Modification of scintillation material to improve gamma detection efficiency

SuJung Min, SoOn Park, BumKyoung Seo, ChangHyun Roh, SangBum Hong*
Korea Atomic Energy Research Institute, Daejeon 34057, Korea
*Corresponding author: sbhong@kaeri.re.kr

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1. Introduction

Gamma ray and neutron detection technology is necessary for nuclear security and non-proliferation. Gamma ray measurement is widely used for non-destructive measurement, measurement of decommissioning sites of nuclear facilities, and radioactive waste classification. Since neutron detection technology is used for nuclear security, fast and efficient neutron source detection technology is required.

In this study, liquid scintillator that can be used not only non-destructive measurement and decommissioning site measurement fields, but also nuclear security field were fabricated. The primary solute used in this study is PPO(2.5-diphenyloxazole), and the secondary solute is POPOP(1,4-bis [5-phenyl-2-oxazole] benzene) and DMC(7-Diethylamino-4-methylcoumarin). DMC selected in this study is a benzopyrone derivative and has colorless crystals. DMC has high fluorescence and high quantum yield in the visible light region and has excellent light stability. In addition, As shown in the fig. 1, since the stokes shift is large, light loss caused by self-absorption is minimized. In this study, DMC was selected as an alternative to POPOP, which is generally used as a secondary solute, and its applicability was evaluated.

In this study, a liquid scintillator was used to compare the performance of DMC and POPOP, which can save time and cost compared to using a solid scintillator(plastic scintillator). In addition, since it was confirmed that there was no difference in performance compared to the scintillator manufactured in solid form, a liquid scintillator was used.

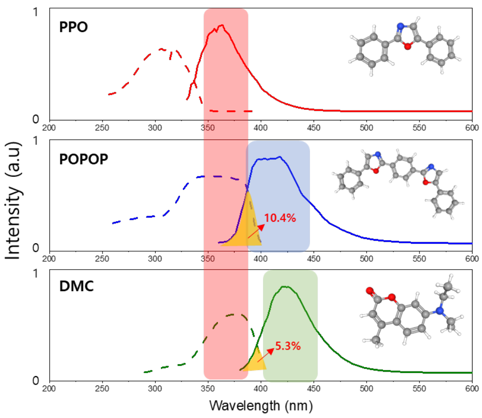

Fig. 1 Absorption and emission spectra of primary solute and secondary solute.

2. Materials and Methods

The liquid scintillator used a quartz cell with a diameter of 50 mm, and after each scintillation material was added to the solvent, it was mixed at room temperature for 2 hours or more. The used quartz cell had a diameter of 50 mm, and an optical path length of 50 mm. Quartz cell has a volume of 86 ml, and the content of primary and secondary solute for the 86 ml capacity was calculated. To optimize the content of DMC, a test was performed after fabricating a liquid scintillator with various concentrations. Measurement data using a liquid scintillator was compared with the results of a commercial liquid scintillator, BC501A with a diameter of 3 inches (Saint-Gobain, St. Great Lakes parkway, OHIO, USA). Gamma detection performance was evaluated using Cs137 (gamma), and neutron/gamma separation performance (PSD, Pulse Shape Discrimination) was additionally evaluated using a neutron source (Cf-252). The experimental setup used in this study is shown in Fig. 2.

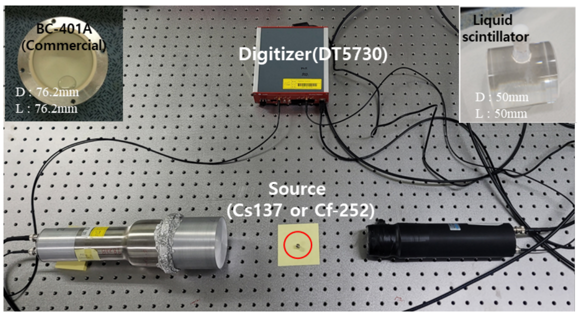

Fig. 2 Gamma detection and PSD experimental setup.

3. Results

Efficiency compared the Compton edge area, and the relative light yield was calculated using the channel of the Compton edge compared to the previously used secondary solute, POPOP. Efficiency was calculated with compton edge using energy weighted algorithm (EWA), and the spectrum to which EWA was applied is shown in Fig. 3. The formula for EWA is as follows.

$$Count(Energy\ weighted\ algorithm) = C_i \times E_i$$

Here, C_i is the count for each channel, and E_i is the energy for each channel.

