A Method of Beta-ray and Gamma-ray Separation Using Plastic Scintillators with Different Size

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1. Introduction

Rapid characterization of the radioactivity is important for the site monitoring during remediation of the site after nuclear decommissioning and radiation monitoring during emergency [1]. In general, gamma-rays and beta-rays were independently detected with different detector. General methods of detecting gamma-rays are using scintillator or semiconductor-based radiation detector such as NaI(Tl) or high purity germanium (HPGe). However, those detectors are hard to detect charged particles such as beta-ray or alpha-ray because of protecting material for the scintillator or semiconductor. On the other hand, a common method for in-situ detection of beta-ray is the Geiger-Müller counter-based scanner. Geiger-Müller counter is useful to quick scanning for large area of sample, but it lacks ability to identify the type of particle. To detect the gamma-ray and beta-ray simultaneously, a concept of phoswich detector was developed using a combination of multiple scintillators for different purpose. However, it had an issue that the counting rates of beta-ray and gamma-ray overlap each other about 8% [2].

To overcome this issue, a novel method of simultaneous detection of beta-ray and gamma-ray was proposed in this study. Counting rates of beta-ray and gamma-ray were analytically separated from the total measured counting rate using two different sizes of plastic scintillators. Two different scintillators had different sensitivity to the gamma-ray while had similar sensitivity to the beta-ray. A portion of beta-ray counting rate from a total measured counting rate was derived and characterized.

2. Methods and Results

The mechanism for losing energy to the beta-ray is related to the range of beta-ray and it is sufficiently short to lose its energy in a 10 mm of plastic medium. However, the mechanism for losing energy to the photons is related to the attenuation, which means that the number of photons decreases during flight in a medium. The attenuation coefficient depends on the atomic number, mass density, and the energy of a photon. In case of using same medium and same energy of photon incidents to the medium, the degree of attenuation is exponential to the length of the medium. Therefore, scintillators with different sizes show similar detection efficiency for beta-rays and show different detection efficiency for gamma-rays if the length of scintillator is enough long to lose all the energy of beta-ray and to make a significant difference of attenuation of gamma-ray. Based on this, the calculation of the portion of beta-ray in the total measured counting rate was derived.

2.1 Beta-ray Portion in Counting Rate

A simple mathematical calculation was used to derive the beta-ray portion. The ratios of counting rates between two scintillators were characterized for the beta-ray and gamma-ray.

The beta-ray portion detected in the large scintillator (X_{big}) and the small scintillator (X_{small}) were defined as eq. (1) and (2).

$$\mathrm{X_{big}} = \frac{C_{beta,big}}{C_{total,big}} = \frac{C_{beta,big}}{C_{beta,big}+C_{gamma,big}} \quad (1)$$

$$\mathrm{X_{small}} = \frac{C_{beta,small}}{C_{total,small}} = \frac{C_{beta,small}}{C_{beta,small}+C_{gamma,small}} \quad (2)$$

where $C_{beta,big}$, $C_{gamma,big}$ and $C_{total,big}$ were counting rates of beta-ray, gamma-ray, and measured sample for big scintillator, and $C_{beta,small}$, $C_{gamma,samll}$ and $C_{total,samll}$ for small scintillator. The counting rate ratio, R_a, was defined in Eq. (3).

$$R_a = \frac{C_{a,big}}{C_{a,small}} \quad (3)$$

where the subscript "a" could be replaced as beta, gamma or total. By using beta-ray, gamma-ray, and measured counting rate ratios, the X_{big} could be derived as eq. (4).

$$\mathrm{X_{big}} = \frac{\frac{1}{R_{gamma}} - \frac{1}{R_{total}}}{\frac{1}{R_{gamma}} - \frac{1}{R_{beta}}} \quad (4)$$

2.2 Experimental Setup

Figure 1 shows the schematic of the detecting system for the experiment to detect the beta-ray and gamma-ray. It consisted of photomultiplier tube (PMT), a plastic scintillator and radiation sources. The scintillator was placed in front of PMT (h10722-110, Hamamatsu) 2.6 cm away from it. The scintillator interacted with radiation particle and produced scintillation light. The produced light signal was recorded by the PMT, the signal from PMT was amplified (575, ORTEC) and counted by single channel counter (928, ORTEC).

The scintillators of the same model (EJ-260, Eljen technology) with different geometry were used in the experiment. Both scintillators were manufactured in the form of cylindrical type with different size where the size of a smaller one is 0.4 cm in radius and 1.5 cm in height, and a bigger one 0.6 cm in radius and 2.0 cm in height, respectively.

