A Study of Performance Specification of $CdWO_4$ Scintillator Based Partial Defect Detector

Yeongjun Kim[a], Haneol Lee[b], Man-Sung Yim[a*]

[a]Department of Nuclear and Quantum Engineering, KAIST 291 Daehak-ro, Yuseong-Gu, Daejeon, Republic of Korea

[b]Korea Institute of Nuclear Nonproliferation and Control,1418 Yuseong-daero, Yuseong-Gu, Daejeon, Republic of Korea

Introduction

- Scintillator-based partial defect detector(SPDD) is a passive gamma counting detector under development in KAIST and consists of $CdWO_4$ scintillator and amorphous silicon photodiode.
- In this research, performance of SPDD is analyzed with different operation histories(initial enrichment, total burnup) and cooling time of spent fuel based on the WH 17x17 fuel assemblies.
- The performance criteria of quantity verification by SPDD is the amount of spent fuel required to divert 1 significant quantity of fissile Pu in a single fuel assembly based on the KN-12 transportation cask.

Purpose

- Analyze the effect of variation of gamma spectrum due to the different operation history of spent fuel on the performance of SPDD
- Verify the SPDD has enough detection capability to identify the amount of fuel rods equal to 1SQ of fissile plutonium
- Determine the maximum performance of SPDD in terms of minimum detectable number of dummy rods(minDDR) with a random distribution

Detection methodology and the test scenarios for the simulation

- The estimated current distribution of SPDD located in the guide tubes can be obtained with the modeling and simulation with normal spent fuel assemblies and it is compared with the measured current distribution of real measurement. If there is a difference between those signals more than 95% of confidence interval, it is decided that there exists a potential partial defect. MCNPX 2.7.0 is utilized to make the measurement environment and simulations.
- Test scenarios are based on the random distribution of dummy rods as shown in figure 4 for the verification of performance of SPDD with the RDR. More difficult scenarios with the distribution of dummy rods as shown in figure 5 are used to determine the maximum performance of SPDD in terms of minDDR.

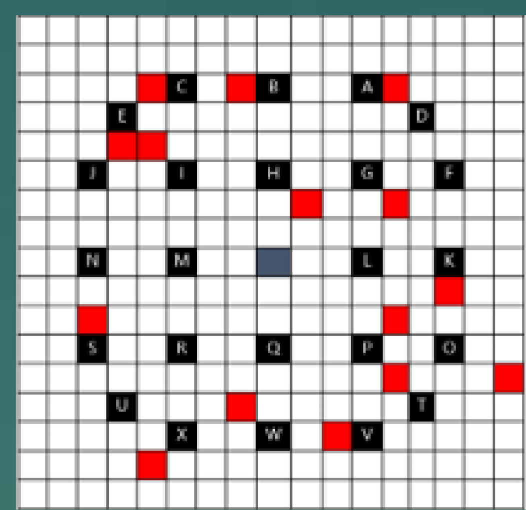

Fig. **4.** Random distribution of dummy rods (Red : dummy, Black : guide tubes)

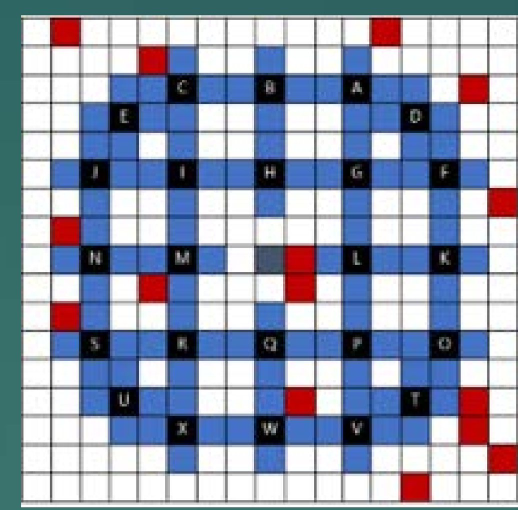

Fig. **5.** Modified distribution of dummy rods (Dummies can't be situated in blue fuel rods nearest from SPDDs)

Detection performance criterion

- Performance criteria is estimated as the required number of dummy rods(RDR) to obtain 1 significant quantity of fissile Pu in a single WH17x17 fuel assembly.
- Generated amount of plutonium is calculated with ORIGAMI provided in SCALE package 6.2.3. with different initial enrichment(0.72~6.0 wt% of U-235), burnup(15~72GWD/MTU), and the cooling time(1~100 years).

