

Elimination of self-activity signals using peak-to-charge discrimination method for LaBr₃:Ce scintillator



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Introduction

In recent years, inorganic scintillators using various materials have been researched and developed, and their performance has been dramatically improved. LaBr₃:Ce scintillators are attracting attention as an alternative detector for semiconductor detectors because it has high energy resolution and fast decay-time characteristics^[1-3]. However, there is a drawback that a self-radioactive background signal is always generated from the scintillator due to the decay of the radionuclide contained in the scintillator. LaBr₃:Ce scintillator contains ²²⁷Ac series nuclides, which emit alpha particle of 5 to 6 MeV due to alpha decay, which are equivalent to gamma rays signals from 1.5 to 3 MeV^[4]. Since these self-radiations are generated in a relatively small number, it might be negligible for high-frequent gamma-ray measurement, however, it cannot be ignored when used for measurements with a low counting rate, such as environmental radioactivity measurement.

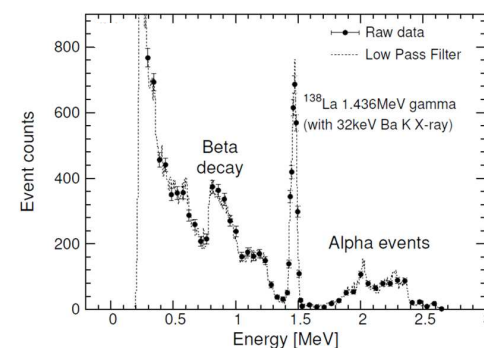


Fig. 1 Self-activity energy spectrum of LaBr₃.

Objective

In this presentation, we will report on a novel analysis method named peak-to-charge ratio (V_p/Q_{total}) discrimination, aiming at background rejection especially for alpha decay self-activity in LaBr₃:Ce scintillators.

Materials and Methods

Measurement system

- The electric signal waveforms from a PMT (R6231-100, Hamamatsu Photonics) equipped with a LaBr₃:Ce scintillator (38S382/B380, BrillanCe™ Saint-Gobain) were measured using an oscilloscope (Wave Runner 64xi, LeCroy, 5 GS/s) without electronic devices such as a shaping amplifier.

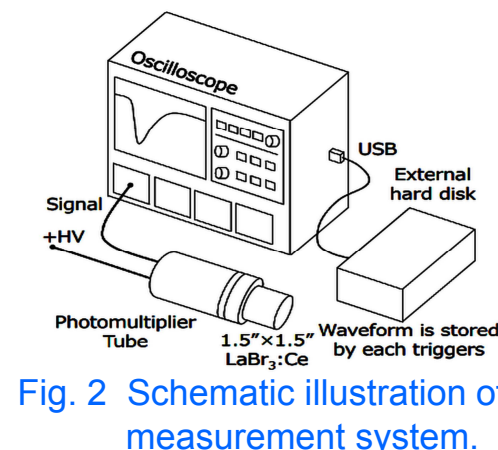


Fig. 2 Schematic illustration of measurement system.

Results and discussion

Signal separation using V_p/Q_{total} value

- Figure 5 shows the energy dependence of the V_p/Q_{total} value for self-activity of the LaBr₃:Ce scintillator. Two components of the V_p/Q_{total} value at the energy range of 1.5 – 2.7 MeV were observed.
- The α -induced events should be distributed at a higher value than the gamma-induced events. For the lower component of V_p/Q_{total} , it is considered to be a gamma-induced event from environmental radiation such as ²⁰⁸Tl (2.615 MeV).
- Threshold functions of 1 to 3 $\sigma_{V_p/Q_{total}}$ were obtained by the calibration using a fitting analysis with $\sigma_{V_p/Q_{total}} = kQ_{total}^{-1} + l$ ($k = \text{const.}$, $l = \text{const.}$).
- As shown in Fig 5, the fitting curves adequately discriminated α -events from γ -events.

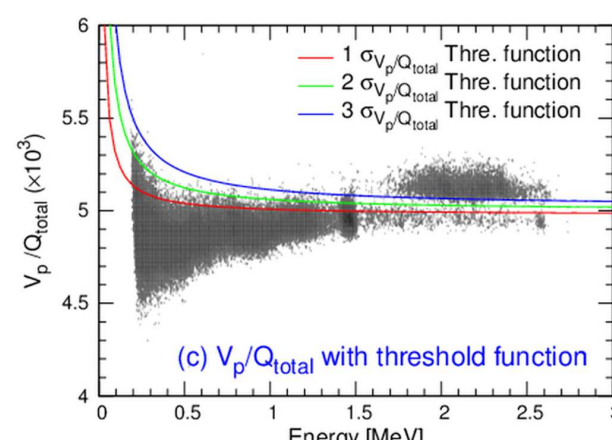


Fig. 5 The energy dependence of the V_p/Q_{total} for self-activity.

