

Feasibility Study on Gamma-Ray Emitting Radionuclide Identification Based on Scintillation Light Output Ratio

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1. Introduction

Scintillator materials demonstrate a fundamental linear relationship where the energy deposited by incoming radiation correlates directly to the intensity of emitted light [1]. This proportional response is governed by material-specific constants that remain consistent for each scintillator type [2,3]. Such predictable behavior makes these detectors invaluable for gamma radiation applications in both nuclear safety monitoring and medical diagnostic systems. Among available options, inorganic scintillators dominate traditional gamma spectrometry due to their superior performance characteristics: enhanced photon absorption, high material density, and efficient light production. Despite these advantages, manufacturing defects, structural irregularities, and processing-induced deterioration can substantially limit the precision of energy measurements in spectroscopic applications.

In this study, we proposed an alternative approach for determining gamma-ray energies based on scintillation light output (SLO) ratios between inorganic and plastic scintillator materials. The proposed method exploits the inherent linearity of scintillator response by creating normalized ratios that eliminate source activity variations. This normalization process produces energy-dependent ratios that enable isotope discrimination through concurrent light measurements from dual detector configurations.

Experimental validation employed custom-designed fiber-optic sensors integrating both scintillator types, complemented by Monte Carlo N-Particle (MCNP) computational modeling to verify the correlation between measured and predicted SLOs. Performance evaluation utilized gamma sources ¹³⁷Cs (0.662 MeV) and ⁶⁰Co (1.17, 1.33 MeV).

2. Method and Results

2.1 Materials and Methods

Gamma radiation deposits energy in absorbing materials through successive interaction mechanisms [1]. This energy transfer process adheres to Beer-Lambert principles, where the extent of energy absorption is predominantly governed by the effective atomic number of the target medium. Applying this theoretical basis, two distinct scintillation materials

were selected: Cerium-doped gadolinium gallium aluminum garnet (GAGG:Ce) and plastic scintillator. Both materials were fabricated as cylindrical elements measuring 15 mm in length with 3 mm diameter. A brass housing with density of 8.07 g/cm³ serves as the structural framework for the detector assembly. The complete sensor dimensions are 19 mm in thickness × 19 mm in width × 26 mm in height, positioned 1 mm from the gamma source. As shown in Fig. 1, the fabricated detector assembly was connected to two photon counters (H11890-210, Hamamatsu Photonics) using 0.5 cm optical fibers. And equivalent geometric conditions were implemented in the MCNP simulations.

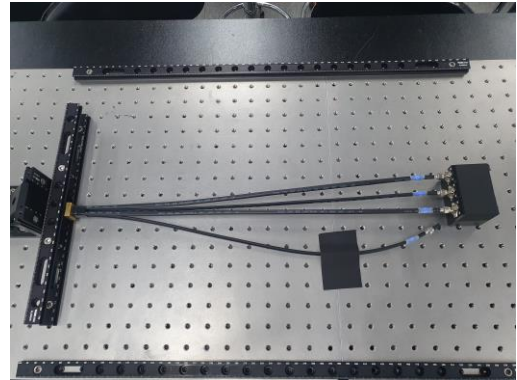


Fig. 1. Experimental setup for scintillation light counting

Previous research established the correlation between SLO and energy deposition in each scintillator as shown in equation (1):

$$SLO = \frac{E_d}{2.5 E_p} \eta \quad (1)$$

where E_d is deposited energy, E_p is energy of scintillation photon, η is overall quantum efficiency [2]. Consequently, the SLO of each scintillator can be determined by incorporating the MCNP-simulated energy deposition values into equation (1).

Therefore, the SLO produced by scintillator materials in response to gamma radiation is proportional not only to the incident gamma-ray energy but also to the radioactive source activity as shown in Fig. 2.

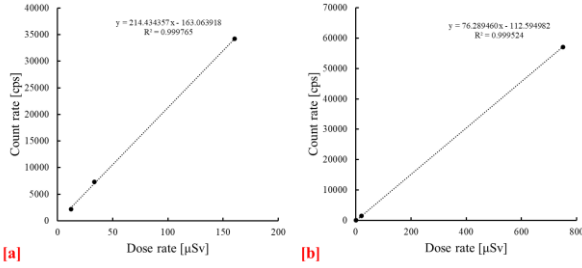


Fig. 2. Relationship between dose measured by conventional dosimeters and count rate for different radionuclides: [a] ¹³⁷Cs, [b] ⁶⁰Co

This dual dependency presents a fundamental challenge in photon counting-based radionuclide identification, as direct SLO measurements cannot establish a pure energy-dependent relationship due to the confounding influence of source activity variations. To address this limitation, the proposed methodology exploits the inherent linearity of scintillator response by creating normalized ratios that eliminate source activity variations. By taking the ratio of SLOs from two different scintillator materials exposed to the same gamma source, the activity-dependent terms cancel out, leaving only energy-dependent response characteristics for radionuclide identification.

