Effect of Drawer Master Modeling of ZPPR15 Phase A Reactor Physics Experiment on Integral Parameter

Jaewoon Yoo*, Sang-Ji Kim
Korea Atomic Energy Research Institute, 1045 Daedeog-daero, Yuseong, Daejeon 305-353
**Corresponding author: jwyoo@kaeri.re.kr*

1. Introduction

As a part of an International-Nuclear Engineering Research Initiative (I-NERI) Project, KAERI and ANL are analyzing the ZPPR-15 reactor physics experiments [1]. The ZPPR-15 experiments were carried out in support of the Integral Fast Reactor (IFR) project.

Because of lack of the experimental data, verifying and validating the core neutronics analysis code for metal fueled sodium cooled fast reactors (SFR) has been one of the big concerns. KAERI is developing the metal fuel loaded SFR and plans to construct the demonstration SFR by around 2028. Database built through this project and its result of analysis will play an important role in validating the SFR neutronics characteristics.

As the first year work of I-NERI project, KAERI analyzed ZPPR-15 Phase A experiment among four phases (Phase A to D). The effect of a drawer master modeling on the integral parameter was investigated. The approximated benchmark configurations for each loading were constructed to be used for validating a deterministic code

2. Methods and Results

2.1 Effect of drawer modeling on integral parameter

In order to develop a benchmark configuration of each ZPPR-15 Phase A loading, an effect of drawer master modeling on the integral parameter was investigated by using MCNP5 code and by analyzing various configurations of a drawer master. The drawer models consist of one reference 3-dimensional configuration, two 2-dimensional configurations, three 1-dimensional configurations, and finally complete homogeneous model. All the models were constructed separately for each axially distinct region such as core and axial blanket.

Two 1-dimensional configurations, the 1D Case1 and Case2, do not conform to the original plate order and location. In the 1D Case1, the matrix tube and drawer are placed in both sides of the model while those are in the near center of the model in the 1D Case2. The fuel and sodium covers, matrix tube, drawer, and void regions are treated as separate region and the thickness of each plate in the model is adjusted to preserve total plate volume.

Table I show the results of k_{inf} values calculated with various configurations of drawer masters 102. The result of 2D X-Y model is very close to that of the reference 3D as-built configuration. It implies that the heterogeneity effect arising from the material discontinuity to z-direction is not significant. This can be also seen between 1D and 2D Z-X models. However, the 2D Z-X model underestimates k_{inf} by 143 pcm Δk. Main difference between two models are from the way of homogenizing the matrix tube, drawer and void gaps. The matrix tube and drawer are relatively thicker than other cover regions. Only a small portion of fuel and sodium covers was homogenized into the corresponding plate in the 2D X-Y model, while relatively thick matrix tube and drawer were homogenized into the plate in the 2D Z-X model. As results, their homogenization make neutron slowing down and neutron streaming smaller.

Table I: Effect of drawer modeling on k_{inf}
(drawer master 201 outer core drawer master)

Model	k_{inf}	Diff. [pcm Δk]
3D	1.66242±0.00013	-
2D X-Y	1.66211±0.00013	-31±18
2D Z-X	1.66099±0.00013	-143±18
1D	1.66055±0.00012	-187±18
1D Case1	1.66255±0.00013	13±18
1D Case2	1.66146±0.00013	-96±18
0D	1.65155±0.00012	-1087±18

The 1D Case1 models yield better results than that of 1D model. The results of the 1-dimensional models of drawer master 103 representing inner core regions show the similar trend to those of drawer master 201.

The axial blanket regions of the drawer master 103 and 201 were also analyzed using various drawer homogenization methods. The 2D Z-X and 1D Case2 models were excluded in the analyses because of their poor accuracy in the previous analysis and inconsistency with axial blanket region. The matrix tube, drawer, and void region must have discontinuity between the core and axial blanket regions if different models are applied to core and blanket regions, separately. The axial blanket model contains the adjacent core model to examine the interface effect between core and blanket region.

Table II show the variation of multiplication factors with respect to the combinations of the core and axial blanket models. As shown in the table, the difference in the blanket models does not make significant impact on the multiplication factors when the 3D model is used for core region. However, the change of core model makes a considerable difference in the multiplication factor even with the same blanket model. 2D X-Y and 1D Case models underestimate the multiplication factors by about 228, 219 pcm Δk respectively. The completely homogenous drawer model (0D model) of axial blanket overestimates the multiplication factor by

221 pcm Δk. Similar trends were observed for the drawer master 103 axial blanket model.

