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Energy Resolution of the Fabricated Plastic Scintillator

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1. Introduction

In order to evaluate absorption dose of a plastic scintillator for γ-ray therapy, a precise gamma-calibration of a plastic scintillator is required. For the precise calibration, the accurate position of the Compton edge in Compton electron spectrum must be known in the plastic scintillator. The position of the Compton edge is determined as a function of the detector resolution [1]. Thus, it is important to determine the energy resolution.

In this study, the plastic scintillator to be used for radiotherapy was fabricated using DLP 3D printer, and the energy resolution depending on the various energies of the photons was derived from the experiment and Monte Carlo simulation.

2. Methods and Results

2.1 Experimental Setup

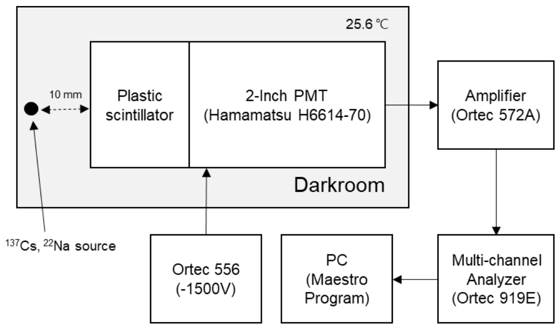

Fig. 1. Schematic of the experimental setup for measurement of pulse-height spectrum for γ-ray sources ^{137}Cs and ^{22}Na

The experimental setup to measure the pulse-height spectrum is as follows (Figure 1). A cube-shaped plastic scintillator (10 × 10 × 10 mm^3) was fabricated using a DLP 3D printer with the developed resin. The fabricated plastic scintillator was coupled to a photomultiplier (PMT, Hamamatsu H6614-70) to which a reverse bias of 1500 V was applied. γ-ray sources (^{137}Cs, ^{22}Na) were placed at a distance of 10 mm in front of the plastic scintillator. Spectroscopy amplifier Ortec 572A was used for shaping the PMT signal and Multi-channel analyzer Ortec 919E was used to analyze a stream of voltage pulses and sort them into a histogram. The pulse-height spectra for Compton electron from the sources were measured (Figure 3).

2.2 Linear Fit for Energy Calibration

Energy calibration is usually carried out by the linear relationship between the pulse height and the corresponding energy. The position of Compton maximum of the measured spectrum (L_{max}) can be used as Compton edge due to the smallest variance to the real Compton edge [2]. For energy above 40 keV, the function for linear fit is given by the following equation:

$$L = c(E_e - E_0) \quad (1)$$

where L is the pulse height, E_e is Compton electron energy, E_0 the intercept energy, and c is the slope which is characteristic of the experimental system.

The linear fit result for the positions of Compton maximum of the measured spectra for the γ-ray sources (^{137}Cs, ^{22}Na) are shown in Figure 2. The intercept energy was 63.11 keV, which represents the nonlinearity because of quenching effects in plastic scintillator fabricated for small electron energy [3].

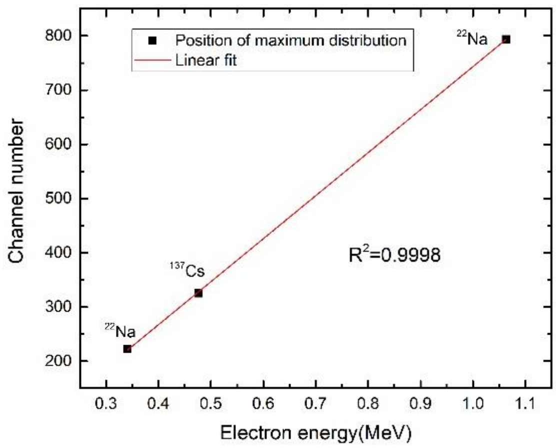

Fig. 2. Linear fit between Compton electron energy and pulse height values for γ-ray sources (^{137}Cs, ^{22}Na).

