Comparative Study of DIMPLE benchmark with Two-step and Direct Modelling Approaches

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1. Introduction

The DIMPLE benchmark problem has been analyzed using both a two-step approach with SERPENT/PARCS and direct Monte Carlo modeling with SERPENT and MCNP. Detailed computational models are developed in this paper and the calculation results of SERPENT/PARCS are compared against those of Monte Carlo codes SERPENT and MCNP.

2. DIMPLE S06 Critical Experiment

The experimental program reported in Reference 1 encompassed critical experiments with low-enriched uranium dioxide fuel rods containing 3.0 w/o ^{235}U with light-water moderation and reflection. The experiments were performed in the DIMPLE low-power reactor at AEA Technology's Winfrith site during the late 1980's and early 1990's [1]. These experiments were designed to simulate peripheral regions of a PWR and modeled the equivalent of twelve 16x16 PWR fuel bundles, arranged in a cruciform array. The first configuration (S06A) represented the relevant twelve bundles with a water reflector, the second configuration (S06B) added a stainless-steel baffle of 2.67cm thickness around the cluster of assemblies, with a surrounding water reflector. Ordinary water was used for the reflector and moderator. The pin pitch for both configurations was 1.2507cm [2]. The fuel pin was composed of fuel, aluminum wrapper, and cladding in which each diameters was 1.0130cm, 1.0398cm, and 1.0937cm. The pin-cell configuration is shown in Fig. 1.

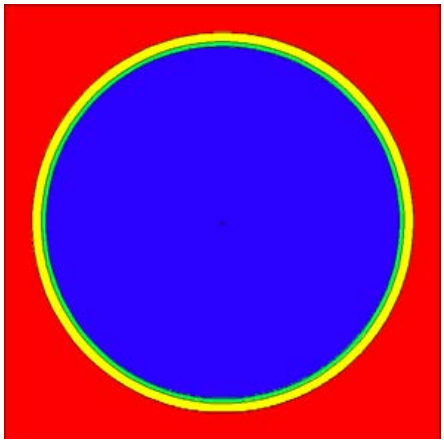

Fig. 1. Configuration of DIMPLE S06 pin cell.

3. Computer Code System

3.1 SERPENT1.1.19

Serpent (version 1.1.19) is a 3D continuous-energy Monte Carlo calculation code developed since 2004 and optimized for reactor physics applications [3]. In this benchmark modeling, SERPENT 1.1.19 code was used to generate homogenized two-group constants for 2D nodal calculation in PARCS 3.0. SERPENT 1.1.19 gives homogenized transport, absorption, intra group scattering cross-sections and fission spectrum for each energy group. The code was also used to calculate eigenvalues for the DIMPLE S06 critical core.

3.2 MCNP6

The MCNP (version 6) code has general 3D geometry description, neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate eigenvalues for critical systems [4]. For this benchmark calculation, MCNP6 was used to calculate eigenvalues for the DIMPLE S06 critical core.

3.3 PARCS3.0

PARCS (version 3.0) is a 3D reactor core simulator which solves the steady-state and time dependent, multi-group neutron diffusion and SP3 transport equations in square and hexagonal geometries. PARCS 2D models were constructed to calculate eigenvalues with homogenized square assemblies by SERPENT 1.1.19. The nodal expansion method for multi-group is used to calculate eigenvalues [5].

4. Calculational Models

4.1 MCNP6 and SERPENT1.1.19 models

For this benchmark, a two dimensional DIMPLE S06 model is used to calculate eigenvalues. Two full core models of DIMPLE S06 critical experiments are explicitly modeled for S06A and S06B cores. Detailed views of these models created by SERPENT 1.1.19 geometry plotter are shown in Fig. 2 and 3. All the simulations are performed with a total number of

1.2×10^8 neutron histories using 1,000 active cycles and 200 inactive cycles. All of the calculations are performed using the ENDF/B-VII continuous energy cross-section library.

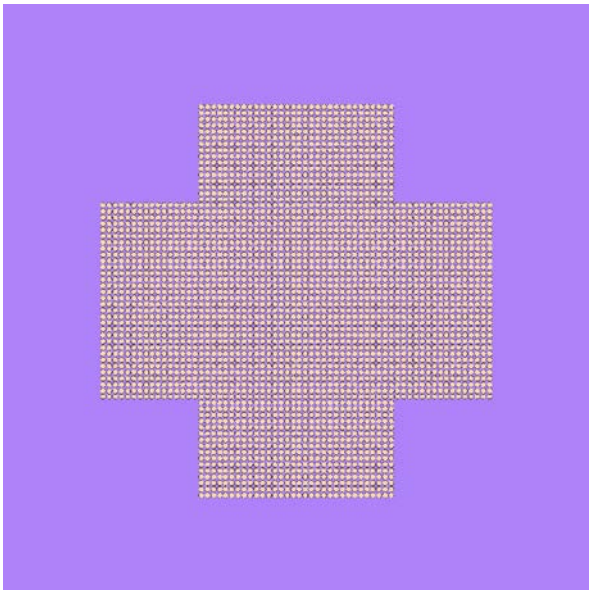

Fig. 2. Plan view of DIMPLE S06A.

