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Performance evaluation of prompt response characteristics of cobalt SPND

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1. Introduction

OPR1000 and APR1400 power plants perform core protection using the neutron flux measured by the Ex-core detector installed outside the reactor, and core monitoring using the neutron flux measured by ICIs installed in the core. ICIs have the advantage of low uncertainty in neutron flux measurement compared to Ex-core detector because it is mounted on a guide tube in the center of nuclear fuel assembly and measures neutron flux at short distance. ICI is the assembly of axially arranged Self-Powered Neutron Detectors (SPNDs), which generate electron current proportional to the neutron flux through the reaction of neutrons with matter. SPND is divided into prompt response detectors and delayed response detectors according to the response time of the current generated after the neutron reaction. Delayed response detectors are only used for monitoring core because they produce electrons after delay-time beta decay and do not reflect immediate core states. Rh-103 and V-51 are delayed response emitter materials mainly used to measure the electron current generated by the (n, β) reaction.

$$Rh^{103} + n \rightarrow Rh^{104} \xrightarrow{42.3\ \text{sec}} Pd^{104} + \beta$$

$$Co^{59} + n \xrightarrow{(n,r,e)} Co^{60} \xrightarrow{6.26yr} Ni^{60} + \beta$$

$$\searrow \xrightarrow{(n,r,e)} Co^{61} \xrightarrow{9.9\ min} Ni^{61} + \beta$$

On the other hand, the prompt response detectors are used for protecting core because it can check the state of the core by measuring the prompt electron current generated by the prompt gamma-ray generated during the neutron capture reaction of the emitter material. [1, 2] Prompt response detectors using Co-59 and Pt-195 emitter are used to protect the core of AREVA EPR and CANDU plants, respectively.

In this study, the characteristics of prompt response Co-59 SPNDs were evaluated prior to the development of ICI.

2. Fabrication of cobalt SPND

SPND consists of an emitter that generates electrons by reacting with neutrons, a signal wire that transmits an emitter current signal, an insulating material that insulates the emitter and emitter signal wire, and a sheath on which the generated electrons are charged. (see Fig 1.)

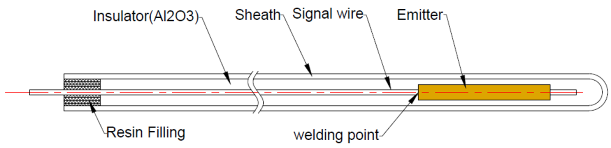

Fig. 1. Self Powered Neutron Detector

SPNDs were fabricated using purity 99.95% Co-59 emitter, Inconel 600 for signal wire and sheath, and alumina (Al_2O_3) for insulation material. The fabrication dimension values of the Co SPND are shown in Table I.

Table I: Problem Description

SPND OD	Emitter OD	Signal wire OD
4.0mm	2.0mm	1.58mm

3. Description of SPND response test in UCI TRIGA reactor

The overall length of the UCI TRIGA reactor's nuclear fuel bundles is about 720mm and 381mm is the core length loaded with uranium. SPNDs were installed in the dry central thimble of the reactor so that the detector center aligns with the core center.

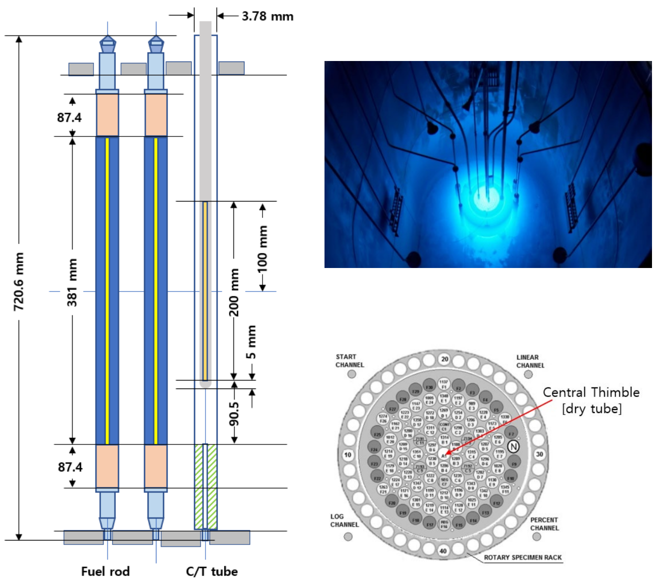

Fig. 2. SPND installation in TRIGA reactor

4. Evaluation of Co-59 SPND signal response

4.1 Prompt response during power ascending

UCI TRIGA reactor has a thermal power capacity of 250kW. [3] The signal evaluation used compensated ion chamber (CIC) signal for thermal neutron measurements provided by TRIGA reactor in addition to the reference rhodium SPND with corrected sensitivity. Above 2kW power, the level of reference Rhodium SPND and Cobalt SPND current signals were sufficient for signal processing, and the neutron flux calculated using the reference Rhodium SPND current values at 2kW and 250kW were 1.04×10^{11} n/cm^{2}s and 4.78×10^{12} n/cm^{2}s. In the case of OPR100 plant, at 1% power, the neutron flux at the outer region of the reactor is 2.0×10^{11} n/cm^{2}s or higher, so Cobalt SPND can be used in commercial reactors. The current signal of reference Rhodium SPND showed a delay characteristic of saturation after a certain period of time when the power was changed, but the current signal of Cobalt SPND showed a prompt characteristic consistent with power change. (see Fig 3) Furthermore, when normalizing the current signal of the Cobalt SPND and CIC, the maximum error level was only ±0.8% below 5kW power. (see Fig 4)

