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Performance Testing on the Safeguards Instruments for CANDU Spent Nuclear Fuel Verification : OFPS

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1. Introduction

The CANDU reactor, utilizing natural uranium as fuel and deuterium as coolant and moderator, features approximately 380 to 480 horizontal pressure tubes and employs two fueling machines for loading fresh fuel and removing spent fuel. The spent nuclear fuel from CANDU reactors is stored in stacks within a spent fuel pond and must undergo verification for item counting and gross defect by national and IAEA inspectors.

To address limitations in verifying certain areas and detection capabilities, KINAC developed the Spent CANDU Fuel Verifier (SCAV) in 1998 for this purpose1[1]. However, challenges were identified such as accessing bottom areas and detection limits. As a supplement, KINAC developed the Optical Fiber Radiation Probe System (OFPS) which received official certification by the IAEA in 2008 and has since been utilized for national and IAEA inspections[2].

This study focuses on the performance testing for the OFPS, aiming to evaluate its capabilities and effectiveness in the context of spent fuel verification. Through the experiments and analyses, this research reviewed the operational parameters of the OFPS that influence the quality and reliability of measurement outcomes. Key factors such as the direction of detector movement, detector movement velocity, and the positioning of the current offset are examined for their impact on the system's performance.

The discussion section of this paper builds upon the results of the performance testing, offering insights into the implications of these findings for the future of spent nuclear fuel verification processes. Furthermore, recommendations derived from the analysis aim to guide the continued development and deployment of the OFPS, ensuring that it remains a vital tool in the arsenal of technologies available for ensuring the secure and safe management of nuclear materials.

2. Methods and Results

2.1 OFPS(Optical Fiber Radiation Probe System)

The OFPS is a device designed for the measurement of gross gamma intensities using a Ce-doped Li-7 scintillator. This scintillator generates light when it interacts with radiation, which is then transmitted through an optical fiber to the end of a lengthy cable. Developed as a complement to address the constraints of the existing SCAV, the major features of OFPS are outlined below.

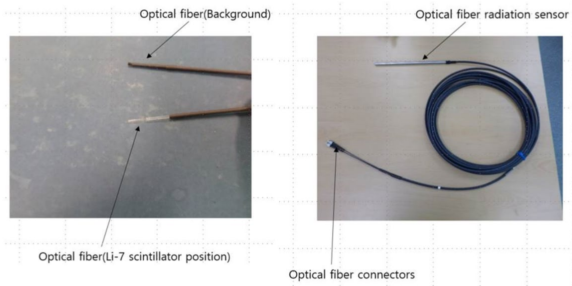

Fig1. Sensing part of the OFPS

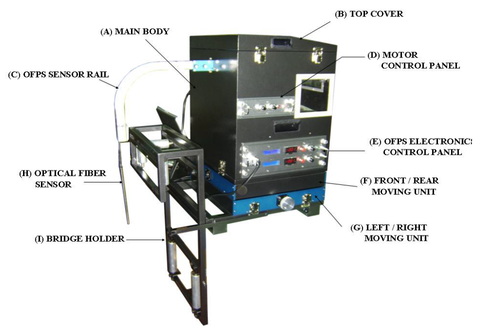

Fig2. Picture of OFPS's main part and components

Table1. Major differences between SCAV and OFPS

	SCAV	OFPS
Detector Type	Semiconductor (CdZnTe)	Scintillator (Ce doped Li-7)
Verification Method	662keV gamma intensity	Total gamma intensity
Insert area	Outside of Stack	Inside of Stack

The SCAV utilizes a semiconductor detector for radiation sensing, allowing for the collection of pulse height spectra through a multi-channel analyzer. By focusing on the 662 keV region of interest corresponding to Cs-137 emission energy, a key characteristic of spent nuclear fuel, pulse counts per unit time are measured at various locations.

In contrast, the OFPS employs a Ce-doped Li-7 scintillator, differentiating it from the SCAV. Consequently, the high gamma flux surrounding the detector prevents the OFPS from collecting pulse height spectra, necessitating measurement of electrical current variations resulting from gross gamma rays instead. Additionally, the SCAV requires thick shielding to minimize radiation interactions and amplify the signal, leading to a larger physical size of the sensing component. On the other hand, the OFPS can be designed to be smaller since it only needs protection against high radiation and water. As a result, the OFPS can be situated between two bundles within a stack configuration.

2.2 Factors affected to the Output Signal Quality

The OFPS gathers the light produced by the scintillator via the optical fiber and directs it to the Photomultiplier Tube (PMT), where it is converted into an electrical signal. This signal is then processed through an operational amplifier, where it is subtracted from the signal obtained from the dummy cable and subsequently amplified. Following this process, adjustments for offset setting are made for the two current signals originating from the scintillator and the dummy before conducting measurements on spent nuclear fuel either above or below. Moreover, the detector's movement direction has two options, and its velocity can be adjusted within the range of 1 to 10 cm per second. These parameter values may influence the quality of spectrum measurement.

2.3 Field Experiment Condition

Several experiments were carried out at the spent fuel bay of Wolsong unit 3 to investigate the factors outlined in section 2.2. The measured fuel is situated in Row B, D, and Column 13, where the detector was inserted into the fifth and sixth bundle of each stack.

