Analysis of Two-Dimensional Full-Core One-Step Calculation with Bamboo-Lattice

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INTRODUCTION

Nuclear design of a Pressurized Water Reactor (PWR) core requires a code system to carry out fuel management calculation to provide the coupled neutronics, thermal-hydraulics and nuclide depletion analysis. A PWR-core fuel management calculation code system named NECP-Bamboo has been designed and developed in Xi'an Jiaotong University aiming at three targets simultaneously. (1) Reactor core design evaluation verification. To fully take advantage of the numerical description and prediction functions, reliability of the reactor core design tools must be verified by using a code-to-code comparison to reduce the risk and cost in experimental and engineering validations as low as possible. (2) Scientific research. To improve the nuclear evaluation methodology, a tool system is required to analyze the approximations currently employed to recognize and then eliminate the main approximations. (3) Nuclear force education. In addition to the theoretical explanations in class and nuclear power plant tour, it enables the students to experience an active nuclear reactor core design process to better understand the actual consideration from both physical and engineering points of view. Currently, there are three components in the NECP-Bamboo code system, including a two-dimensional lattice code named Bamboo-Lattice for few-group assembly-homogenized constants generating, a three-dimensional whole-core steady-state evaluation code named Bamboo-Core, and a three-dimensional whole-core transient simulation code called Bamboo-Transient. In this summary, the Bamboo-Lattice code is introduced briefly and verified by two-dimensional full-core calculations of AP1000 and BEAVRS cores.

DESIGN OF BAMBOO-LATTICE

The main flowchart of the code is shown in Fig. 1. The pin-cell homogenization process is eliminated by using direct whole-assembly heterogeneous calculation. Its ability of the 2D full-core calculation provides an opportunity of 2D full-core data library group-structure high-fidelity calculation

Nuclear data libraries from ENDF/B VII.0

There are 200 nuclides in total with 116 depletion ones including 24 actinides, 43 resonant nuclides and 56 fission products. The depletion data library was compressed by using a quantitative evaluation [1] without empirical experience based assumptions. There are nine decay heat precursors for each actinide, and six delayed neutron precursors for each fissile nuclide. Different types of neutron absorbers are contained in the library, including Hafnium, boron, silver, indium, cadmium, gadolinium, et al. Three energy group structures are available in the code, including the WIMS-D-69, WIMS-D-172 [2] and SHEM-361 [3] group structures.

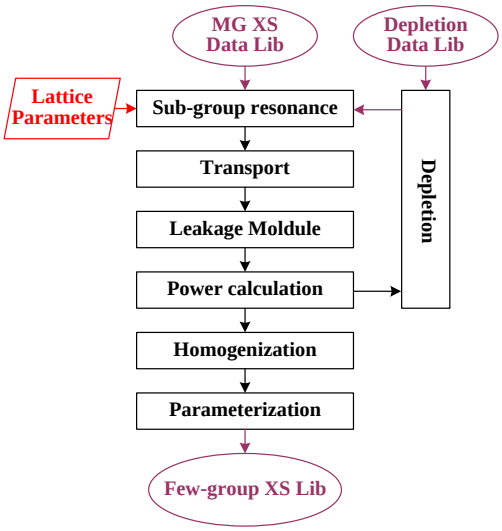


Fig. 1 Main flowchart of Bamboo-Lattice

Subgroup resonance self-shielding treatment

The subgroup method is employed to eliminate the limitations in lattice geometry and to guarantee both accuracy and efficiency. Subgroup parameters are on-line generated. When more than one resonant nuclide exist, the Bondarenko iteration method is employed to treat the resonance interference effect.

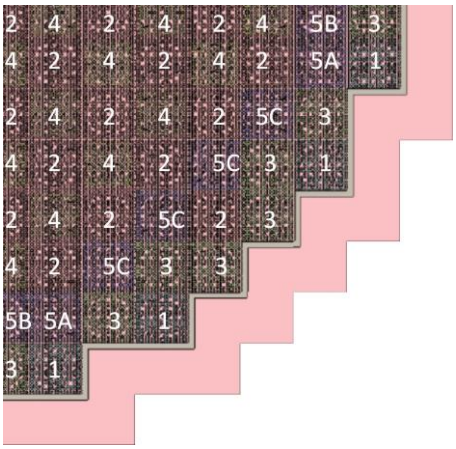
Heterogeneous neutron transport solver

To solve the two-dimensional steady-state multi-group neutron transport equation, an assembly-modular MOC solver [4] is employed. Each assembly can be constructed by a certain number of rectangular pins, and can be surrounded by a thin water gap (~0.1cm). Each pin can be constructed by straight lines or circle curves. For anisotropic scattering, three transport corrections are implemented, including the consistent-Pn, the outflow and the inflow transport approximations. In addition, the MOC solver can be accelerated by using a two-level coarse mesh finite difference (CMFD) scheme.

