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Assembly Weighting Factors of Ex-core Detector Based on Forward Neutron Transport Calculation

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1. Introduction

In OPR1000 (Optimized Power Reactor 1000) plant the core power is monitored by in-core detectors and ex-core detectors. Total 45 in-core detectors are inserted to the fuel assemblies through the guide tubes. Each in-core detector assembly has axially 5 level Rhodium detectors along to the full fuel length [1]. With these in-core detectors the power distributions for those fuel assemblies are measured directly. For the fuel assemblies which have no in-core detector, the power distributions for those assemblies are estimated using the coupling coefficients generated at the physics design process. Therefore whole 3 three dimensional core power distributions including radial, azimuthal, and axial direction can be measured. These three dimensional core power distributions measured by the in-core detectors are continuously monitored during the plant operation.

On the other hand, the ex-core detectors are also monitoring the core power level at the outside of the reactor vessel. Fig. 1 shows the locations of the ex-core detectors for OPR1000 plant. As shown in this figure, each channel has two detectors, one is fission chamber called as safety channel and the other one is BF3 proportional counter.

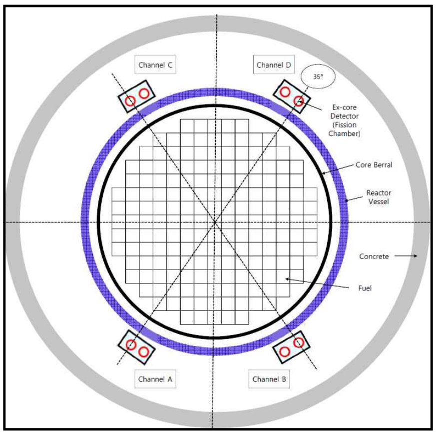

Fig. 1. The Locations of the Ex-core Detectors for OPR1000 Plant

Generally the BF3 proportional counters are used during the reactor start-up, on the other hand the safety channels of fission chamber are used to monitor power level during the power operation. Fig. 2 is the front view of the safety channel which composed of axially three fission chambers. Therefore OPR1000 plant has total twelve fission chambers which axially and azimuthally dispersed at the outside of the reactor vessel.

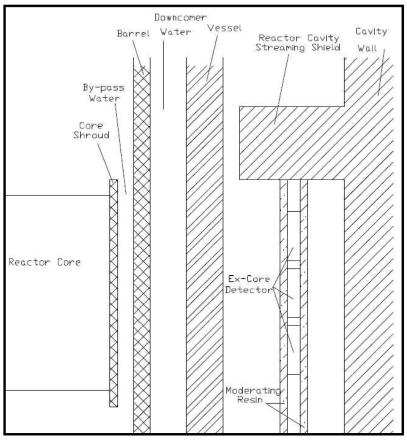

Fig. 2. Axial Locations of the Fission Chamber Ex-core Detectors for OPR1000 Plant

At the low power level of the beginning of cycle, the signal of each fission chamber should be calibrated with the three dimensional core power distribution measured by in-core detectors and with thermal power measured by inlet and outlet coolant temperatures. Generally this ex-core detector calibration process is performed at 30% low power level. Assembly Weighting Factors (AWFs) and Shape Annealing Functions (SAF) are utilized in this calibration process.

2. Methods

2.1 Assembly Weighting Factor

AWF is the normalized response for each fuel assembly power contributed to the ex-core detector signal. For the assemblies close to the ex-core detector, the AWFs of these assemblies are greater than others which are far from the ex-core detector. Generally these AWF values are normalized thus the total sum of the AWFs will be 1.0. Fig. 3 shows the brief concept of AWFs.

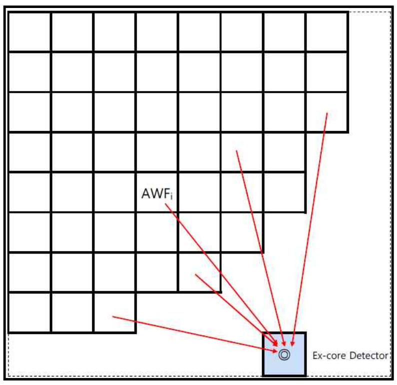

Fig. 3. Brief Concept of Assembly Weighting Factors

AWFs for ex-core detector have been evaluated by adjoint MCNP calculation without considering the rod-by-rod power distributions [4]. Each fuel assembly of OPR1000 reactors has 16x16 fuel rods, and thus the total number of fuel rods is 256. And each assembly has 5 guide tubes for control rod and in-core instrument. Each guide tube occupies an area equivalent to 4 fuel rods. Therefore the total number of active fuel rods in one assembly is 236.