Accuracy of α -discrimination

- Figures 6(a) and 6(b) show the energy spectrum for the background subtraction and V_p/Q_{total} discrimination methods, respectively. The energy spectrum without radiation source was normalized by the integrated event counts in the energy range of >2 MeV for background subtraction. As shown in Figure 6(b), only the ⁶⁸Ga 1.883 MeV gamma ray peak remained clear by using the $3\sigma_{V_p/Q_{total}}$ threshold function.
- Total absorption peak spectrum processed with the V_p/Q_{total} discrimination method for ⁶⁸Ga 1.883 MeV gamma rays, where the energy was overlapped with background α -events, reproduced exactly the same result as that of conventional background-subtraction method.
- The accidental rejection ratio of gamma-induced events was evaluated to be 0.17%.
- Total absorption peak spectrum processed with the V_p/Q_{total} discrimination method for ⁶⁸Ga 1.883 MeV gamma rays, where the energy was overlapped with background alpha events, reproduced exactly the same result as that of the background subtraction method.
- The difference in measured peak counts of both methods was 0.716%, and the statistical error in the V_p/Q_{total} discrimination method and background subtraction was 4.81% and 8.70%, respectively.

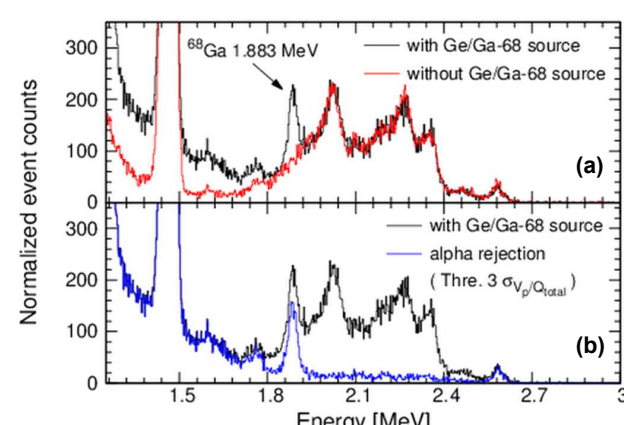


Fig. 6 Normalized energy spectra w/ and w/o ⁶⁸Ga source.

Noise reduction

- Since the peak value V_p is influenced by signal fluctuation such as high frequency noise, noise reduction was conducted using moving average and digital low pass filter.
- The digital low pass filter using Fast Fourier Transform (FFT) with inverse FFT (IFFT) suppressed the noise component of >50 MHz in the entire waveform.

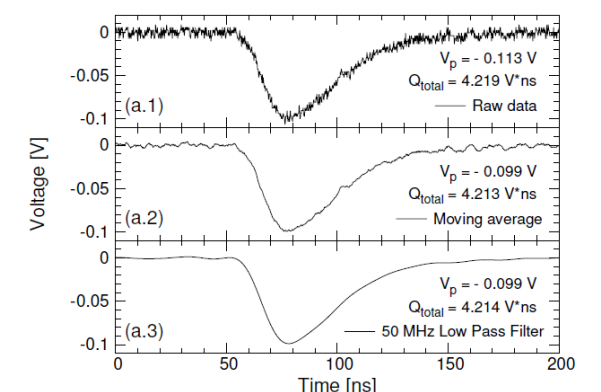


Fig. 3 Noise reduction using FFT.

α -event discrimination using V_p/Q_{total}

- The peak-to-charge ratio V_p/Q_{total} is expected to be constant for gamma events, and a different constant value is expected for alpha events.
- However, the V_p/Q_{total} value fluctuated according to the uncertainties of V_p and Q_{total} values.
- Equation (1) deduced from an error propagation of V_p/Q_{total} value was used for discriminating alpha and gamma events.

$$\sigma_{V_p/Q_{total}} = \sqrt{\left(\frac{1}{Q_{total}}\sigma_{V_p}\right)^2 + \left(\frac{V_p}{Q_{total}^2}\sigma_{Q_{total}}\right)^2} \quad \text{Eq. (1)}$$

