Non-Proprietary

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Validation of MCNP Application on SAF Using Test Results from SKN 1

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ABSTRACT

DORT code had been used as a conventional methodology for the SAF (Shape Annealing Function) calculation before SAF issues were experienced at Shin-Kori Nuclear Power Plant Unit 1 (SKN-1). There was a design change of the ex-core detector system for the first time at SKN-1. In viewpoint of SAF calculation, the shape of the moderator (Resin material) surrounding the ex-core detector was changed and the volume has been reduced to half. For the changed geometry of the ex-core detector for SKN-1, the application of the conventional method using DORT code failed to pass the detector signal error check during startup physics testing. The reason that the conventional method was not fit for the changed ex-core detector design was searched and found. The two-dimensional calculation model could not represent the small and local geometry of the ex-core detector adequately since the DORT code simulates the detector structure simply as annulus, which yields a large discrepancy between real structure and simulated geometry. Before design change, the conventional method could work because the surrounding moderator volume was not so small that the annulus representation of the ex-core detector geometry was acceptable. Therefore an updated methodology using three-dimensional MCNP code which allows a much better representation of the complex geometry was introduced. The application of the updated methodology to the SKN-1 startup test produced improved and acceptable results. The updated methodology was also applied to the conventional nuclear power plants cases and has shown improved results compared to the conventional method by DORT code.

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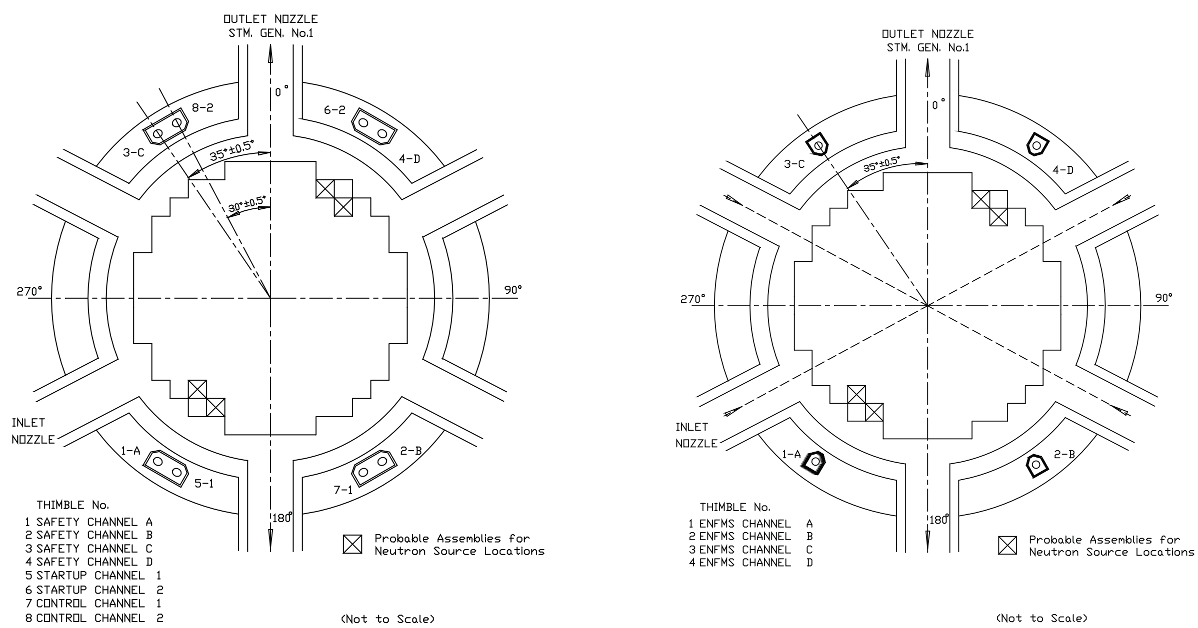
ACRONYMS AND ABBREVIATIONS