RDR

Variable	Range	Control
Initial enrichment	0.72 – 6.0 % of U-235	40GWD/MTU , 0.03y
Total burnup	15 – 72 GWD/MTU	4.5% U-235, 0.03y
Cooling time	0.03y - 100y	40GWD/MTU, 4.5% U-235

Table 1. Tested range of each variable

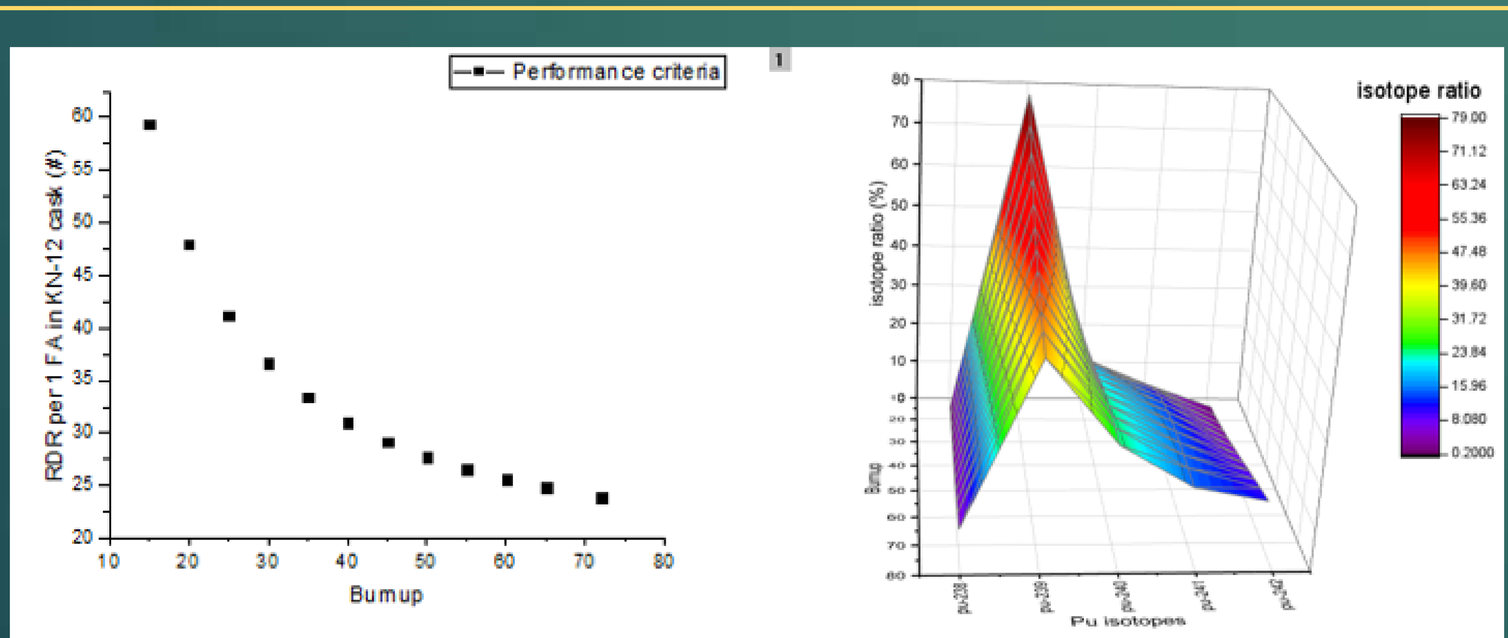

Fig. **1.** RDR with different burnup / Pu isotopes concentration with different burnup

