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Sensitivity of Gaussian energy broadening function of MCNP pulse height spectra on CLYC7 scintillation detector

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Abstract. The Cs_2LiYCl_6:Ce crystal (CLYC) is an inorganic scintillator which has been developed for the γ-ray and neutron measurement with the high detection efficiency, high resolution, and no need unfolding technique. To enhance the measurement of the fast neutron, the CLYC with ^{7}Li-enrichment (CLYC7) scintillator is developed. In this work, the response of the CLYC7 detector to γ-ray is obtained using ^{137}Cs γ-ray calibration source and calculated using Monte Carlo N-Particle transport code (MCNP). A comparison of measured and calculated γ-rays spectra is complicated by the fact that physical radiation detectors have finite energy resolution. In this study, we treated detector energy resolution effect by Gaussian energy broadening (GEB) in MCNP pulse height spectra calculation. We observe the parameters in the GEB function which provides simulation spectrum matches the experiment spectrum, especially on the photopeak region. The detail sensitivity of GEB function on CLYC7 scintillation detector is presented in this work.

1. Introduction
The Cs_2LiYCl_6:Ce crystal (hereafter called as CLYC) is an newly developed inorganic scintillator which has been developed for the radiation measurement with the high detection efficiency, high resolution, no need unfolding technique, and excellent pulse shape discrimination in the mixed radiation fields of neutron and γ-ray [1-4]. In the field of neutron measurement, CLYC scintillator is used to detect thermal neutron. The enrichment of ^{7}Li in CLYC7 scintillator (the so-called CLYC7) allows a better detection of fast neutron. Due to their attractive performances, the CLYC7 have been used in the fast neutron spectrometer [5, 6] in the Large Helical Device (LHD) of National Institute for Fusion Science (NIFS), Japan. Note that neutron measurement is beyond the scope of this paper. In this work, we discuss about the response function of the CLYC7 to the γ-ray in the measurement and calculation. In the calculation, the Monte Carlo simulation using Monte Carlo N-Particle transport code (MCNP) [7] is performed. However, a comparison of measured and calculated γ-ray spectra is complicated by the fact that physical radiation detector has finite energy resolution. Thus, the Gaussian energy broadening (GEB) option in MCNP had been used in this work. Here, we discussed the sensitivity of GEB's parameters to obtain a good agreement between calculation and measurement.

2. Experiment setup and MCNP modelling
The experiment was performed at NIFS. CLYC7 scintillation detector and electronics equipment used in reference [6] are set up. Figure 1(a) shows the 1-inch in diameter and 1-inch in length of CLYC7

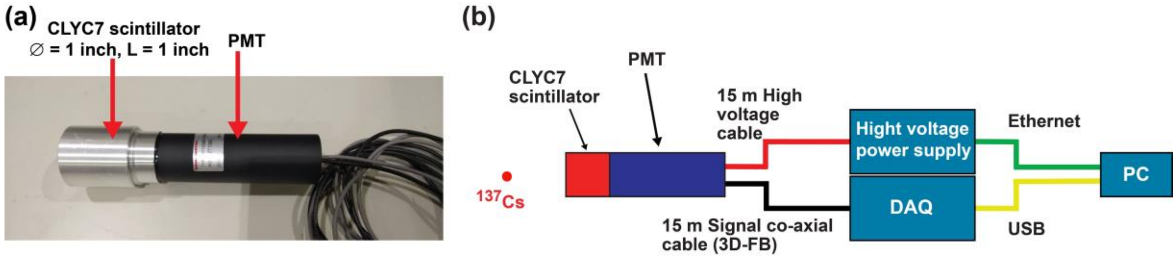

Figure 1. (a) CLYC7 scintillation detector. (b) The experiment set up.

