New Physics: Sae Mulli,
Vol. 69, No. 6, June 2019, pp. 625∼630
http://dx.doi.org/10.3938/NPSM.69.625

Characteristics of Beta-ray Measurements of Plastic Scintillators Containing Gd_2O_3 or CdTe

Jong Soo NAM
Department of Physics, ChungBuk National University, Cheongju 28644, Korea
Korea Atomic Energy Research Institute, Daejeon 34057, Korea

Sang Bum HONG · Bum Kyung SEO
Korea Atomic Energy Research Institute, Daejeon 34057, Korea

Yong Uhn KIM*
Department of Physics, ChungBuk National University, Cheongju 28644, Korea

(Received 8 April 2019 : revised 14 May 2019 : accepted 17 May 2019)

In order to determine the decontamination that is necessary to reuse sites contaminated with radioactive materials, the use of scintillation counters to measure beta radiation in the field is essential. We fabricated a casting detector by adding Gd_2O_3 or CdTe to a commercial organic scintillation material (0.20 PPO : 0.01 POPOP (wt%)). The transmittance of the scintillator with CdTe added was not significantly changed by the amount of added CdTe, but the transmittance of the scintillator with Gd_2O_3 added showed a large variation with the amount added. The scintillator with CdTe added had better transmittance than the conventional scintillator. Also, the spectra of ^{90}Sr radiation source and background could be clearly distinguished. In addition, the detection efficiency of the plastic scintillators with CdTe was much higher than that of plastic scintillators without CdTe. Among the plastic scintillators with different concentrations of CdTe, the characteristics of the plastic scintillators with CdTe of 0.10 (wt%) were prominent. A large-scale plastic scintillator with CdTe (0.10 wt%) may be useful for assessing ^{90}Sr contamination levels at sites contaminated by radioactive materials.

PACS numbers: 29.40.Mc
Keywords: Plastic scintillator, Organic scintillation material, Compound

I. Introduction

With the gradual end of the life cycle of nuclear power plants, interest in decontamination and decommissioning is increasing. Generally, the phase of decontamination and decommissioning is composed of preparation of a dismantling plan, dismantling, decontamination, waste disposal and environmental remediation. Experts in the field of decontamination and decommissioning expect it to take 30 to 50 years to complete all phases. In the environmental remediation stage, technology for quickly measuring the contamination level on the site is required. Sampling and in-situ methods are mainly used for measuring the contamination level. The sampling methods must be done many times and much money must be expended in sampling, preprocessing, measurement and analysis. The in-situ methods can be carried out for rapid measurement. There are various methods to measure radiation. Methods for detecting radiation are excitation, ionization, extinction, scintillation, chemical reaction, etc [1]. Among the methods of radiation detection, the method of using scintillation light is one of the oldest and most useful techniques [2,3]. Nuclear and high-energy physics have been widely used for radiation

*E-mail: yukim@chungbuk.ac.kr

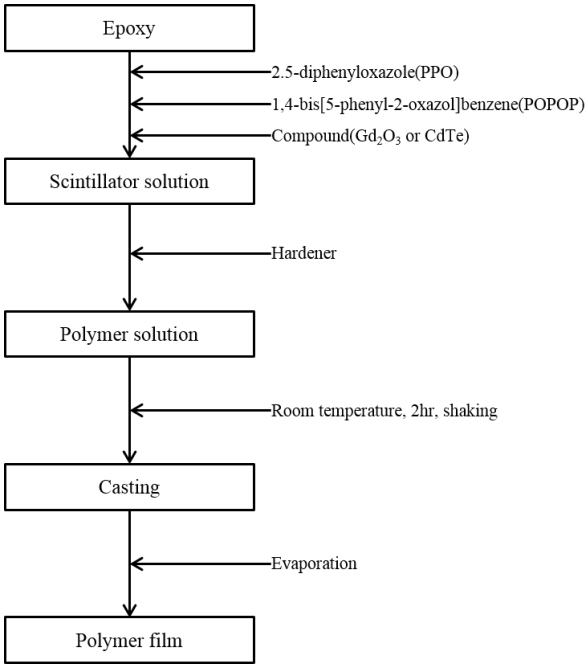

Fig. 1. The process of producing the plastic scintillator.

measurement [4–6]; detectors using plastic scintillators are well known to be easy to operate [7].