2.3 Monte Carlo Simulation

Based on the energy calibration obtained from the linear fit, Monte Carlo simulation using MCNPX code was conducted under the same condition as the experiment condition. F8 tally for energy spectrum and GEB card for Gaussian energy broadening were used in MCNPX code. The simulated energy spectra were calibrated to the pulse-height spectra, and matched to the measured pulse-height spectra in trial and error for manipulating the parameters of GEB card (Figure 3). The parameters acquired by matching the spectra are the components of the following FWHM equations:

$$FWHM = \mathrm{a} + \mathrm{b}\sqrt{E_e + cE_e^{\,2}} \qquad (2)$$

The FWHMs corresponding to the Compton electron maximum energies (E_c) were calculated by using the above equation, and the energy resolutions $\Delta L/L$ were derived by dividing the FWHM (ΔL) with the Compton electron maximum energies (L). Table I shows the FWHM and energy resolutions $\Delta L/L$ for the Compton electron maximum energy.

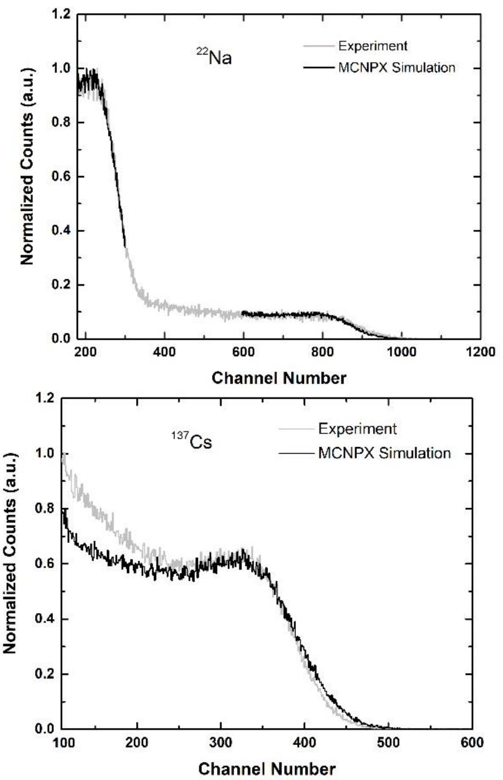

Fig. 3. Measured and simulated pulse-height spectra with γ-ray sources (^{137}Cs, ^{22}Na).

Table I: FWHM and energy dependent resolutions $\Delta L/L$ corresponding to Compton electron maximum energies E_c.

Source	**^{22}Na**	**^{137}Cs**	**^{22}Na**
E_c (MeV)	0.341	0.477	1.062
FWHM (MeV)	0.117	0.123	0.144
$\Delta L/L$	0.342	0.257	0.136

2.4 Empirical Function for Resolution

The energy resolution $\Delta L/L$ with Compton electron energy E_e was represented by the following empirical approximation [3]:

$$\frac{\Delta L}{L} = \sqrt{\alpha^2 + \frac{\beta^2}{E_e} + \frac{\gamma^2}{E_e^{\,2}}} \qquad (3)$$

Through the acquired energy resolutions corresponding to Compton electron maximum energy, the energy resolution was best fitted by the empirical function (Figure 4), and the parameters are α = 0.000%, β = 10.093%, γ = 10.071%. α is a value for optimizing the experimental setup, β is a value that mainly determines the resolution and is very sensitive to light output of a scintillator, and γ is determined by the dark current and electronic noise parameter. It is expected that energy resolution will be improved by reducing the values of β and γ by improving the light output and minimizing the signal noise.

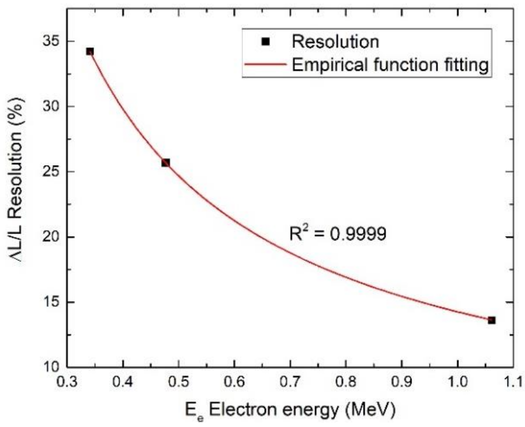

Fig. 4. Energy dependent resolution $\Delta L/L$ for the fabricated plastic scintillator.

3. Conclusions

In this study, the plastic scintillator to be used for radiotherapy was fabricated using the DLP 3D printer and energy resolution for the scintillator was derived from the experiment and Monte Carlo simulation.

Next, we will study on the positions of Compton edge depending on the energy resolutions which were obtained from this study, and derive the function of energy resolution to determine the position of Compton edge.

REFERENCES

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