NUMERICAL RESULTS

2D AP1000 core problem

The results presented in this paper refer to a radial core slice, including the reflector, at the core axial mid-plane of the AP1000 core [5]. Its geometry and material specifications are displayed in Fig. 2. The reference assembly power distribution obtained with continuous energy Monte Carlo code Serpent [6] (ENDF/B VII) for this simulation is given in Fig. 3. The relative error of assembly-averaged power of Bamboo-Lattice are given in Fig. 4. The Serpent pin power distribution is shown in Fig. 5 with the relative error of Bamboo-Lattice in Fig. 6. A summary of the results can be found in Table I. The eigenvalue provided by Bamboo-Lattice agree with Serpent. The RMS and maximum differences of assembly power are 0.63% and 1.33% respectively. The agreement in the pin power prediction is also notable, with RMS and maximum differences of 0.57% and 2.06% respectively.



(a) Geometry

Region Group	Fraction of Total	U235 Average	IFBA Rods	WABA Rods
1	0.10	0.740	0	0
2	0.31	1.580	0	0
3	0.18	3.200	0	0
4	0.23	3.766	68	12
5A	0.05	4.376	88	4
5B	0.03	4.376	124	0
5C	0.10	4.376	124	8

(b) Fuel specifications

Fig. 2 AP1000 core: radial slice at the axial mid-plane

2D BEAVRS core problem

For the BEAVRS [7] problem, the tilt corrected radial detector map comparison is shown in Fig. 7. The RMS and maximum error for the axial-integrated detector signal are 1.57% and 3.01% respectively. A summary of the eigenvalues compared with CASMO-5 [8], RattleSnake [8], Serpent [8] and NECP-X [9] are summarized in Table II. Good agreement can be found in those results.

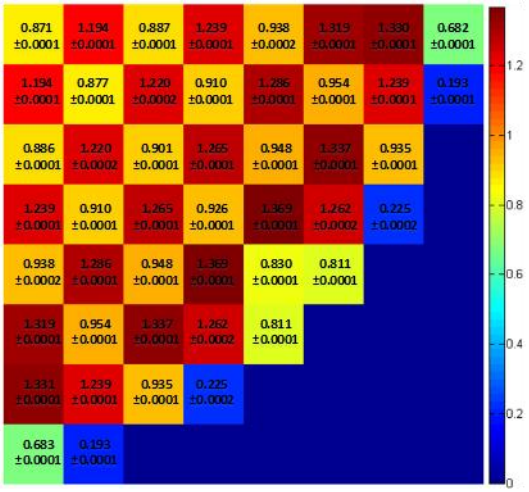


Fig. 3 The reference assembly power from Serpent for the 2D AP1000 core problem

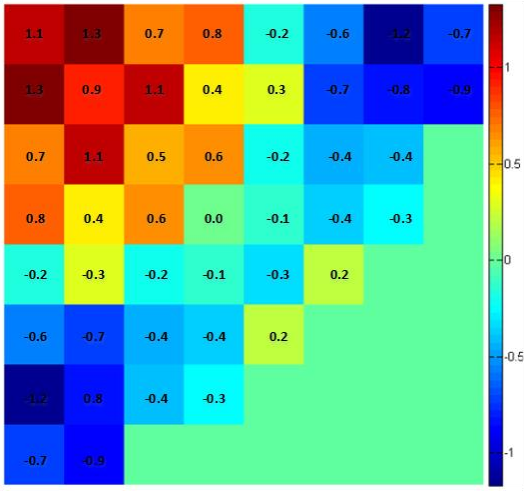


Fig. 4 Relative error of assembly power for the 2D AP1000 core problem (%)