APR1400	Advanced Power Reactor 1400
ASI	Axial Shape Index
CECOR	A Code which Synthesizes Three-Dimensional Box and Peak Pin Power Distributions for a Number of In-Core Detector Signals
CPC	Core Protection Calculator
DORT	2-Dimensional Discrete Ordinates Transport Code
ICI	In-Core Instrumentation
KSNP	Korean Standard Nuclear Power Plant[a]
MCNP	3-Dimensional Monte Carlo Transport Code
OPR1000	Optimized Power Reactor 1000
SAF	Shape Annealing Function
SKN-1	Shin-Kori Nuclear Power Plant Unit 1 (OPR1000 Type Plant)
SKN-3	Shin-Kori Nuclear Power Plant Unit 3 (APR1400 Type Plant)

[a] Old name for OPR1000, not used officially but used for convenience in this report

1. INTRODUCTION

There has been a design change of ex-core detector system from KSNP to OPR1000 as shown in Figure 1. In view of the SAF calculation, the configuration of moderator Resin[a] surrounding the ex-core detector has been changed as shown in Figure 2. Even though the conventional DORT [Ref. 1] calculation model[b] approximately simulate the ex-core detector system of KSNP as shown in Figure 3, the calculated SAF works appropriately in the CPC (Core Protection Calculator) system. But for a new design with reduced volume of the moderator Resin, the SAF calculation results using DORT R-Z model fail to pass the test criteria performed during startup physics testing since the calculation model couldn't reflect the smaller and more localized ex-core detector geometry adequately in the calculation model. SAF is sensitive to Resin configuration and three-dimensional (3-D) effects are not fully considered in two-dimensional (2-D) R-Z DORT model. Therefore, 3-D Monte Carlo calculation code MCNP [Ref. 2] was proposed to reduce the geometry modeling error. Figure 4 shows 3-D MCNP model for SAF calculation for OPR1000.



KSNP OPR1000

Figure 1 Layout of Ex-core Detectors for KSNP and OPR1000

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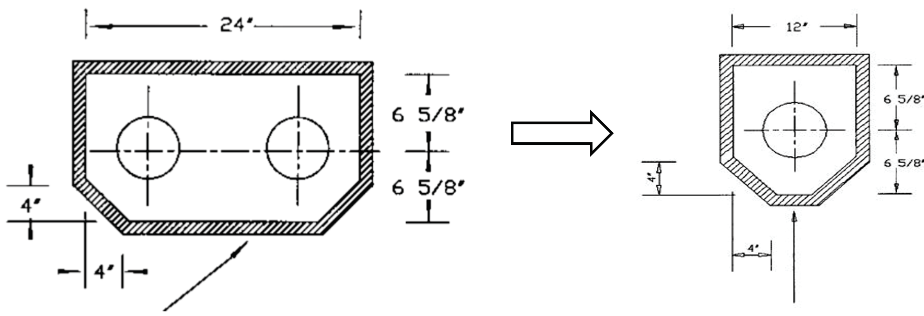
[a] The real geometry of the ex-core detector system has the cylindrical shape of the detector assembly and hexagonal shape of the surrounding moderator which are localized in the reactor cavity region. The surrounding moderator, called Resin, is used to enhance the detector efficiency by slowing down incident neutron energy to the thermal energy range.

[b] For SAF calculation using DORT code, the reactor components and ex-core detector system have to be modeled in R-Z coordinates. Therefore, the DORT code can only approximately model the ex-core detector system as a few concentric annuli centered on the reactor core center as shown in Figure 3.