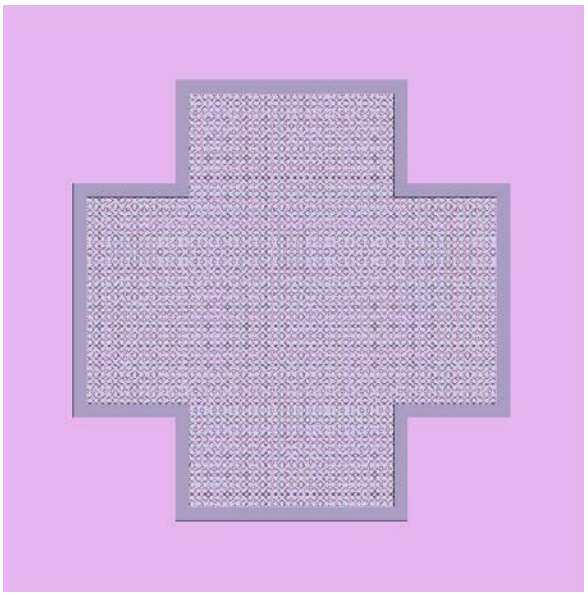

Fig. 3. Plan view of DIMPLE S06B.

4.2 PARCS/SERPENT cross-sections models

The generation of homogenized group constants for PARCS 3.0 is performed by SERPENT 1.1.19 using three unit assemblies with a 2-group structure in which the group boundary is 0.625eV. Detailed views of unit models are shown in Figs. (4-6). All the simulations are performed with a total number of 1.2×10^8 neutron histories using 1,000 active cycles and 200 inactive cycles based on the ENDF/B-VII continuous energy cross-section library. Homogenized unit models were reconstructed for the PARCS models (S06A, S06B). The unit models are named “F”, “R”, and “RB”. “F” is a 16×16 fuel assembly 20.0112cm pitch. “R” is a reflector of the same pitch next to fuel assembly “F”. “RB” is a reflector with baffle next to fuel assembly “F”. PARCS core configurations using these cross-sections are shown in Figs. 7 and 8.

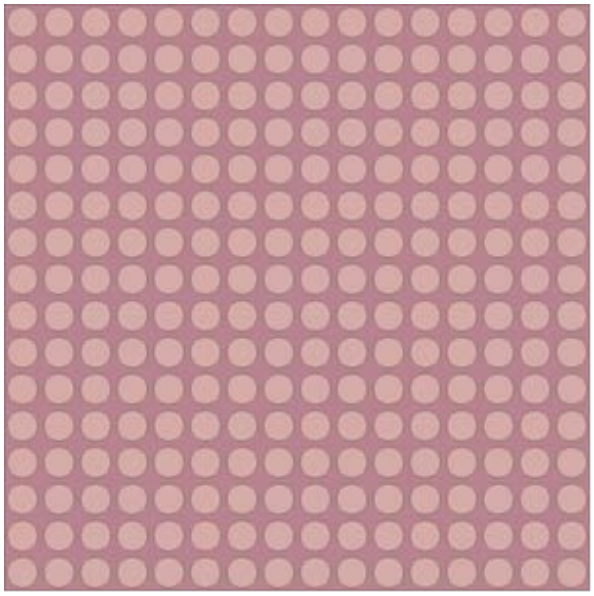

Fig. 4. Plan view of unit model “F”.

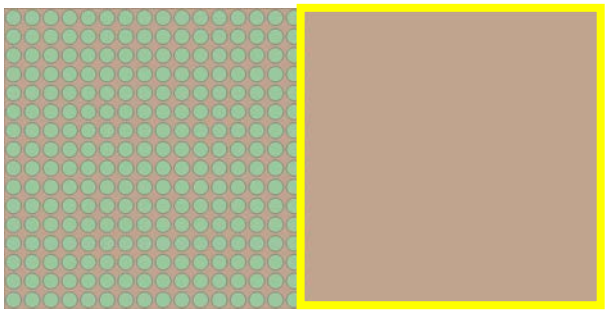

Fig. 5. Plan view of unit model “R”.

