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Evaluation of prompt and delayed signal fraction for SPNDs in HANARO test

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1. Introduction

Self-Powered Neutron Detector (SPND) is used to provide real time flux distribution of the core in the nuclear power plant. Generally, SPND consisted of an emitter, a signal wire, an insulator and a sheath, and SPND is divided into prompt type and delayed type by the reaction time characteristics of the emitter materials. Prompt type SPND measures the electron current generated by gamma emitted immediately after the neutron absorption of the emitter material. Delay type SPND measures the electron(beta) current generated by beta-decay following neutron capture of emitter material. Typical emitter materials for prompt type SPND are cobalt, platinum and hafnium, and the delayed type SPND use rhodium and vanadium.

OPR1000 and APR1400 power plant measure the core flux distribution using ICI assembly made of rhodium emitter-base SPNDs. However, the reactor cycle has increased from 12 months to 18 months, and the uranium concentration of fuel has increased from 3% to 4.6%, resulting in problem that the burnup life of ICI has been decreased. As a study to develop ICI with long burnup life, SPNDs manufactured using rhodium, vanadium and cobalt are being tested in HANARO test reactor. [1] This paper presents the evaluation of the prompt and delayed fraction of SPNDs signal acquired in the HANARO test.

2. Description of SPND burnup test in HANARO

3 types of SPNDs were manufactured. Rhodium SPNDs were manufactured to provide the reference flux, Vanadium and Cobalt SPNDs were manufactured in a large emitter diameter to increase the signal level. SPNDs were inserted into the loading capsule and then loaded at the location of the OR5 irradiation hole outside HANARO core. This test was conducted at 25MW thermal power, and the neutron flux at the OR5 irradiation hole position was predicted to be $1.2E10^{14}$ n/cm^2. Data Acquisition System (DAS) with 1nA resolution was manufactured and installed to process micro output current signals generated by SPNDs. DAS amplifies the SPNDs output current signal, processes current-to-voltage conversion and analog-to-digital conversion, and stores them in the computer at 100ms intervals.

Table 1. SPND dimension

SPND	Emitter Dia.	Sheath Dia.	Emitter length
Rh	0.46 mm	1.58 mm	400 mm
V	1.4 mm	2.83 mm	400 mm
Co	2.0 mm	4 mm	400 mm

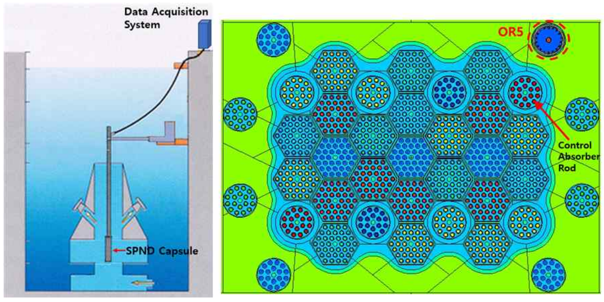

Fig. 1 HANARO test set-up

3. SPND Signal components

SPND is used to calculate the incident neutron flux by measuring the magnitude of the current generated by the reaction of the neutron and the emitter material. The output current of the SPND is mainly generated by (n,*r*,e), (n,β) reaction. The (*r*,e) reaction by external gamma-ray also contributes to the SPND output current.

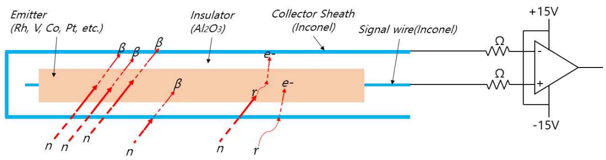

Fig. 2 neutron and SPND material interaction and output current

The prompt gamma-ray reaction, (n,*r*,e), generate compton electron or photoelectron, which appear as prompt signal of the SPND. External gamma-ray reaction, (*r*,e) also appear as prompt signal of the SPND. The positive and negative electron generated by the pair production, (*r*,+e,-e), are canceled in the generation of the SPND output current[2], and thus do not contribute to the SPND output current. Since the beta decay reaction, (n, β), has inherent half-life time, it appear as delay signal of the SPND. In the decay chain, Rh-104($T_{1/2}$=42.3s) and V-52($T_{1/2}$=3.76min) have 99.6% and 100% beta-decay, and the generated beta signal appears as delay signal. Since Co-60 has a half-life of 5.26 years, the delayed beta does not contribute to SPND signal. Referring to the above, the reactions related to prompt and delayed signal response of rhodium, vanadium and cobalt SPND are classified as follows.