In general, a plastic scintillator is manufactured by adding an organic scintillation material to a polymer material such as polymethylmethacrylate (PMMA), polyvinyltoluene (PVT) or polystyrene (PS). The most commonly used organic scintillation materials are anthracene, stilbene, toluene, 2.5-diphenyloxazole (PPO) and 1,4-bis [5-phenyl -2-oxazol] benzene (POPOP) [8]. It is common to use the above mentioned polymer materials. However, these materials take a long time to dry and smell bad. Recently, combinations of plastic scintillators and optical fibers have been used to transmit the light emitted in the scintillator [9]. This method of combining a plastic scintillator and optical fibers causes a loss of light.

In this study, a plastic scintillator was manufactured by adding Gd_2O_3 or CdTe compunds to the epoxy resin consisted of a polymer material and organic scintillation material of PPO and POPOP. The ratio of the mixture of PPO to POPOP was set at 0.20 wt% : 0.01 wt% [10]. The reason for adding the compound is to decrease the decay time and the region of the emission wavelength varies depending on the size of the compound. Therefore, light of various wavelength reaches the photomultiplier tube (PMT) to increase the amount of light. Compound was added to improve the detection efficiency of

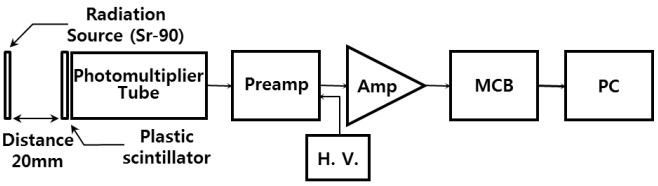

Fig. 2. The experimental set-up for measuring the radiation spectra.

Table 1. Weight percentage of organic scintillation materials and compound.

Scintillator Name	Organic scintillation material		Compound	
	PPO (wt%)	POPOP (wt%)	Gd_2O_3 (wt%)	CdTe (wt%)
S00-0	0.20	0.01		
SGO-1	0.20	0.01	0.05	
SGO-2	0.20	0.01	0.10	
SGO-3	0.20	0.01	0.50	
SGO-4	0.20	0.01	1.00	
SCT-1	0.20	0.01		0.05
SCT-2	0.20	0.01		0.10
SCT-3	0.20	0.01		0.50
SCT-4	0.20	0.01		1.00

SGO and SCT mean the Gd_2O_3 added plastic scintillator and CdTe added plastic scintillator respectively

the plastic scintillator. Various characteristics were investigated to determine the optimal mixture ratio of the compound. The optimal mixture ratio to prepare the plastic scintillator added to the compound was derived by analyzing transmittance and emission spectra. We compared the radiation spectra of the radiation source using plastic scintillators prepared by adding compound derived at the optimal mixture ratio.

II. Experimental setup

In order to prepare the plastic scintillator, a polymer material using epoxy resin (WE-300A, Won Chemical Co. Korea) and organic scintillation material were added to the PPO (Sigma-Aldrich Korea) as the first solute and to the POPOP (Sigma-Aldrich Korea) as the second solute. The ratio of the mixture of PPO to POPOP was fixed at 0.20 wt% : 0.01 wt% (S00-0). We then added the compound. The compound was used to prepare the plastic scintillator and was chosen as a material that is easy to obtain. The chosen compounds were Gd_2O_3 and

