Efficiency Calculation of Plastic Scintillator for *in situ* Beta Measurement System

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1. Introduction

Characterization of radioactive contamination at decommissioned sites has historically been carried out using sampling and separate pretreatment procedure in conjunction with measurement in laboratories. This method is especially employed for analysis of alpha or beta emitting radionuclides. However, such analysis is costly, time consuming and results in long delay between sampling and obtaining results [1].

To overcome this situation, an *in-situ* system, where the detection part comes into direct contact with the matter, is required for the measurement of beta nuclides with the short range at D&D site. Plastic scintillator is used as it is non-hygroscopic and can be fabricated into various shapes with large sensitive area.

Plastic scintillator is in charge of converting radiation energy to photons, which overall can affect the efficiency of monitoring system. Predicting the efficiency of plastic scintillator before building the system is of importance issue.

Thus, in this study, the efficiency of polystyrene-based plastic scintillator for *in-situ* beta measurement system was determined, using MNCP6 simulation and experiment with four pure beta sources in the water aqueous form.

2. Material and Method

The concept of in-situ measurement system was illustrated in figure 1.

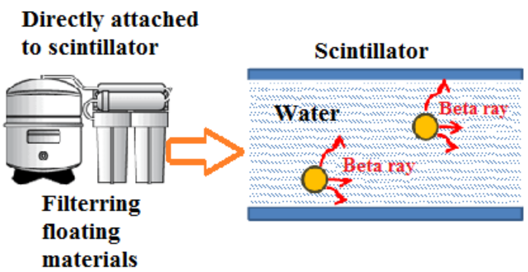

Figure 1. Concept of on-situ beta monitoring with plastic scintillator.

2.1. MCNP simulation:

The plastic scintillator was modelled as a commercial plastic scintillation plate manufactured by Saint Gobain with different thickness, namely 0.5, 1, 1.5, 2, 3 and 5 mm [3]. ^{3}H. ^{14}C, ^{32}P, ^{90}Sr/^{90}Y were beta emitting radionuclides used in the simulation. ^{90}Sr/^{90}Y was modeled as in equilibrium state with a ratio of 1:1, respectively.

MCNP6 is a Monte Carlo radiation-transport code designed to track many particle types over broad ranges of energies [2]. As MCNP did not take into account the scintillation process. The efficiency of the plate was determined instead by the energy deposition of beta particles using F8 (e,p) tally. Any non-zero energy deposition of beta particles within the scintillator would be regarded as a count. Due to this limitation, the spectra of energy deposition within the plastic scintillator were also calculated for further discussion relating to efficiency.

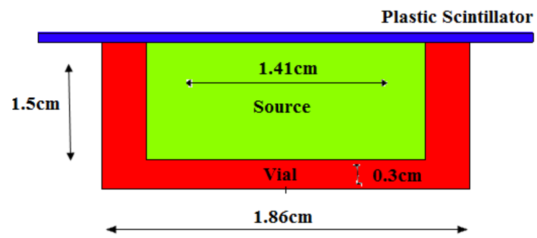

Figure 2. Model for MCNP6 calculation.

Table 1. Material component used for simulation.

Component	Composition	Density (g/cm^3) [4]
(1)	(2)	(3)
Plastic scintillator	Polystyrene	1.05
Source	Approximate by water	1.00
Vial	Polyethylene	0.93

2.2. Experiment:

After considering simulation results, a suitable thickness of scintillator plate was chosen and an experiment was carried out. The dimension of vial was similar to simulation one. Radioactive samples were prepared by following procedures:

- Extract each radionuclide source as 500 μl.
- Check the mass of extracted source.

- Fill the sample case with radioactive source (500 μl) and distilled water (5,000 μl)
- Check the mass of sample case filled with source and water.
- Calculate the radioactivity concentration. Encapsulate the sample case with nylon film wrapping.
- Each sample was measured during a period of 600 s.

Table 2. Pure beta ray emitting nuclide sources

Nuclide	Radioactivity concentration (Bq/g)	Mass of solution (g)
(1)	(2)	(3)
^{3}H	5,952,891.44	5.85
^{14}C	66.88	6.03
^{32}P	45.00	6.16
$^{90}Sr/^{90}Y$	130.54	5.99

Source information after preparation was presented in table 2.

3. Results and Discussion

In this section, the efficiencies of plastic scintillator were presented. The effect of plastic's thickness on energy deposition of beta particles was also considered. Afterwards, experiment results of 1 mm plastic scintillator were compared with those from simulation.

3.1. Efficiency of plastic scintillator from simulation

Low energy beta emitters have short range and those generated at deeper location would be stopped within the source medium and unable to reach the scintillator. Thus, efficiencies were extremely low for ^{14}C and ^{3}H sources. High energy beta emitters (^{32}P and $^{90}Sr/^{90}Y$) yielded higher efficiency.

