Review of applicability of Cobalt SPND for Reactor Core Protection

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1. Introduction

The core protection system performs the function that shut down the reactor before core operation variables increase to the fuel damage level. Among the operation variables input to the core protection system, such as the temperature, flow rate, pressure and neutron flux of the core, the operating variable that can quickly know the state of the core is the neutron flux. Ex-core detectors and in-core detectors are used to measure the neutron flux of the core, and ex-core detector is used to protection system of all OPR1000 and APR1400 reactor. However, because ex-core detector measures neutrons leaking out of the reactor, ex-core detectors have relatively high uncertainty of measuring neutron flux. On the other hand, in-core detector has the advantage of lower measurement uncertainty than ex-core detector because it measures neutrons at a close distance of fuel assembly.

ICI(In-Core Instrument) assembly is used to measure neutron flux in the reactor, and ICI assembly consists of SPNDs(Self-Powered Neutron Detectors). SPNDs are classified into prompt response SPNDs and delayed response SPNDs based on the time characteristics of the current generated by the neutron reaction with emitter material. Delayed response type SPND has time delay due to the beta decay half-life of the (n, β) reaction. [1,2] Prompt response type SPND has no time delay as (n, *r*, e) reaction in which the prompt electron current generated by the prompt gamma ray is generated. [2]

In this study, the response characteristics to rapid step power change of test reactor were evaluated to confirm the applicability of the core protection of prompt response cobalt SPND.

2. Cobalt SPND response Test

Rh^{103} and V^{51} materials have delayed response signal characteristics through neutron reactions, and Co^{59} and Pt^{195} have prompt response signal characteristics through neutron reactions. Cobalt SPND and Rhodium SPND were fabricated to compare prompt and delayed response characteristics, and response test were performed in the UC Irvine TRIGA reactor.

2.1 Manufacture of SPND

SPND consists of emitter, emitter lead wire, insulating material, and sheath, and the emitter uses a material with a large neutron cross-section, and the rest uses a material with a small neutron cross-section. SPNDs were manufactured using Rh^{103} and Co^{59} emitter with 99.5% purity, Inconel 600 for emitter lead wire and sheath, and Al_2O_3 for insulator. The SPND shape and dimensions are shown in Fig.1. and Table I.

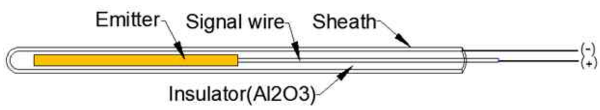

Fig. 1. Self-Powered Neutron Detector

Table I : SPND Description

Emitter Material	Emitter OD (mm)	SPND OD (mm)
Rh-103	0.46	1.58
Co-59	2.0	4.0

2.2 Description of signal measurement

The SPND output current is measured as the current generated by the potential difference between the emitter (+) and the sheath (-). The SPND output current generated by neutron irradiation is stored in the signal storage PC as a digital current value through a differential amplifier and an analog-to-digital converter. The compensated ion chamber signal for neutron flux measurements installed in TRIGA was also connected to the signal processing unit.

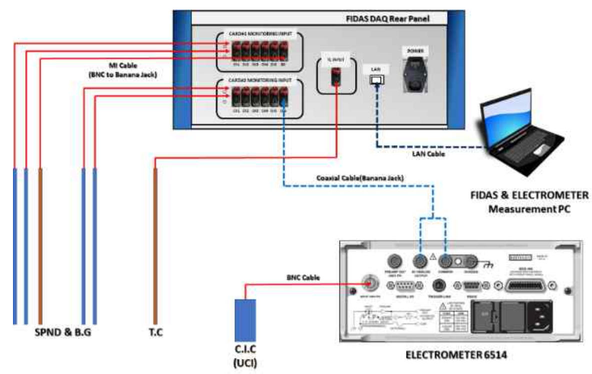

Fig. 2. SPND and CIC signal connection

2.3 Description of power control for test

The neutron flux of OPR1000 reactor for power operation is 10^{11}~10^{13} n/cm^{2}s. The full power of TRIGA reactor is 250kWth, and the neutron flux measured at the 250kW power of TRIGA reactor was evaluated to be 4.78×10^{12} n/cm^{2}s using reference rhodium SPND. The test was conducted according to 50-250-50-250kW power change plan to confirm that the SPND output current followed for rapid step power changes.