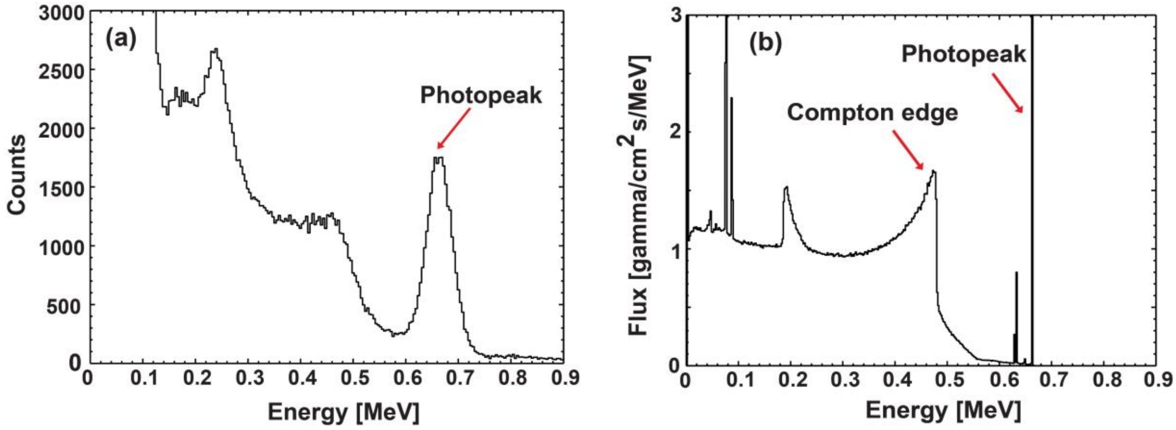

Figure 2. (a) The measured γ-ray spectrum of ^{137}Cs. (b) The simulated detector response function of ^{137}Cs γ-ray source using MCNP code.

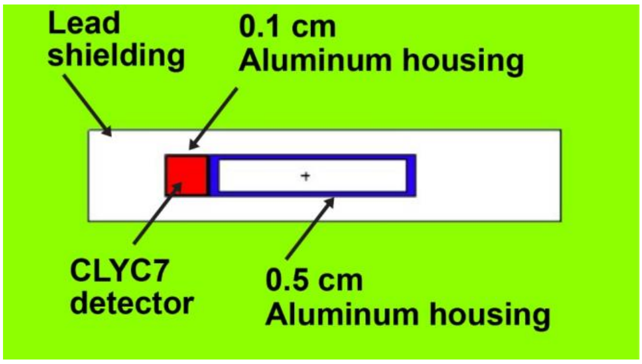

Figure 3. 2D geometry of the CLYC7 scintillation detector.

scintillator which is coupled with a high-gain stability photomultiplier tube (PMT), (H10580-100-01, Hamamatsu Photonics K.K.). The detector is biased with a high voltage of -1300 V by a quad high voltage power supply (RPH-033, HAYASHI-REPIC Corp.). The signal of the CLYC7 scintillation detector is fed into the data acquisition system (DAQ) equipped with the 12 bit/±2Vp analog-to-digital converter (ADC) with a sampling rate of 250 MHz with an online pulse shape discrimination function (DT5720B, CAEN). The response of the CLYC7 scintillator to γ-ray was obtained using ^{137}Cs γ-ray calibration sources (figure 1(b)). The 0.662 MeV photopeak produced by the ^{137}Cs γ-ray source has been obtained (figure 2(a)).

Figure 3 shows 2-D MCNP model. In order to calculate the response function of the ^{137}Cs γ-ray, F8 tally, which is specific for pulse height determination, i.e., energy deposition in the scintillator, is used. Number of particle history is 10^8 particles. Figure 2(b) shows the calculated response function of ^{137}Cs γ-ray. The result shows a narrow photopeak at 0.662 MeV and Compton continuum corresponding to Compton scattered electrons with the sharp Compton edge. Here, the detector resolution is added by the GEB function which has parameters *a*, *b*, and *c* to specify the full-width-at-half-maximum (*FWHM*) as:

$FWHM = a + b(E+cE^2)^{1/2}$ where E is energy [MeV]. The unit of a, b, and c is MeV, $MeV^{1/2}$, and none, respectively. Here, the *FWHM* is expressed in Gaussian distribution (figure 4) by: $FWHM = 2.358\sigma$ where σ is standard deviation of Gaussian distribution. The detector energy resolution is expressed by $R(E) = FWHM/E_0$ where E_0 represents the centroid of the Gaussian distribution.