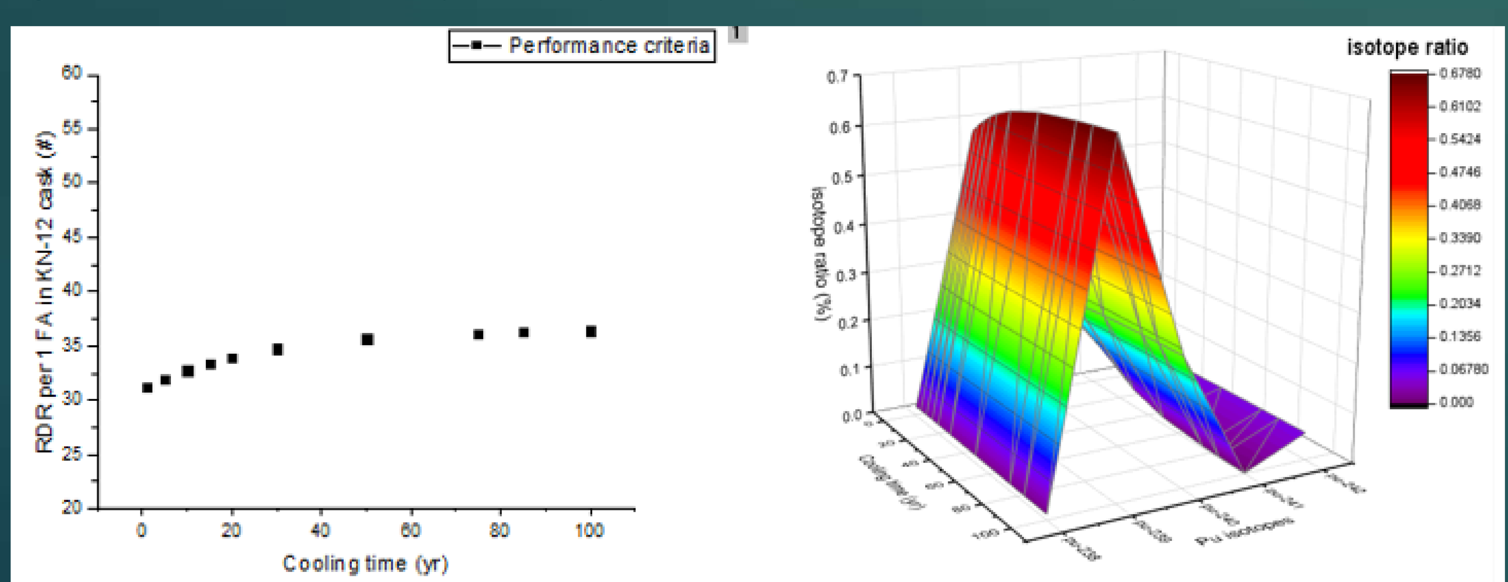

Fig. **2.** RDR with different cooling time / Pu isotopes concentration with different cooling time