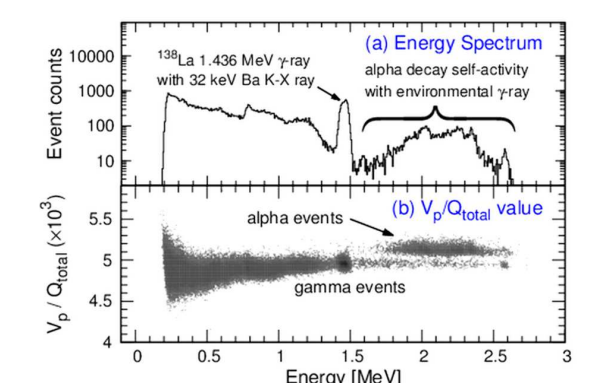


Fig. 4 Concept of α -event discrimination using V_p/Q_{total} value.

Evaluation of α -event rejection

- Since the energy range of background alpha-decay is distributed from 1.5 to 3 MeV (gamma equivalent), 1.883 MeV gamma rays from ⁶⁸Ga was used for evaluation.
- The rejection accuracy of α -induced events was assessed by comparing the energy spectrum between the V_p/Q_{total} discrimination method and conventional background-subtraction method.
- Waveforms of 60,000 events were used for the comparison.

Detection of low-rate environmental gamma ray

- As shown in Figure 7, the contribution of ²⁰⁸Tl (2.614 MeV) gamma rays was clearly detected. This means that Thorium series nuclei exist in the measurement environment.
- In the raw data, ²¹⁴Bi (1.764 MeV) of Uranium series could not be identified, however, they were clearly identified using the V_p/Q_{total} discrimination method. On the other hand, ²¹²Bi (1.620 MeV) of Thorium series nuclei could be observed in both cases of raw data and alpha rejection.
- For the conventional background-subtraction method, the actual background spectrum also depends on the surrounding materials and it would therefore be quite difficult to eliminate from it the ubiquitous presence of ²¹²Bi.
- The V_p/Q_{total} discrimination method can be considered more practical approach compared to the conventional background-subtraction method for surveying environmental radiation.

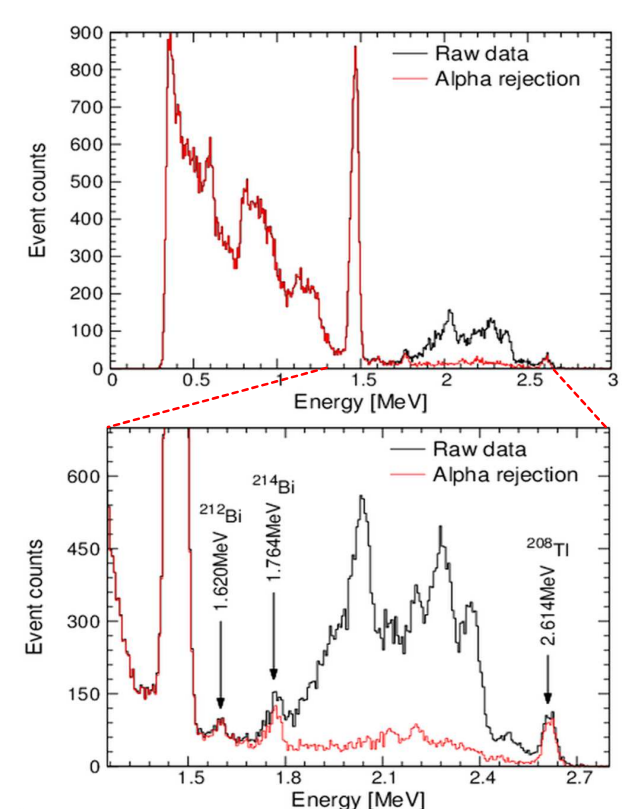


Fig. 7 The energy spectrum of environmental radiation

Conclusion

In the present research, alpha-decay events of the LaBr₃:Ce scintillator self-activity were discriminated by analyzing the peak-to-charge ratio V_p/Q_{total} of the PMT-output waveform. The V_p/Q_{total} discrimination method has demonstrated only small accidental gamma rejection, and the energy spectrum after alpha-rejection could be reproduced exactly as that of the background subtraction method with higher-accuracy. The presented method uses measurable parameters (V_p and Q_{total}) using flash ADC, and the entire process can be implemented with an electric circuit. We believe that the V_p/Q_{total} discrimination method will be used as one of the standard techniques for gamma ray energy spectrometry using LaBr₃:Ce scintillators especially for environmental gamma ray surveys.

References

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