Light Collection Efficiency of Large-volume Plastic Scintillator for Radiation Portal Monitoring System

Jin Hyung Lee[a], Jong Bum Kim [a*]
[a] *Radioisotope Research Division, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, Republic of Korea, 34057*
[*] *Corresponding author: jong@kaeri.re.kr*

1. Introduction

Radiation portal monitors (RPM) which deployed in ports and airports are composed of detecting and alarming system by using large-volume plastic scintillator [1]. The operating process of RPM is detecting the gamma ray count rates while the container loaded vehicle goes through the RPM. And it alarmed when illicit radioactive materials detected over reference level. However the false alarm from the natural occurred radioactive materials (NORM) cause difficulties in managing the RPM. Recently, many researchers are studied for decreasing false alarm that occurred by NORM materials, such as the optimization of RPM alarmed reference level, and the development of radionuclide identification algorithm, etc. Mostly, these researches are not depends on the experimental results but the Monte Carlo simulations because of its several limitations, such as characteristics of the system, difficulty of field test, etc [2].

However, the Monte Carlo based simulation results have some difference compared with the real RPM experiment results. Many reasons for these differences are mainly caused by the light photons collection efficiency in a large-volume plastic scintillator based on its location [3]. When the gamma-ray incidence and generate the light photons in the organic scintillator then, the electrical pulse signal occurred by transporting the light photons to the photo multiplier tube (PMT) that coupled with the scintillator. Nevertheless the light photons generated from the same gamma energy, it have a difference in a pulse height before the electronics, such as amplifier, etc. Because the self-absorption phenomenon in the scintillator came from the difference in distance between PMT and the position of the light photon generated. Finally, it occurred the fluctuation of energy spectrum of the detectors and the difference between the simulation and experiment results. The schema energy spectrum fluctuations are illustrated in Fig. 1.

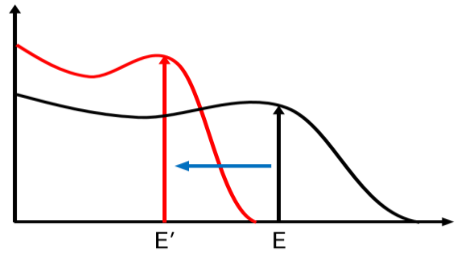

Fig. 1. The Schema of Energy Spectrum Fluctuation.

In this paper, we used DETECT2000 simulation code for a quantitative analysis of difference between measurement and simulation results because of light photons self-absorption in a scintillator. The DETECT 2000 code is based on the Monte Carlo simulation for light photon transportation in inorganic scintillation crystals and organic scintillator. By using the DETECT2000, position based light photon collection efficiencies were acquired, respectively. And then, the fluctuation in the plastic scintillator energy spectrums were analyzed and evaluated. Lastly, the simulation results compared with the realistic experimental results to verifying the light correction factor with DETECT 2000.

2. Methods and Results

2.1 Plastic Scintillation Detector

The simulation and experimental studies are based on the plastic scintillator (Ej-200, Eljen Technology ™) that widely used for radiation portal monitors in the ports and airports. The size of plastic scintillator is 850 × 285 × 65 mm^3. It composed by polyvinyl toluene (PVT) plastic and the major properties are shown in Table 1. To prevent the light loss in PVT scintillator, it covered with an l mm thickness aluminum housing. The bottom side scintillators are optically coupled with two PMTs (9266B photomultiplier, ET Enterprise ™), and the size of PMTs are 2 inches, respectively.

Table I: Properties of Plastic Scintillator (EJ-200)

Property	EJ-200
Scintillation Efficiency [Photons/MeV]	10,000
Wavelength of Max. Emission [mm]	425
Light Attenuation Length [cm]	380
Rise Time [ns]	0.9
Decay Time [ns]	2.1
Density [g/cm^3]	1.023
Refractive Index	1.58

2.2 DETECT2000 Simulation

The plastic scintillator was designed with Monte Carlo based DETECT2000 simulations. The DETECT2000 could simulate the light photons generation and transportations inside the scintillator.

Based on the center of the X and Y axis in the scintillator (The position of X=420mm, Y=140mm), 5 × 5 array were selected. Fig. 2 shows the 5 × 5 array in a large-volume plastic scintillator. It shows the interval of X and Y axis with 200 mm and 60 mm, respectively. Then, the light photons were generated in each array. It acquired the light collection efficiency of 25 position in plastic scintillator.

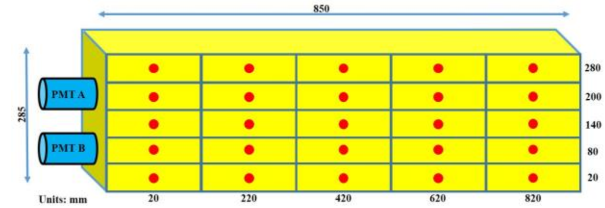

Fig. 2. A 5 × 5 Array in the PVT Scintillator.

2.3 Experimental Measurements

The experiments were carried out with an equivalent properties of PVT scintillator to verify the DETECT2000 simulation. The 5 × 5 array of each energy spectrums were acquired by irradiation of the 5μ Ci ^{137}Cs point source on the plastic scintillator away from 40 mm in 600 seconds of measurement time. A ^{137}Cs source is embedded in a cylindrical capsule with a diameter of 25 mm and a length of 2.5 mm. And the source is covered with a lead material collimator to response straightly between scintillator and gamma-ray source, with an equivalent condition to DETECT2000 simulation. The experimental study processes for the 5 × 5 array PVT scintillator are illustrated in Fig. 3.

