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Comparison of depth of interaction method for radiation measurement in high temperature environment

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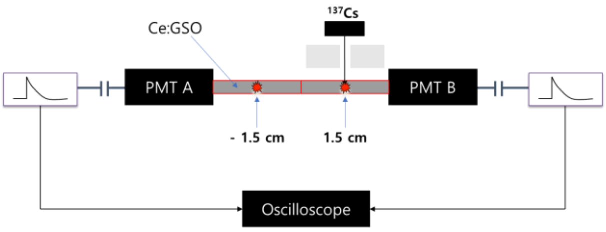
1. Introduction

Monitoring gamma rays from the nuclear reactor is essential for the safe operation of nuclear reactors. However, because of the high temperature around the nuclear reactor, it makes it difficult to measure the gamma rays emitted from nuclear reactors by a conventional gamma ray detector. The high temperature environment surrounding nuclear reactor can greatly influence the performance of radiation measurement system. In case of in direct radiation measurement system the temperature will not only influence the performance of photo-detector but as well as scintillator detector. Therefore, the detector used in such environment should highly be temperature resistant. The special focus is put on to use the simple geometry for with minimum components which are capable to withstand this adverse environment. Scintillators such as Ce: GSO [1], Pr: LuAG [2] are commonly used due to their stable performance in harsh temperature environment. On the other hand, the high temperature photomultiplier tube (PMT) can be utilize as photo-detector. The high temperature PMT have shown promising performance in such environments.

In this study, we have designed a detector configuration with minimum components for radiation measurement in high temperature. The depth of interaction (DOI) method was used to analysis the data. Experiments were performed to compare the performance of the different configurations of the detector. We have also compared the performance of each configuration by using energy ratio and time stamp DOI method.

2. Methods and Results

2.1 Materials



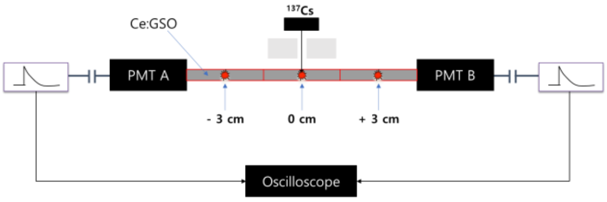


Fig. 1. The overall schematic diagram of radiation source measurement experiment (6 cm (up) and 9 cm (down) length detector).

In this study, we used Ce:GSO(Oxide) scintillator with dimension 3 × 3 × 30 mm^3. Two R3991A-07 PMTs (3/4 in. diameter, HAMAMATSU) were used as photodetector in a dual-end readout method. Two detector setups were tested using two layers and three layers scintillator detector. In both configurations the size of each layer was kept the same. Both ends of the phoswich scintillator detectors were coupled to the PMTs using optical grease as shown in Figure. 1. The outputs of both PMTs were optimized by adjusting the bias voltage supply. The bias voltage 1600 V and 1680 V was supplied to first PMT (PMT A) and second PMT (PMT B) respectively. The anode signal of each PMT was sent to a WaveRunner 604Zi oscilloscope (20GS/s, TELEDYNE LECROY) for digitizing and capturing raw data for post processing. The post processing of data was performed using MATLAB.

A standard disk type ^{137}Cs source (90 μCi) was used as a gamma-ray source. The gamma ray was irradiated at the positions of - 1.5 cm, + 1.5 cm for two layers DOI detector and - 3 cm, 0 cm and + 3 cm for three layers DOI detector from the center of the detector with a collimator as depicted in figure 1. The data acquisition was performed in coincidence of two PMTs for both DOI detector configuration.

2.2 Methods

The two different methods for DOI encoding utilizing 1) energy ratio and 2) time stamps method were applied on the acquired data. The first DOI method is to use the energy ratio of coincidence signals. The farther the PMT is from the location of the scintillation, the lower the recorded energy and vice versa. Therefore, we can determine the DOI by comparing the energy of the coincidence signal measured at each PMT. The energy information of the coincidence signal was obtained by integrating the signal, and the energy ratio (E_R) was determined using Equation (1).

$$E_R = E_A / (E_A + E_B) \quad (1)$$

For the coincidence signals, the E_A and E_B represent the energy of the signal at PMT A and PMT B, respectively. E_R are histogrammed and fitted using Gaussian function to calculate FWHM and average value of E_R.

The second DOI method is to use the time stamp difference of coincidence signals. To obtain the time stamps, signals were digitized at 10 GS/s using oscilloscope. Time stamps are determined by leading-edge time pickoff method with fixed trigger levels. The time stamp differences of coincidence signal are histogrammed and fitted to a Gaussian function to calculate coincidence resolving time (CRT) [3].