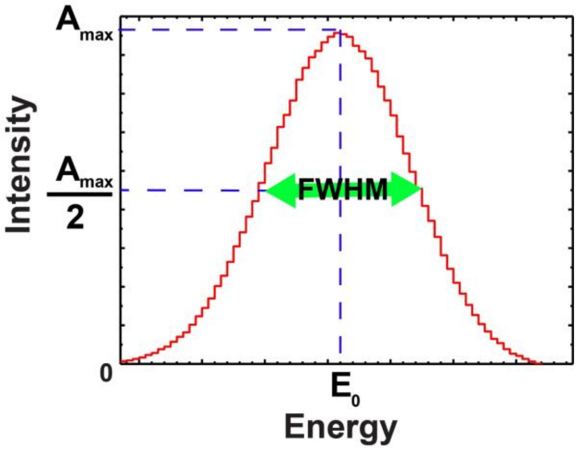

Figure 4. The Gaussian distribution and full-width-at-half-maximum.

3. Results and discussion

In the measurement (figure 2(a)), the *FWHM* at photopeak of ^{137}Cs γ-ray is approximately 58.25 keV. Here, we vary parameters a, b, and c in GEB function in order to match the calculation photopeak with experiment photopeak. The *FWHM* at photopeak is obtained. The sensitivity of GEB's parameters is then discussed in this paper.

3.1. Sensitivity of parameter a

Parameter a is varied between 0.00 and 0.19 MeV whereas parameters b and c are set to be 0.039 $MeV^{1/2}$ and 0.588, respectively. Figure 5(a) shows an example of response function of ^{137}Cs γ-ray source calculated by w/ and w/o GEB function. It is clearly seen the broadening of the photopeak when parameter a is increased. The results show that *FWHM* increases with an increase in parameter a (figure 5(b)). The linearly trend line has the slopes of 1031.7 keV/MeV, 2348.6 keV/MeV, and 830.4 keV/MeV when parameter a is varied between 0-0.1 MeV, 0.1-0.14 MeV, and 0.14-0.2 MeV, respectively.

3.2. Sensitivity of parameter b

Parameter b is varied between 0.00 and 0.20 $MeV^{1/2}$ whereas parameters a and c are set to be 0.027 MeV and 0.588, respectively. Figure 6(a) shows an example of response function of ^{137}Cs γ-ray source calculated by w/ and w/o GEB function. It is clearly seen the broadening of the photopeak when parameter b is increased. The results show that *FWHM* increases with an increase in parameter b (figure

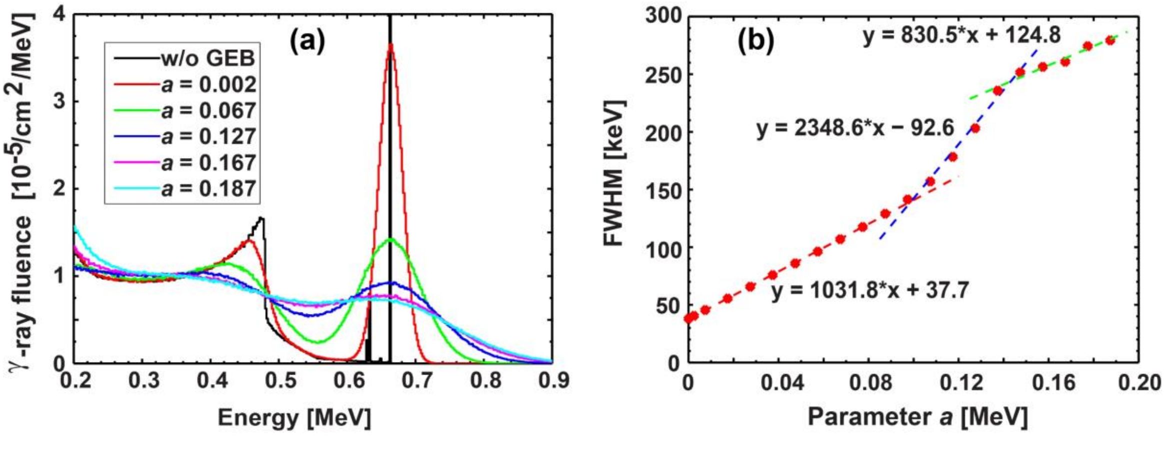

Figure 5. (a) Example of response function of ^{137}Cs γ-ray source calculated by w/ and w/o GEB function whereas parameter a is varied. (b) The relation between parameter a and *FWHM*.