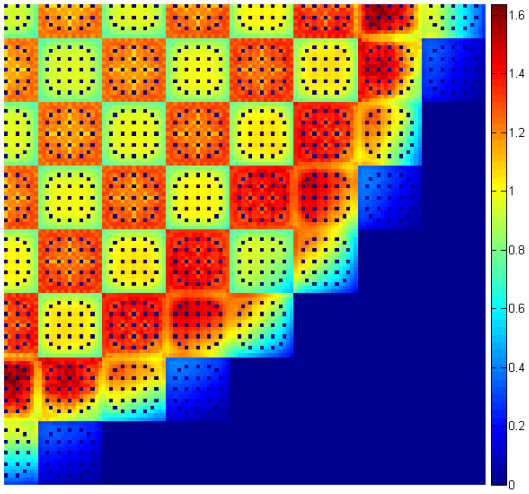


Fig. 5 The reference pin power profile from Serpent for the 2D AP1000 core problem

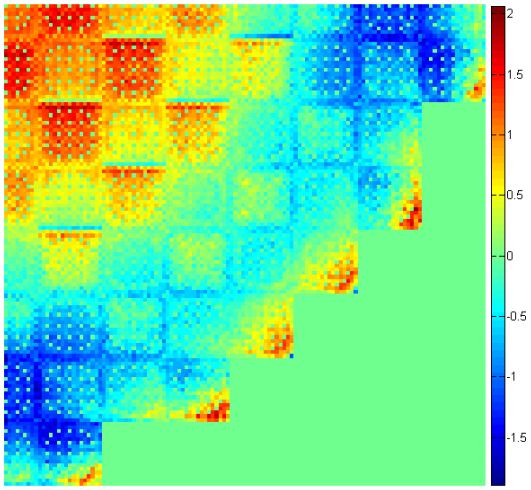


Fig. 6 The relative error of pin power for the 2D AP1000 core problem

Table I Results for the 2D AP1000 core problem

Serpent	Bamboo-Lattice		Bamboo-Lattice vs Serpent			
k_{inf} (±2pcm)	k_{inf}	Δk_{inf} (pcm)	RMS ΔP_{Asm} (%)	Max ΔP_{Asm} (%)	RMS ΔP_{Pin} (%)	Max ΔP_{Pin} (%)
0.99588	0.99598	10	0.69	1.33	0.57	2.06

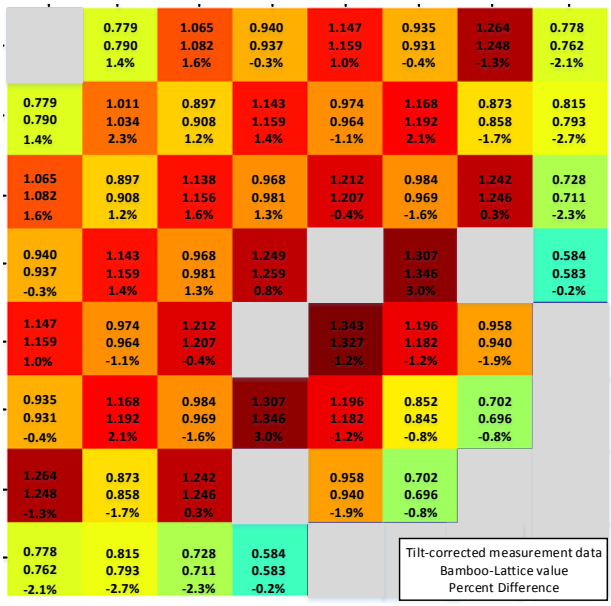


Fig. 7 Axially-integrated detector signals comparison

CONCLUSION

To validate the two-dimensional full-core one-step library group structure calculation ability of the Bamboo-Lattice code, the reactivity, power distribution and detector response for two-dimensional AP1000 and BEAVRS cores are compared with Monte Carlo simulations or the tilt-corrected measurement data. This ability provides a good tool to analyze the error sources for assembly-homogenization based two-step method and to develop pin-cell homogenization based pin-by-pin calculation scheme.

Table II Eigenvalues for the 2D BEAVRS core problem

Analysis Method	Eigenvalue Results	Nuclear Data Lib
CASMO-5	1.00271	ENDF/B VII
RattleSnake	1.00690	ENDF/B VII
SERPENT	1.00530±0.00001	ENDF/B VII
NECP-X	1.00331	ENDF/B VII
Bamboo-Lattice	1.00213	ENDF/B VII

ACKNOWLEDGEMENT

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