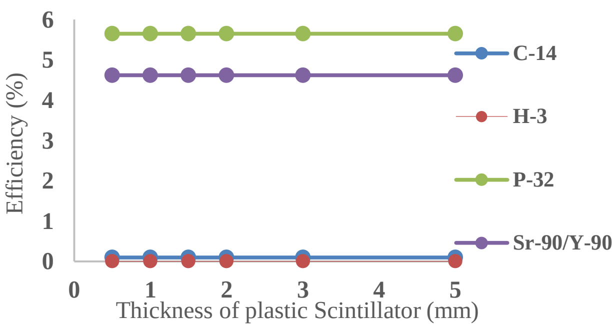

Figure 3. Efficiency of plastic scintillator with different thicknesses.

It may be concluded that for a specific beta emitting radionuclide, the thickness of plastic scintillator had insignificant effect on counting efficiency. However, F8 tally was used to count non-zero energy deposition events regardless of the magnitude of the energy deposition. For example, the amount of energy deposition in scintillator was different in both scenarios shown in figure 4 but F8 tally results would be similar to each other, leading to same efficiency.

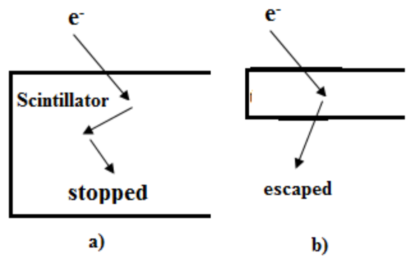

Figure 4. Possible scenarios for electron traversing plastic layer.

Discussion as to the energy deposition in plastic scintillator was presented in the next section

3.2. Energy deposition in plastic scintillator

Energy deposition spectra of ^{14}C and ^{3}H were similar for plastic scintillators with different thickness. Most of low energy electrons deposited all of its energy in a plastic scintillator of 0.5 mm thick (figure 5).

For high energy beta particles, there was possibility that these particles just deposited a small amount of energy and escaped the plastic layer as shown in figure 4b). Due to this effect, spectra of energy deposition for ^{32}P and $^{90}Sr/^{90}Y$ were different with different thickness of plastic scintillator as illustrated in figure 6

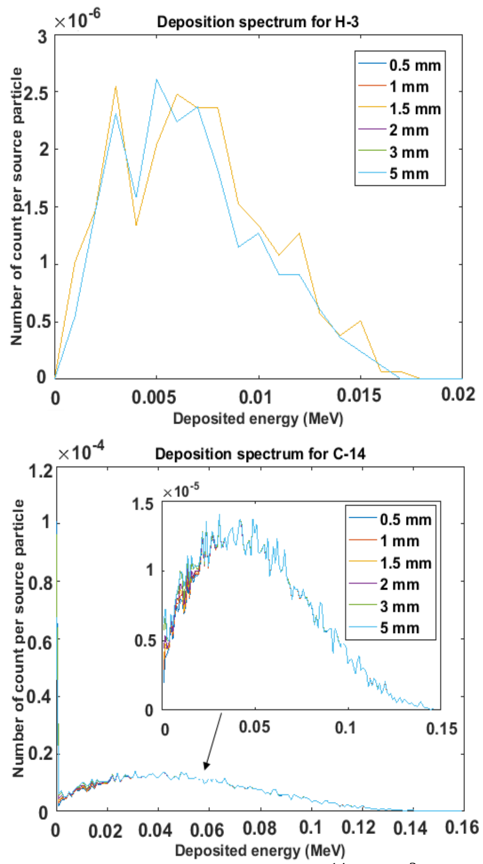

Figure 5. Energy deposition spectra for ^{14}C and ^{3}H in plastic scintillator with different thickness.