KSNP Ex-core Detector

OPR1000 Ex-core Detector

Figure 2 Design Change of Ex-core Detector System

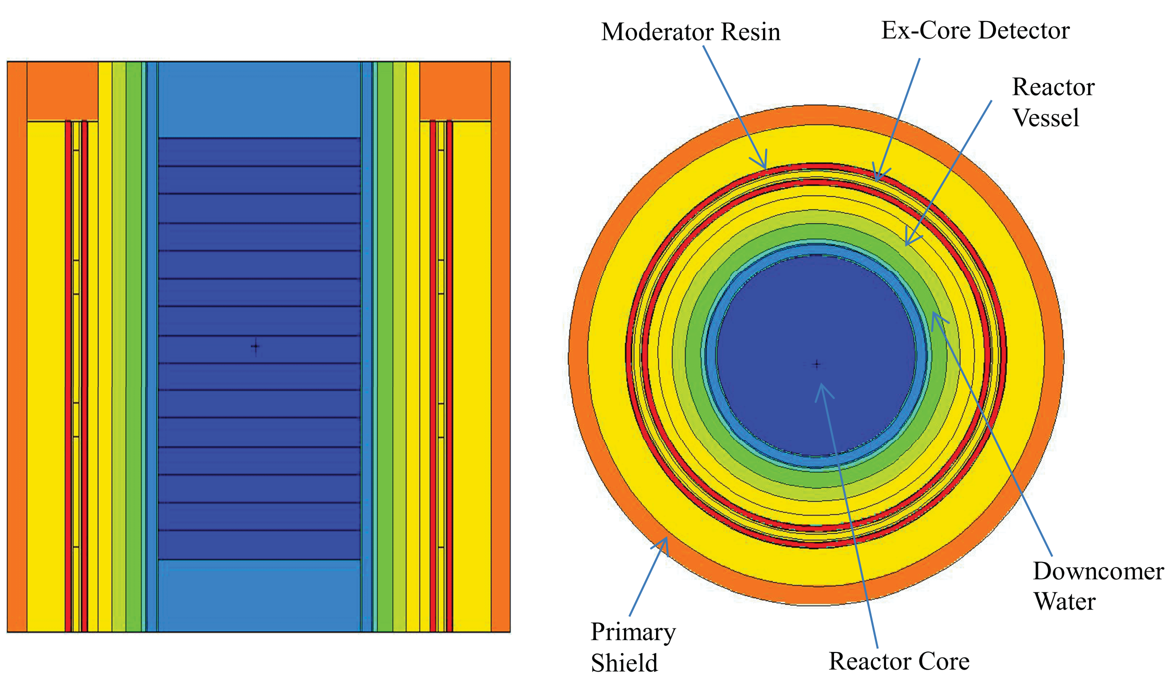


Figure 3 DORT R-Z Model (2-D) for SAF Calculation

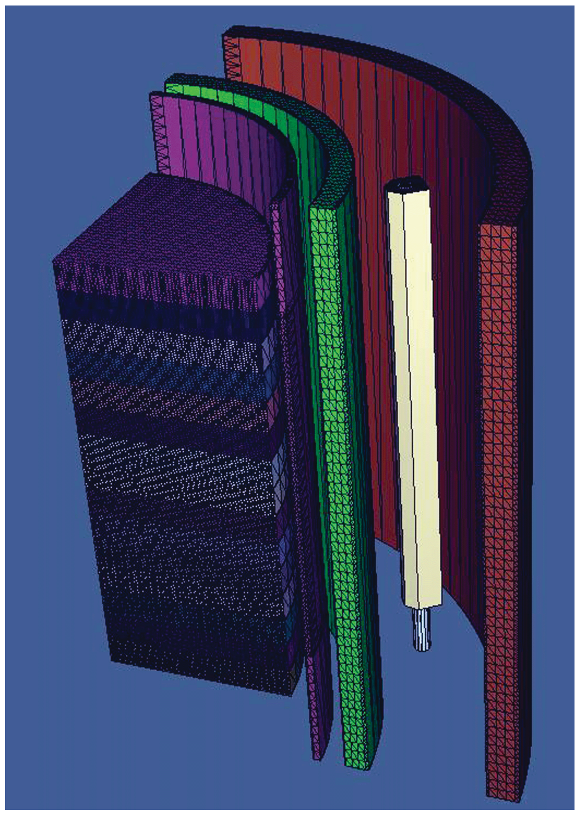


Figure 4 MCNP Model (3-D) for SAF Calculation

2. SAF CALCULATION

The MCNP 3-D effects in the SAF calculation [Ref. 3] are shown in Figure 5 which compares the SAFs obtained from 2-D DORT model and 3-D MCNP model for SKN-1 reactor (OPR1000). Figure 6 shows SAFs obtained from DORT and MCNP calculations [Ref. 3] for the ex-core detector system of KSNP. As shown in Figure 6, the differences are not as big as those of the OPR1000 cases. Figure 6 explains why the conventional method for SAF calculation could work for KSNP even though the SAF was obtained from rough modeling by DORT code. Additional calculations have been performed to compare the 2-D simulation of MCNP calculation with the conventional 2-D DORT calculation by setting up all the geometries in the MCNP model as R-Z cylinders. The calculation results [Ref. 3] are shown in Figure 7 and the two calculation models yield almost the same results.

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Figure 5 SAFs from 3-D MCNP and 2-D DORT Calculations for OPR1000

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Figure 6 SAFs from 3-D MCNP and 2-D DORT Calculations for KSNP

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Figure 7 SAFs from 2-D simulation of MCNP Model and Conventional DORT Model

3. SKN-1 STARTUP TEST RESULTS

The SAF issues had been experienced at SKN-1 (OPR1000) and changes to the SAF calculation methodology were made in order to improve the accuracy of the SAF used in startup physics testing. The updated methodology was based on the use of the three-dimensional MCNP Monte Carlo code in place of the two-dimensional DORT discrete ordinates code to simulate the reactor geometry. The use of the three-dimensional methodology allows a much better representation of the complex geometry of the reactor cavity area. The application of the updated methodology to the SKN-1 startup test produced improved and acceptable results. The methodology is now planned for startup tests at SKN-3 (APR1400) and beyond.