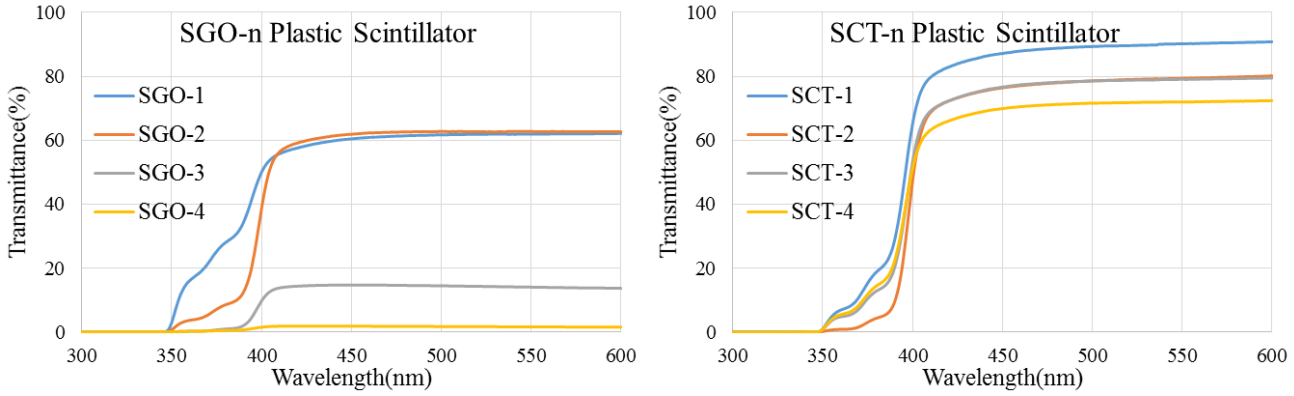

Fig. 3. (Color online) Transmittance of SGO-n (Gd_2O_3 added plastic scintillator, left) and SCT-n (CdTe added plastic scintillator, right).

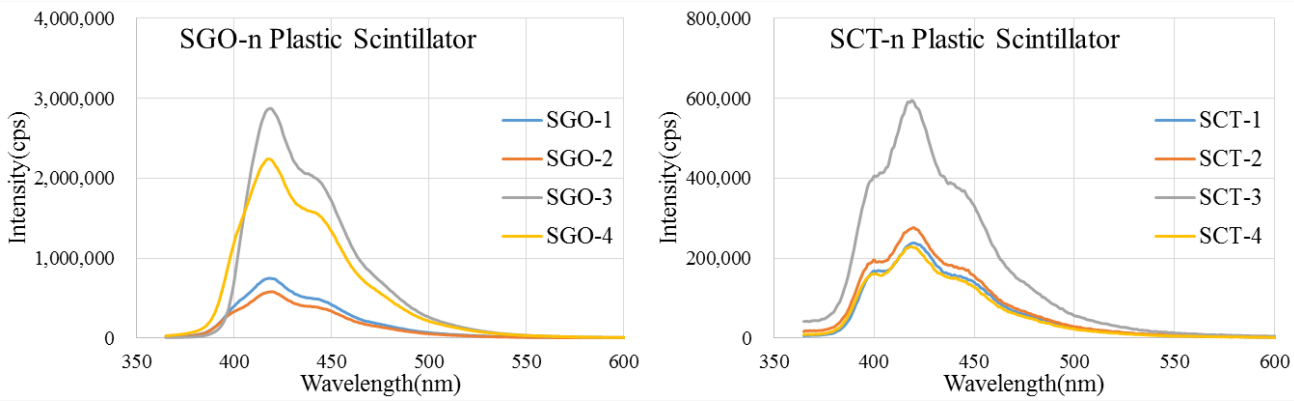

Fig. 4. (Color online) Emission spectra of SGO-n (Gd_2O_3 added plastic scintillator, left) and SCT-n (CdTe added plastic scintillator, right).

