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Feasibility Study on the Application of ^{4}He Gas Scintillator Detector in Differential Die-Away(DDA) System by using MCNP Simulation

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1. Introduction

Dry storage casks were considered to temporarily store spent nuclear fuel in a Pressurized Light Water Reactor (PLWR or PWR). According to relevant domestic laws and regulations, the account of spent nuclear fuel information should be provided. The information on spent nuclear fuel includes the history of irradiation, burn-up rate, uranium mass (special nuclear material), shape, and mass.

The Differential Die-Away(DDA) analysis method measures induced fission neutrons generated by irradiating fissile material with neutrons. The amount and type of nuclear material can be estimated by measurement of induced fission neutrons. The DDA analysis techniques based on ^{3}He detectors are studied for analyzing the quantitative production of special nuclear materials in spent nuclear fuel in various countries [1-3].

In this study, MCNP simulation studies are conducted to analyze the feasibility of applying the ^{4}He gas scintillation detector (S670e, Arktis) to the DDA system to verify the burn-up rate and history of irradiation.

2. Method of Analysis

2.1 Neutron Detection Principle of S670e Detector [4]

This section describes the principle of fast neutron and thermal neutron measurement through the S670e detector to be used in the study. The S670e detector can acquire fast neutron and thermal neutron measurement signals simultaneously, and it uses two types of mechanisms - scintillation pulse and conversion light pulse.

The S670e detector chamber is filled with ^{4}He gas at 180 bar. The scintillation pulse is emitted by excited ^{4}He by scattering ^{4}He gas and fast neutrons. Inner wall side of the chamber, ^{6}Li is applied to detect thermal neutrons by using ^{6}Li(n, alpha)^{3}H. The generated alpha rays scattered with ^{4}He atoms and emitted the conversion light pulse.

The SiPM has measured the signal of the scintillation pulse and conversion light pulse. Each pulse characteristic has a difference. Thus, the S670e can separate the detection signal.

2.2 MCNP simulation method and DDA time-signal analysis method

MCNP simulation with ^{4}He gas scintillator detector was performed for neutron detection in the DDA system, and the geometry of the simulation is shown in Fig. 1.

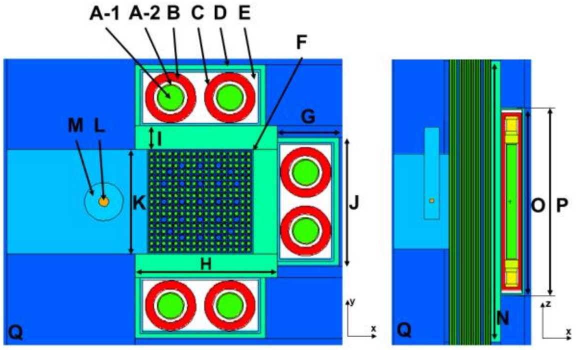

Fig. 1. Geometry of MCNP simulation.

Table I: Dimension of Component in MCNP Simulation [9]

	Component	Dimension (cm)
A-1	^{4}He detector	Dia.: 5.214 Height: 60.826
A-2	^{6}Li film	Thickness: 0.001
B	HDPE	Thickness: 0.0, 1.75
C	Cd layer	Thickness: 0.0, 0.05
D	Detector Box	Width: 11.74 Length:24.96 Thickness: 0.5
E	Detector Box	
F	Fuel assembly Guide	Thickness: 0.23
G	Lead shield	12.74
H	Lead shield	29.41
I	Lead shield	5.0
J	Lead shield	26.96
K	Tungsten shield	21.86
L	Target of neutron generator	Dia.: 2, Height: 2
M	Neutron generator	Dia.: 8, Height: 50
N	lead shield	150
O	Detector Box	Height: 99
P	Lead shield	100
Q	Water	

The spent nuclear fuel assumed Westinghouse type 17x17, and its characteristics were derived using Scale code 6.2. The S670e detector was placed around the spent nuclear fuel, and the detailed specifications of the analysis modeling are shown in the following table 1. The HDPE and Cd layer are used for considering the effects of the neutron detection signal. HDPE is applied for analyzing the moderation effect. The cd layer is considered to analyze the measurement effect of low-energy neutrons below 0.5 eV. The D-T (Deuterium-Tritium) generator is used as a neutron source. The neutron energy is 14.1 MeV. In this case, the neutron is generated through the neutron generator from 0 to 90 μs by using 'tme' option. The spontaneous fission neutrons emitted from spent nuclear fuel were not considered. For the DDA time and signal analysis, the numerical equation was derived from each neutron detection data during 101~200 μs.

3. Results and Discussion

3.1 Fast and Thermal Neutron Detection

Neutron measurement signals were analyzed for cases where the initial concentration was 2.0%, the cooling period was 5 years, the burnup was 10 and 60 GWd/tU, and the effects of HDPE and Cd layers were compared. The fast and thermal neutron detection results are shown in figures 2 and 3, respectively.

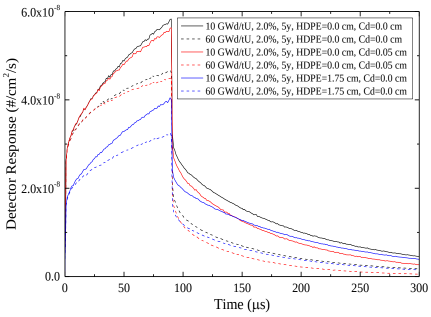

Fig. 2. Effects of HDPE and Cd layer in fast neutron detection.

