Benchmark Analysis of KALIMER-600 Simplified Core Model by Using ECCO/ERANOS2.1 System

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1. Introduction

KAERI(Korea Atomic Energy Research Institute) has been developed Gen-IV sodium cooled fast reactor. One of the recent achievements of the development is the design of KALIMER-600[1], which has also been selected as the Gen-IV reference core design with JSFR(Japanese Sodium-cooled Fast Reactor, Japan).

KAERI has collaborated with CEA Cadarache on the sodium cooled fast reactor core design and analysis since 2005. In this context, KAERI introduced the CEA core analysis system called as ECCO/ERANOS2.1[2] to support the KAERI calculation system (K-CORE) as a backup. The ECCO/ERANOS2.1 system has known as a reliable calculation system for MOX fueled SFR core through the experiences of Phenix and Super-Phenix and has been also validated for the metallic fueled critical assemblies of BFS-73-1, BFS-75-1[3].

This paper describes the results of analysis for the KALIMER-600 breakeven core and provides directions of further improvement of KAERI code system.

2. Methods and Results

2.1 Simplified KALIMER-600 Model

The KALIMER-600 has been designed as an equilibrium state, so that the atomic number density is different throughout all the fuel subassemblies. So as to avoid this unnecessary complication of the region-wise assignment of the composition, the atomic number densities are averaged over the region. The simplified KALIMER-600 breakeven core model has three regions having difference atomic number density as shown in Fig. 1. The brief descriptions of the KALIMER-600 operation conditions and dimensions are listed in Table I.

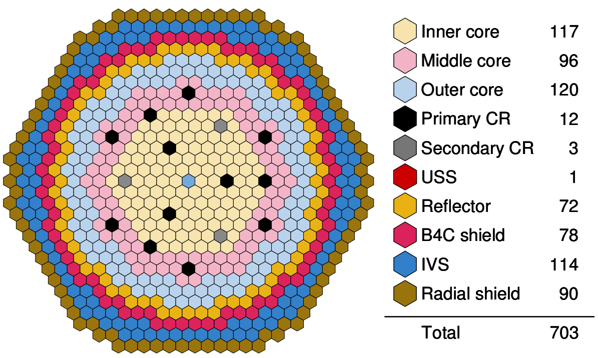

Fig. 1. Radial layout of KALIMER-600 core

All the fission products are removed from the composition to keep the consistency between ECCO/ERANOS and K-CORE system by removing the differences in the fission product depletion model between two code systems.

Table I: KALIMER-600 Description

Core power [MWt/MWe]	1523.4/600.0
Cycle length [EFPD]	540
Number of refueling batch	4
Active core height [cm]	94
Charged fuel	Self recycled
Fuel type	U-TRU-10%Zr
Assembly pitch [cm]	18.7
Number of fuel pins in an assembly	271
Fuel rod diameter [cm]	0.9
P/D ratio	1.167
Moderator region height [cm]	14.9

2.2 Calculation Methods

The calculations with ECCO/ERANOS2.1 system is mainly based on the VARIANT nodal transport solution (Simplified P3 approximation) with Hex-Z geometrical approximation. The VARIANT version 9 has been implemented into the ERANOS2.1 packages. In parallel with the VARIANT calculation, the BISTRO S_N transport solution for R-Z or X-Y geometry has been used for treating the control rod heterogeneity effect, and so on.

The DIF3D nodal diffusion solution has been used as the results of K-CORE calculations with the effective cross sections generated from the TRANSX/TWODANT system. The TWODANT code is also used for the correction of transport effect by comparing the results with those of DIF3D in R-Z geometry.

The multigroup neutron cross section libraries derived from the JEFF-3.1 are used for the analysis since the JEFF-3.1 is included in both code systems. The ECCO/ERANOS2.1 system uses 33-group cross section collapsed from the 1968-group cross section while 25-group neutron library is used for the K-CORE calculation collapsed from 150-group MATXS library.

The basic comparison is carried out with the calculation results from the homogeneous configuration of fuel subassemblies, but the heterogeneous configuration is used for the specific cases such as control rod heterogeneity effect evaluation.

2.3 Calculation Results

The calculation results of K-CORE and ERANOS2.1 system are listed in Table II with comparison. The results show a good agreement in the most parameters, however, the axial expansion coefficient shows relatively large discrepancy more than 7%. This is supposed to result from the immature treatment of radial leakage at the core boundary. Only a flat flux approximation at the radial boundary is available for the Hex-Z geometry in the DIF3D code. This effect does not significantly affect on the radial expansion coefficient because the change of the radial leakage is only dominant in the axial expansion.

Table II: Summary of Benchmark Analysis Results

	ERANOS	K-CORE	Diff.[a)]
Burnup reactivity swing [pcm]	546.0	661.9	115.9
BOC k-effective	1.00244	1.00111	-0.00133
Conversion ratio	0.997	0.998	0.13%
Relative radial power			2.75%
β-effective [pcm]	361.3	351.0	2.9%
Sodium void reactivity [$]			
BOC	7.6	7.4	-0.2$
EOC	7.4	7.2	-0.2$
Control rod worth at BOC [pcm]			
Primary	5384	5401	0.3%
Secondary	2096	2017	-4.1%
Expansion reactivity coefficient at BOC			
Radial [pcm/°C]	-0.580	-0.597	2.87%
Axial [pcm/%]	-76.94	-83.09	7.40%

[a)] The difference means (K-CORE – ERANOS)

The control rod heterogeneity effect has been often reported in the sodium cooled fast reactor analysis. The homogeneous configuration of the control rod tends to overestimate the control rod worth. The amount of overestimation depends on the degree of spatial self shielding effect influenced by the control rod dimension, the absorber strength, and the adjacent fuel subassembly.

The control rod heterogeneity effect is evaluated by using reactivity equivalent control rod homogenization technique implemented into the ERANOS2.1 system[4]. The control assembly is described as either 2-D X-Y representation or cylindrical 1-D model with adjacent fuel assembly. The calculations are carried out with homogeneous and approximated heterogeneous configurations. Finally, the control rod cross section is adjusted iteratively to reproduce the control rod worth of the heterogeneous configuration.

Table III: Control Rod Heterogeneity Effect on Rod Worth

Type.	Homo. [pcm]	Model	Hetero. [pcm]	Relative Diff.[a)] [%]
Primary	5384	1-D	4920	-9.4
		2-D	4992	-7.9
Secondary	2096	1-D	1874	-11.9
		2-D	1872	-12.0

[a)] Relative difference=(Homo-Hetero)/Hetero.*100 [%]

The results of the control rod heterogeneity effect evaluation are listed in Table III. It should be noticed that the control rod worth in homogeneous configuration tends to overestimate the rod worth as around 8% for primary control system and 12% for secondary system of KALIMER-600 control rod design.

It can be also found that the simplified cylindrical 1-D model is very efficient for evaluating the heterogeneity effect. The 1-D model could also evaluate control rod heterogeneity effect appropriately with reduced calculation time.

3. Conclusions

The simplified KALIMER-600 model has been analyzed by both KAERI and CEA calculation systems. The results by both systems are in a good agreement except for the axial expansion coefficient.

The control rod heterogeneity effect for the KALIMER-600 design is evaluated to be 8~12%. Then, the methodological improvement for KAERI calculation system should be toward high order treatment of radial leakage in the nodal solution and the development of appropriate method for the control rod worth evaluation.

Acknowledgement

This study was supported by Ministry of Education, Science Technology (MEST) in Korea. Author appreciates to Dr. Robert Jacqmin of CEA Cadarache for their helpful suggestions and discussions on using ECCO/ERANOS2.1 system.

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