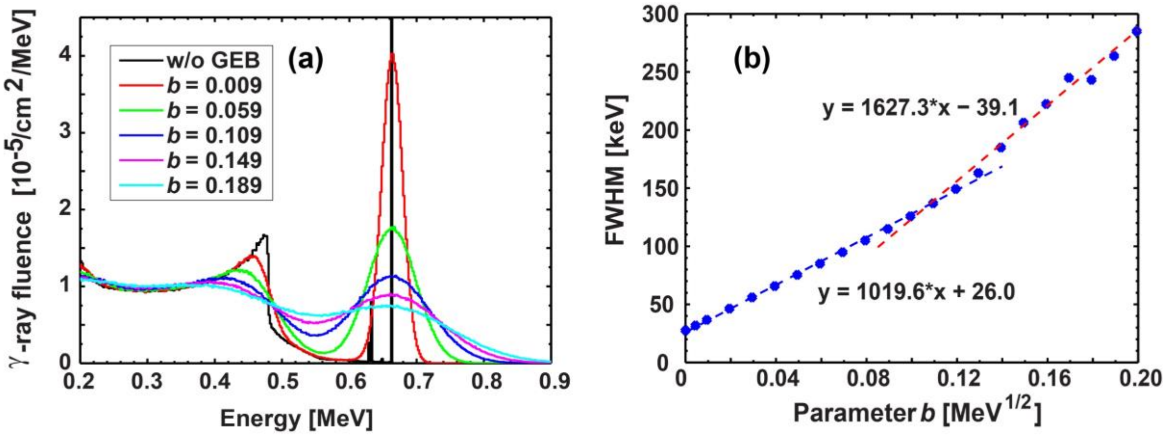

Figure 6. (a) Example of response function of ^{137}Cs γ-ray source calculated by w/ and w/o GEB function whereas parameter *b* is varied. (b) The relation between parameter *b* and *FWHM*.

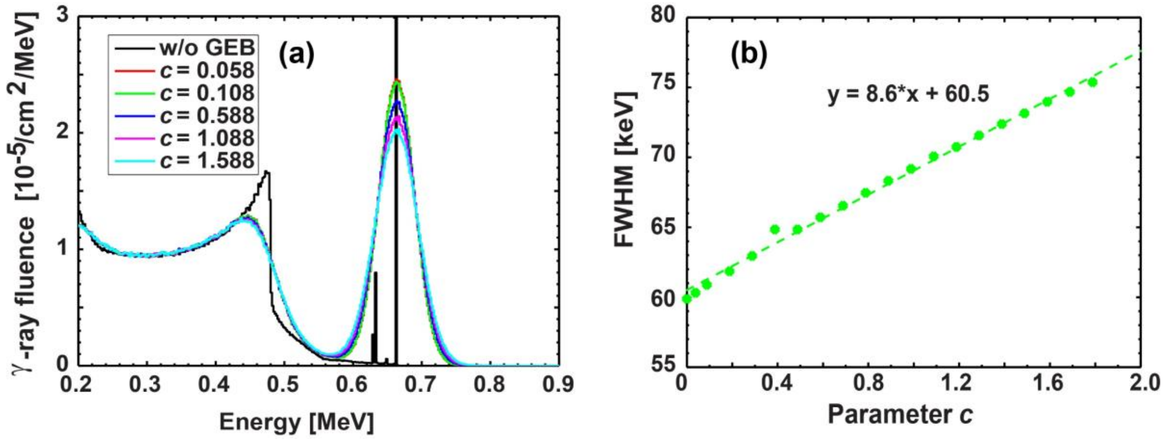

Figure 7. (a) Example of response function of ^{137}Cs γ-ray source calculated w/ and w/o GEB function whereas parameter *c* is varied. (b) The relation between parameter *c* and *FWHM*.

6(b)). The linearly trend line has the slopes of 1019.59 keV/MeV$^{1/2}$ and 1627.30 keV/MeV$^{1/2}$ when parameter *b* is varied between 0-0.1 MeV and 0.1-0.2 MeV, respectively.

