Energy and resolution calibration of low resolution SiPM-based CsI(Tl) spectrometer for radionuclide identification

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1. Introduction

Scintillator detector has been widely used in many fields such as radiation portal monitors and medical imaging. Gamma spectroscopy is powerful method to identify or quantify radioactive isotopes. With development of technology, silicon photomultiplier (SiPM) rapidly replaces photomultiplier (PMT). It has many advantages compared with PMT such as cheap price and compact size. CsI(Tl) Scintillator is generally used coupled with SiPM since it has high effective Z-number and lower cost. For radionuclide identification, the spectrometer should be capable of distinguish different gamma energy.

In this paper, we performed the energy and resolution calibration of low resolution SiPM-based CsI(Tl) spectrometer to measure the gamma ray energy for the identification of radioactive nuclides using gamma ray spectra obtained by detector and we verified the result through MCNP6 simulation.

2. Materials and Methods

2.1 Experimental method

6×6×15mm3 CsI(Tl) scintillator was polished on all sides and coated with a white epoxy. The SiPM was mounted on PCB board (MicroFJ-SMA-60035-GEVB) and coupled with scintillator. Spectroscopy Amplifier (Ortec 673) and digital multichannel analyzer (MCA-8000D, AMETEK) was used to obtain the gamma spectrum of spectrometer. Four gamma sources (^{22}Na, ^{57}Mn, ^{60}Co and ^{137}Cs) which emit clearly distinguished gamma rays were used for energy and resolution calibration. Two gamma sources (^{133}Ba, ^{152}Eu) were used to validate the result of calibration. The distanced between the source and the CsI(Tl) was 11.2cm.

2.2 Fitting methods for Energy and Resolution Calibration

In energy calibration, the relation between gamma ray energy and the channel number of MCA is identified. We used linear and quadratic equations which are known as the best fitting methods [1]. To calibrate energy resolution of scintillator, the Gaussian energy broadening (GEB) fitting function which calculate the response function of detector using convolutional operation [2].

$$\boldsymbol{S}^{*}(E, a, b, c) = \boldsymbol{f}\,(E_0, a, b, c) * \mathbf{S}\,(E_0) \qquad (1)$$

$$\boldsymbol{f}(E_0, \mathrm{a}, \mathrm{b}, \mathrm{c}) = \mathrm{A}e^{-\left(\frac{2\sqrt{2\ln 2}(E-E_0)}{FWHM(E_0,a,b,c)}\right)^2} \qquad (2)$$

$$FWHM\,(E_0, a, b, c) = a + b\sqrt{E_0 + cE_0^2} \qquad (3)$$

where $\boldsymbol{S}^{*}$ is the energy broadened spectrum, $\boldsymbol{S}$ is originally deposited energy spectrum, a,b and c are GEB parameters, FWHM is full width at half maximum at specific energy, E is the broadened energy, and E_0 is the original energy before broadening. The a, b and c values in eq. (3) was calculated by photopeaks (32 keV, 511 keV, 662 keV, 854 keV, 1173 keV, 1274 keV, 1332 keV) in measured gamma spectrums using Gaussian fitting. Genetic algorithm which is well known to perform with nonlinear or discrete objective functions was used to optimize the parameters in eq. (3).

3. Results and Discusstion

3.1 Energy and Resolution Calibration

Table I shows the gamma ray sources used for calibrations and the measurement results of channel number and FWHM values.

Table I: Gamma ray sources used for calibrations.

Channel #	Energy (MeV)	FWHM (MeV)	Source
23.9	0.03219	0.0118	^{137}Cs
289.6	0.511	0.0552	^{22}Na
370	0.662	0.064	^{137}Cs
455	0.8384	0.0716	^{54}Mn
617	1.1732	0.0836	^{60}Co
660.8	1.274	0.0843	^{22}Na
684	1.3325	0.0874	^{60}Co

Fig. 1. shows the results of fitting using linear and quadratic equations. Both equations fitted well with high R-square values. Using calculated FWHM values, the parameters of eq. (3) for resolution calibration was optimized. The optimum values for each a, b and c were 0.000349854109, 0.075910934916, 0.009793058936.