2.4 Results of Performance Testing

Figure 3 illustrates the measurement outcomes based on the direction of detector movement, with "going-down" indicating top to bottom and "going-up" indicating bottom to top. The net currents from both directions displayed a symmetric shape, indicating a minimal impact.

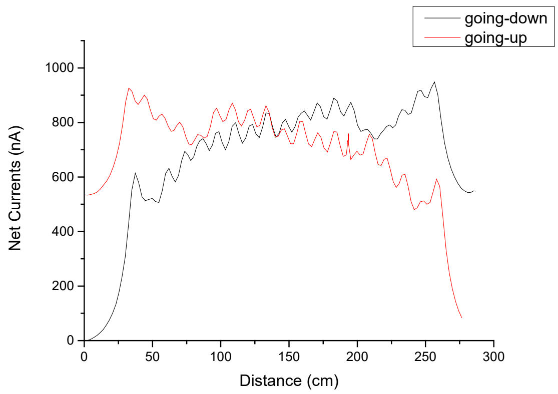

Fig3. Effect on the direction of the detector moving (black) going-down (red) going-up

In Figure 4, the measurement results are portrayed according to the velocities of detector movement. It was observed that as the detector velocity increased, the output signal size decreased due to reduced exposure to gamma rays over a specific time interval.

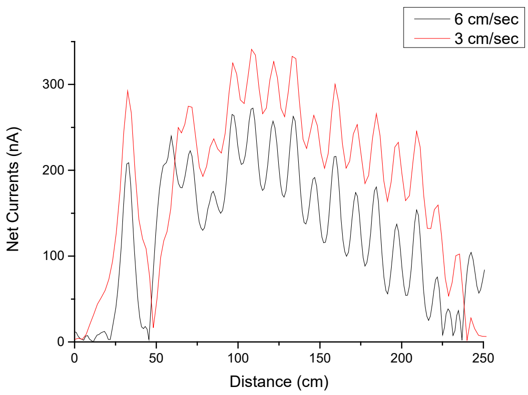

Fig4. Effect on the velocity of the detector moving (black) 6cm/sec (red) 3mm/sec

Additionally, the effect of the offset location for the two types of signals was examined. Setting the offset at the top of the spent nuclear fuel yielded higher signals compared to setting it at the bottom. This discrepancy can be attributed to the higher presence of background radiation at the bottom of the spent fuel pond compared to the top.

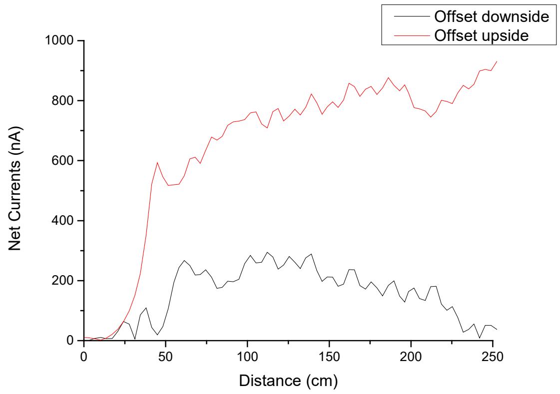

Fig5. Effect on the location of the current offset (black) offset downside (red) offset upside

3. Discussions

Considering results of the performance testing, the three recommendations are suggested to improve the measurement quality of the OFPS.

- Implementing a standardized protocol for the detector's movement direction during measurements to ensure consistency across all measurements. Although the impact is minimal, standardizing the direction could eliminate any potential variations in measurement outcomes.

- Developing an algorithm to dynamically adjust the detector's movement velocity based on the detected radiation intensity. This algorithm would speed up the detector in areas of high radiation to maintain efficiency, and slow down in lower radiation areas to increase exposure time and accuracy.

- Positioning above the spent nuclear fuel is more recommended. This approach exploits the reduced background, aiming to capture stronger gamma-ray signals, thereby improving verification accuracy.

These solutions involve integrating intelligent control systems into the OFPS to adaptively optimize measurement parameters based on real-time data, thereby enhancing measurement accuracy and reliability in verifying spent nuclear fuel.

4. Conclusions

The paper outlines the OFPS's development as a response to the need for more efficient and accurate verification methods capable of accessing difficult areas and overcoming detection limits. It compares the OFPS with the SCAV, highlighting significant differences in detection mechanisms, insertion areas, and overall capabilities. The OFPS experimental results presented in the paper demonstrate the impact of various factors on the measurement quality, including the direction of detector movement, detector movement velocity, and positioning of the current offset. The study finds that the direction of detector movement has minimal impact on measurement outcomes, whereas the velocity of movement and the position of the current offset significantly affect the quality of the current signal. Finally, we suggest three key recommendations to improve the measurement quality of the OFPS: standardizing the detector movement direction, developing an algorithm for dynamically adjusting the detector's velocity, and positioning the current offset above the spent nuclear fuel. These improvements aim to optimize the OFPS's performance by accounting for factors like spent fuel burnup, cooling time, and storage configuration, thereby enhancing the accuracy and reliability of spent nuclear fuel verification processes.

Acknowledgement

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