Performance evaluation of an EJ-276 plastic scintillator using ^{252}Cf neutron source

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Background and Objective

Fast neutron measurements are an indispensable technique in the field of experimental nuclear physics.

As a typical detector for fast neutrons, organic liquid scintillators are widely used. But there are problems that

- ✓ The volume decreases over time.
- ✓ Import and export procedures are complicated because they are toxic and flammable liquids.

On the other hand, plastic scintillators are convenient due to

- ✓ Their physical hardness
- ✓ Non-toxicity
- ✓ Lower flammability.

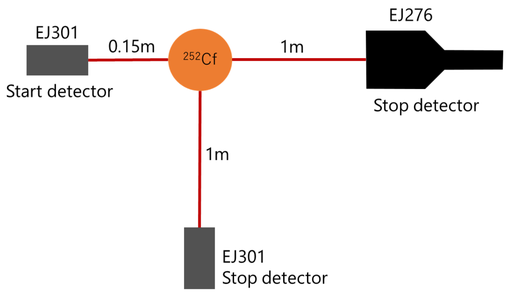
EJ276 is one of the latest pulse-shape discriminating plastic scintillators, but there are few measurements of detector characteristics.
This study aims to

- ✓ Evaluate the capability to discriminate between neutrons and gamma rays
- ✓ Derive the neutron response function.

Experiment

The time of flight of neutrons from ^{252}Cf neutron sources was measured.

Detectors



Experiment Setup

Measurement Objects

- Waveforms of neutrons and gamma rays from ^{252}Cf sources
- Time differences between particles incident on the start detector and the stop detectors

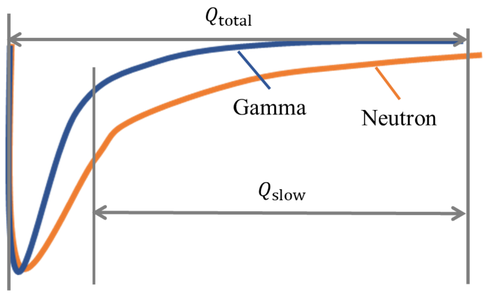
Signals from the PMTs were fed to a digitizer, CAEN-V1730SB, to convert the analog waveforms into digital data. Waveforms were acquired by self-trigger.

Evaluation of n-γ discrimination performance

Pulse Shape Discrimination(PSD)

Particle identification method focuses on that the output signal differs depending on the amount of linear energy transfer by the incident particle.

