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Characterization of a CLYC detector for gamma-ray and neutron detection

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1. Introduction

Cs_2LiYCl_6:Ce (CLYC) is a one of the scintillators that is suitable for gamma and neutron detection due to its gamma detection capabilities and neutron detection from neutron capture with ^{6}Li. Based on its good applicability of pulse shape discrimination (PSD) technique, CLYC can be used as dual-particle detector [1]. A 1 cm-thick CLYC crystal with the Li component enriched to 95% showed ~80% efficiency for thermal-neutron detection, and CLYC offered energy resolution as good as 4% for 662-keV gamma rays, better than that of scintillators commonly used for gamma-ray spectroscopy, such as NaI:Tl and CsI:Tl [2].

Recently, we introduced a CLYC detector at the first case in Korea, and in present study, we performed the characterization of CLYC detector with 95% ^{6}Li enrichment (5.08 cm-long and 5.08 cm-diameter crystal) for future implementation in various applications including dual-particle imager [3,4]. The detector response was characterized using gamma-ray sources and several measurements of ^{252}Cf with varying the thickness of polyethylene (PE) moderator. In addition, the capability of special nuclear material (SNM) detection was demonstrated with measurement experiments using standard reference material (SRM) 969, nuclear fuel pellets and rods.

2. Methods and Results

2.1 Gamma-ray Detection Efficiency

To investigate the gamma-ray response, we measured ^{137}Cs, ^{60}Co, ^{133}Ba, ^{54}Mn and ^{22}Na sources (R-type rod, Eckert&Ziegler, Germany) for 20 minutes per each measurement. The sources were located at a distance of 25 cm from the front face of the detector. Absolute full-energy absorption peak efficiencies were calculated by the following equation [5]:

$$\varepsilon(E) = \frac{A^i}{\Lambda^i \cdot Y(E) \cdot t} \cdot K_i$$

where A^i is the peak area of the radionuclide i, Λ^i is the reference activity of radionuclide i, $Y(E)$ is the emission probability of the radionuclide at energy E, t is the spectrum collection time (live time) and K_i is the decay correction factor which is defined using the difference between the reference date of the source and the experimental date.

Fig. 1 shows the measurement experiment setup and measured gamma-ray detection efficiencies for various gamma-ray energy peaks. The results show good agreement between two measurements.

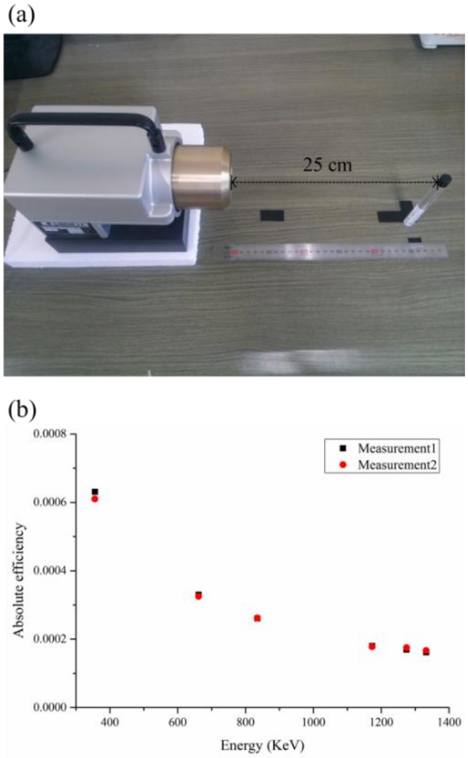

Fig. 1. Gamma-ray experiment: (a) experimental setup and (b) measured gamma-ray detection efficiencies.

2.2 Neutron Moderation and Detection Efficiency

The neutron response was characterized using ^{252}Cf source (A3014-01, Eckert&Ziegler, Germany) at KINAC. The number of neutron capture reactions with ^{6}Li was measured varying the thickness of the PE moderator for 20 minutes per each measurement, and measurement experiments were performed as shown in Fig. 2 (a). We calculated the absolute efficiencies of the CLYC with 11 different thicknesses of the PE moderator.

The neutron count was maximized when using approximately 5 cm PE moderator. The results show the similar trend in a previous study [6], and detection efficiencies from two measurements are similar with each other.

