Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

Measurement of Radionuclide Positions Using a Cherenkov Radiation Sensor Based on a Liquid Light Guide

Sangjun Lee[a], Seunghyeon Kim[a], Hyungi Byun[a], Siwon Song[a], Jae Hyung Park[a], Jinhong Kim[a], Seokhyeon Jegal[a], Junwon Kim[a], Bongsoo Lee[a*]
[a]*Department of energy systems engineering, Chung-Ang University, 84, Heuk-Seok ro, Seoul, Korea*
[*]*Corresponding author: bslee@cau.ac.kr*

1. Introduction

When considering the decommissioning of a nuclear facility, essential tasks include evaluating radiation levels, pinpointing the sources of radiation at the facility site, and measuring the radioactive contamination of facility materials. Recently, the utilization of a plastic scintillation fiber has been employed to rapidly and precisely assess radiation across a wide area [1].

An alternative approach based on the Cherenkov radiation principle can be proposed. Cherenkov radiation provides distinct generation principles for gamma and beta-rays, allowing for their differentiation [2]. Typically, the position spectrum measurements based on the Cherenkov radiation include time-of-flight (TOF) measurements using two Photomultiplier Tubes (PMTs) and a glass or plastic optical fiber. However, the practical application of two PMTs presents difficulties, especially for assessments within hard-to-detect areas, such as the interior of pipes where precise sensor placement is crucial.

A liquid light guide (LLG) has high transmissivity for UV light compared to other optical fibers [3]. This characteristic makes LLG particularly well-suited for capturing the Cherenkov light, the intensity of which is inversely proportional to the cube of the wavelength [4].

In this study, a Cherenkov radiation sensor using a reflective film-coated LLG was developed. The LLG has a diameter of 5 mm and a length of 10 m. Source position spectra and pulse height distribution were measured using gamma-ray emitting nuclide ^{137}Cs and beta-ray emitting nuclide ^{90}Sr.

2. Method and Results

2.1 Cherenkov radiation

Cherenkov radiation occurs when the velocity of charged particles in an optically transparent medium with a refractive index is greater than the speed of light in that same medium. The condition for generating Cherenkov radiation is expressed as Equation (1) [5].

$$\beta \geq \frac{v_p}{c}\left(\frac{1}{n}\right) \qquad (1)$$

Where v_p is the velocity of the particle, c is the speed of light in a vacuum, n is the refractive index, and β is the particle relative phase velocity.

2.2 Experimental setup

The Cherenkov radiation sensor using the reflective film-coated LLG was composed of a PMT (H10721P-01, Hamamatsu Photonics), a LLG (Series 300, Lumatec), a fast amplifier (ABL0300-00-4030, WENTEC), a reflective film (ESR-100, 3M), and an oscilloscope (SDS5104X, Siglent). Fig. 1 shows the experimental setup for the Cherekov radiation sensor with the reflective film-coated LLG.

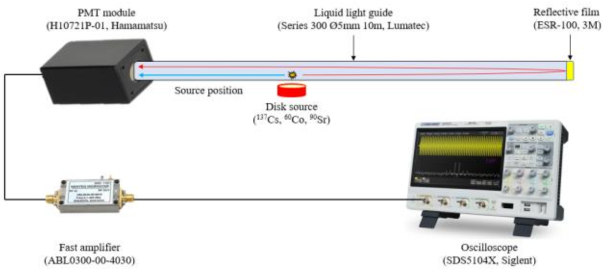

Fig. 1. Experimental setup

The Cherenkov light generated within the LLG is transmitted to the PMT, and the light reflected by the reflective film is also transmitted to the PMT after a certain delay. As a result, two signals with a time difference are observed on the oscilloscope. The time difference between these signals and the speed of light in the medium can be used to calculate the location where the Cherenkov light was generated. This relationship is expressed as Equation (2).

$$Time\ difference = \frac{(2 * LLG\ length - position) - position}{c/n} \qquad (2)$$

2.3 Results

Figs. 2 and 3 show the obtained position histograms for ^{137}Cs (38.317 μCi) and ^{90}Sr (0.0858 μCi), respectively.

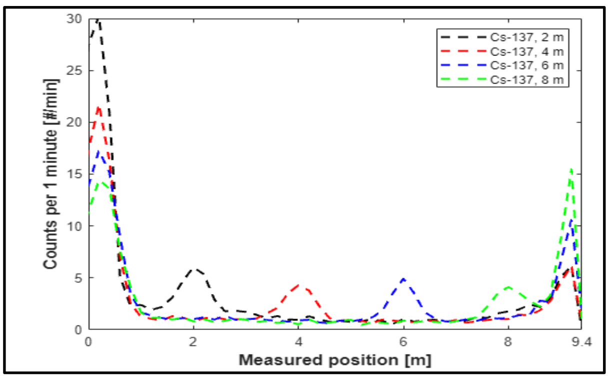

Fig. 2. Measured positions of ^{137}Cs source (38.317 μCi)

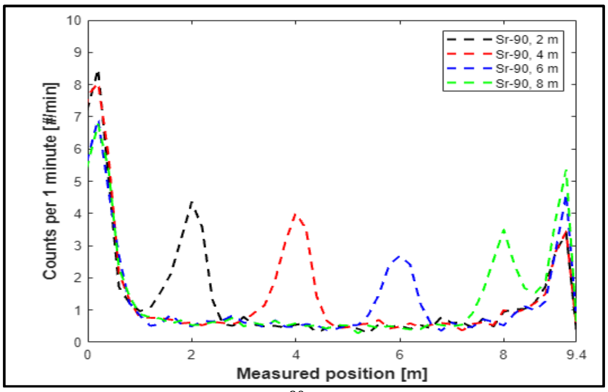

Fig. 3. Measured positions of ^{90}Sr source (0.0858 μCi)

These sources were positioned at distances of 2, 4, 6, and 8 m, respectively. Noticeable peaks are observed at positions 0.2 m and 9.3 m, which are undesirable. The peak at 0.2 m is attributed to reflections between the PMT window and the front face of LLG, while the peak at 9.3 m is connected to reflections between the PMT window and the reflective film on the opposite side of the LLG. The average position resolution for ^{137}Cs, and ^{90}Sr is 62.427 cm and 54.919 cm, respectively. We verified that the resolution at positions 2 and 8 m is compromised due to the impact of the undesirable peaks, which affect the precise determination of the source position.