In one fuel assembly, fuel rods have different power distributions; this is rod-by-rod power distributions. If we assume all fuel rod has the same power distribution, this power distribution is so called flat power distribution.

The goal of this paper is to evaluate the effect of the rod-by-rod power distribution to AWFs of the ex-core detector. In order to do that, DORT forward transport calculations were performed with flat power distributions and rod-by-rod power distributions.

2.2 Forward Neutron Transport Calculations

In this paper AWFs for OPR1000 plant were calculated on the basis of forward neutron transport calculations using DORT two-dimensional discrete ordinates code Version 3.2 [2] and BUGLE-96 cross-section library [3]. The BUGLE-96 library provides a 67 group coupled neutron-gamma ray cross-section data set produced specifically for LWR application.

In order to calculate the detector response for each fuel assembly, the assembly power of the interested assembly was set to 1.0 and others were set to 0.0. In this calculation the neutron spectrum at the location of the detector can be calculated and thus the U-235 reaction rate can be derived by multiplying the U-235 fission cross-section to the spectrum. The reason why the U-235 fission cross-section was applied is because the fission chamber is composed of U-235. By one transport calculation we can generate the ex-core detector response for the only one interested assembly, and thus total 52 transport calculations are needed, because the total number of assemblies on the quadrant is 52. However the ex-core detector responses for the interior of the core were very negligible, and thus total 25 assemblies were considered.

Finally the AWF for the i-th assembly was derived by using the following relation:

$$AWF_i = \frac{\text{Reaction Rate of Assembly } i}{\sum_{i=1}^{n} \text{Reaction Rate of Assembly } i}$$

In this paper the effects of rod-by-rod power distributions on the AWFs were also observed. In order to do that, first case was performed with the flat power distributions, and the second case was performed with the realistic rod-by-rod power distributions.

3. Results and Conclusions

Fig. 4 shows the AWFs for the first case which used flat power distributions. In this Figure, "AWF-this" is the results of this paper and "AWF-Ref" means the results of the reference paper [4]. As shown in Fig. 4, the AWFs calculated in this paper are well agreed with the reference paper.

Fig. 5 shows the effects of rod-by-rod power distributions to the AWFs. In this Figure, "AWF-FLAT" means AWFs calculated using flat power distributions, and "AWF-Pin" means AWFs calculated using the realistic rod-by-rod power distributions. From Fig. 5, for the maximum AWF (pink color), the difference between the two cases is about 6.2%. So it is recommended that the realistic rod-by-rod power distributions be considered in AWF calculations.

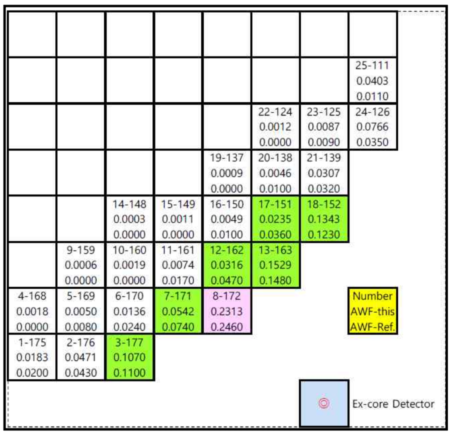

Fig. 4. AWFs for Flat Power Distributions

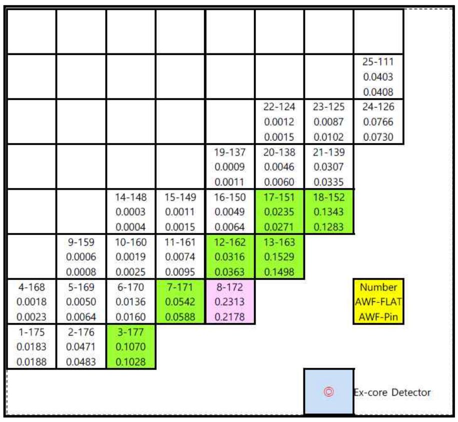

Fig. 5. Effects of Rod-by-Rod Power Distributions to AWF

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