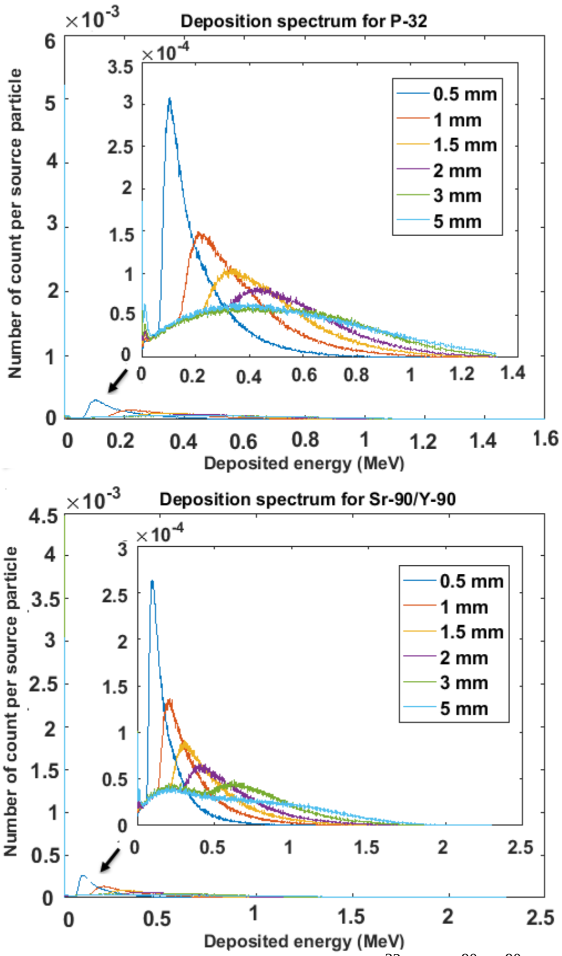

Figure 6. Energy deposition spectra for ^{32}P and $^{90}Sr/^{90}Y$ in plastic scintillator with different thicknesses.

^{32}P and ^{90}Y are high energy beta emitters, with the maximum energy being 1.709 MeV and 2.28 MeV, respectively. These high energy betas traverse a thin plastic layer and just deposited a small amount of energy, mostly located in low energy region of 20 keV (the peak of 0.5 mm line shown in Figure 6). In real measurement, electrical pulse generated from such low energy deposition events are registered at low channels of the MCA, coinciding with pulses from noise and background.

It was predicted that efficiency of 0.5 mm thick plastic layer would have some deviation coming from background and noise. The high background disturbance would degrade the detection accuracy of a direct measurement device.

Thick plastic scintillator, on the other hand, would absorb gamma rays which is undesirable during gross beta measurement. Hence, 1 mm of plastic scintillator was chosen to check the efficiency in real experiment.

3.3 Experiment results of 1mm plastic scintillator:

Detected spectra of 1mm plastic scintillator for pure beta ray emitting nuclide sources were shown in the following figure:

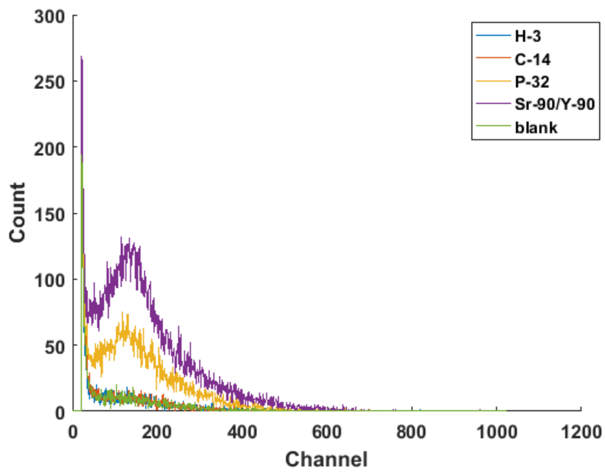

Figure 7. Detected spectra of 1mm plastic scintillator for pure beta ray emitting nuclide sources.

The spectrum of ^{32}P and $^{90}Sr/^{90}Y$ could be checked but spectrum of ^{3}H and ^{14}C were not detected as these spectrums were similar to the spectrum of blank sample. The efficiency was calculated only for ^{32}P and $^{90}Sr/^{90}Y$ source. The net count is defined as the difference between total count of each sample and blank sample.

Table 3. Experiment results compared to simulation

Source (1)	Net count (2)	Experiment efficiency (%) (4)	Simulation efficiency (%) (5)	Relative difference (%) (6)
^{32}P	9.22E+03	5.55E+00	5.65E+00	1.8
$^{90}Sr/^{90}Y$	2.16E+04	4.60E+00	4.62E+00	0.4

Experiment results were slightly lower compared to simulation results, with the relative difference being 1.8% and 0.4% for ^{32}P and $^{90}Sr/^{90}Y$ source, respectively. The difference was accounted by:

-In real measurement, the production of photon is nonlinear for high LET particles (low energy beta particles), resulting in lower number of generated photons, in other words, lower efficiency. MCNP was unable to simulate this energy conversion process.

-The presence of a thin air layer and the nylon film wrapping between radiation source and plastic scintillator was excluded in simulation process.

4. Conclusion

The efficiency of plastic scintillator was calculated based on MCNP simulation and experiment. The main results were stated as follows:

-Good agreement was shown between simulation and experiment, giving the relative error of 1.8% for ^{32}P source and 0.4% for $^{90}Sr/^{90}Y$ source.

-1 mm of plastic scintillator could be used in *in-situ* system to measure high energy beta emitting radionuclides but was not suitable for analysis of ^{14}C and ^{3}H with low energy.

- It could be deduced from spectra of energy deposition that very thin plastic layer (0.5 mm) would pose a problem in real measurement of high energy beta emitting radionuclides.

REFERENCE

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