Experimental Investigation of the photo-peak detection efficiency of SiPM-based CsI(Tl) spectrometer with uncertainty calculation

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1. Introduction

Since there are many issues such as radioactive waste problem and wastewater from Fukushima, it is crucial to quantifying the amount of radioactive materials in nature like soil and seawater. Gamma spectroscopy is widely used because of its unique ability to identify ambiguous radioactive materials and quantify them.

Accurate quantification of radioactive materials, however, is difficult because of many uncertainty factors arising from radiation detector system, samples, stochastic nature of radioactive decay. In this study, we investigated the photo-peak detection efficiency of SiPM-based scintillator detector and evaluated the uncertainty of detection efficiency using uncertainty propagation method.

2. Materials and Methods

2.1 Experimental method

The detector was configured with 6×6×15mm3 CsI(Tl) scintillator and the SiPM which was mounted on PCB board (MicroFJ-SMA-60035-GEVB). Spectroscopy Amplifier (Ortec 673) and digital multichannel analyzer (MCA-8000D, AMETEK) was used for gamma spectroscopy. Several calibration gamma-ray sources (^{57}Mn, ^{60}Co, ^{133}Ba, ^{137}Cs and ^{152}Eu) were used to measure various gamma-ray energies. The distanced between the source and the scintillator was 10 cm as shown in Fig. 1 and all measurements was conducted during 300 s in live time.

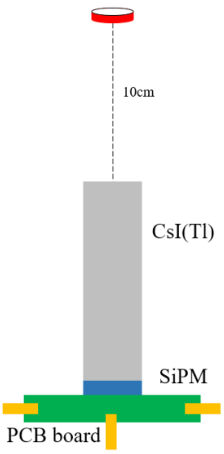

Fig. 1. The experimental setup of gamma spectroscopy for photo-peak efficiency calculation.

2.2 Basic theory of calculating photo-peak efficiency and standard uncertainty

The photo-peak efficiency for specific energy (ϵ_i) can be obtained using eq (1). N_i is the number of net count of photo-peak with energy E, T_i is the number of total count of photo-peak with energy E, B_i is the number of background count of photo-peak with energy E, A_i is the activity of source, I_i is the emission probability of energy E and is the acquisition time in second [1].

$$\epsilon_i = \frac{N_i}{A_i \cdot I_i \cdot t} \quad (1)$$

$$N_i = T_i - B_i \quad (2)$$

The standard uncertainty of photo-peak efficiency can be calculated by propagation of the standard uncertainties. With the uncertainty propagation, the standard uncertainty of photo-peak efficiency ($\mu(\epsilon_i)$) can be written as

$$\frac{\mu(\epsilon_i)^2}{\epsilon_i} = \frac{\mu(N_i)^2}{N_i} + \frac{\mu(A_i)^2}{A_i} + \frac{\mu(I_i)^2}{I_i} \quad (3)$$

where $\mu(N_i)$, $\mu(A_i)$, $\mu(I_i)$ is the standard uncertainty of net count, radioactivity and emission probability. We assumed that the relative uncertainty of radioactivity was 3% and coverage factor (k) was 2. The expanded uncertainty of emission probability followed by reference and all values in Table I. was expressed as expanded uncertainty with confidence level of 95% [2].

3. Results and Discusstion

3.1 The result of calculating photo-peak efficiency and the standard uncertainty

Table II shows the calculation results of photo-peak efficiency, the relative uncertainty of photo-peak efficiency and the effective degrees of freedom which was assumed by Welch-satterthwaite equation. Since the effective degrees of freedom is higher than 11 in all gamma energies, we can use the value of k as 2 for the photo-peak efficiency values with 95% confidence interval.

Photo-peak efficiency curve was fitted using measurement data as shown in Fig. 2. Because the values of standardized residuals were between -1 and 1 randomly, we can prove that the result of experiments for

Table I: Details of gamma-ray sources

Source	Acitivity (MBq)	γ-ray energy (keV)	Emission probability (%)
^{57}Mn	0.647 ± 0.039	834.848	99.9752 ± 0.0005
^{60}Co	2.407 ± 0.144	1173.288	99.85 ± 0.03
		1332.492	99.9826 ± 0.0006
^{133}Ba	1.048 ±0.063	80.9979	33.31 ± 0.3
^{137}Cs	2.896 ± 0.174	661.657	84.99 ± 0.2
^{152}Eu	2.960 ± 0.178	121.7817	24.41 ± 0.13
		344.2785	26.59 ± 0.12
		1408.013	20.85 ± 0.08

photo-peak calculation was valid.

But there was a lot of photo-peak efficiency uncertainty in high gamma-ray energy (> 1MeV) compared with relatively low gamma-ray energy. The reason is that low count at high energy channel caused by low geometric efficiency and short measure time contributed the statistical fluctuation of photo-peak efficiency. Also backscattered photons induced by gamma-rays which interact with surrounding materials and the difference in photo-peak cross section according to gamma-ray energy reduced the photo-count efficiency of high energy gamma-ray.

Table II: The results of photo-peak efficiency and its relative uncertainty and effective degree of freedom

γ-ray energy (keV)	Photo-peak efficiency (1E-5)	Relative uncertainty (%)	Effective degree of freedom
80.9979	7.362	3.14	20
121.7817	4.037	3.04	16
344.2785	1.444	3.08	17
661.657	5.078	3.05	12
834.848	2.716	5.69	13
1173.288	0.592	14.47	20
1332.288	0.693	9.15	15
1408.013	0.999	15.86	19

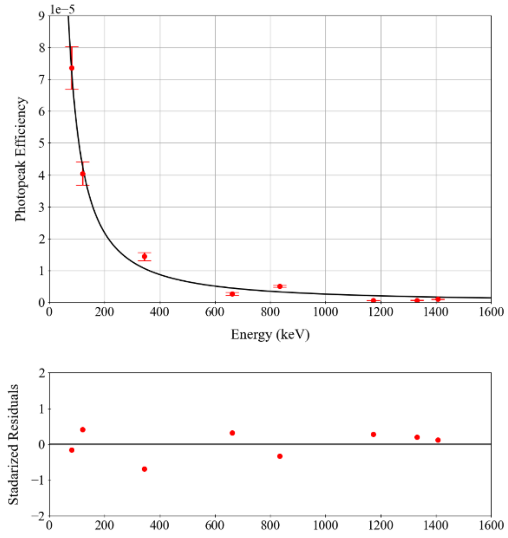

Fig. 2. The result of photo-peak efficiency curve fitting with 95% confidence level and standardized residuals.

4. Conclusion

In this study, we investigated the photo-peak efficiency of SiPM-based CsI(Tl) spectrometer and calculated the uncertainty as a function of gamma-ray energy. Due to the difference in count rate induced by the difference of gamma-ray energy, the uncertainty of photo-peak efficiency increased as gamma-ray energy increased. In addition, another uncertainty factors such as pile-up, coincidence, attenuation and half-life are not considered. We will conduct the experiments for more accurate uncertainty evaluation in the future.

5. Acknowledgement

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