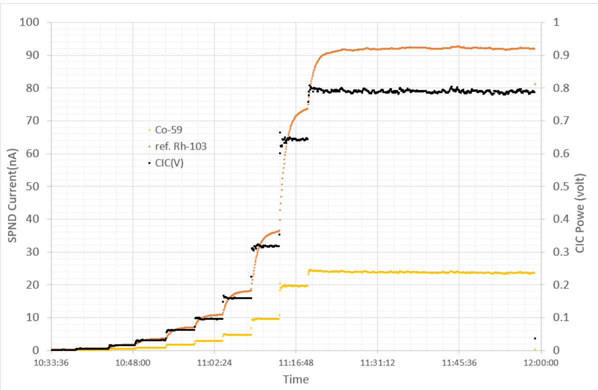

Fig. 3. SPND signal trend during power ascending

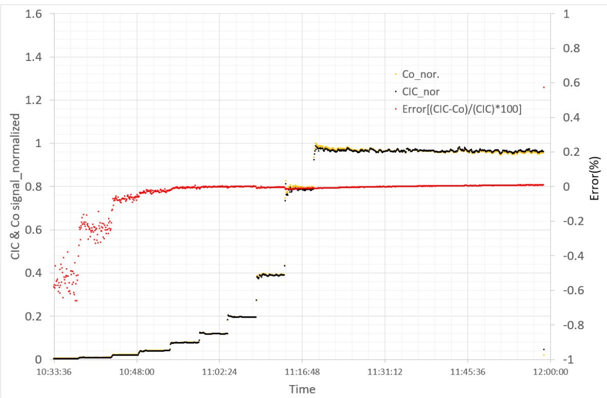

Fig. 4. CIC vs. Co-59 SPND signal normalized error

4.2 Signal linearity to power

With the power change rate maintained at 5kW/min, the Co SPND signal changed linearly when the power was raised from 50kW to 250kW and then remained stable, and the power was reduced from 250kW to 50kW again. (see Fig 5) When Co SPND and CIC signals were normalized, the error was evaluated to be less than ±0.1%. (see Fig 6)

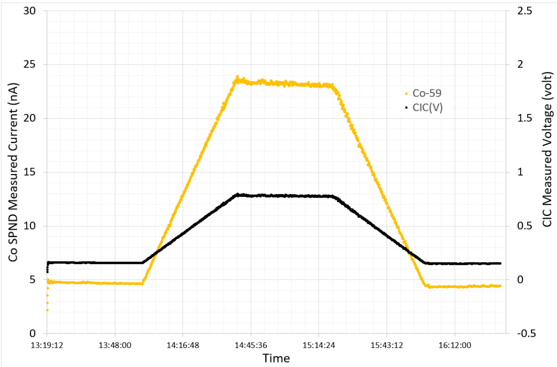

Fig. 5. Constant rate power ascending & descending

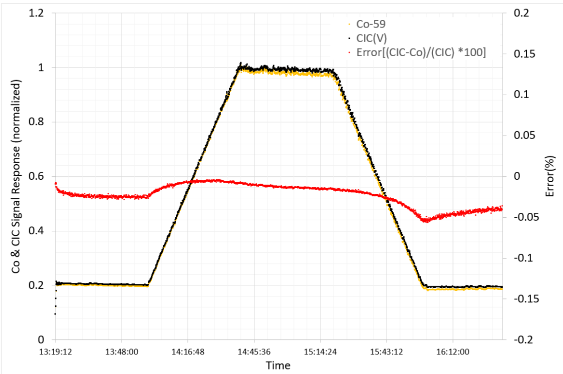

Fig. 6. CIC vs. SPND signal normalized error

3. Conclusions

Through TRIGA reactor test, the prompt response characteristics of Co-59 SPND current signal were confirmed. Since the signal response error at the low neutron flux level is not large and the linearity of the signal response to the reactor power change is evaluated to be good. Therefore, it is judged that it will be possible to manufacture ICI using Co-59 SPNDs.

REFERENCES

[1] Warren and Sulcoski, Performance of Prompt and Delayed Responding Self-Powered In-Core Neutron detectors in PWR, Nuclear Science and Engineering, 86, 1-9, 1984

[2] Maria Do Carmo Lopes and Jorge Molina Avila, Prompt Response Self-Powered Neutron Detectors I : The Effective Charge per Neutron Captured, Nuclear Science and Engineering, 96:4, 303-309, 1987.

[3] Nuclear Analysis of the UCI TRIGA Reactor, Docket No05000326