A Study on Modeling the Plate Geometry Cells of the ZPPR-15A Critical Experiments

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1. Introduction

This paper presents the analysis results for ways of modeling a three-dimensional cell of plate geometry into a one-dimensional (1-D) slab cell. As-built three-dimensional (3-D) cell models for the ZPPR-15A critical experiments involve descriptions on the matrix tube, air gap between the matrix tube and the drawer and various plates of which constituent material such as plutonium and sodium is encased in the cladding.

VIM [1] Monte Carlo calculations with the libraries based on ENDF/B-V.2 were performed for heterogeneous cell models in full detail of the ZPPR-15 Loading 15 Assembly and respective volume-homogenized cells. The deviation between these two models was as large as 1,324 pcm Δk.

This result strongly suggested that the cross section generation for the deterministic calculations should be based on heterogeneous drawer models.

2. Calculation Methods and 3-D Model Buildup

2.1 MC²-2/SDX Methodology for Treating Plate Heterogeneity

Plate heterogeneity effects are taken into account by MC²-2/SDX code system [2] from unit cell calculations. For each unit cell, the microscopic resonance cross sections are calculated in a 230-group structure for each plate using the generalized analytic integral formulation and the equivalence theory in SDX. These resonance cross sections are combined with the non-resonance cross sections determined from the MC²-2 calculation, and a 230-group integral transport calculation in one dimensional slab geometry is performed in SDX for each heterogeneous unit cell. Using the resulting 230-group flux solution, cell-averaged 230-group cross sections are determined by a spatial homogenization without group-collapsing

2.2 Description of ZPPR-15 Loading 15

The ZPPR-15 experiments [3] were conducted in four phases from April 1985 through July 1986 under the Integral Fast Reactor (IFR) Benchmark Physics Test Program. Loading 15 was the initial criticality configuration in Phase A.

The ZPPR fast critical assembly is a split table machine holding lattices of stainless steel tubes with a square cross section of a 5.5 cm outside dimension. These tubes are loaded with stainless steel drawers filled with plate-type unit cell loadings.

VIM Monte Carlo models were built 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.

3. Analysis Results

3.1 One-dimensional Unit Cell Modeling Methods

The unit cell loadings are approximately one-dimensional, but the variations in the plate dimensions make them three-dimensional as depicted in Fig. 1. Since the SDX calculation is based on 1-D slab geometry integral transport, development of a model that transforms a 3-D matrix tube loading to an equivalent 1-D computational model is an essential part of the homogenization process.

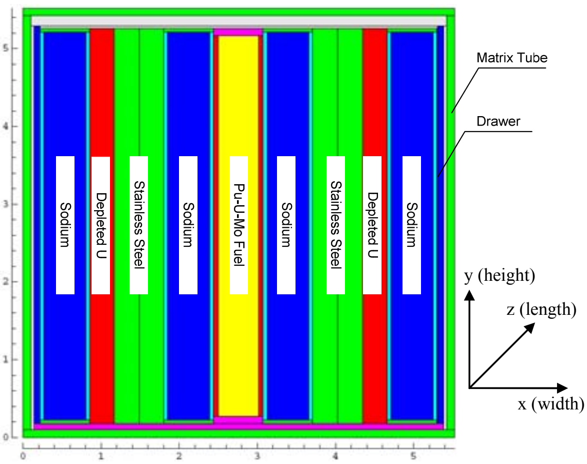

Fig. 1. Schematics of representative unit cell [cm]

The first model (Model 1) is a 1-D slab model constructed along the drawer width (x-direction). The thickness of each distinctive material region was represented as it is, except for the small gap between drawer and matrix tube, which was homogenized with the drawer and matrix tube into a single material region. The heterogeneities in the y- and z-directions were removed by smearing the structural materials from the periphery of the physical cell into the regions that do not include resonance isotopes. The number density of each material was adjusted to preserve the mass of each material in the drawer. The second model (Model 2) was made along the x-direction using the physical number densities at the drawer mid-height without smearing the periphery structural materials. The third model (Model 3) was built in the same way as the Model 1, but the physical number densities at the drawer mid-height were used for heavy elements.

3.2 Calculation Results

Using the three 1-D unit cell models, the infinite multiplication factors (k_∞) of a representative unit cell was calculated using the VIM Monte Carlo code with the ENDF/B-V.2 data. The resulting values were compared in Table I with the reference values obtained with the as-built 3-D models. The heterogeneity effect of each 1-D model was estimated in comparison with the corresponding homogeneous model. Although none of the 1-D models could reproduce exactly the heterogeneity effect of the as-built 3-D model (1.85 %Δk for the inner core unit cell), Model 1 yielded the closest result to the actual 3-D heterogeneity effect. The heterogeneity effects determined with Model 1 were lower by 0.21 %Δk for the inner core unit cell.

For each 1-D unit cell and the corresponding homogeneous cell, 230-group cell-averaged cross sections were generated using the MC^2-2/SDX system. Using these cell-averaged cross sections, TWODANT calculations were performed for the homogeneous model whose number densities were determined to preserve each material mass in the drawer, as in Model 1. As shown in Table I, the k_∞ values of each 1-D or homogeneous model obtained from the MC^2-2/SDX calculations agreed well with the corresponding VIM Monte Carlo results, within 0.2 %Δk. The heterogeneity effect of each 1-D model determined with MC^2-2/SDX calculations showed even better agreement with the VIM result, within 0.04 %Δk. The k_∞ values of TWODANT also agreed well with the VIM result for the 1-D model with the same material densities (Model 1).

4. Conclusions

Based on the calculation results on the three different modeling methods, the MC^2-2/SDX scheme of Model 1 proved to be adequate for generating cell-averaged homogenized cross sections. In addition, the TWODANT results showed that the k_∞ value of the homogenized unit cell is relatively insensitive to the material number densities used in generating cell-averaged cross sections.

Acknowledgement

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Table I: Comparison of infinite multiplication factors of a core unit cell determined with different unit cell models

Model		VIM	Heterogeneity effect, %Δk	SDX	TWODANT
Reference	3-D	1.18127 ± 0.00015	1.849		
Model 1	1-D	1.17912 ± 0.00015	1.642	1.17734	1.17734
	homogeneous	1.16270 ± 0.00012	-	1.16096	1.16096
Model 2	1-D	1.25050 ± 0.00013	1.528	1.24975	1.17671
	homogeneous	1.23522 ± 0.00016	-	1.23416	1.16197
Model 3	1-D	1.23998 ± 0.00013	1.598	1.23902	1.17744
	homogeneous	1.22400 ± 0.00018	-	1.22287	1.16194