A Constructive Calibration of Axial Spatial Weighting Functions of Ex-Core Detectors

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1. Introduction

This paper describes a constructive mathematical modeling of the excore neutron detectors using a calibration factor of power and burnup independent shape annealing function for Korean Optimized Power Reactor (OPR-1000) and demonstrates its validity via comparison with the measurement data. Validity tests for the calibration method show that the detector responses can be estimated very accurately, within 1% error.

2. Methods and Results

2.1 Mathematical Model for Detector Response[1,2,3]

The 2-dimensional weighting functions, often called assembly weighting factors, are obtained by solving a 2-dimensional adjoint transport problem over the *x-y* plane. They are usually used in conjunction with the axial spatial weighting function to calculate the detector response. Given a 3-dimensional power distribution $P(x,y,z)$, the peripheral axial power distribution is obtained by

$$P_{peri}(z) = \int P(x,y,z)\omega_{2D}(x,y)dxdy, \qquad (1)$$

then the detector response is given by

$$R = \int P_{peri}(z)\omega_{1D}(z)dz, \qquad (2)$$

where $\omega_{1D}(z)$ is the axial spatial weighting function and $\omega_{2D}(x,y)$ indicates the 2-dimensional assembly weighting function. It should be noted that all integrations in this section are approximated by the summation in the actual computation since the calculation is usually performed in the discrete phase space.

2.2 Calculation Model

The adjoint neutron transport calculation was performed for OPR-1000 core configuration. The safety channel of excore neutron detector is composed of 3 axial segments and the axial core power distribution is synthesized. The DORT2.8.14 code, based on the discrete ordinate transport method, was used to evaluate spatial weighting functions for the 3-segment excore detector. The 47-energy-group DORT calculations were performed with P_3, S_8 approximation in 2-dimensional geometries. The cross section data used in this study were from the BUGLE-library.

2.3 Axial Spatial Weighting Functions

The core axial spatial weighting functions can be efficiently obtained by using an $r-z$ DORT model for the. The $r-z$ DORT model was constructed with 101 radial meshes and 150 axial meshes of different size. The core shroud region and bypass region were transformed into the $r-z$ geometry such that the volume is preserved and the resin region (neutron moderating annulus) of excore detector was modeled as having the same thickness to preserve the same moderating power. The core region was divided into 26 axial subregions in order to consider material property changes caused by axial power distribution. The water density in both bypass region and downcomer regions was calculated by keeping in mind that water temperature in those regions is equal to the inlet coolant temperature. Figures 1 and 2 show that impact of the core power level and the core burnup on axial spatial weighting functions, respectively.

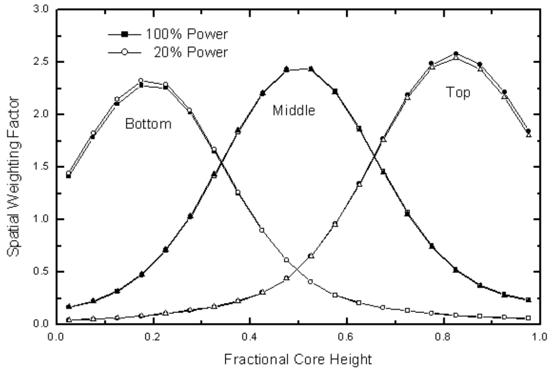

Figure 1. Axial weighting functions with power level

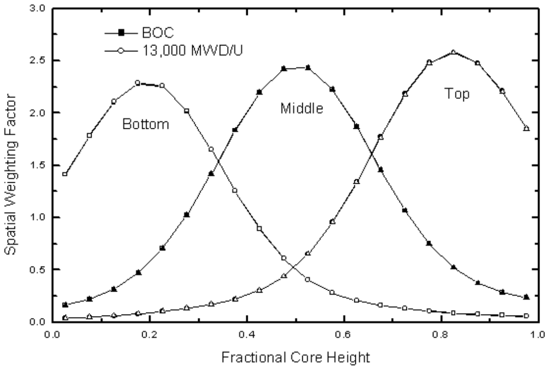

Figure 2. Axial weighting functions with burnup

2.4 Comparison with Measurement Data

The conventional normalized axial spatial weighting functions are calibrated as follows. First, it is assumed that a measured data, i.e., a peripheral axial power distribution and the corresponding excore detector signal, is given as reliable. Note that the peripheral axial power distribution can be obtained with the assembly-wise spatial weighting functions. A scaling factor is defined such that the calibrated spatial weighting functions provide exact detector signals for the measured (reference) power distribution:

$$f_{ren} = \frac{R_{measured}}{R_{calculated}}, \qquad (3)$$

where $R_{measured}$ and $R_{calculated}$ are the measured and calculated excore detector signals, respectively. If the calibration factor is found using Eq. (3), the calibrated axial spatial weighting functions can be obtained by

$$\omega_{ren}(z) = f_{ren}\omega(z), \qquad (4)$$

where $\omega(z)$ is the normalized core axial spatial weighting functions.

2.5 Application to Plant Excore Detector Channels

Table 2 demonstrates the validity of the calibration scheme for various core conditions of the initial cycle of YGN-3. The calculated detector signals are obtained using the normalized axial spatial weighting functions and the calibrated signals are obtained using the calibration factors referenced to the measurement data taken at 80% core power level.

The 80% power level data is used as the reference case since various tests associated with the nuclear design and reactor operations are performed at the 80% power.

3. Conclusion

A constructive calibration method of the excore neutron detectors has been developed using a calibration of power and burnup independent shape annealing function of the excore neutron detectors for OPR-1000s and its validity are demonstrated via comparison with the measurement data. Validity tests for the calibration method for YGN-3 cycle 1 and 2 show that the detector responses can be estimated very accurately, within 1% error for various power levels and power distributions.

REFERENCES

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Table 2. Validity of axial spatial weighting functions for channel A excore detectors of YGN-3, Cycle 1

Burnup, MWD/T [Power Level]	Detector	Measured Signal	Calculated Signal (Error,%)	f_{ren}	Calibrated Signals(1) (Error,%)	Calibrated Signals(2) (Error,%)
126 [20%]	TOP	0.2929	0.3011(-2.80)	0.9728	0.2929(0.00)	0.2947(-0.61)
	MID	0.4257	0.4143(+2.68)	1.0275	0.4254(+0.07)	0.4253(+0.08)
	BOT	0.2814	0.2846(-1.14)	0.9888	0.2817(-0.10)	0.2799(+ 0.52)
542 [50%]	TOP	0.2875	0.2943(-2.37)	0.9769	0.2874(+0.04)	0.2883(-0.28)
	MID	0.4244	0.4153(+2.15)	1.0219	0.4240(+0.09)	0.4240(+0.09)
	BOT	0.2880	0.2905(-0.87)	0.9914	0.2886(-0.20)	0.2877(+0.11)
1421(3) [80%]	TOP	0.2889	0.2931(-1.70)	0.9833	0.2884(+0.16)	0.2884(+0.16)
	MID	0.4236	0.4163(+2.02)	1.0210	0.4235(+0.01)	0.4235(+0.01)
	BOT	0.2875	0.2906(-1.29)	0.9873	0.2880(-0.18)	0.2880(-0.18)
2000 [100%]	TOP	0.2888	0.2933(-1.56)	0.9847	0.2890(-0.06)	0.2874(+0.48)
	MID	0.4242	0.4152(+2.12)	1.0217	0.4239(+0.08)	0.4238(+0.10)
	BOT	0.2870	0.2916(-1.60)	0.9842	0.2871(-0.05)	0.2888(-0.62)
5200 [100%]	TOP	0.3032	0.3108(-2.51)	0.9756	0.3035(-0.09)	0.3018(+0.48)
	MID	0.4054	0.3948(+2.61)	1.0269	0.4050(+0.09)	0.4049(+0.11)
	BOT	0.2914	0.2944(-1.03)	0.9898	0.2915(-0.04)	0.2933(-0.65)
13650 [100%]	TOP	0.3225	0.3303(-2.42)	0.9764	0.3227(-0.07)	0.3208(+0.54)
	MID	0.3796	0.3691(+2.77)	1.0285	0.3792(+0.10)	0.3792(+0.11)
	BOT	0.2979	0.3006(-0.91)	0.9910	0.2981(-0.06)	0.3001(-0.72)

(1) power-dependent axial spatial weighting functions
(2) power-independent axial spatial weighting functions
(3) reference measurement data