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A Study on a Nuclear Material Analysis Capability of the Gamma Imaging System, i-PIX

Yewon Kim

Korea Institute of Nuclear Nonproliferation and Control (KINAC),1534 Yuseong-daero, Yuseong-gu, Daejeon, 34054, South Korea

**Corresponding author: yewonkim@kinac.re.kr*

1. Introduction

Gamma imaging systems are able to identify the location of gamma-ray sources by overlapping images with their location information using semiconductor detectors such as CZT, CdTe, or HPGe. Depending on the types of devices, functions such as energy spectrum, radioactivity, radiation dose, and nuclide identification are provided. The performance and function of such devices can be used in safeguards field for nuclear material detection. The performance of each device was tested through eight types of experiments with the manufacturer of eight Gamma imaging systems through the 2016 Technology Demonstration Workshop (TDW) on Gamma Imaging-External in IAEA [1].

In this paper, the research on nuclear material measurement for the application of iPIX Gamma imaging systems to the field of national safeguards is described. In particular, it is described for the analysis capability of the i-PIX for less than 4.5% of low-enriched uranium, which is mainly used in Korea nuclear power plants.

2. Methods and Results

In this section

2.1 Radiation Measurement System

The i-PIX (Portable Gamma-Ray Imaging System, MIRION) is a type of semiconductor detector using CdTe that can detect and image gamma rays emitted from radioactive materials.

iPIX is based on a Timepix CMOS readout photon counting chip, hybridized with 14x14x1mm CdTe substrate [2]. The active area is divided into 256x256 pixels (55µm side) working in single photon counting mode. Every pixel is consisted with an analog part and a digital part, which is considered as an individual counter. The semiconductor detector of the Timepix is able to convert from gamma-ray into electrical signal driectly, which replaces inefficient conversion steps of scintillation detectors [3].

Fig. 1. The i-PIX (Portable Gamma-Ray Imaging System, MIRION) and the operating software

The coded masks made by tungsten alloy identified by their rank and thickness. The i-PIX can use three masks (R7e4, R7e8 and R13e2) that providing two different mask ranks and three different thicknesses. The benefit to the higher mask rank is that it is more precise with angular resolution, albeit with a decrease in efficiency (due to less open area). Increasing the mask thickness, provides better accuracy in order to enhance the signal-to-noise ratio, SNR, albeit with an increase of weight and a decrease the off-axis response due to the local photon collimation. The iPIX mask design is based on the MURA (Modified Uniformly Redundant Array) pattern, which can be inverted by a 90° rotation to perform “anti-mask” measurements. By using such masks with a stream of incident photons (from a remote radioactive source within the system field-of-view), the detected events of interest can be discriminated, without the use of additional shielding as a shadow of the part of the mask pattern illuminated by the radioactive source is directly cast onto the Timepix sensor [3, 4].

Characteristics	Value
Dimensions	19 x 11 x 11 cm
Weight	2.5 kg
Field of view, degrees	41.4° – 44.8°
Imaging energy range, keV	30 - 1200
Energy resolution, % 662 keV	< 2.5
Detector type	Semiconductor
Imaging technology	Coded-aperture
Detector material	CdTe
Detector type	2D Position sensitive
Detector size	14 x 14 x 1 mm
Number of detector elements	256 x 256 pixels

2.2 Radioactive materials

2.2.1 Nuclear Materials

The uranium samples with various enrichment from 0.3 to 4.5 % were prepared to measure the analysis capability of the nuclear material for i-PIX. Fig. 2 is the schematic of the uranium sample containers. The aluminum container contains uranium dioxide powder. The U^{235} enrichments of the samples were 0.3 U^{235}%, 0.7 U^{235}%, 1.9 U^{235}%, 2.9 U^{235}% and 4.5 U^{235}% respectively

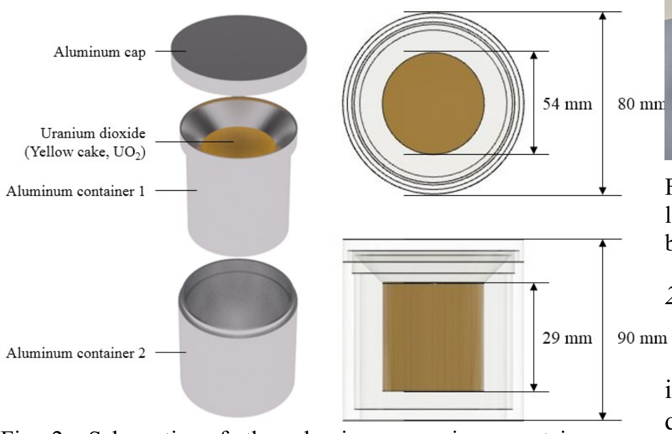

Fig 2. Schematic of the aluminum uranium container. Uranium dioxide powder with 0.3 U^{235}%, 0.7 U^{235}%, 1.9 U^{235}%, 2.9 U^{235}% and 4.5 U^{235}% of the U^{235} enrichment respectively.