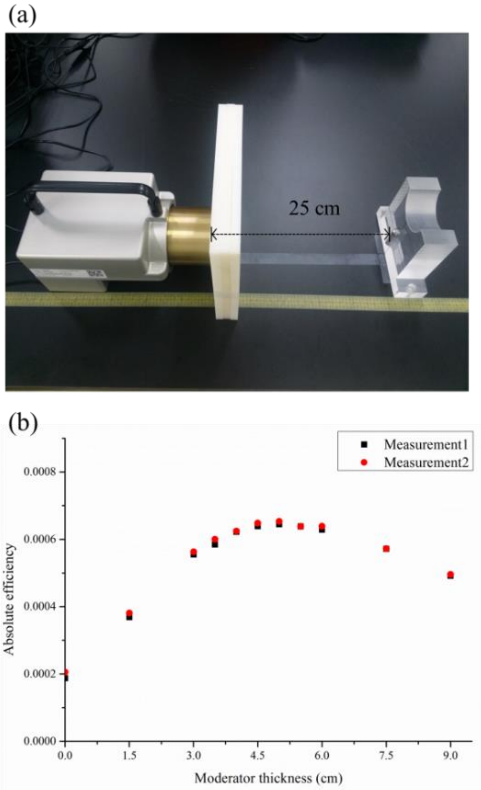

Fig. 2. Neutron Experiment: (a) experimental setup (b) measured neutron detection efficiency at various moderator thicknesses.

2.3 Measurement Experiments on Nuclear materials

In order to check the capability of special nuclear material (SNM) detection using CLYC, we performed measurement experiments using SRM 969, nuclear fuel pellets and rods in KINAC for 20 minutes per each measurement as shown in the Fig. 3. By calculating the ratio between 185.7 keV gamma-peak area which was emitted from ^{235}U and 1001.0 keV gamma peak of ^{234m}Pa, daughter of ^{238}U, the enrichment of uranium samples can be determined for each geometry.

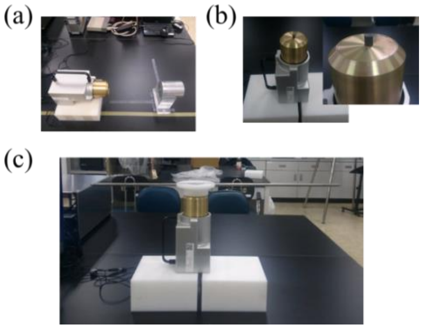

Fig. 3. Experimental setup for nuclear material: (a) standard reference material (SRM) 969 (enrichment of 0.3%, 0.7%, 1.9%, 2.9% and 4.5%), (b) nuclear fuel pellets (enrichment of 0.2%, 1.28%, 3.6%, 3.8% and 4.4%) and (c) nuclear fuel rods (enrichment of 2.34% and 4.1%).

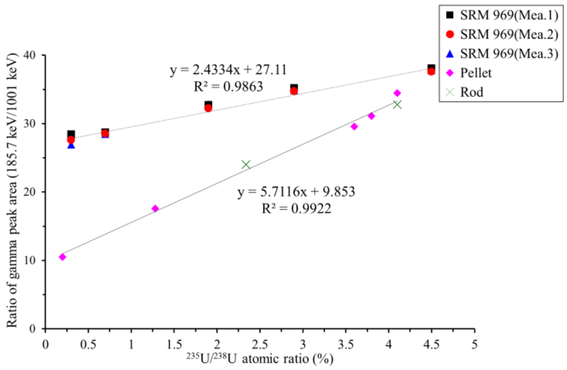

Fig. 4. Calibration curve of ^{235}U/^{238}U atomic ratio.

Fig. 4. shows the calibration curve of ^{235}U/^{238}U atomic ratio. We obtained linear relationships between the ratio of gamma peaks and enrichment with good R-square values. Also, the SRM 969 measurements showed good performance in terms of reproducibility. Based on these simple equations, we can estimate the uranium enrichment of unknown samples.

3. Conclusions

We characterized the CLYC detector system for its detection efficiency using gamma-ray sources and neutron source. In addition, we demonstrated the capability of special nuclear material (SNM) detection using CLYC. The CLYC detector showed the good potential to be utilized as various applicators based on dual-particle detection (~15% intrinsic peak efficiency for 662 keV gamma rays and ~25% intrinsic efficiency for ^{252}Cf source with 5 cm PE moderator). The obtained results will be used as references for follow-up studies and various applications using CLYC detector.

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