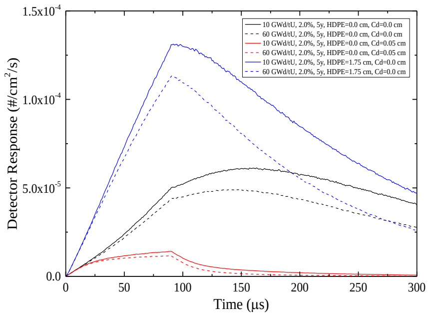

Fig. 3. Effects of HDPE and Cd layer in thermal neutron detection.

The effect of HDPE and Cd layers was observed. In detecting fast neutrons, a rapid decrease in the measurement signal was observed immediately after 90 μs when the neutron generator was turned off. The fast neutron signal is slightly decreased in Cd layer results. However, the HDPE results show that the fast neutron signal decreased $6x10^{-8}$ to $4x10^{-8}$ #/cm^2/s. The thermal neutrons results show the different effect of HDPE and Cd layer. The thermal neutron detection signal (w/o HDPE and Cd layer) is increased after 90 μs. The thermal neutron signal in 90 μs is about $5x10^{-5}$ #/cm^2/s. When the HDPE is applied, the thermal neutron signal in 90 μs is increasing $5x10^{-5}$ to $1.2x10^{-4}$ #/cm^2/s. It is seen that the decrease in the fast neutron signal causes an increase in the thermal neutron signal. However, when the Cd layer is applied, the thermal neutron signal decreases $5x10^{-5}$ to $2x10^{-5}$ #/cm^2/s. It can be shown that the Cd layer interrupts the incident of scattered neutrons in the water below 0.5 eV to the detector.

3.2 DDA time-DDA signal analysis

This section discusses the DDA time and DDA signal analysis results with HDPE and Cd layer effects. In this case, various spent nuclear fuel properties are used as follows:

- Initial enrichment: 2.0, 3.0, 4.0, 5.0%
- Burn-up rate: 15, 30, 35, 40, 45, 50, 55, 60 GWd/tU

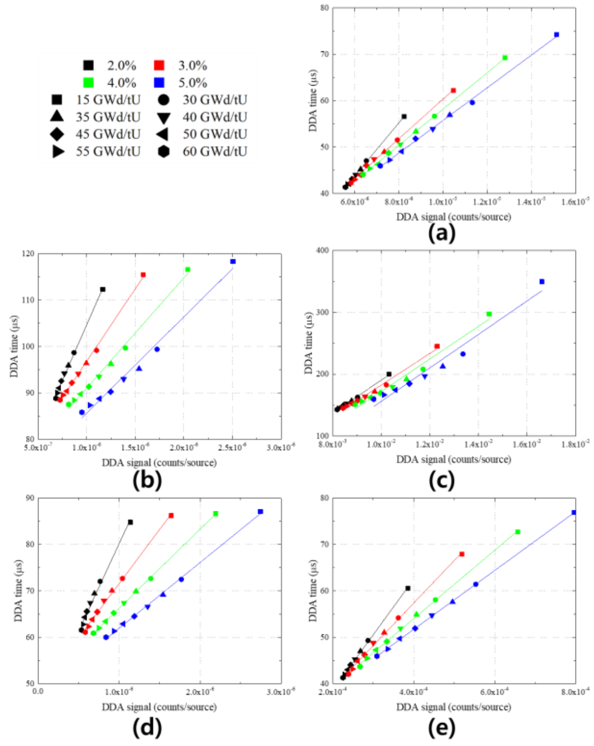

Fig. 4. DDA signal-DDA time analysis results.

Figure 4(a) shows the results of previous studies (6 bar of ^{3}He detector used) [3]. The results show the DDA signal range is 5.5x10^{-6}~1.5x10^{-5} counts/source, and the DDA time range is 41~75 μs. In these results, the high initial enrichment with a low burn-up rate case has the largest DDA signal and time. It has the most significant amount of nuclear material in simulated cases. However, the lower initial enrichment with a high burn-up rate case has the smallest DDA signal and time. In other words, if the amount of nuclear material is small, the DDA signal and DDA time are also small.

Figures 4(b) and 4(c) are the DDA signal and DDA time analysis results for fast neutrons and thermal neutrons of the S670e detector with HDPE, respectively. In the fast neutron results, the DDA signal is lower than in previous results (Fig. 4(a)). However, the DDA time increased to 85~120 μs. In the thermal neutron results, the DDA time was significantly increased to 150~350 μs compared to the previous results of 40~75 μs, and the DDA signal was about 103 times larger.

Figures 4(d) and 4(e) are the DDA signal and DDA time analysis results for fast neutrons and thermal neutrons with the Cd layer. In the fast neutron results, the DDA time is 60~87 μs, and the DDA signal is 5x10^{-6}~2.7x10^{-6} counts/source. Compared to fig. 4(a) and fig. 4(d), the DDA signal slightly decreased in this case, but DDA time increased. However, the thermal neutron results showed no significant difference in DDA time, but the measured signal increased about 30~50 times.

As a result of DDA time and DDA signal analysis, the case of using the S670e detector shows a more apparent difference in the DDA signal and DDA time than the case of using the existing ^{3}He detector. Therefore, it can be confirmed that there is an advantage in applying the S6703 used in this study to the DDA system.

4. Conclusion

The DDA analysis method confirms the special nuclear material in spent nuclear fuel. The induced fission neutron and spontaneous fission neutron energy are above 1 MeV. Thus, the fast neutron detection without moderation method can be considered for the DDA analysis method. The ^{4}He detector has some advantages of being applied to DDA analysis technology. It can measure fast and thermal neutrons at the same time. In this study, S670e, fast and thermal neutron detector, is used for the analysis of applying the DDA system by using MCNP simulation. The results show that the S670e fast and thermal neutron detector applies to the DDA system. In the future, quantitative studies will determine the amount of specific nuclear materials in spent fuel using the ^{4}He gas scintillation detector (S670e)-based DDA system.

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