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Relative Sensitivity Prediction of Rhodium Detectors for KSNP

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1. Introduction

Most PWRs with an installed fixed In-core Instrumentation (ICI) system rely on fixed in-core rhodium self-powered neutron detectors (SPNDs) which have a long and successful history of proven plant operation. However due to the depletion of the rhodium and the resultant decrease in rhodium detector sensitivity, ICIs comprised of rhodium detectors must be replaced periodically as the uncertainties associated with the inferred core power distribution increase. As a result, the use of rhodium detector results in maintenance costs associated with ICI hardware procurement, installation, disposal and other ICI replacement operations.

The current criterion for ICI replacement due to rhodium detector depletion is 1/3 of its initial sensitivity that is the ICI lifetime. This criterion ensures that the uncertainties in core power peaking factors derived from fixed in-core detector signals are maintained within the limit specified in the CECOR Topical Report[1]. According to the ICI replacement criterion, all ICIs of which relative sensitivities will become less than 1/3 at the end of the next cycle should be replaced during the overhaul in advance because the replacement of ICIs cannot be permitted during reactor operation. Table 1 shows the current status of ICI replacement for Korea Standard Nuclear Power Plants (KSNPs).

Table 1. ICI Replacement Status for KSNPs

Cycle	YGN-3	YGN-4	UCN-3	UCN-4
4	25	25	25	26
5	7	6	9	11
6	6	45	12	11
7	24	0	20	-
8	11	16	-	-
9	8	19	-	-
10	45	-	-	-
Total	126	111	66	48
AVG	18.0	18.5	16.5	16.0

A precise estimation of the depletion of Rhodium detectors for the next cycle is very important in order to reduce the cost, maintenance time, and radiation waste. And a good method of estimating the relative sensitivity of the rhodium detector for upcoming cycle was introduced[2]. This method can be used for selecting the ICI strings which should be replaced during the overhaul for the site staffs as well as for the nuclear designers. In this paper this new method of estimating the relative sensitivity of the rhodium detector for upcoming cycle is introduced and verified by measurement data.

2. Methods

The detector sensitivity is considered as a linearly decreasing function, $\alpha = 1.0$ in Eq. (1), with respect to the accumulated detector charge Q which is the value of the time integration of background corrected detector signal[3], i.e.,

$$S = S_0(1 - \frac{Q}{Q_\infty})^{\alpha} \quad (1)$$

where
S_0 = initial detector sensitivity based on activation
Q = accumulated detector charge at any time
Q_∞ = total theoretical charge (335 Coulomb for KSNP)
α = experimentally determined fitting parameter.

According to the Eq. (14) of Reference 2, the best estimated relative sensitivity for EOC (End of Cycle) of the next cycle, $(S/S_0)_{eoc}$, can be expressed as

$$(\frac{S}{S_0})_{eoc} = (\frac{S}{S_0})_{boc} - [(\frac{N}{N_0})_{boc} - (\frac{N}{N_0})_{eoc}] \cdot Bias \quad (2)$$

and

$$Bias = -0.1 \cdot [(\frac{N}{N_0})_{boc} + (\frac{N}{N_0})_{eoc}] + 1.1 \quad (3)$$

where $(S/S_0)_{boc}$ are the BOC (Beginning of Cycle) relative sensitivities for the next cycle, which are equivalent those at EOC of the current cycle, and (N/N_0) are the rhodium depletion fractions which can be obtained 3-dimensional coarse and fine mesh depletion calculation with nuclear design code such as ROCS[4].

Eqs. (2) and (3) can be used to obtain the best estimated detector relative sensitivities at any time of the upcoming cycle for site staffs as well as for nuclear designers. In order to verify Eqs. (2) and (3), three test calculations were performed and the results are discussed in the results section.

3. Results and Conclusion

The relative sensitivities of detector level 3 of Yonggwang Nuclear Unit 3 cycle 7 and 8 at 14,000 and 16,500 MWD/MTU, respectively, were estimated by using Eqs. (2) and (3) and then the results were compared to the measurement data from the CECOR output. Another test was performed for Ulchin Nuclear Unit 3 cycle 5 at 16,200 MWD/MTU. Table 2 shows the comparisons for the three test cases and the calculations are in good agreement with the measurements.

Table 2. Comparisons with Measurement Data

ICI #	Relative Sensitivity Differences at EOC		
	YGN-3 Cy 7	YGN-3 Cy 8	UCN-3 Cy 5
1	*	0.004	-0.002
2	-0.001	0.000	-0.001
3	-0.003	0.000	-0.005
4	*	0.002	-0.005
5	0.000	0.002	-0.005
6	0.000	*	-0.004
7	-0.002	*	-0.005
8	-0.003	-0.002	-0.003
9	-0.003	*	-0.001
10	0.002	0.002	0.000
11	0.001	0.000	-0.005
12	-0.004	0.000	-0.007
13	0.000	-0.001	-0.002
14	*	0.001	0.000
15	-0.001	0.003	-0.002
16	0.001	0.001	0.000
17	0.004	0.004	-0.002
18	0.000	-0.003	-0.004
19	0.000	-0.001	-0.001
20	0.004	-0.001	-0.001
21	0.000	*	-0.002
22	0.000	*	0.000
23	*	-0.001	0.002
24	-0.001	-0.001	0.000
25	0.001	0.003	0.001
26	0.002	0.000	-0.001
27	-0.002	-0.002	-0.003
28	-0.002	-0.005	-0.004
29	0.001	0.005	-0.002
30	-0.001	0.003	-0.001
31	*	0.002	-0.005
32	0.003	0.007	-0.002
33	0.002	0.000	-0.002
34	-0.002	-0.004	-0.006
35	0.000	-0.002	-0.003
36	-0.003	-0.004	0.000
37	-0.003	-0.006	-0.006
38	*	0.001	-0.003
39	-0.002	*	-0.006
40	0.001	*	-0.003
41	0.001	0.000	-0.001
42	*	0.000	-0.004
43	-0.004	-0.004	-0.006
44	0.000	0.002	-0.001
45	0.000	*	0.000

* Not available due to detector fail

An accurate estimation of the rhodium detector relative sensitivities for the upcoming cycles in selection of the replacement ICIs is connected directly with the reduction of management cost and radiation waste.

In this paper a new method to estimate the relative sensitivity of the rhodium detector for upcoming cycle is introduced and the results from this method are in good agreement with the real measurement data. This method can be used for selecting the ICI strings which should be replaced during the overhaul for the site staffs as well as for the nuclear designers for KSNP plants.

If the cross-section libraries of ROCS were changed, the coefficients of bias in Eq. (3) should be re-evaluated for the new cross section libraries because the rhodium depletions might be affected by them. And for the case of changing the design code used in rhodium depletion calculations the bias also should be re-evaluated, however the main theory of this paper will be still utilized.

A study for the extension of rhodium detector lifetime is recommended as a further work and if so the results of this study will also be useful.

REFERENCES

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