CdTe. The method to prepare the plastic scintillator is shown in Fig. 1. The plastic scintillators were prepared by adding organic scintillation materials such as PPO, POPOP and compound to epoxy resin. The mixture ratio of organic scintillation material to compound is shown in Table 1. SGO-n and SCT-n mean Gd_2O_3-added scintillator and CdTe-added scintillator respectively. PPO, POPOP and compound were added to the epoxy resin according to the mixture ratio. The scintillation solution was mixed with a hardener (WE-300B, Won Chemical Co. Korea) at room temperature for 2 hours. The polymer solution was spread evenly above the planchet. The polymer solution was dried in an electric oven for 2 hours. The diameter and thickness of the prepared plastic scintillator were 50 mm and 3∼4 mm, respectively [10].

In order to derive an optimal compound to mixture ratio, the prepared plastic scintillators were evaluated for their optical properties. The optical properties of the prepared plastic scintillators were determined by measuring the transmittance, emission and ^{90}Sr radiation source. The transmittance and emission spectra in visible light of the prepared plastic scintillator were measured using a spectrofluorometer. The experimental setup for measuring the radiation spectra is shown Fig. 2. Radiation spectra of the plastic scintillator prepared using ^{90}Sr radiation source with 3,700 Bq (ref. date : October 2012) of radioactivity were observed. In order to calculate the counting rate and the detection efficiency with ^{90}Sr radiation source of the plastic scintillators made by adding the compound, the gross counts with the whole channel of radiation spectra were calculated. Based on the above results, the ratio of compound in the prepared plastic scintillator was derived. We compared the changes of the detection efficiency with the addition of compounds.

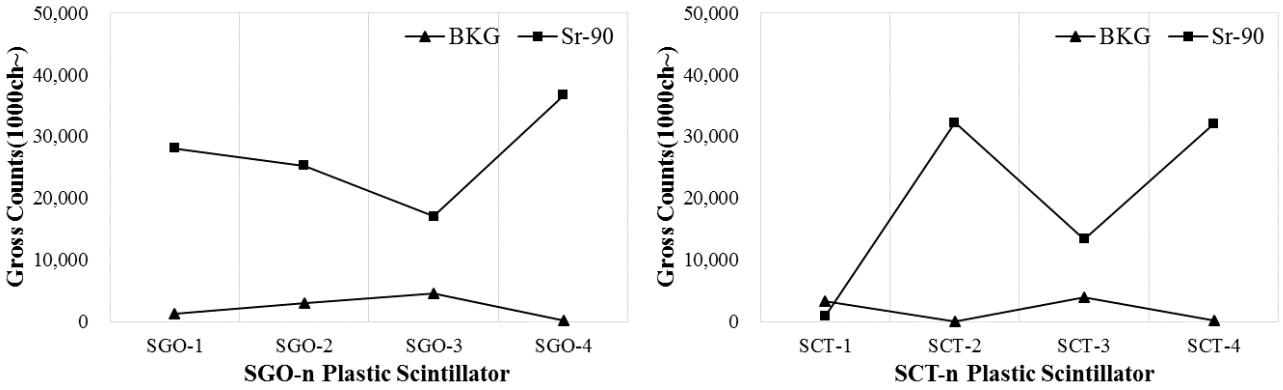

Fig. 5. Gross counts of background, SGO-n (Gd_2O_3 added plastic scintillator, left) and SCT-n (CdTe added plastic scintillator, right).