The radiation sources were located 2.6 cm in radial distance next to the scintillator. A sealed source of beta-ray, ^{90}Sr with corrected radioactivity of 7,240 Bq with consideration of secular equilibrium with ^{90}Y [3], and of gamma-ray, ^{60}Co with corrected radioactivity of 33,500 Bq were used. The measurements were conducted with four conditions: background, ^{90}Sr only, ^{60}Co only and combined ^{90}Sr and ^{60}Co (^{90}Sr+^{60}Co). Background counting rate was measured without any source. The source conditions of ^{90}Sr only and ^{60}Co only were placement of single radioactive source and ^{90}Sr+^{60}Co was placement of both ^{90}Sr and ^{60}Co source to make a mixed beta-ray and gamma-ray condition. From the measured counting rate of ^{90}Sr+^{60}Co condition, the portion of beta-ray was calculated using eq. (4) and it was compared with the measured counting rate of ^{90}Sr only condition. Each condition was measured for 60 seconds and repeated 3 times for the bigger scintillator. These steps were repeated after replacement of the scintillator as the smaller scintillator.

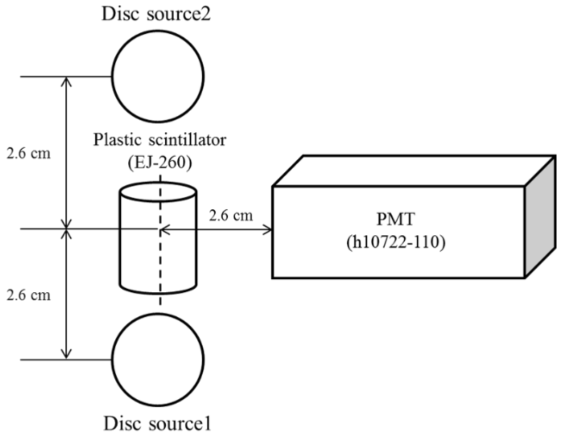

Fig. 1. The scintillator, source and PMT layout used in the experiment.

2.3 Measurement Results

Table 1 represents the counting rates of the radioactive sources of ^{90}Sr, ^{60}Co, and combined ^{90}Sr and ^{60}Co, for big and small scintillators. The represented counting rate per minute (CPM) was net counting rate. The net counting rate was obtained by subtracting the background counting rate from the counting rate of the radioactive sources where the background counting rate of big and small scintillators were 301±18 CPM and 201±14 CPM, respectively.

Table 1. Summary of measured counting rates for big and small scintillators

Type of source	CPM for big scintillator	CPM for small scintillator
^{90}Sr only	3,540±67	1,817±26
^{60}Co only	2,121±26	714±31
^{90}Sr+^{60}Co	5,661±72	2,530±41

The detecting efficiencies for big scintillator were 0.81% for ^{90}Sr source, 0.11% for ^{60}Co. The range of beta-ray with the energy of 2 MeV in plastic scintillator was 0.975 cm where it implied the beta-ray emitted from ^{90}Sr/^{90}Y source would lose its energy even in such a small scintillator as one with 0.4 cm in radius and 1.5 cm in height. The linear attenuation coefficients of photons with energy of 0.6 MeV and 1.25 MeV are 0.08936 cm^{-1} and 0.06310 cm^{-1} [4]. Those attenuation coefficients implied that the scintillators with the radius of 0.4 cm and 0.6 cm were not sufficient to fully absorb the incident gamma radiation. Therefore, the detection efficiency of gamma-ray was different between scintillators. Accordingly, the detecting efficiency of beta-ray was much higher than that of gamma-ray, at least 8 times higher.

2.4 Parameters Used in Derivation of Beta-ray Portion

Table 2 shows the characterized counting rate ratios of each source and derived beta-ray counting rate. R_{Sr}, R_{Co}, and R_{Sr+Co} were 1.949±0.046 CPM, 2.972±0.136 CPM and 2.237±0.046 CPM, respectively. The portion of beta-ray in the counting rate of big scintillator measured by combined ^{90}Sr and ^{60}Co source ($X_{big,Sr+Co}$) was 0.625±0.034. The derived counting rate of beta-ray from the total measured counting rate was 3,538±201 CPM while the counting rate of single ^{90}Sr source measured by the big scintillator was 3,540±67 CPM. The relative error between counting rates derived by the calculation and independently measured with single source was 0.05%. The relative standard deviation of the derived beta-ray counting rate was 5.7% where the originally measured counting rate of ^{90}Sr was 1.9%. The relative standard deviation was enlarged by three times during the step of the calculation.

The portion of beta-ray counting rate was successfully derived using the parameters defined in this study. The relative standard deviation was necessarily increased because of error propagation during the characterization of the parameters and calculation of the portion of beta-ray.

Table 2. Calculation results for parameters (counting rate ratio, X_{big}) and derived counting rate of ^{90}Sr

Parameter	Value
R_{Sr}	1.949±0.046
R_{Co}	2.972±0.136
R_{Sr+Co}	2.237±0.046
$X_{big,Sr+Co}$	0.625±0.034
Counting rate of ^{90}Sr; derived using $X_{big,Sr+Co}$	3,538±201 (CPM)

3. Conclusions

The method of deriving beta-ray portion from the measured counting rate using two scintillators with different size was suggested for the in-situ measurement. The presented experimental work showed the feasibility on the in-situ measurement despite the relative error was increased by three times compared to before the calculation. It was thought that the method could be used to effectively detect the high level of beta-ray emitting radionuclide and accordingly to find the hot spot of contamination in the soil or in case of emergency.

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