2.2.2. Radioisotopes

To verify the energy range of the device, five types radioisotopes, Am^{241}, Na^{22}, Cs^{137}, Co^{60} were prepared and the properties were shown on the Table 1.

Table 1. The Gamma-ray energies of the five radioisotopes prepared to verify the energy range of the device.

Radioisotopes	Gamma-rays energy, MeV
Am^{241}	0.059
Na^{22}	0.511, 1.274
Cs^{137}	0.661
Co^{60}	1.173, 1.332

2.3 Experimental Geometry

The UO2 sample was fixed with a PMMA holder at a distance of 50 cm from the detector as shown on the Fig. 3. The i-PIX was shielded using four lead shields to reduce noise signals from other sources located in the laboratory. The measurement time was measured according to the time automatically determined by the equipment. The coded application used Red, which is a 8 mm thick tungsten mask with a modified uniformly redundant array, MURA engraved on it. Mirion's NDI nuclide analysis module was not installed separately.

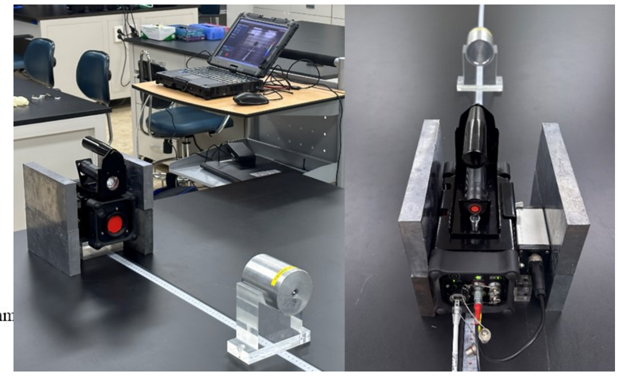

Figure 3. The experiment geometry. The Uranium sample located in fromt of the Gamma imager and the distance between detector and sample was 50 cm

2.4 Result

Fig. 4 shows the measurement results of gamma-ray images of 4.5% UO2 powder using the i-PIX. The difference between the gamma-ray image measured with the CdTe detector and the visible light image taken with the camera is significant because the location of the CdTe detector and the visible light camera is about 3 cm apart and the sample and equipment are very close at 50 cm.

The location of the sample could be accurately determined by i-PIX when only one UO2 sample was present. The results of the experiment according to various experimental conditions will be announced at the conference.

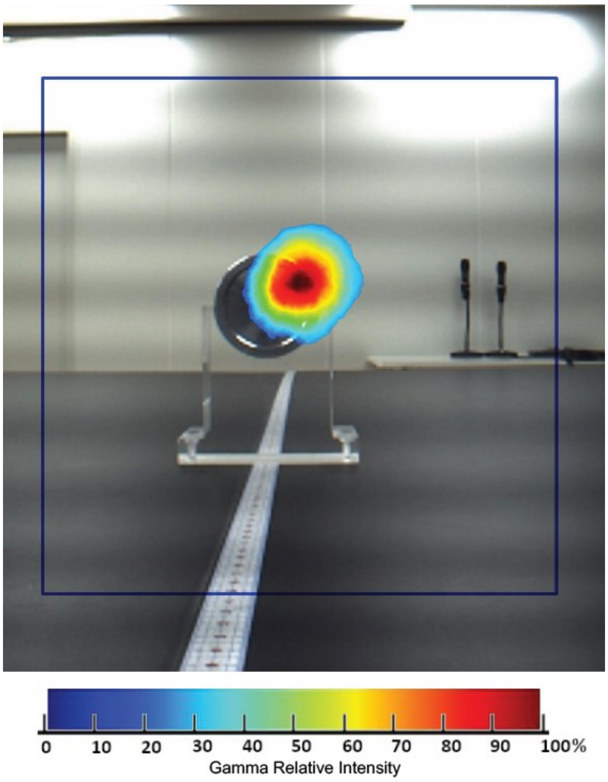

Fig. 4. The measurement results of gamma-ray images of 4.5% UO2 powder using the i-PIX. The difference between the gamma-ray image measured with the CdTe detector and the visible light image taken with the camera is significant because the location of the CdTe detector and the visible light camera is about 3 cm apart and the sample and equipment are very close at 50 cm.

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