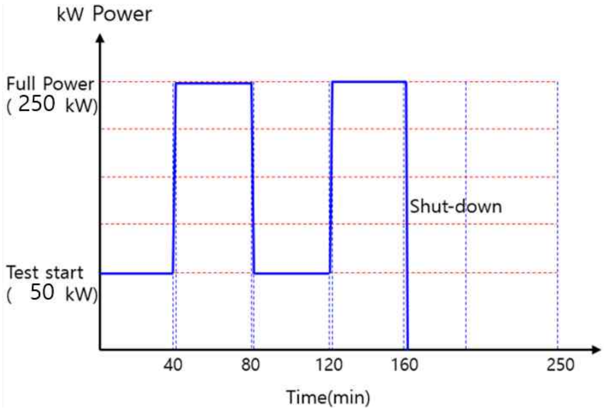

Fig. 3. Power control scheme.

3. Cobalt SPND response characteristics

3.1 SPND response signal trend to step power change

In Fig. 4. The step change in TRIGA reactor power can be identified as the CIC signal(block), and the trend of the cobalt SPND response current(red) and the rhodium SPND response current(yellow) can be observed. The output current of the cobalt SPND exhibits a prompt response characteristic that was immediately saturated with the step change, whereas the output current of the rhodium SPND showed a delayed response characteristic that saturated with delay of approximately 20 minutes to target power level.

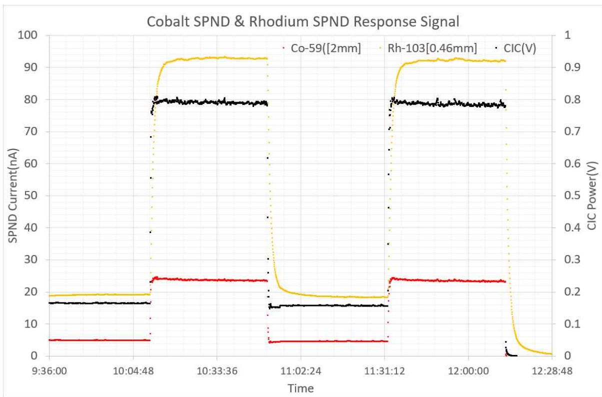

Fig. 4. SPND Power control scheme.

3.2 Cobalt SPND response signal error to step power change

The relative error of the response signal to the step power change was calculated by normalizing the CIC signal used as TRIGA reactor power and the cobalt SPND response signal. In the 50kW and 250kW power stable states, the fluctuation of the error is less than about 0.01% and 0.005%, respectively, and it can be seen that the fluctuation of the error appeared lower at higher power level. The calculated relative error in the stable state of 50kW and 250kW power is found to be less than -0.03% level. When the power is increased from 50 to 250kW, the relative error increase of about 0.03% in the (+) direction is shown, and when the power is decreased from 250 to 50kW, the relative error increase about 0.1% in the (-) direction is shown. It was confirmed that the relative error was up to ±0.1% even when the step change of the power including the stable power state of TRIGA reactor.

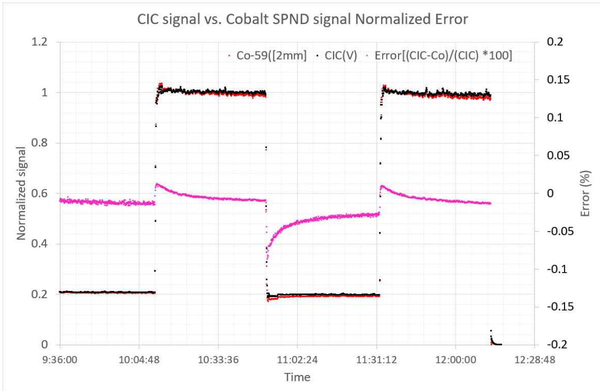

Fig. 5. Power control scheme.

4. Conclusions

A signal characteristic test was performed at UCI TRIGA reactor to confirm whether the signal of domestically fabricated cobalt SPND can be applicable to core protection. It was confirmed that the cobalt SPND response signal has a prompt response characteristic compared to the rhodium SPND response signal. The relative error for the rapid step change in the reactor power was within ±0.1%, so it is evaluated to be applicable to core protection.

REFERENCES

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