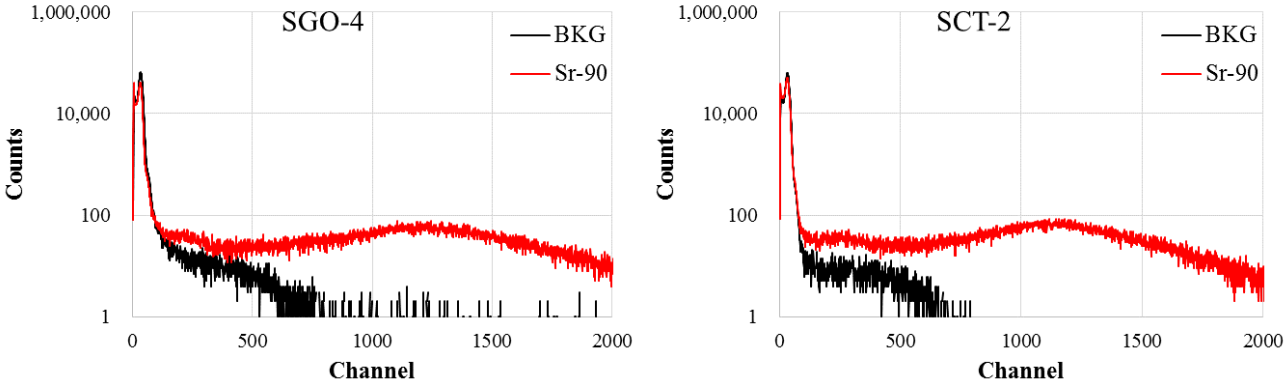

Fig. 6. (Color online) Radiation spectra of SGO-4 (Gd_2O_3 added plastic scintillator, left) and SCT-2 (CdTe added plastic scintillator, right).

III. Experimental results

The optical properties of the plastic scintillators prepared by adding compound were evaluated. Fig. 3 shows the results of measuring the transmittance of the plastic scintillators prepared by adding compounds such as Gd_2O_3 or CdTe. As the amount of compound increased, the transmittance gradually decreased in the 420 nm region. Especially, it was found that the transmittance of the plastic scintillator prepared by adding Gd_2O_3 decreased sharply as the amount of compound increased. This result is due to the fact that Gd_2O_3 is originally in white powder form and the plastic scintillator becomes increasingly opaque as the amount of Gd_2O_3 increases. The transmittance of the plastic scintillator with added CdTe also decreased as the amount of CdTe increased. However, it can be seen that the transmittance is much better than that of the plastic scintillator with added Gd_2O_3. CdTe does not dissolve in the process of preparing the plastic scintillator but remains in the form of small granules. Therefore, it is considered that the influence on the transmittance is small even if the added amount increases.

The emission of the plastic scintillators prepared by adding compound was investigated. Fig. 4 shows the results of measuring the emission of plastic scintillators prepared by adding compound such as Gd_2O_3 or CdTe. In particular, it was found that the amount of emitted light of the plastic scintillator with 0.50 wt% added compound was the maximum. The amount of light emission decreases at 1.00 wt% addition, which is the maximum amount of compound added, because this is too great an added amount. It is considered that the transparency of the plastic scintillator is lost and the amount of light emission is reduced.

The ^{90}Sr radiation source was measured using a detector that combined PMT with the plastic scintillator

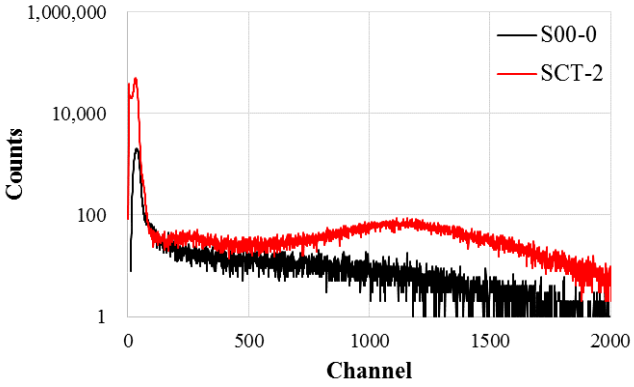

Fig. 7. (Color online) Radiation spectra of S00-0 and SCT-2.

Table 2. Comparison of detection efficiency of plastic scintillator with S00-0 and SCT-2.