M. Moszynski *et al.*: Nuclear Inst. And Methods in Physics Research, A, 343, (1994), 563

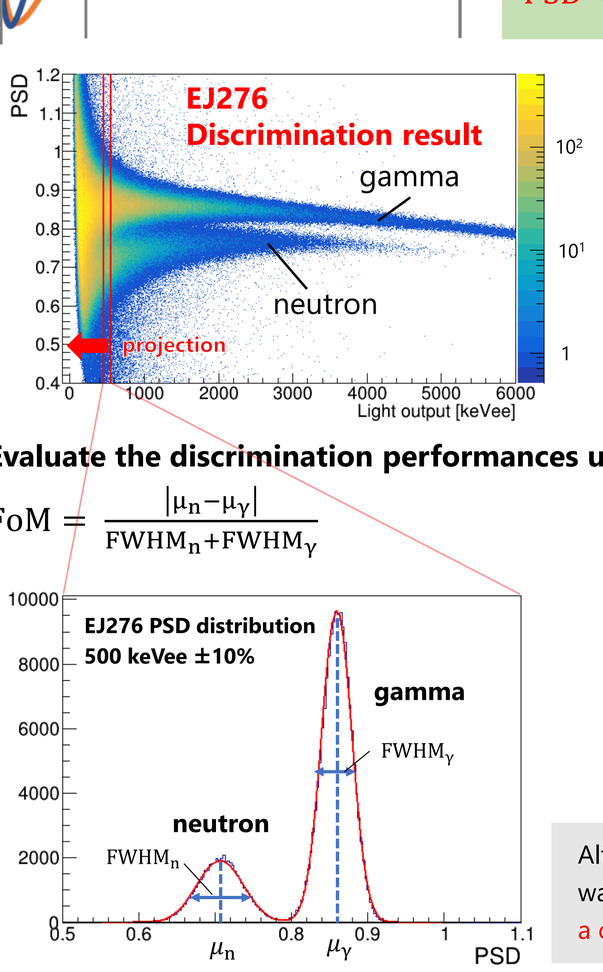


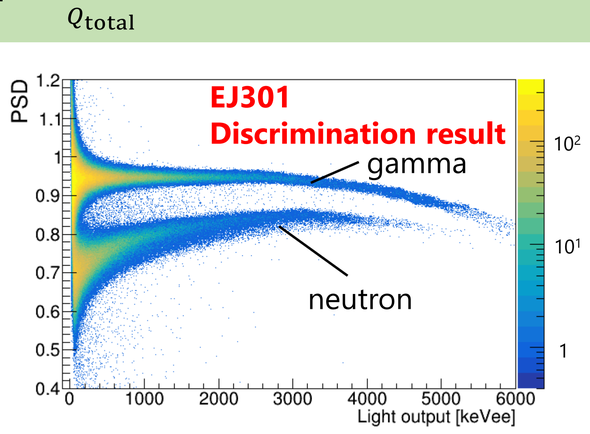
Define the following values

Q_{total} : integral of the waveform over the long gate

Q_{slow} : integral of the waveform over the slow gate

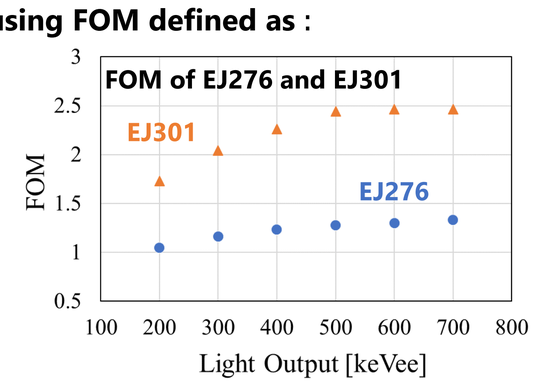
$$\mathrm{PSD} = \frac{Q_{\mathrm{total}} - Q_{\mathrm{slow}}}{Q_{\mathrm{total}}}$$





Evaluate the discrimination performances using FOM defined as :

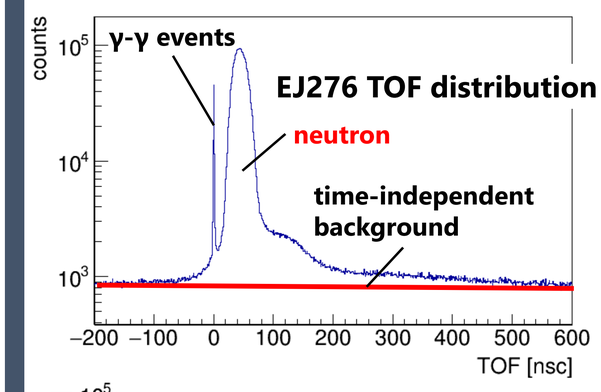
$$\mathrm{FoM} = \frac{|\mu_n - \mu_\gamma|}{\mathrm{FWHM_n} + \mathrm{FWHM_\gamma}}$$

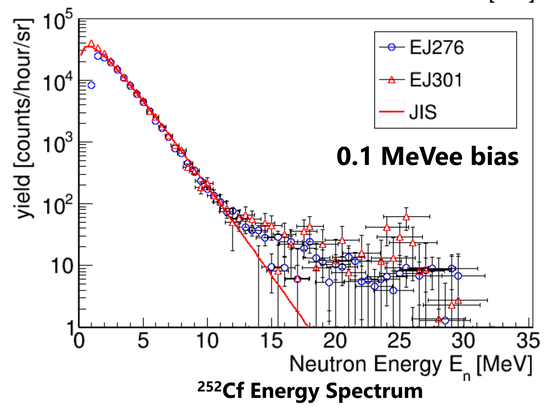


Although the discrimination performance of EJ-301 was superior to EJ-276, EJ-276 was also found to have a certain level of discrimination performance.

Energy spectrum by Time Of Flight method

In the TOF method, neutron energy is calculated from TOF using the following equation.





^{252}Cf Energy Spectrum

Formula for converting TOF to energy

$$E_n = \frac{m_n c^2}{\sqrt{1 - \left(\frac{L}{c t_{n-\gamma} + L}\right)^2}} - m_n c^2$$

- E_{n} : neutron energy
- m_{n} : mass of the neutron
- c : speed of light
- L : neutron flight distance
- t_n : Arrival time of neutron to stop detector
- t_γ : Arrival time of gamma to start detector
- $t_{n-\gamma} = t_n - t_\gamma$: time of flight (TOF)

JIS-recommended neutron energy spectrum

$$B_E = \frac{2}{\sqrt{\pi} \cdot T^{3/2}} \times \sqrt{E_{\mathrm{n}}} \times e^{-E/T} \times B$$

- T : Spectral parameter given by 1.42 MeV
- B : Normalized parameter

Detector efficiencies were calculated by PHITS-SCINFUL.
The experimental results were compared with the JIS-recommended neutron energy spectrum for ^{252}Cf neutron source.