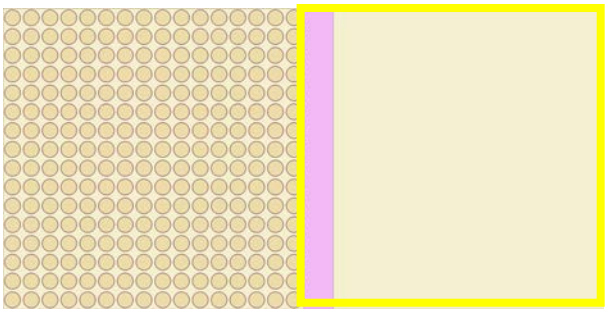

Fig. 6. Plan view of unit model “RB”.

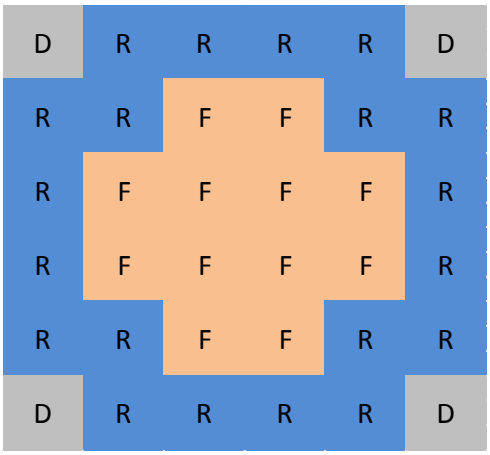

Fig. 7. PARCS model of S06A core.

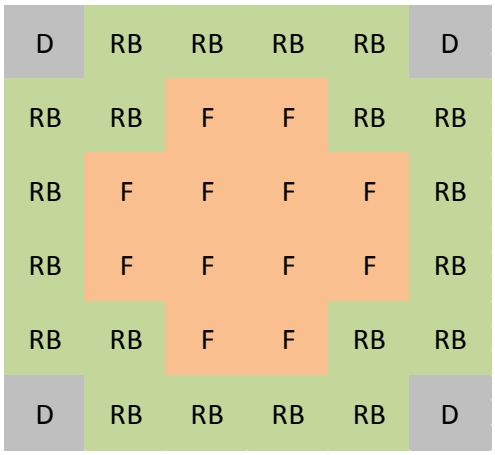

Fig. 8. PARCS model of S06B core.

5. Results

5.1 Unit models

The MCNP6 and SERPENT 1.1.19 calculation results for the three unit models are shown in Table I. The results of models "F" and "R" show good agreement of eigenvalues with differences within 100pcm between MCNP6 and SERPENT 1.1.19. But the result for model "RB" shows an eigenvalue difference around 200pcm relative to SERPENT 1.1.19 and MCNP6.

Table I: Unit models eigenvalues for DIMPLE S06 using SERPENT 1.1.19 and MCNP6

Model	Code	Eigenvalue	Standard deviation [pcm]
F	MCNP6	1.21835	6
	SERPENT 1.1.19	1.21767	5
R	MCNP6	1.08071	7
	SERPENT 1.1.19	1.08000	8
RB	MCNP6	1.06309	6
	SERPENT 1.1.19	1.06083	8

5.2 2D full core models

The MCNP6 and SERPENT 1.1.19 calculation results for two core configurations (S06A, S06B) are shown in Table II. SERPENT/PARCS result show good agreement of eigenvalues for the S06A core with differences of 128 and 224pcm relative to MCNP6 and SERPENT 1.1.19 respectively. The results for S06B show an eigenvalue difference of more than 1,500 pcm relative to SERPENT 1.1.19 and MCNP6.

Table II: 2D full core eigenvalues for DIMPLE S06A and S06B using SERPENT 1.1.19 and MCNP6

Model	Code	Eigenvalue	Standard deviation [pcm]
S06A	MCNP6	1.09629	7
	SERPENT 1.1.19	1.09533	7
	PARCS3.0	1.09567	-
S06B	MCNP6	1.08336	7
	SERPENT 1.1.19	1.08240	7
	PARCS 3.0	1.09695	-

6. Conclusions

The SERPENT 1.1.19 code was employed to homogenize the fuel assembly and reflector domains for nodal calculation. Then, the PARCS 3.0 code was used to solve two group neutron diffusion equations, and the results were compared to the full-core heterogeneous solution calculated with SERPENT 1.1.19 and MCNP6. The results show that the reflector with baffle requires the use of assembly discontinuity factors (ADF). It is presumed that the homogeneous results would have been improved if ADFs were used.

REFERENCES

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[5] T. Downar, "PARCS v3.0 U.S. NRC Core Neutronics Simulator USER MANUAL," May, 2013.