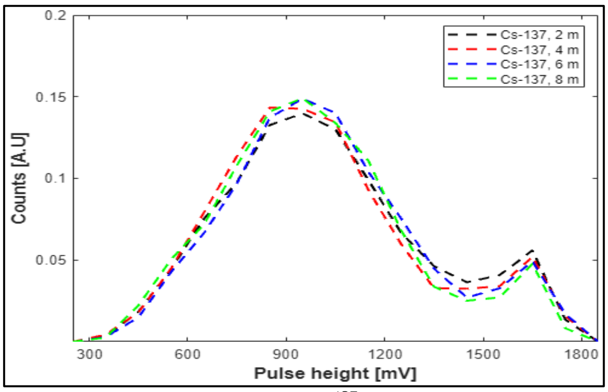

Fig. 4. Pulse height histogram of ^{137}Cs

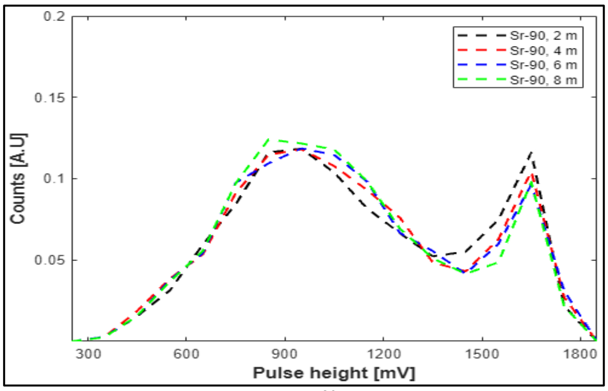

Fig. 5. Pulse height histogram of ^{90}Sr

Figs. 4 and 5 show the pulse height histograms of ^{137}Cs, and ^{90}Sr for the signals directly reaching the PMT, respectively. To enable a comparison of pulse height histograms across different count rates, arbitrary units are used, with the histogram sum standardized to 1. In both cases, they exhibit two distinct peaks around 950 mV and 1600 mV, the heights of which depend on the source position. Through a deconvolution method, the two peaks were isolated from the pulse height histogram, and the ratio of each peak's height (peak-to-peak height ratio) was presented in Fig. 6.

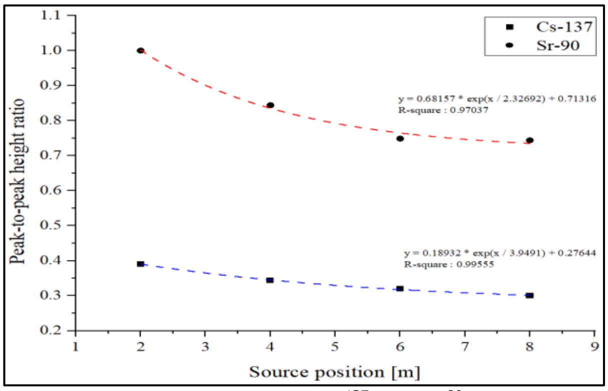

Fig. 6. Peak-to-peak height ratio of ^{137}Cs, and ^{90}Sr

As the source position from the PMT increases, the intensity of Cherenkov radiation incident on the PMT decreases. This phenomenon is associated with the attenuation length of the LLG and can be verified through the peak-to-peak height ratio.

3. Conclusions

In this study, the position spectrum measurements and pulse height distribution analyses were performed using a Cherenkov radiation sensor based on a reflective film-coated LLG. We demonstrated the capability to determine source positions through the TOF method using an oscilloscope.

In further studies, our focus will be on conducting measurements in challenging environments, such as underwater conditions and assessing radiation contamination within the interiors of pipes. In addition, we will attempt to analyze the pulse height distributions of various types of radionuclides to order to assess their energy dependencies.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MIST) (No. 2020M2D2A2062457, 2022M2D4A1084440) and the Ministry of Science and ICT (RS-2023-00257279).

REFERENCES

[1] Siwon Song, Jinhong Kim, Jae Hyung Park, Seunghyeon Kim, Taeseob Lim, Jin Ho Kim, Sin Kim, Bongsoo Lee, Measurements of low dose rates of gamma-rays using position-sensitive plastic scintillation optical fiber detector, Nuclear Engineering and Technology, Volume 54, Issue 9, 2022.

[2] Physics and Engineering of Radiation Detection, Syed Naeem Ahmed, 2014.
[3] Jae Hyung Park, Siwon Song, Seunghyeon Kim, Taeseob Lim, Jinhong Kim, Bongsoo Lee, Flexible liquid light-guide-based radiation sensor with LaBr3:Ce scintillator for remote gamma-ray spectroscopy, Nuclear Engineering and Technology, Volume 55, Issue 3, 2023.
[4] Lambert J, Yin Y, McKenzie DR, Law S, Suchowerska N, Cerenkov light spectrum in an optical fiber exposed to a photon or electron radiation therapy beam. Appl Opt. 2009.
[5] G. F. Knoll, Radiation Detection and Measurement, John Wiley & Sons, New York, 2010.