Analysis of Metallic Uranium Fueled BFS Critical Assemblies with the ECCO/ERANOS2.1 Code System

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1. Introduction

As part of a collaboration between KAERI and CEA France, the fast reactor neutronics analysis system, ECCO/ERANOS-2.1[1], developed by CEA has been used by KAERI to study the properties of metallic fueled fast reactor cores. This code system has been extensively validated for sodium-cooled mixed oxide cores, in particular through the analysis of many experiments and the operating experience of the Phenix and Super Phenix power reactors. However, it has not been validated for metallic fueled cores with a harder neutron spectrum.

The main purpose of this study is to analyze the metallic uranium fueled BFS-73-1 and -75-1 experiments with ECCO/ERANOS-2.1 in order to evaluate the applicability of the code to a future Sodium Cooled Fast Reactor core design.

2. The BFS-73-1 and BFS-75-1 experiments

The BFS-73-1 and –75-1 experiments had been carried out in 1997 (2004 for MA reaction rate ratio) and 1999 as the mock-up of the early phase of a metallic uranium fueled KALIMER-150 core design. The average uranium enrichment of the experiment is 18.5wt% for both experiments while the uranium of BFS-75-1 was split into two zones (15wt% and 20wt%). The unit fuel cell of BFS-75-1 has a more heterogeneous configuration than that of BFS-73-1 because the height of the unit fuel cell is double and the medium (36wt%) and highly enriched (90wt%) uranium disks are placed in the fuel cell.

3. Calculation Methods

The ECCO/ERANOS-2.1 system mainly consists of nuclear data libraries, effective multi-group cross section generation modules, diffusion and transport codes, and a large set of calculation procedures, including sensitivity and perturbation analysis procedures. The ERANOS-2.1 system contains several nuclear data libraries derived from the JEFF-3.1, JEF-2.2, and ENDF/B-VI.8 nuclear data files, as well as a JEF-2.2-based adjusted library, ERALIB1. Each cross section library is available in a fine-group structure (1968 groups).

Typical core calculations use 33-group effective cross sections generated by the ECCO lattice code, starting from one of the above 1968-group libraries. The sub-group method is used for a resonance shelf-shielding, in combination with the collision probability method for the lattice flux calculation. Various geometrical descriptions are available in the ECCO module: homogeneous, 1-D (cylinder, plane) and 2-D (slab, plate, hexagonal, rectangular lattice and hexagonal lattice).

Core calculations may be performed by using either diffusion or S_N transport (BISTRO), or variational nodal transport method (VARIANT) for 1-D, 2-D and 3-D geometries. In the present study, we made use of the BISTRO P_1S_8 transport module for the core calculations, with effective cross sections generated from the heterogeneous unit fuel cell model in ECCO.

4. Results and discussion

4.1 k-effective

The calculated-vs.-experimental (C/E) values of the k-effective are listed in Table I for each nuclear library used. The calculated k-effective is in good agreement with the measured value within 300 pcm when JEFF-3.1 library is used. The heterogeneity effect is also calculated by comparing the k-effective between the results for the homogeneous and heterogeneous configurations. The results (119 pcm for BFS-73-1, 548 pcm for BFS-75-1) agree well with those obtained with two other calculation systems by IPPE (~150 pcm for BFS-73-1) and KAERI (~615 pcm for BFS-75-1).

Through the perturbation analysis, it is found that the different results between JEFF-3.1 and JEF-2.2 mainly arise from the difference in the U-235 nu-fission cross sections in the neutron energy range of 10 keV to 2 MeV, U-238 inelastic cross sections and sodium scattering cross sections. These are also consistent with the result of the other validations[2] and with the revision of the sodium cross section in JEFF-3.1[3].

4.2 Spectral Indices and Reaction Rate Ratios

The C/E values of the spectral indices and relative reaction rate ratios are listed in Table II. The results of the spectral indices (F49/F25, F28/F25 and C28/F49) show a reasonable agreement with the measured values within 4.8% for both the BFS-73-1 and –75-1 critical assemblies. The accuracy of the reaction rate ratio of Np-237 is significantly improved when the JEFF-3.1 nuclear data library is used. However, the calculated reaction rate ratios of Am-243, and Pu-238 show large discrepancies with the measured values.