3.3. Sensitivity of parameter c

Parameter *c* is varied between 0.00 and 1.78 whereas parameters *a* and *b* are set to be 0.027 MeV and 0.039 MeV$^{1/2}$, respectively. Figure 7(a) shows an example of response function of ^{137}Cs γ-ray source calculated by w/ and w/o GEB function. The results show that *FWHM* is almost constant with an increase in parameter *c*. The linearly trend line has the slopes of 8.58 keV when parameter *c* is varied between 0 and 1.78 (figure 7(b)).

3.4. Comparison of experiment and calculation

The calculated *FWHM* obtained by varying parameter *a*, *b*, and *c* is then compared to the measured *FWHM* of 58.25 keV obtained in the experiment (figure 8(a)). Therefore, parameter *a* of 0.021 MeV, *b* of 0.034 MeV$^{1/2}$, and *c* of 0.558, which provide calculated *FWHM* near 58.25 keV, have been selected and used in the final calculation. Figure 8(b) shows the comparison of experiment and calculation of ^{137}Cs γ-ray spectra when the parameter *a* of 0.021 MeV, *b* of 0.034 MeV$^{1/2}$, and *c* of 0.558 is used in the calculation. The agreement between experiment and calculation at photopeak is found. The detector energy resolution *R*(E) of approximately 8.7% is obtained. The discrepancy of the Compton continuum

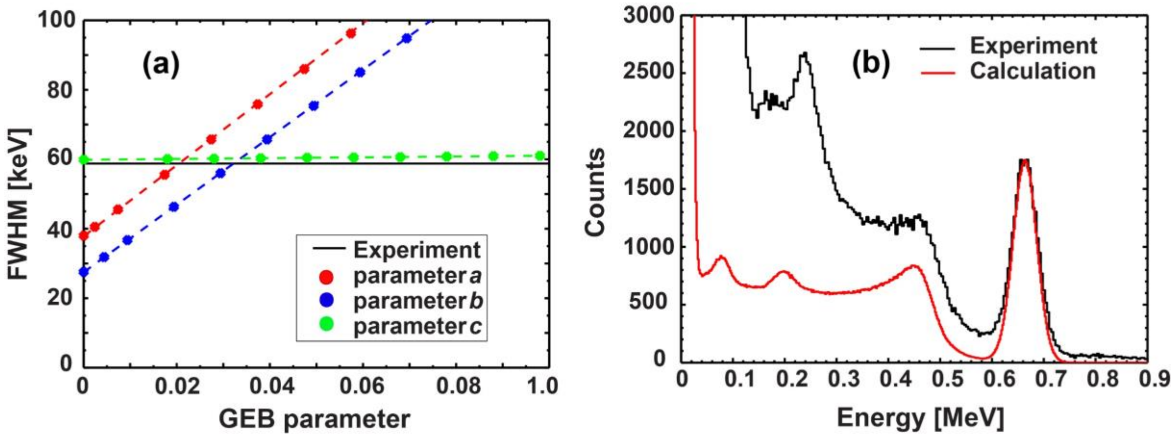

Figure 8. (a) Comparison of obtained *FWHM* from the changed of parameters *a*, *b*, and *c* with the *FWHM* obtained in the experiment. (b) The comparison of the ^{137}Cs γ-ray spectrum from the experiment and MCNP calculation with the GEB function.

might be caused by the background radiation and detector's absorption of X-rays or γ-rays which occurs by particles of high atomic number in the measurement. In addition, the study of detector resolution function on the Compton continuum energy region will be our future work.

4. Summary

In this work, we obtained the detector response function and energy resolution of CLYC7 scintillation detector to γ-ray provided by ^{137}Cs γ-ray calibration source. The response function of CLYC7 is obtained using MCNP simulation. We treated detector energy resolution by GEB function in MCNP pulse height spectra. The results show that the spectrum broadening is significantly affected by changing in parameter *a* and *b* in GEB function. By matching the calculation and measurement spectra, parameter $a = 0.021$ MeV, $b = 0.034$ MeV$^{1/2}$, and $c = 0.558$ are obtained for CLYC7 scintillation detector. However, the study of energy resolution in wide γ-ray energy range will be our future work.

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