D. Satoh, T. Sato, J. Nucl. Sci. Technol. 59(8), (2022), pp. 1047-1060
Japanese Industrial Standards, JIS Z 4521 (2006)

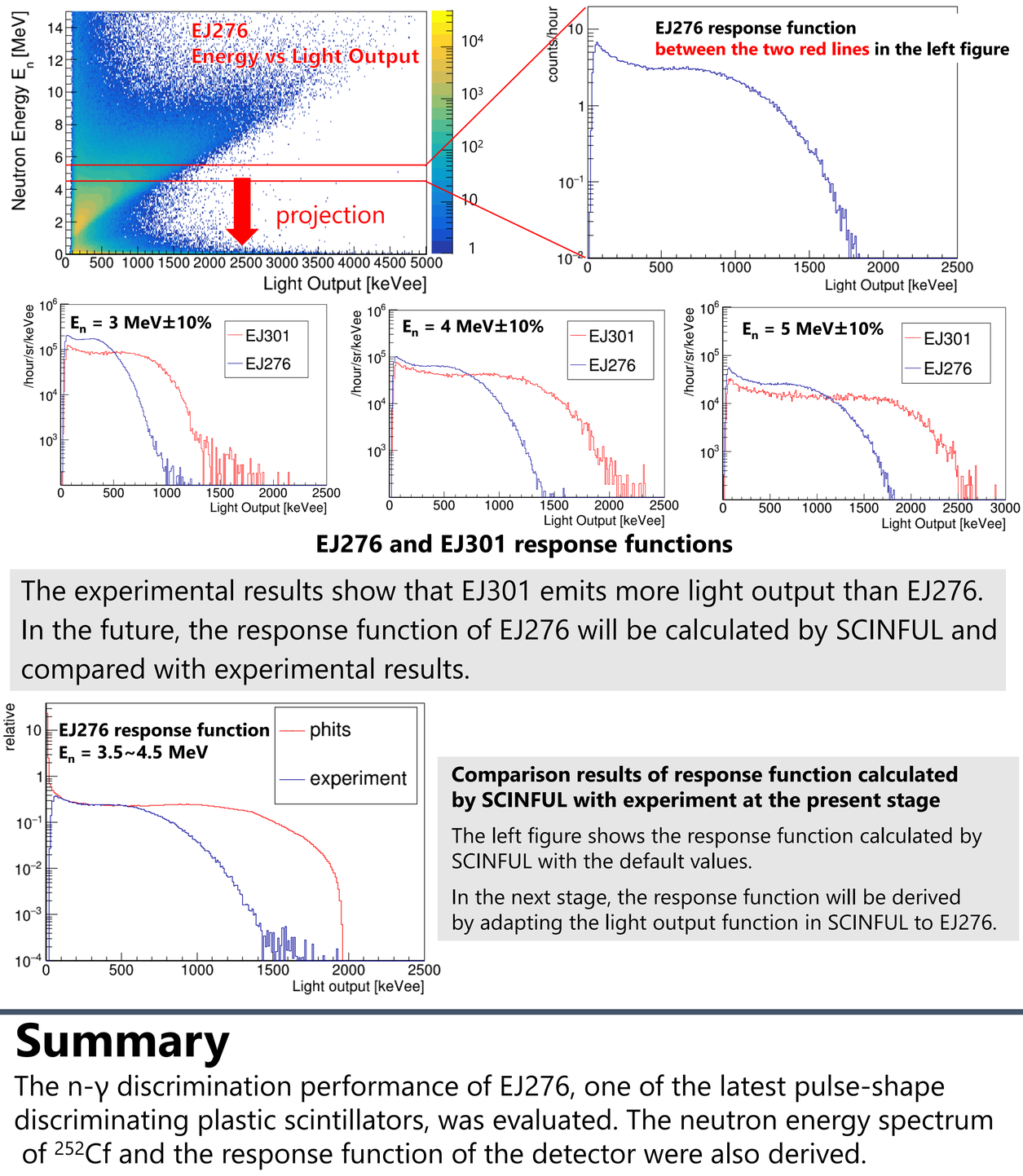
The experimental results and the energy distribution of JIS were in agreement in the range of 2–11 MeV.

Response function R(E_{n}, L)

The response function $\mathrm{R}(E_{\mathrm{n}}, L)$ is the light output distribution L of incident neutrons with energy E_{n}. The detection efficiency ε can be calculated using the response function.

$$\varepsilon = \int_{\mathrm{threshold}}^{\infty} \mathrm{R}(E_{\mathrm{n}}, L)\, \mathrm{d}L$$

The response function was derived by projecting a specific energy range of the following histogram onto the x-axis.



EJ276 and EJ301 response functions

The experimental results show that EJ301 emits more light output than EJ276. In the future, the response function of EJ276 will be calculated by SCINFUL and compared with experimental results.

Comparison results of response function calculated by SCINFUL with experiment at the present stage

The left figure shows the response function calculated by SCINFUL with the default values.

In the next stage, the response function will be derived by adapting the light output function in SCINFUL to EJ276.

Summary

The n-γ discrimination performance of EJ276, one of the latest pulse-shape discriminating plastic scintillators, was evaluated. The neutron energy spectrum of ^{252}Cf and the response function of the detector were also derived.

Outlook

- Investigation of energy spectrum disagreement in the range below 2 MeV and above 11 MeV
- Comparison of response functions obtained from the experimental data with PHITS SCINFUL calculations.