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Optimization of Signal Condition for Tritium Detection

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1. Introduction

Tritium is representative hard-to-detect radionuclide because it emits low-energetic beta ray. Tritium in air has been monitored using ionization chamber with a suction pump. Because the ionization chamber collects the ionizing current, the fluctuation of the background level is relatively large. Therefore, the ionization chamber is suitable for the high-tritiated environment such as nuclear power plant. To monitor the natural or higher level of tritium, the detector should be stable and have lower detection limit

In previous study, small plastic scintillator pellets were used to increase the detection efficiency of tritium. Although some improvement was confirmed compared with a single channel using a couple of planar scintillators, the minimum detectable activity (MDA) was unsatisfactory. In this study, multi-channel tritium detection chamber was manufactured, and signal acceptance condition was carefully adjusted. The efficiency changes rapidly according to the signal acceptance condition, and the optimum measurement condition was derived from the figure of merit (FOM) evaluation.

2. Methods and Results

In this section manufactured multi-channel tritium detection chamber, parameters used in the signal acceptance condition and experimental setup was described.

2.1 Multi-channel Tritium Detector

The beta ray emitted from tritium disintegration has extremely low energy which have maximum energy of 18.6 keV and average energy of 5.7 keV, therefore, the range of it is few mms in air [1]. Because of this, detection efficiency of tritium using a scintillator is very low. Because of this, small scintillation pellet or a method of pressing a small paper filter with tritiated vapor onto a scintillator were used to increase the detection efficiency [2]. To increase the detection efficiency, the distance between scintillators should be lowered. However, as the distance between the scintillators decreases, the measurable volume decreases, resulting in a smaller MDA. Figure 1 shows the manufactured multi-channel tritium detection chamber. Plastic scintillator plates with dimension of 77×77×1 mm^3 were parallelly inserted in the acrylic cubic chamber at intervals of 5 mm. The internal standard of the acrylic chamber was 100×100×100 mm^3. Two faces with slits were enclosed using optical cement (BC-600, Saint-Gobain Crystals). The chamber was used for the experiment after thoroughly checking for leaks.

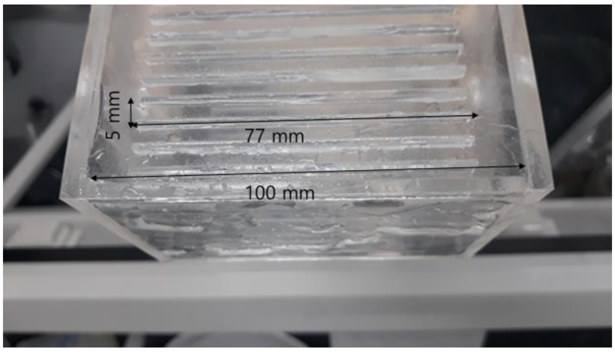

Fig. 1. A picture of the manufactured multi-channel tritium detection chamber

2.2 Experimental Setup

Two 5-inch photomultiplier tubes (PMTs) were attached to the detection chamber with an optical grease. The PMTs were mounted on the PMT socket with preamplifier (276, Ortec Inc.) and high voltage of 1.5 kV was supplied for each PMT. The pulse signal from the preamplifier output was amplified by dual spectroscopy amplifier (855, Ortec Inc.). For timing coincidence, two timing single channel analyzers (t-SCAs) and time-to-amplitude convertor (TAC) were used. Each output from the spectroscopy amplifier was delayed by 100 and 350 ns, respectively, using the t-SCAs. Each output from the t-SCAs was input to the TAC and the TAC converted the time difference to the pulse height output.

170 kBq/m^3 of tritiated hydrogen gas was prepared by electrolysis. The volume of the detection chamber except for the volume of the plastic scintillators was 421 cm^3. Each measurement was carried out for 3 min and repeated 3 times.

2.3 Signal Acceptance Condition

The figure of merit in radiation detection is defined by ε^2/B where ε is the detection efficiency and B is background counts. Because the pulse height generated by interaction of low-energetic beta ray must be low, the pulse signal should be amplified with a proper gain.