2.3 DOI determined by energy ratio

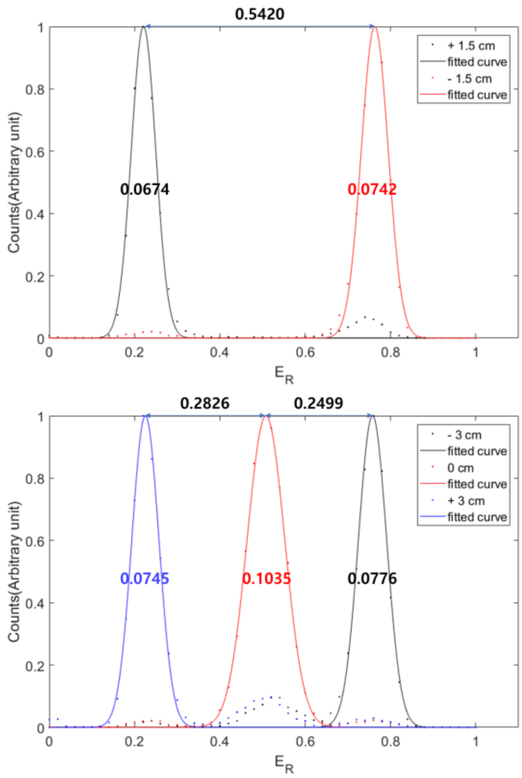


Fig. 2. Energy ratio of two connected (up) and three connected (down) Ce:GSO at different gamma-ray source positions.

For the two layer DOI detector, average values of energy ratios are 0.7630 and 0.2210 at – 1.5 and + 1.5 cm with source position, were calculated. These average values, when converted to the position of interaction, corresponds to – 1.58 and 1.67 cm, respectively. The difference from the actual position is -0.08 and 0.17 cm.

For the three layer DOI detector, average values of energy ratios are 0.7578, 0.5079 and 0.2253 at – 3, 0 and 3 cm with source position, were acquired. These average values, when converted to the position of interaction, corresponds to - 2.32, - 0.07 and 2.47 cm, respectively. The difference from the actual position is -0.68, 0.07 and 0.53 cm.

2.4 DOI determined by time stamp difference

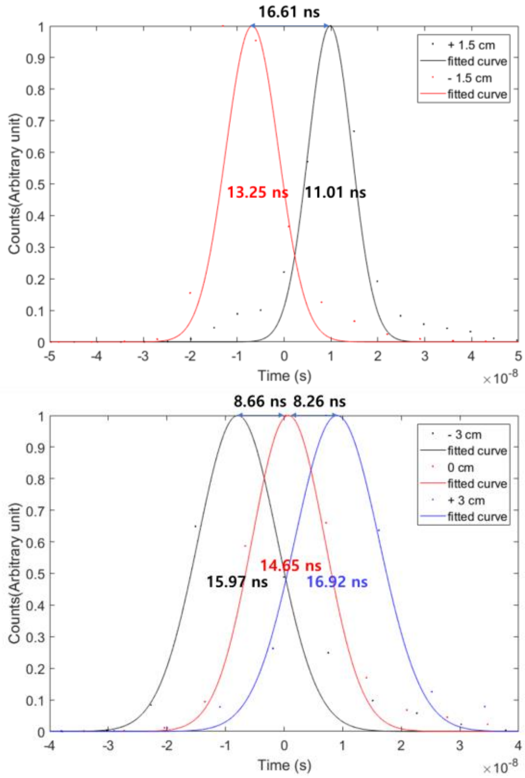


Fig. 3. CRT of of two connected (up) and three connected (down) Ce:GSO at different gamma-ray source positions.

For the two layers DOI detector, average value of time stamp difference and CRT are 13.25 ns and -6.81 ns for - 1.5 cm and 11.01 ns and 9.80 ns for + 1.5 cm for gamma-ray source position.

For the three layers DOI detector, average value of time stamp difference and CRT for - 3 cm are 15.97 ns and -7.91 ns, While the average values are 14.65 ns and 7.46 ns for 0 cm. and 16.92 ns, 9.01 ns for + 3 cm gamma-ray source position.

3. Discussion and Conclusions

In this study, we compared the performance of two different DOI encoding techniques using two different configurations of phoswich scintillator detector. Results of the first DOI method – energy ratio method – showed better performance as compare to the second DOI method that use time stamp difference. The direction of the light generated in the scintillator by the gamma ray is a random process. So, light photons produced by the scintillator undergoes several reflections rather than a straight path to the PMT resulting in large fluctuations in arrival times and thus leads to a larger value of CRT larger than expected. Therefore, the DOI method using the energy ratio provided better DOI performance compared to the time stamp difference method in this study.

On the other hand, the two layers DOI detector show better performance than the three layers DOI detector. The conclusion can be drawn that the performance of DOI detector will degrade with increasing layers. It may be due to light loss at the reflector or scintillator layer coupling.

In a future work, we will study about the temperature dependence of this detector and the optimization of DOI detector layers.

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