Based on the efficiency and relative light yield values, 0.04 wt% was analyzed as the most optimal DMC content. Also, when compared with the results of commercial liquid scintillators, it was analyzed that the results of liquid scintillators added with DMC and POPOP showed good results. Based on the efficiency and relative light yield values, 0.04 wt% was analyzed as the most optimal DMC content. When compared with the results of commercial liquid scintillators, it was analyzed that the results of liquid scintillators added with DMC and POPOP showed good results. In addition, DMC not only has a lower self-absorption rate than POPOP, but its detection efficiency is up to 30-40% higher than POPOP. These results demonstrated the performance of DMC.

In case of PSD experiment results, the FOM (Figure of Merit) values of commercial liquid scintillator, POPOP sample, and DMC sample were analyzed as 1.33, 1.53, and 1.42, respectively. In this study, DMC was evaluated to be lower than the performance of the existing material, POPOP, but showed an error within 10% and showed similar performance to POPOP, so it can be substituted for the existing POPOP material. Also, it was confirmed that the PSD performance of POPOP and DMC was higher than that of commercial liquid scintillator.

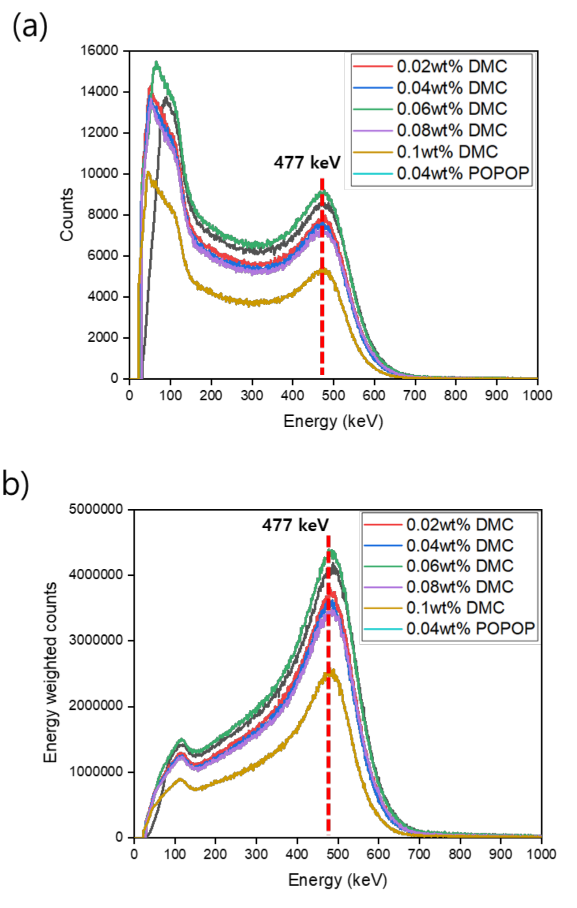

Fig. 3 Gamma spectrum (a) and spectrum with EWA applied (b) by DMC content.

4. Conclusions

In this study, the possibility of using DMC as a secondary solute was evaluated to compensate for the disadvantages of the existing secondary solute, POPOP. The absorption wavelength range of DMC coincides with the emission wavelength with the primary solute like PPO and exhibits a narrower emission peak than POPOP. In addition, it was confirmed that DMC has excellent solubility in toluene, a solvent, and that the emission wavelength of DMC is 400~450 nm. The biggest advantage of DMC is that the Stokes shift is large, so the effect on self-absorption is less than that of POPOP. Based on these characteristics, it was confirmed that DMC can be used as a secondary solute. DMC content of secondary solute needs to be optimized for the purpose of this study.

For the content optimization test, gamma radiation sources (Cs-137) were used, and it was finally confirmed that the amount of 0.04 wt% was the most optimized content. In addition, as a result of performing the neutron/gamma identification test (PSD), it showed lower performance than the POPOP-based liquid scintillator, but showed a difference within 10%, showing sufficient potential as a secondary solute.

Based on the results of this study, it has been proven that DMC can be used instead of POPOP. Based on this, if studies on changes in the composition of secondary solute or the use of nanoparticles are conducted, it will be possible to manufacture and utilize a scintillator with improved efficiency compared to the existing scintillator.

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