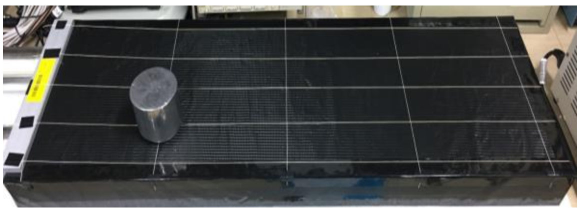

Fig. 3. Experimental study of the PVT Scintillator.

Then the signal processing with Portable NIM (AP-3) made by CANBERRA, and Multi-Channel Analyzer (EASY-MCA-8K) made by ORTEC were used to acquire the pulse of energy spectrum. Then, the energy spectrum of each arrays are analyzed with a Compton edge channels to verify its simulation results.

3. Results

The experimental measurements energy spectrums are shown in Fig. 4. To evaluate an influence of the energy spectrum caused by the light photon transportation inside the large-volume PVT scintillator, simulation results were compare with the experimental results. Fig. 5 shows simulation and the measurement results with 3 × 3 array position (center) criteria normalized.

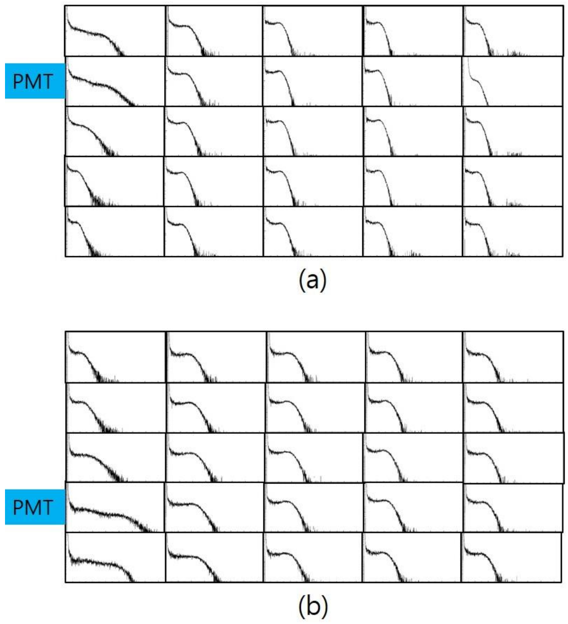

Fig. 4. Energy Spectrum of measurements with (a) PMT A, and (b) PMT B.

1.9875	1.2163	0.9404	0.9154	0.7774
2.7743	1.1473	0.9185	0.8370	0.7649
1.1975	1.1066	1.0000	0.8213	0.7931
0.3605	0.9718	0.8809	0.8213	0.8589
0.3166	0.9843	0.8652	0.8056	0.7680

DETECT2000 Results in PMT A

2.0108	1.1583	0.8813	0.8561	0.7878
2.2122	1.1007	0.9388	0.8597	0.8237
0.9496	1.0540	1.0000	0.8417	0.7698
0.6547	1.0108	0.9173	0.8417	0.8201
0.6043	0.9856	0.9101	0.8957	0.8777

Experimental Results in PMT A

0.3030	0.9424	0.9121	0.7727	0.8182
0.3061	0.9152	1.0030	0.8636	0.8909
1.0121	1.0697	1.0000	0.8242	0.8606
2.5697	1.1333	0.9030	0.8061	0.7788
2.0152	1.2273	0.9545	0.8455	0.7788

DETECT2000 Results in PMT B

0.7466	1.0162	0.9704	0.9434	0.9111
0.7278	1.0404	1.0755	0.9218	0.8814
1.0404	1.2075	1.0000	0.8841	0.9191
2.3100	1.3423	1.0512	0.9973	0.9111
2.0431	1.3693	1.1105	0.9515	0.9030

Experimental Results in PMT B

Fig. 5. Normalized Light Collection Efficiency of Simulation and Measurements.

As a results, the simulation and measurement are well matched and shows the difference of the light collection efficiency based on a PMT positions. The more increased distance between PMT and position of the light photon was generated, and the less light collection efficiency are shown. And, the most difference are shown in the PMT coupled with or without scintillator area.

4. Discussion and Conclusions

The fluctuation of the energy spectrum caused by the difference of the light collection efficiency based on PMT position. If the energy deposit were only considered in the simulation code, such as MCNP F8 tally, it could be a major disparity between simulation and measurement results. And, it has less time than Geant4 with optical simulation. In this case, it could possible to analyze quantitatively when applying the correction factor of scintillator light collection efficiency in Monte Carlo based simulation.

In this paper, simulation and experimental results indicate that it is possible to utilize Monte Carlo based simulation results by using correction factor. It is also indicated that the matched correction factor for light collection efficiency based on the geometry of PVT scintillator is feasible and compact for a Monte Carlo based simulation.

REFERENCES

[1] T. Burr, J. R. Gattiker, K. Myers, G. Tompkins, Alarm criteria in radiation portal monitoring, Applied Radiation Isotopes, Vol. 65, p.569, 2007

[2] E.R. Siciliano, J. H. Ely, R. T. Kouzes, J. E. Schweppe, D. M. Strachan, S. T. Yokuda, Energy calibration of gamma spectra in plastic scintillators using Compton kinematics, Nuclear Instruments and Methods In Physics Research A, Vol. 594, p.232, 2008

[3] J. S. Neal, J. T. Mihalczo, M. T. Hiatt, J. D. Edwards, Large Plastic Scintillation Detectors for the Nuclear Materials Identification System, Institute of Nuclear Materials Management Annual Meetings, 2004, Orlando, FL