harm. Illicit trafficking or smuggling of nuclear or other radioactive materials including special nuclear material (SNM) is an existing problem all over the world. The scientists analyze the samples using a variety of techniques, including chemical and isotopic measurements. Many kinds of technologies is presently under development to detect SNM, and these technologies principally fall into two categories: (1) passive detection and (2) active interrogation systems. Passive detection systems attempt to capture characteristic gamma rays and neutrons emitted by SNM. In other hands, active interrogation systems measure the interaction of externally applied radiation, typically high-energy neutrons and photons, for SNM [2].

Among the passive detection, gamma-ray detection technologies are the most widely deployed, and the complexity of the photon detection challenge has and will continue to motivate considerable research and development effort. To achieve this goal, currently the Jeju National University has developed a coded-aperture based gamma camera. The developed gamma camera is known to be capable of imaging and detecting nSv/hr at a 1 meter. Therefore, we look at the ability to detect small-weight SNMs using developed gamma camera.

2. Methods and Results

This section describes the components and performance of the developed gamma camera and covers the technology and measurement results of the sample to be measured.

2.1 Epsilon-G

The developed gamma camera, termed EPSILON (**E**nergetic **P**article **S**ensor for the **I**dentification and **L**ocalization of **O**riginating **N**uclei)-G(gamma), can read-out 12 × 12 silicon photomultipliers (SiPMs), resulting in an instrument with 144 pixels which is coupled with 4 × 4 × 20 mmt cerium doped gadolinium aluminum gallium garnet ($Gd_3Al_2Ga_3O_{12}$(Ce) or GAGG(Ce)) scintillator array and an intercepts area of 50.2 × 50.2 mm^2. GAGG(Ce) is a high-density, high absorption coefficient material and can provide scintillation performance characteristics that are competitive with both traditional scintillation solids (NaI(Tl), CsI(Tl)) as well as advanced cerium doped silicates such as LYSO(Ce) and $LaCl_3$(Ce). The use of this scintillator with these excellent properties allowed them to have excellent sensitivity and ability to analyze nuclides. In addition, unlike the Compton camera, the application of the coded-aperture mask allowed excellent angular resolution and linearity to dose to be competitive [3].

Fig. 1. Design of EPSILON-G (left) and illustration of use examples of equipment (right)

2.2 The Sample of SNM

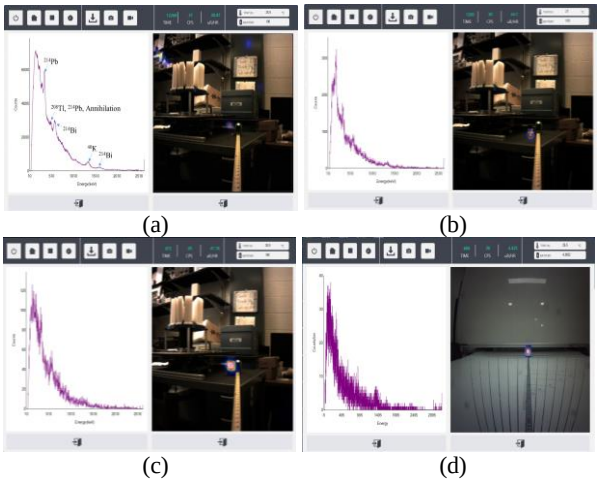
Specimens used for testing the detection capabilities and imaging performance of a trace amount of SNM are 1 g highly enriched uranium(HEU, CRM U970, 97.7% enrichment of ^{235}U), 75 g depleted uranium (DU, CRM 115. 0.2% enrichment of ^{235}U), owned by Department of Nuclear Engineering and Rad. Sci. in the University of Michigan. It was also compared using 100 g of Uranyl Nitrate Hexahydrate material ($UO_2(NO_3)_2 \cdot 6H_2O$, 0.7% enrichment of ^{235}U).

(a) (b) (c)

Fig. 2. The trace amount of SNM used in the experiment: (a) 1g HEU, (b) 75g DU, and (c) Uranyl Nitrate Hexahydrate

2.3 Measurement and Results for Trace SNM

The prepared SNM samples were located one meter away from the camera and tested for the possibility of image acquisition and the time required for acquisition.



(a) (b) (c) (d)

Fig. 3. Spectral and imaging results for SNM samples that are dropped at a distance of 1 meter using EPSILON-G: (a) background radiation, (b) 1g HEU, (c) 75g DU, and (d) 100g Uranyl Nitrate Hexahydrate.

We first tested how images are implemented when only background radiation is present, and as a result, we confirmed that images are implemented randomly by background radiation. The same experiments on several samples under these prior conditions were conducted as shown in Fig. 3. The time required to obtain an image to determine the exact source location using the acquired data was examined, and the result was that 1g of HEU was able to obtain valid images within 2 minutes, 75g of DU was within 10 minutes, and 100g of Uranyl Nitrate Hexahydrate was able to obtain valid images within 4 minutes. The reason why data collection time varies to acquire one image is found to influence the concentration of ^{235}U of each sample. In other words, higher concentrations can lead to higher amounts of gamma rays contributing to images, which can reduce the time required to acquire images.

2.4 Spectrum Analysis for the ^{235}U Enrichment

In the previous section, the results of the image acquisition time according to the enrichments of ^{235}U were compared to the possibility of determining the enrichment through spectral comparison analysis. As shown in Figure 4, spectra were obtained for each sample on a spectral basis for background radiation, and spectra were compared according to concentration by subtracting the portion of background radiation from each spectrum..

As is well known, emissions from ^{235}U are characteristic X-rays of 96 keV and gamma-ray of 186 keV. The analysis and comparison of the ratio of each peak to each sample shows the analysis of the each sample. We will present more details at the conference.

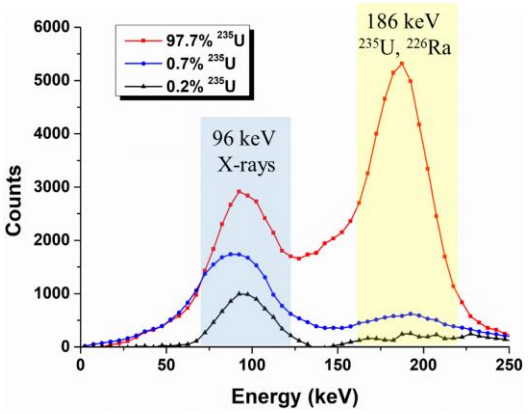


Fig. 4. Spectrum comparison with different 235U enrichments samples

3. Conclusions

Several technologies have been developed for nuclear safety and security in terms of nuclear nonproliferation. In particular, technologies that directly detect and forensics gamma rays emitted from SNM are still actively being studied. To this end, we developed a gamma camera using coded-aperture mask using sensors with very high sensitivity, which compared it to samples with ^{235}U of enrichment for imaging and spectral analysis for trace SNMs. It is also expected that the coded-aperture based gamma camera developed to identify the ^{235}U enrichment of the specimen to be measured will be able to utilize the time of acquisition depending on the degree of each ^{235}U enrichment, and the difference in the amount of X-rays in the spectrum and the photopeak area for 186 keV peak of ^{235}U.

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