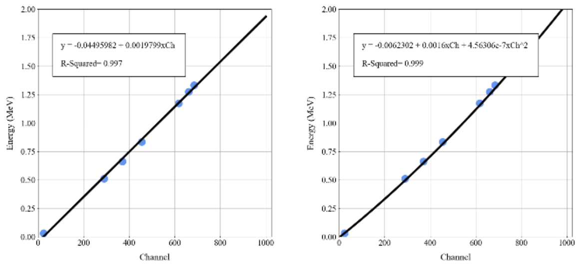

Fig. 1. The results of energy calibration with two equations.

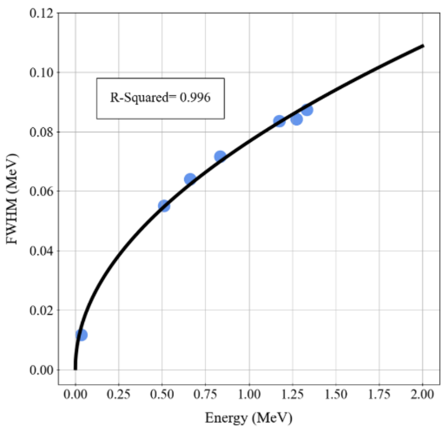

Fig. 2. The result of resolution calibration with optimized parameters.

3.2 MCNP6 Simulation results

To validate the results of calibrations, we compared the measured spectrum with MCNP6 simulation. F8 tally was used to simulate gamma spectrum and simulated spectrum was broadened by GEB function. As shown in Fig. 3. the gamma spectrum calibrated by quadratic equation (blue line) was more accurate than the linear equation (green line).

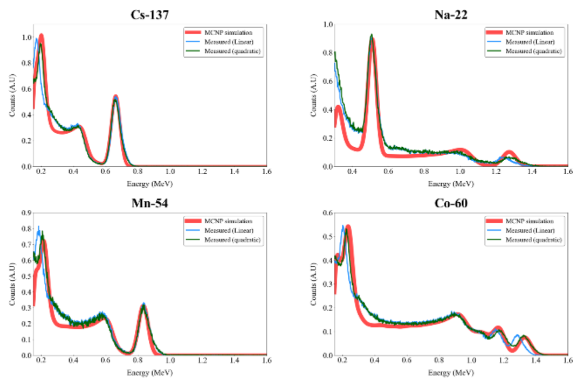

Fig. 3. The measured spectrum (green, blue) and MCNP6 simulation results (red) of ^{22}Na, ^{57}Mn, ^{60}Co, ^{137}Cs

To validate the results of calibrations and the ability to identify radionuclide isotopes, we measured the spectrum of ^{133}Ba, ^{152}Eu and compared with simulated spectrum broadened by GEB function as shown in Fig. 4.

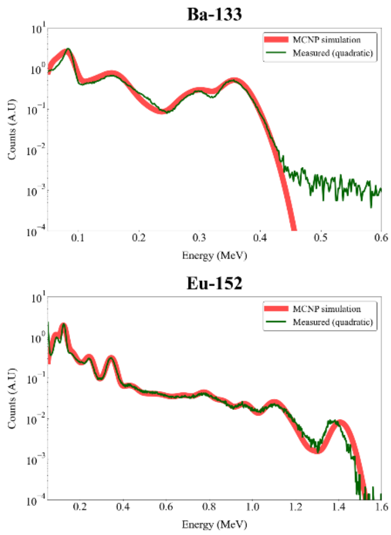

Fig. 4. The measured and simulated spectrum of ^{133}Ba, ^{152}Eu

4. Conclusions

In this paper, we conducted the energy and resolution calibration of low resolution SiPM-based CsI(Tl) spectrometer. The quadratic equation was best for energy calibration and resolution calibration was also confirmed by comparing with the MCNP6 simulated results. Based on the calibration results of this study, we will development the method for radionuclide identification using low resolution spectrometer.

5. Acknowledgement

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