However, when the gain is increased background count due to random noise from the PMTs are also increased. Therefore, the lower discrimination level (LDL) and the gain should be optimized. The LDL was adjusted from 0.4 to 1.4 V, the fine gain was changed to 6 and 9, and the coarse gain was maintained at 100.

2.4 Detection Efficiency and FOM evaluation

The detection efficiency was evaluated by ε = CR/(T•V) where CR, T and V were the net counting rate, tritium concentration of tritiated hydrogen gas and volume of the chamber, respectively. The evaluated detection efficiencies and FOMs were summarized in table I and table II. The maximum efficiency and FOM was 43±4.3% and 0.1196 where the fine gain and LDL were 6 and 0.6, respectively. When the fine gain was 9 and LDL was 0.6, background counts were dramatically increased. Because there were a lot of signals from the random noise, coincidence did not work well, therefore, relative error of efficiency was increased.

In fig. 2, the evaluated FOMs according to the LDL were illustrated. When the fine gain was 9, the optimum point was found at 0.8 for LDL. For a fine gain of 6, the best FOM was obtained when the LDL was 0.6. Since we did not find the optimal point, we need to adjust the LDL more finely to find the optimal point and perform additional experiments.

Table I: Efficiency and FOM evaluation with fine gain of 6

Lower Discrimination Level (V)	0.6	0.8	1	1.2	1.4
Background Counts for 3 min (#)	15477 ±460	7804 ±86	6445 ±65	5867 ±79	5640 ±75
Net Counting Rate (cpm)	1847 ±161	474 ±43	379 ±36	354 ±38	236 ±36
Detection Efficiency (%)	43 ±4.3	11 ±1.1	8.8 ±0.95	8.2 ±0.98	5.5 ±1.2
FOM	0.1196	0.0156	0.0121	0.0116	0.0054

Table II: Efficiency and FOM evaluation with fine gain of 9

Lower Discrimination Level (V)	0.6	0.8	1	1.2	1.4
Background Counts for 3 min (#)	40001 ±200	14733 ±85	7808 ±133	5885 ±34	5280 ±29
Net Counting Rate (cpm)	340 ±95	1157 ±53	485 ±54	362 ±30	365 ±28
Detection Efficiency (%)	7.9 ±2.2	27 ±1.8	11 ±1.4	8.4 ±0.81	8.5 ±0.78
FOM	0.0015	0.0493	0.0163	0.0121	0.0138

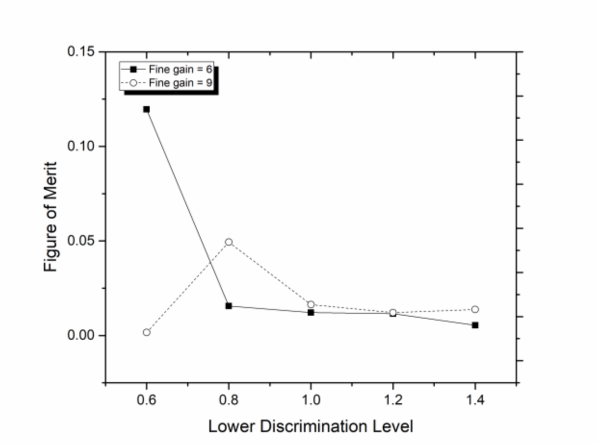

Fig. 2. Evaluated FOMs for each fine gain according to the various LDLs

3. Conclusions

A multi-channel plastic scintillator detection chamber was manufactured for tritium detection. The tritium detector was expected to show a low MDA because of the large capacity and narrow spacing between the scintillators. Instead of calculating MDA, FOM was used as an evaluation index. The maximum efficiency was 43±4.3%, which was the highest at FOM. For complete optimization, it is necessary to fine-tune the LDL near this point and perform a precise evaluation. Future studies will evaluate the feasibility of using a lower concentration of tritium gas and evaluate the applicability in a real natural or decommissioning environment by connecting a suction pump.

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