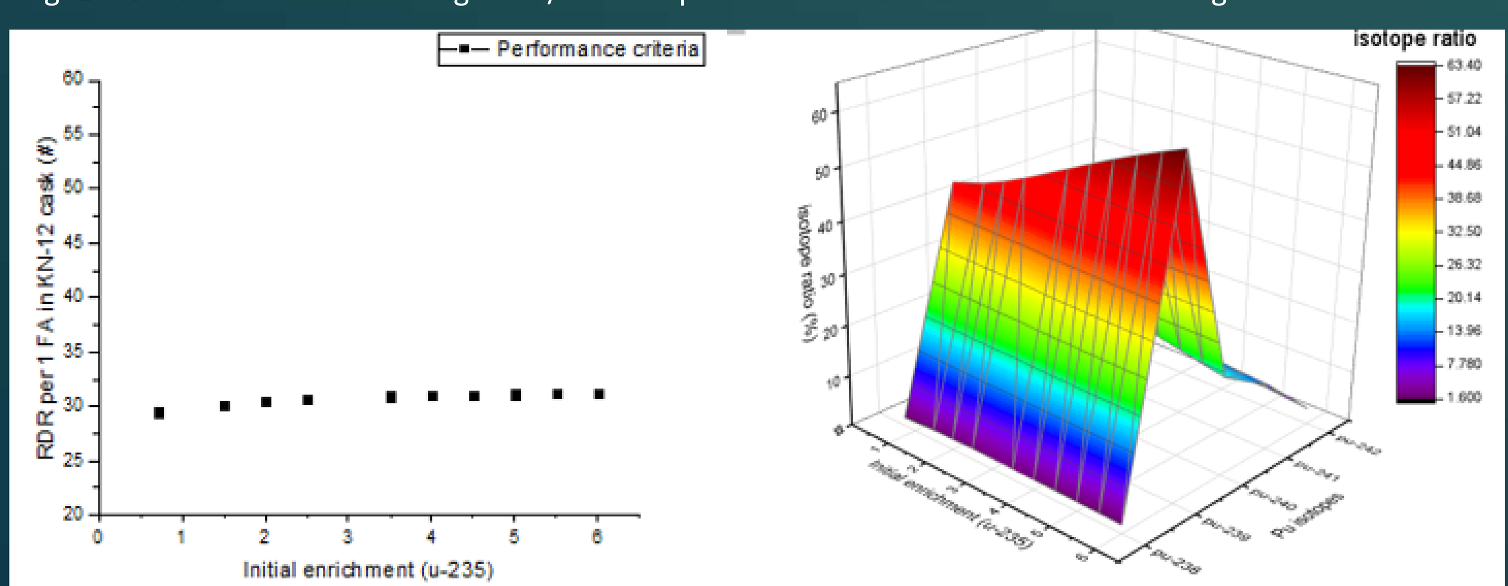

Fig. **3.** RDR with different initial enrichment / Pu isotopes concentration with different initial enrichment

Performance evaluation

- When the burnup increases from 15GWD/MTU to 72GWD/MTU, the SPDD is able to identify the RDR even though the performance criteria becomes difficult from 59(22.3%) dummy rods to 23(8.7%).
- In cases of variations of cooling time and initial enrichment, the performance criteria is hardly changed and it is shown that the SPDD can identify the RDR with all considered range of variables.
- The maximum performance in terms of minDDR of SPDD is about 20 dummy rods with random distribution which is 7.6% of total number of fuel rods in a single WH 17x17 fuel assembly. It is shown that the minDDR is not changed with the different operation histories of spent fuels and it means that the performance of SPDD is not affected by the variation of gamma spectrum and the gamma intensity.

Total burnup (GWD/MTU)	RDR # (%)	Number of SPDD units which identified DR (# of batch : 3)	Minimum number of detectable dummy rods (MinDDR)
15	59 (22.3%)	22 / 24	20
25	41 (15.5%)	22 / 24	
35	33 (12.5%)	16 / 24	
45	29 (11.0%)	10 / 24	
55	26 (9.8%)	10 / 24	
60	25 (9.5%)	8 / 24	
65	24 (9.1%)	11 / 24	
72	23 (8.7%)	8 / 24	

Table 2. SPDD performance with different burnup

Cooling time (years)	RDR # (%)	Number of SPDD units which identified DR (# of batch : 3)	Minimum number of detectable dummy rods (MinDDR)
1	31 (11.7%)	12 / 24	20
10	32 (12.1%)	11 / 24	
20	33 (12.5%)	16 / 24	
30	34 (12.9%)	15 / 24	
50	35 (13.3%)	15 / 24	
75	36 (13.6%)	15 / 24	
85	36 (13.6%)	18 / 24	
100	36 (13.6%)	18 / 24	

Table 3. SPDD performance with different cooling time

Initial enrichment (wt% of U-235)	RDR # (%)	Number of SPDD units which identified DR (# of batch : 3)	Minimum number of detectable dummy rods (MinDDR)
0.72	29 (11.0%)	13 / 24	20
1.5	30 (11.4%)	14 / 24	
2.5	30 (11.4%)	11 / 24	
3.5	30 (11.4%)	14 / 24	
4.5	31 (11.7%)	12 / 24	
4.95	31 (11.7%)	11 / 24	
5.5	31 (11.7%)	14 / 24	
6.0	31 (11.7%)	13 / 24	

Table 4. SPDD performance with different initial enrichment