Figures 8 ~ 10 show the ex-core detector signal errors[a] obtained during the startup test for SKN-1 using SAFs from DORT and MCNP calculations [Ref. 3]. The green and red dots in the Figures represent detector signal errors using SAF from MCNP calculations tested on different days while the black dots represent the detector signal errors using SAF from conventional 2-D DORT calculations. As shown in the Figures, the test results using SAF from MCNP calculations are well within the test criteria (< ±6% for bottom and top detectors, < ±4 % for middle detector).

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Figure 8 Ex-core Detector Signal Errors for SKN-1: Bottom Detector

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[a] $E_i = \frac{D_i^M - D_i^{CECOR}}{D_i^{CECOR}} \times 100,$

where

E_i= top, middle or bottom ex-core detector error

D_i^M= measured ex-core signal fraction

D_i^{CECOR}= CECOR synthesized ex-core detector fraction (ICI measurement × SAF× other factors)

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Figure 9 Ex-core Detector Signal Errors for SKN-1: Middle Detector

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Figure 10 Ex-core Detector Signal Errors for SKN-1: Top Detector

4. CONCLUSION

The SAF calculation results as shown in Figures 5 ~ 7 explain that using two-dimensional DORT code for the geometry which has small and localized structures is improper for the SAF calculation since the ex-core detector of OPR1000 cannot be represented adequately by R-Z DORT model. Therefore, a three-dimensional MCNP code was introduced to utilize the capability of describing complex geometry for the calculation of SAF. As a consequence, the updated methodology using MCNP code not only has yielded acceptable results for the test criteria but also has shown greatly improved accuracy compared to the conventional method using DORT code as shown in Figures 8 ~ 10. The successful applications of the updated methodology using MCNP code to KSNP cases are referred to Reference 3.

REFERENCES

1. "MCNP-A General Monte Carlo N-Particle Transport Code, Version 5-1.51," Los Alamos National Laboratory, LA-UR-09-00384, January 2009.

2. CCC-650/DOORS3.2a, "One-, Two- and Three Dimensional Discrete Ordinates Neutron/Photon Transport Code System," Oak Ridge National Laboratory, October 2003.

3. "Submit of Final Evaluation Report for Shape Annealing Function for Shin Kori Unit 1," SRD/KK- 100051M, KEPCO E&C, November, 2010.