4.3 Control Rod Worth

Table III shows the C/E values for the control rod worths for each control rod location and type. The control rod location 7 represents the core center, the types of 1 to 6 denote symmetric positions at the sixth hexagonal ring. As listed in the table, all the calculated control rod worth agree well with the measured value within 5% regardless of the nuclear data libraries used.

4.4 Sodium Void Reactivity

Table IV shows the C/E values of sodium void reactivity with different nuclear libraries. The JEFF-3.1 library shows the best result for the sodium void reactivity among them. Except when the JEFF-3.1 library is used, the calculation largely underestimates the sodium void reactivity to be less negative.

The difference in the sodium void reactivity between JEFF-3.1 and JEF-2.2 mainly comes from the difference in the sodium scattering cross section, which occupies about 50% of the reactivity difference.

5. Conclusions

The performance of the ECCO/ERANOS2.1 system has been assessed for two metallic uranium fueled critical assemblies. Through the analysis of the k-effective, spectral indices, control rod worth and sodium void reactivity worth, it could be concluded that the ERANOS2.1 system is applicable to a metallic fueled core with a good accuracy. Although the microscopic cross section ratios for a few minor actinides (Am-243 and Pu-238) show relatively large discrepancies, their impacts on the core neutronic performance will not be significant because the total amount of these nuclide is very small in a typical TRU burner cores of which TRU enrichment is less than 30wt%.

Acknowledgement

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

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Table I C/E values of k-effective

	JEFF-3.1	ENDF/B-VI.8	JEF-2.2	ERALIB1
BFS-73-1	0.99744	0.99728	1.00336	0.99707
BFS-75-1	0.99921	1.00384	1.00883	1.00422

Table II C/E values of spectral index and reaction rate ratio

	Uncertainty (1σ) [%]	JEFF-3.1	ENDF/B-VI.8	JEF-2.2	ERALIB1
BFS-73-1					
F49/F25[1)]	1.345	0.992	0.996	0.984	1.004
F28/F25	1.377	0.962	1.012	0.997	0.997
C28/F49	1.596	0.952	0.941	0.966	0.953
F37/F49	3.346	0.958	0.982	0.918	0.933
C37/F49	4.579	0.965	1.018	1.060	1.032
F51/F49	3.947	0.901	0.961	0.891	0.902
F53/F49	4.571	0.863	0.924	0.928	0.939
BFS-75-1					
F49/F25	1.170	1.004	1.009	0.996	1.013
F28/F25	1.563	0.995	1.076	1.055	1.038
C28/F49	1.639	0.962	0.954	0.966	0.978
F37/F49	1.987	1.001	1.038	0.961	0.963
F51/F49	3.486	0.967	1.052	0.964	0.963
F53/F49	4.294	0.759	0.829	0.829	0.828
F48/F49	1.275	1.174	1.156	1.139	1.134
F64/F49	1.524	0.940	1.010	0.967	0.969
F40/F49	2.271	1.045	1.092	1.030	0.998

[1)] XYZ/XYZ: X=reaction type (F=fission, C=capture),
Y=last digit of atomic number
Z=last digit of mass number

Table III C/E values of control rod worth in BFS-75-1

Cases[1)]	1σ [%]	JEFF-3.1	ENDF/B-VI.8	JEF-2.2	ERALIB1
CR123456TY5	0.393	1.011	1.001	1.012	1.013
CR135TY5	0.465	1.010	1.000	1.012	1.013
CR14TY5	0.495	0.998	0.990	1.001	1.003
CR1TY5	0.613	1.029	1.019	1.031	1.032
CR7TY2	5.000	0.951	0.967	0.957	0.957
CR7TY3	0.806	1.047	1.015	1.032	1.035
CR7TY4	2.062	0.962	0.944	0.972	0.969
CR7TY5	2.632	0.984	0.972	0.981	0.978
CR8TY1	2.041	1.018	0.993	1.023	1.022

[1)] Case name represents control rod location and type, e.g., C14TY5 represents control rod type 5 at the location 1 and 4

Table IV C/E of sodium void reactivity worth for BFS-75-1 (1σ uncertainty=1.3%)

	C/E	Difference with JEFF-3.1 [pcm]
JEFF-3.1	1.045	-
ENDF/B-VI.8	0.890	-51.99
JEF-2.2	0.924	-40.54
ERALIB1	0.833	-71.14