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Comparative Analysis for the Measured and the Predicted Relative Sensitivity of Rhodium In-Core Detector

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1. Introduction

Self-powered neutron detector (SPND) is widely used as in-core flux monitoring in nuclear power plants. OPR1000 has applied a rhodium (Rh) as the emitter of the SPND. The SPND contains a neutron-sensitive metallic emitter surrounded by a ceramic insulator. When capturing a neutron, the Rh will be decayed by emitting some electrons which is crossing the sheath and produce current. This current can be measured externally using pico-ammeter. The sensitivity of detectors is closely related with the geometry and material of the detectors.

The lifetime of in-core detector is determined by calculating the relative sensitivity of Rh detector. It is required that the Rh detector should be replaced before the burn-up of Rh detector has reached 66% of its original compositions. [1]

To predict Rh detector's relative sensitivity ANC code, advanced nodal code capable of two-dimensional and three-dimensional calculations, is used. It is determined that the Rh detectors should be replaced on the basis of the predicted sensitivity value calculated by ANC code.

When evaluating the life of Rh detectors using ANC code, it is assumed that the uncertainty of the sensitivity calculation include the measurement error of 5%. As a result of the analysis of measured and predicted data for the Rh detector's relative sensitivity, it is possible to reduce the assumed uncertainty.

2. Principles and Characteristics

The interactions between neutrons and atomic nuclei of Rh are used to produce a current which is proportional to the neutron flux. And Rh possesses relatively high cross sections to thermal neutrons, relatively high melting temperatures and is compatible with the manufacturing process.

Table 1 shows the important characteristics of Rh emitter used in power reactor applications. [2]

Table 1. Nuclear characteristics of Rh emitter

Emitter material	Cross-section	Half-life ($T_{1/2}$)	Burnup rate [%/mon.@10^{13}nv]
Rh-103	11b (8%) 135b (92%)	4.4 min 42 s	0.39

The Rh SPND operates on the principle of neutron activation of the Rh^{103} emitter material and signal produced by the rhodium detector is as follows;

1) Photoelectric effect, Compton scattering, Pair production (6 %)

2) Beta Decay of Rh^{104} (87 %)

$$Rh^{103} + n^1 \rightarrow Rh^{104} \rightarrow Pd^{104} + \text{Beta}$$
$$T_{1/2} = 42 \text{ sec}$$

3) Two-stage Decay of Rh104m (7%)

$$Rh^{103} + n^1 \rightarrow Rh^{104m} \rightarrow Rh^{104} \rightarrow Pd^{104} + \text{Beta}$$
$$T_{1/2} = 4.4 \text{ min}, \quad 42 \text{ sec}$$

Process 2) and 3) result in a change in the relative detector sensitivity to neutron flux with time due to Rh depletion.

3. Result of Analysis

3.1 Calculations of Rh relative sensitivity

The code systems(CECOR and COLSS) for fixed in-core detector signal analysis use signals from the Rh in-core detectors to calculate the local power (P) in an instrumented assembly and relative sensitivity calculation formulation of the codes is as follows;

$$\text{Relative Sensitivity}\left(\frac{S}{S_o}\right) = \left[1 - \frac{Q(t)}{Q_\infty}\right] \qquad (1)$$

where, Q_∞ = 335 Coulombs (theoretical charge)
$Q(t)$ = Sensitivity at time t

Eq.(1) is based on the measured data calculated by In-Core Instrumentation (ICI) Processing Program of Plant Monitoring System (PMS).

ANC predicts the sensitivity by calculating rhodium number density as follows ;

$$N(t) = N_0 - \int_0^t N(t)\sigma_a \varphi dt \qquad (2)$$

where, N_0 : Initial Rh number density
$N(t)/N_0$: Relative Sensitivity

3.2 In-core detector replacement

It is required for the in-core detectors to be operable above 75% for monitoring the core power distribution accurately by the plant technical specification. To satisfy this requirement, in-core detectors should be replaced when the burn-up of Rh detector reaches 66% depletion as Fig 1.

