# Measurements of light-output ratios using inorganic and organic scintillators to identify gamma-ray emitting radionuclides

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## 1. Introduction

Scintillators have widely used for radionuclide identification (RI) since the systems with scintillator are easy to design and construct, and the scintillators have no electromagnetic interference. And by coupling scintillator with plastic optical fiber, the sensor can have more advantages such as long-distance measurement, and flexibility. However, many applicative areas used for radionuclide identification require restrictive size of scintillator, which causes critical drawbacks such as low energy resolution and low peak-to-total ratio. It is because small-sized scintillators can show only Compton spectrum [1]. So, it is difficult to apply conventional gamma radionuclide identification method which finds a unique full-energy-peak from gamma spectrum with small size scintillator sensor. Moreover, it is already known that the plastic optical fiber reduces the energy resolution due to modal dispersion [2]. As a result, an alternative way to identify the radionuclides using scintillators is needed to be used in the actual fields.

In this study, we proposed a new gamma radionuclide identification method using the measured light-output of several scintillators. Manufactured sensor is composed with four different kinds of scintillator. When intensity and energy of incident gamma-ray are same, different amount of energy deposited due to differences in characteristics of the scintillator. And they make differences in amount of emitted photon. As the number of emitted photons is proportional to intensity and energy of incident gamma-ray, to make variable independent of intensity, the ratio of light-output of scintillator is calculated.

## 2. Method and Results

### *2.1. Method*

Measured light-output of scintillator is affected by energy and intensity of incident gamma-ray, characteristics of scintillator. When different types of scintillator are used simultaneously, the amount of energy deposited will differ due to the differences in density and component ratio of scintillator, even if the intensity and energy of incident gamma-ray are same. And these differences will cause difference in amounts of emitted photons. If a light-output of scintillator is proportional to energy of incident gamma-ray, the light-output ratio of two scintillators will be same regardless of incident gamma-ray energy. But the number of emitted photons is proportional to deposited energy, the light-output ratio is different depending on the composition of the scintillator and the energy of the incident gamma-ray. Alike conventional radionuclide identification method which specify the energy of incident gamma-ray with full-energy peak, the light-output ratio can specify the energy of incident gamma-ray.

### *2.2. Materials and Experimental setup*

In this study, we manufactured the sensor with four different kinds of scintillators. Based on the emission spectrum, light-yield and density, two inorganic scintillators such as GAGG:Ce, YSO:Ce (Epic-Crystal) and two organic scintillators such as BCF-12, BCF-20 (SAINT-GOBAIN) were selected. The selected scintillators were unified to cylindrical shape with diameter of 3 mm and height of 15 mm. In order to maximize the light collection efficiency and to minimize the external noise, $TiO_2$ paint (BC-620, SAINT-GOBAIN) was applied to the scintillator surface. Considering the precision processability, the brass holder with density of 8.73 g/cm$^3$ was used as shielding material to eliminate the interference with each scintillator [3]. And a 0.5 m-long plastic optical fiber (CK-80, Mitsubishi Rayon Co., Ltd.) with a diameter of 2 mm was attached to the bottom part of each scintillator. The total size of the sensor-tip was thick of 1.9 cm and width of 1.9 cm and height of 2.6 cm. Figure 1 shows a manufactured sensor-tip.

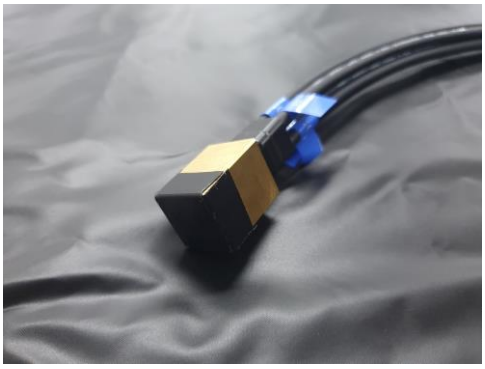

Fig. 1. Manufactured sensor-tip

And four photon counting modules (H11890-210, Hamamatsu photonics) were used as a light measuring detector. The $^{137}$Cs and $^{60}$Co check sources were used and their emitting gamma-ray energies were 0.662 MeV and 1.17, 1.33 MeV, respectively. The gamma-ray

intensity was adjusted by the distance between check source and the sensor.

### *2.3. Results*

The background of scintillator and dark count of photon counting module were measured before each experiment and subtracted as noise. At each experimental condition, 360 photon counting data at interval of five second were obtained. The light-outputs emitted from each scintillator were measured simultaneously with four photon counting modules.

The average light-output ratios of two scintillators with different radionuclide were shown in table I and II.

Table I: Light-output ratio of $^{137}$Cs

| Distance [cm] | GAGG:Ce/ BCF-12 | GAGG:Ce/ BCF-20 | YSO:Ce/ BCF-12 | YSO:Ce/ BCF-20 |
|---|---|---|---|---|
| 1.2 | 26.722 | 32.291 | 13.934 | 16.837 |
| 3.7 | 24.492 | 30.327 | 12.955 | 16.040 |
| 6.2 | 24.746 | 30.682 | 13.084 | 16.217 |

Table II: Light-output ratio of $^{60}$Co

| Distance [cm] | GAGG:Ce/ BCF-12 | GAGG:Ce/ BCF-20 | YSO:Ce/ BCF-12 | YSO:Ce/ BCF-20 |
|---|---|---|---|---|
| 1.2 | 14.740 | 17.913 | 6.844 | 8.32 |
| 3.7 | 13.997 | 17.966 | 6.935 | 8.902 |
| 6.2 | 14.112 | 17.857 | 7.077 | 8.955 |

These light-output ratios are not affected by incident gamma-ray intensity, but only by incident gamma-ray energy. And each ratio is different with a combination of scintillators. With four different kinds of scintillators, six combinations of scintillator can be derived. Although the combination of GAGG:Ce and YSO:Ce has also unique ratio depending on the radionuclide, but it can be ignored with measurement errors. And due to the equality except emission peak wavelengths of two organic scintillators, the light-output ratio of the combination of BCF-12 and BCF-20 is almost same depending on the radionuclide. Therefore, the combinations of the inorganic scintillator and the organic scintillator are effective for radionuclide identification. Based on the difference in light-output ratio, two radionuclides can be sufficiently identified with a five second measurement. Although, manufactured sensor can be divided into four independent scintillator sensors, to minimize uncertainty, we combined these four scintillators with brass holder into one. The combined sensor has relatively low relative standard deviation than four independent scintillator sensors, in same experimental condition.

## 3. Conclusions

In this study, the sensor consisting of four small size scintillators and plastic optical fibers was manufactured. It is confirmed that $^{60}$Co and $^{137}$Cs can be distinguished with manufactured sensor by measuring the ratios of light-outputs of inorganic and organic scintillators. As a result, it is possible to identify two gamma radionuclides without acquiring the gamma spectrum. It is expected that the radionuclide identification method in this study can be used in many applicative fields which require limited size of scintillators and limited measuring time.

Further studies will be carried out to optimize measurement time and to confirm detection limit.

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