	Gross counts	Counting rate (cps)	Efficiency (%)
S00-0	67,720	67.7	1.8
SCT-2	1,319,550	1,319.6	35.7

prepared with added compound. Fig. 5 shows the results of measuring the gross counts of ^{90}Sr and background.

The gross counts of plastic scintillators prepared by adding compound were found to increase as the compound content increased. The two plastic scintillators with the largest gross counts were selected and the background and ^{90}Sr spectra were observed. The results are shown in Fig. 6. SGO-4 and SCT-2 were separated between background and ^{90}Sr spectra. Based on the above transmittance, emission spectra and radiation spectra, the optimum compound is CdTe. The content of 0.10 wt% (SCT-2) is most appropriate.

Radiation spectra of the plastic scintillators with S00-0 and SCT-2 were compared. The results are shown in Fig. 7. As can be seen in the radiation spectra, the gross counts of SCT-2 increased significantly. The detection efficiency was compared based on the measured radiation spectra. The results are shown in Table 2. As can be seen in the results, counting rate of SCT-2 was improved and the detection efficiency was much better.

IV. Discussion and conclusion

A plastic scintillator with compound added to increase the light intensity was prepared by mixing epoxy resin and organic scintillation material such as PPO and POPOP. Gd_2O_3 and CdTe, which are easy to handle, were selected as compounds. Compounds were added to prepare the plastic scintillators. In order to derive the optimum compound and content, the results of the measurement of transmittance, emission spectra and ^{90}Sr radiation source were compared. It was found that the plastic scintillator prepared by adding 0.10 wt% of CdTe had excellent transmittance. However, the emission spectra were slightly lower than those of the other plastic scintillators. On the other hand, the gross counts were the highest measured. Radiation spectra measurement showed background and ^{90}Sr spectra that could be clearly distinguished. Considering the above results, the most suitable compound is CdTe. Its content is 0.10 wt%. The optimum ratio of PPO : POPOP : CdTe is 0.20 wt% : 0.01 wt% : 0.10 wt%. Using these results, a plastic scintillator having improved light emission can be prepared. It was found that the detection efficiency of the plastic scintillator prepared by adding CdTe was excellent. These results will be useful to prepare a large-scale plastic scintillator capable of quickly measuring the contamination level of ^{90}Sr in sites used as nuclear facilities.

ACKNOWLEDGEMENTS

This work has been carried out under the long-term nuclear research and development program (2012M2A8A5025996) sponsored by Ministry of Science, ICT and Future Planning of Korea.

REFERENCES

[1] J. H. Kim, K. S. Joo, Journal of IKEEE **18**, 456 (2014).

[2] G. F. Knoll, *Radiation Detection and Measurement Third Edition*(John Wiley and Sons, Inc., 2010), p. 219

[3] S. N. Ahmed, *Physics and Engineering of Radiation Detection*(Elsevier, 2007), p.319

[4] T. K. Lewellen, Phys. Med. Biol. **53**, R287 (2008).

[5] L. Archambault, T. M. Briere, F. Pönish, L. Beaulieu and D. A. Kuban *et al.*, Int. J. Radiat. Oncol. Biol. Phys. **78**, 280 (2010).

[6] A. Vandenbroucke, A. M. K. Foudray, P. D. Olcott and C. S. Levin, Phys. Med. Biol. **55**, 5895 (2010).

[7] M. Watanabe, M. Katsumata, H. Ono, T. Suzuki and H. Miyata *et al.*, Nucl. Instrum. Methods Phys. Res. A **770**, 197 (2015).

[8] B. K. Seo, G. H. Kim, Z. H. Woo, W. J. Oh and K. W. Lee *et al.*, Anal. Sci. Technol. **18**, 495 (2005).

[9] C. H. Park, J. H. Moon and B. K. Seo, Radiat. Meas. **46**, 687 (2011).

[10] J. S. Nam, Y. U. Kim, S. B. Hong, B. K. Seo and K. H. Kim, New Phys.: Sae Mulli **67**, 1080 (2017.