Analyses of the ZPPR-15A Critical Experiments with ENDF/B-V.2 and –VII.0 Data

Sang Ji Kim[a*], Changho Lee[b], Won Sik Yang[b], Yeong-il Kim[a]
[a]*Korea Atomic Energy Research Institute, 1045 Daedeog-Daero, Yuseong-gu, 305-353 Daejeon, Korea*
[b]*Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, Il 60439, U.S.A.*
[*]*Corresponding author: sjkim3@kaeri.re.kr*

1. Introduction

This paper presents the analysis results for the ZPPR-15A critical experiments. Using the ENDF/B-V.2 and ENDF/B-VII.0 data, three loading configurations of the ZPPR-15 Phase A experiments were analyzed with the ANL code suite for a fast reactor neutronics analysis, including the recently updated MC^2-2 code.

VIM Monte Carlo [1] analyses with 3-D as-built models were at first performed to serve as basic models for the production of deterministic models. For deterministic calculations, composition and region dependent multi-group cross sections were generated using the ETOE-2/MC^2-2/SDX code system [2]. Core calculations were performed with the TWODANT discrete ordinate transport code.

The purpose of this effort is to validate the neutronics design tools and nuclear data for fast reactor analyses against previous critical experiments.

2. Description of ZPPR-15 Critical Experiments

The ZPPR-15 experiments were conducted in four phases from April 1985 through July 1986 under the Integral Fast Reactor Benchmark Physics Test Program [3]. The focus of the program was to provide experimental support for core designs using U-Pu-Zr metallic alloy fuel. The basis for the critical assembly was a 330 MWe sodium-cooled fast reactor. Phase A was a clean physics assembly containing only plutonium, depleted uranium, stainless steel and sodium without zirconium. Tests included diverse reactor physics measurements such as criticality, void worth, region-wise spectral indices, reaction rates, control rod worth, and reactivity coefficients.

In this study, three loading configurations of the ZPPR-15 Phase A experiments were analyzed: the initial criticality configuration (loading 15), a reference configuration for sodium void worth measurement (loading 16), and a configuration with an 18-inch sodium void in a part of the inner core (loading 20).

3. Core Model and Analysis Results

3.1 As-built Monte Carlo Model Development

VIM Monte Carlo models were set up using the as-built data found from the reactor loading records and drawer master information. This implies that there is no geometric approximation in describing the assembly in the VIM model, assuming that every single plate is fully described as it was in the assembly. The as-built Monte Carlo model provided homogenized region number densities over each unit cell for deterministic calculations and became a base model for plate heterogeneity effect evaluation.

As aforementioned, three core configurations of ZPPR-15A were analyzed. In the loading 16, eight double-fuel-column drawers in the outer core region were replaced with single-fuel-column drawers (inner core fuel) to reduce the core k_{eff} before sodium voiding. After a successive replacement of less voided drawers with more voided drawers, the loading 20 achieved an 18 inch axial voiding in each half of the core for a part of the inner core region.

Fig. 1 shows a planar layout of the ZPPR-15A loading 20 that has evolved from the loading 15 of the reference critical configuration. In the figure, the section coloured in yellow or gray was voided for 18 inches, extending from the core mid-plane, except for the detector subassemblies. Fig. 2 shows a schematic diagram for the radial and axial arrangements.