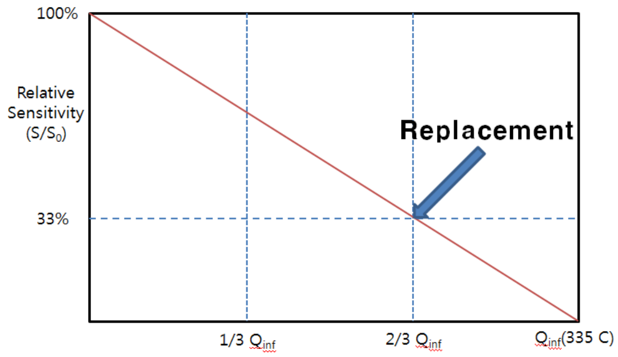

Fig 1. Criteria of ICI replacement

Actually, both the measured and the predicted relative sensitivity values are used to determine the number of ICIs to be replaced at every end of cycle (EOC).

The corrected equation to calculate the relative sensitivity is as follows;

Corrected Relative Sensitivity (for ANC code)
= predicted sensitivity of N+1 cycle EOC
− (predicted sensitivity of N cycle
– measured sensitivity of N cycle)
− { (predicted sensitivity of N cycle
– predicted sensitivity of N+1 cycle)}
× **Uncertainty (0.05)**

To evaluate the life of ICI conservatively, 5% of uncertainty should be applied

3.3 Comparison of measured and predicted sensitivity

CECOR snapshot files generated in operating plant include the information such as plant power, assembly burn-up, Rh detector's accumulated charges, etc. The predicted rhodium sensitivity can be analyzed by comparing measured values at the same burn-up point (Design Burn-up + 500 MWD/MTU) accurately. Table 2 shows the differences between the measured and the predicted sensitivity.

Table 2. Measured and Predicted Sensitivity Error

UCN #5	Cycle 4 (ROCS)	Cycle 5 (ROCS)	Cycle 6 (ANC)	
Uncertainty (Prediction)	No	No	No	5%
Error [(M-P)/M]*100	9.9%	1.9%	**0.6%**	**1.2%**

YGN #5	Cycle 6 (ROCS)	Cycle 7 (ROCS)	Cycle 8 (ANC)	
Uncertainty (Prediction)	No	No	No	5%
Error [(M-P)/M]*100	1.4%	2.1%	**0.8%**	**1.4%**

It is confirmed that an appropriate uncertainty is necessary because ANC code predict less conservatively the ICI lifetime than ROCS code. According to the uncertainty of Rh sensitivity calculation by core design code, it can be assumed that the uncertainty has influenced on the errors between the measured and predicted sensitivity and it needs to analyze much more historical data about the results of ICI replacement.

New uncertainty of 5% for ANC code is valid, and it is necessary to optimize the uncertainty within Technical specification requirement.

4. Conclusions

A comparative analysis between the measured and the predicted rhodium relative sensitivity was performed using the plant's historical real data and core design data (ROCS and ANC code). It is confirmed that an appropriate uncertainty is necessary because ANC code predicts less conservatively the ICI lifetime than ROCS code.

New uncertainty of 5% for ANC code is valid, and it is necessary to optimize the uncertainty through the analysis of many plants data and application of the Monte Carlo method. The Monte Carlo code will predict the "sensitivity" of Rh emitter to beta of various energies. [3]

To minimize the ICI replacement costs, it needs to study for various emitter materials such as Co, Pt, V, Ag and for incore-based reactor protection system for the reactor safety in near future. [4]

REFERENCES

[1] CEOG Final Report, "In-Core Instrumentation (ICI) Life Extension"

[2] William H. Todt, "Characteristics of Self-Powered Neutron Detectors Used in Power Reactors".

[3] H.D. Warren, "Calculational Model for Self-Powered Neutron Detector"

[4] H.D. Warren and N.H.Shah, "Neutron and Gamma-Ray Effects on Self-Powered In-Core Radiation Detectors