2.2 Results

The SLO ratios between GAGG:Ce and plastic scintillator exhibit a decreasing trend with increasing gamma-ray energy due to the energy-dependent nature of photon interaction mechanisms. At lower energies, photoelectric absorption dominates the interaction process, facilitating maximum energy transfer [4]. Figure 1 illustrates the energy-dependent behavior of SLO ratios obtained from MCNP computational analysis. A linear correlation was established by applying interpolation techniques using MATLAB's curve fitting toolbox to quantify this energy-ratio relationship.

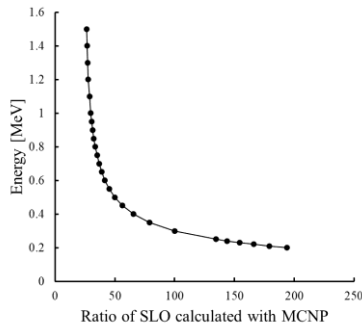


Fig. 3. Energy-dependent behavior of SLO ratios

The correlation between experimentally measured SLO ratios and simulation-calculated values for ¹³⁷Cs identification was established using three gamma-emitting radionuclides: ¹⁰⁹Cd, ¹³³Ba, and ⁶⁰Co, as shown in Fig. 4-[a]. The correlation was determined using

linear-fit. Similarly, for ⁶⁰Co identification, the correlation was established using ¹⁰⁹Cd, ¹³³Ba, and ¹³⁷Cs as reference sources, as shown in Fig. 4-[b]. This correlation was determined using extrapolation.

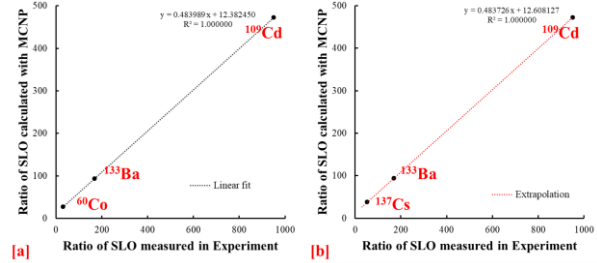


Fig. 4. Correlation between experimental and simulated SLO ratios for radionuclide identification: [a] Linear fit, [b] Extrapolation

To validate the proposed method, measurements were conducted using the fabricated sensor with ¹³⁷Cs and ⁶⁰Co, which emits mono-energetic gamma radiation at 0.662 MeV and poly-energetic gamma radiation at 1.17 and 1.33 MeV respectively. Utilizing the two derived calibration functions, the measured SLO ratio was converted to determine the gamma-ray energy emitted from ¹³⁷Cs and ⁶⁰Co. The mean values of the estimated energies were determined to be 0.6614 MeV for ¹³⁷Cs and 1.2485 MeV for ⁶⁰Co, respectively.

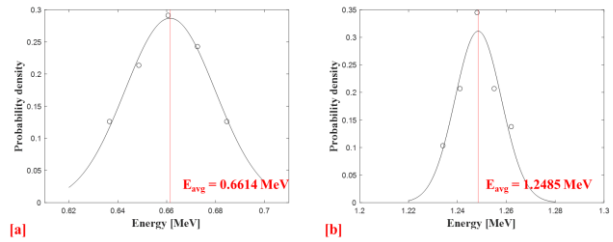


Fig. 5. Estimated gamma-ray energies and Gaussian curve fits for: [a] ¹³⁷Cs, [b] ⁶⁰Co

3. Conclusions

In this study, we have proposed a gamma-ray energy estimation methodology based on the ratio of SLOs from GAGG:Ce and plastic scintillators. The energy of ¹³⁷Cs was estimated as 0.6614 MeV and 1.2485 MeV for ⁶⁰Co. Future studies will evaluate the accuracy of radionuclide identification by comparing energy resolution characteristics of gamma spectra obtained from scintillators with identical geometries using conventional gamma spectroscopy techniques.

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