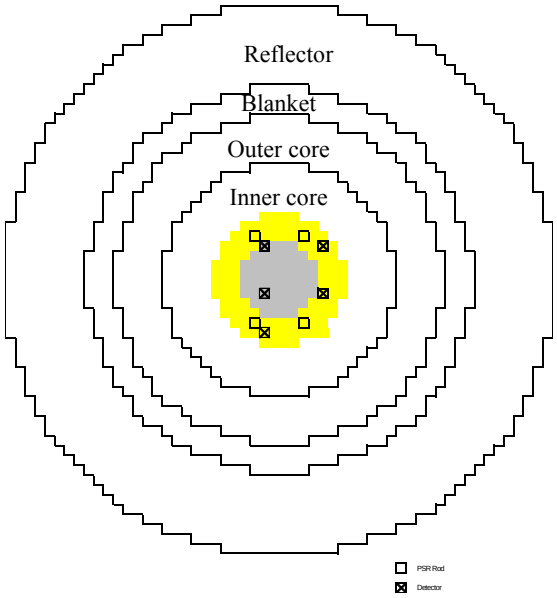

Fig. 1. Planar configuration of ZPPR-15A loading 20

3.2 3-D calculation results

Table I presents the core multiplication factors determined with the ENDF/B-V.2 and ENDF/B-VII.0 data. The experimental uncertainties are not precisely evaluated and therefore the experimental uncertainties of 180 pcm could be assumed which was identified as the maximum experimental uncertainty for the ZPPR-21 [4].

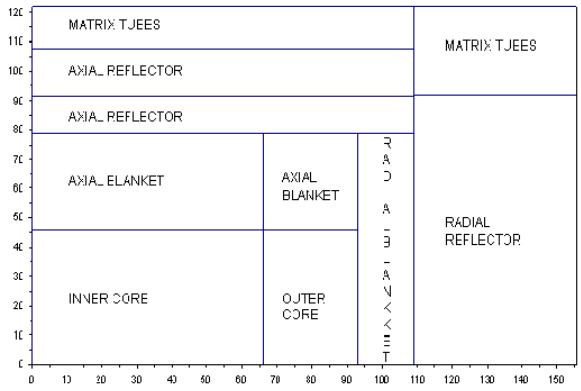

Fig. 2. RZ dimensions of ZPPR-15A loading 15 [cm]

The maximum standard deviation for all the Monte Carlo calculations performed is less than 15 pcm. It is shown that the VIM Monte Carlo solutions obtained with ENDF/B-V.2 data underestimate the experimental k_{eff} values; 399 pcm Δk for the loading 15, 427 pcm Δk for the loading 16, and 324 pcm Δk for the loading 20. With ENDF/B-VII.0 data, the multiplication factors are improved significantly, being increased by 307 pcm on average toward the measured values.

DIF3D nodal transport solutions with ENDF/B-V.2 data shown in Table I agree well with the VIM solutions within 122 pcm Δk. The sodium void worths determined from VIM Monte Carlo and DIF3D nodal transport calculations are also very close to each other: 0.329 vs. 0.324 %Δk.

The DIF3D solutions obtained with the ENDF/B-VII.0 data show relatively large deviations from VIM results, up to 393 pcm. While VIM multiplication factors are increased significantly when the cross section libraries are changed from ENDF/B-V.2 to ENDF/B-VII.0, DIF3D solutions show much smaller changes. The main reason for the deficiency of DIF3D solutions with ENDF/B-VII.0 data is attributed to the generalized analytic integral formulation of the SDX code, which is not sufficiently accurate for treating the significantly increased resolved resonances of ENDF/B-VII.0 relative to ENDF/B-V.2.

4. Conclusions

VIM Monte Carlo analyses with 3-D as-built models showed that the ENDF/B-VII.0 dada significantly improved the core multiplication factors and void worth, relative to the ENDF/B-V.2 data. With the ENDF/B-VII.0 libraries, the deviation in the core multiplication factor was reduced to a maximum of 0.11 %Δk and that of the sodium void worth was reduced to ~24%.

In conclusion, the results of the present study indicate that the MC2-2/SDX methods are adequate for generating the multigroup cross sections for a fast reactor analysis, but the SDX process to account for the heterogeneity effect needs to be improved for an accurate treatment of the significantly increased resolved resonances of the ENDF/B-VII.0 data.

Acknowledgement

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Table I: Multiplication factors of the three core loadings of ZPPR-15A

Loading	Experiment	Library	VIM*	VIM – Exp. [pcm Δk]	DIF3D	DIF3D – VIM [pcm Δk]
15	1.00046	ENDF/B-V.2	0.99647	-399	0.99525	-122
16	0.99627		0.99200	-427	0.99104	-96
20	0.99853		0.99529	-324	0.99428	-101
15	1.00046	ENDF/B-VII.0	0.99985	-61	0.99593	-392
16	0.99627		0.99571	-56	0.99178	-393
20	0.99853		0.99742	-111	0.99426	-316

* Standard deviation ≤ 0.00015