Table II: Effect of drawer modeling on k_{eff} (drawer master 201axial blanket)

Core model	Blanket model	k_{eff}	Diff [pcm Δk]
3D	3D	1.44718±0.00016	-
3D	2D X-Y	1.44739±0.00016	21±23
3D	1D	1.44745±0.00016	27±23
3D	1D Case1	1.44716±0.00015	-2±22
3D	0D	1.44939±0.00016	221±23
2D X-Y	2D X-Y	1.44490±0.00016	-228±23
1D Case1	1D Case1	1.44499±0.00016	-219±23

The radial blanket was modeled as similar way as done for the axial blanket. The configuration for the analysis of the radial blanket includes the outer core model adjacent to the radial blanket. Five drawer master 201s representing the outer core were included in the radial blanket model. The core model placed in the radial blanket model also contains the axial blanket of the drawer master 201.

Table III: Effect of drawer modeling on k_{eff} (drawer master 201radial blanket)

Core model	Blanket model	k_{eff}	Diff [pcm Δk]
3D	3D	1.04297±0.00016	-
3D	2D X-Y	1.04365±0.00018	68±24
3D	1D	1.04407±0.00017	110±23
3D	1D Case1	1.04377±0.00016	80±23
3D	0D	1.04415±0.00016	118±23
2D X-Y	2D X-Y	1.04042±0.00017	-255±23
1D Case1	1D Case1	1.04219±0.00016	-78±23

Table III shows the calculated results of k_{eff} with different drawer models. The variation of blanket model does not make significant changes in the multiplication factor, even in the 0-D model. 2D X-Y core model combined with 2D X-Y blanket model results in a little bit large underestimation. The reason comes from the interface effect between core and axial blanket of the drawer master 201 as shown in Table II rather than that of radial blanket. It appears that there is an offset in 1D Case1 model for both core and blanket region. The interface effect between core and radial blanket was cancelled out by the effect between the core and axial blanket of the drawer master 201.

2.2 Full core modeling of ZPPR-15 experiments and analyses

The analyses of full core model of ZPPR-15 Phase A experiments were carried out with three different drawer models. One is the as-built model of the experiment, another is the 1D Case1 model as analyzed in the previous section, and the other is complete homogeneous model of the drawer master. In the 1D Case1 model, the radial reflector drawer masters and axial reflector region located behind the axial blanket of the drawer masters of core and blanket were modeled as homogeneous regions. The radial blanket was modeled as similar way as done for the axial blanket.

Table IV shows the results of k_{eff}'s with different drawer models. The 1D Case1 model underestimates the k_{eff}'s of ZPPR-15 loading 15 through loading 28 by around 250 pcm Δk and the difference were maintained as almost constant throughout the loadings within 30 pcm Δk. This is because only several detector drawer masters and the central drawer masters acting as the control rods are changed.

Table IV: k_{eff} for full core model of ZPPR-15A experiments with different drawer models

No	Model	k_{eff}	Diff, pcm Δk[a)]
15	Exp.	1.00045 -	-
	As-built	0.99904±0.00002	-141±2
	1D Case1	0.99659±0.00014	-245±14
	Homo.	0.98259±0.00013	-1645±13
25	Exp.	0.99930 -	-
	As-built	0.99783±0.00014	-147±14
	1D Case1	0.99538±0.00014	-245±20
	Homo.	0.98111±0.00013	-1672±19
26	Exp.	0.99769 -	-
	As-built	0.99609±0.00014	-160±14
	1D Case1	0.99362±0.00014	-247±20
	Homo.	0.97956±0.00013	-1653±19
27	Exp.	0.98624 -	-
	As-built	0.98539±0.00014	-85±14
	1D Case1	0.98310±0.00014	-229±20
	Homo.	0.96896±0.00014	-1643±20
28	Exp.	0.98931 -	-
	As-built	0.98883±0.00013	-48±13
	1D Case1	0.98626±0.00014	-257±19
	Homo.	0.97237±0.00013	-1646±18

[a)] For as-built model, the difference is against experiment. For others, the difference is against the as-built model

3. Conclusions

The effect of drawer master modeling of ZRRP-15A on the integral parameter was investigated by analyzing several configurations of the drawer master. The 1-dimensional simplification of the drawer master could well reproduce multiplication factors of the as-built configuration and most of the difference was found to arise from the interface effect between core and axial blanket region. The difference in full core model was evaluated around 250 pcm Δk and kept within 30 pcm Δk throughout the loadings.

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REFERENCES

[1] H. F. McFarlane, et. al., "Benchmark Physics Tests in the Metallic-Fueled Assembly ZPPR-15," Nuclear Science and Engineering, Vol. 101, p.137-152, 1989.