Table 2. SPNDs signal response for reaction

SPND	Prompt signal	Delayed signal
Rh	(*r*,e) (n,*r*,e)	(n, β)
V	(*r*,e) (n,*r*,e)	(n, β)
Co	(*r*,e) (n,*r*,e)	-

4. Evaluation Prompt and Delayed signal of SPNDs

In order to distinguish the signal level between the prompt signal and the delayed signal, the response of SPND output current was analyzed after reactor trip. The signals of V, Rh, Co SPND decreased rapidly by 1500ms, 1700ms and 2800ms, then decreased slowly.

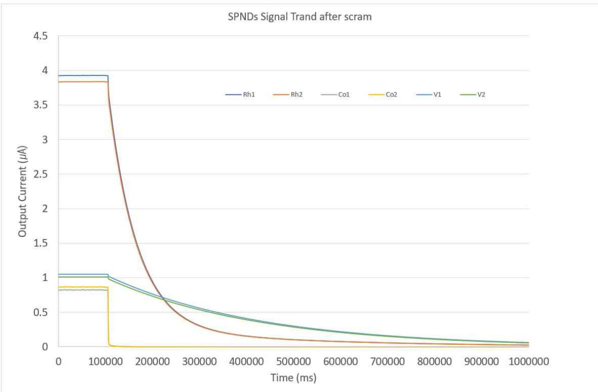

Fig. 3 SPND output signal response after reactor trip

Co and V SPND signal disappeared at 46 seconds and 26 minutes after the reactor trip, and Rh SPND signal was maintained after decreasing below 1 nA level by 37 minutes. This means that the influence of delayed fission neutrons and gamma-rays on the SPND signal components at the OR5 irradiation hole position after the reactor trip is limited.

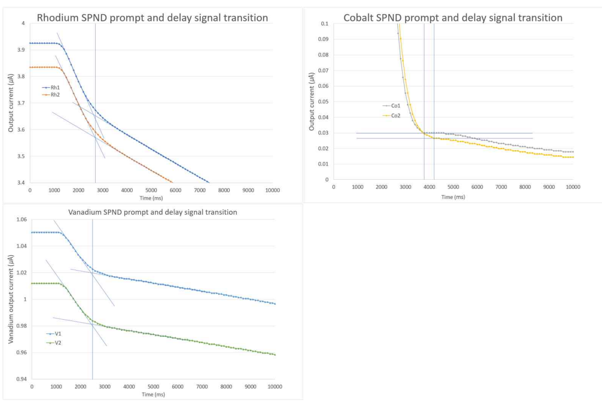

Fig. 4 SPNDs prompt and delay signal transition

The signal fractions measured at the prompt and delayed signal transition points of SPNDs are as follows.

Table 3. SPND delayed signal fraction

SPND	Delay fraction + error (%)	Reference (%)
Rh1	93.31	
Rh2	93.37	93.27[2)]
Avg.	93.34+3.35[1)]	
V1	97.38	
V2	97.21	98.835[2)]
Avg.	97.30+3.35[1)]	
Co1	3.63 (0 after 46s)	
Co2	3.07 (0 after 46s)	0[2)]
Avg.	3.35[1)] (0 after 46s)	

1) Influence of delayed fission neutron and gamma-ray
2) Mono-energy sensitivity calculation result. [3]

5. Summary and Conclusion

The irradiation test was performed in HANARO test reactor to confirm the characteristics of the three types of SPNDs. Cobalt SPNDs showed pure prompt response signal characteristics, and Rhodium and vanadium SPNDs showed that the delay signal components are about 93% and 97%. It was confirmed that as the prompt signal fraction increased, the response signal reduction time increased after the reactor trip.

REFERENCES

[1] Trans. Of KNS Spring meeting, 2019S, p412, Do-Yeon Kim, et all., Status of Vanadium Self-Powered Neutron detecter Depletion Test.
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[3] Jour. of Nucl. Sci. and Tech., 2015, Vo.52, No.5 660-669, Hyunsuk Lee, et all. New calculational model for self-powered neutron detector based on Monte Carlo simulation.