Whole-Core Monte Carlo Calculation Based on Fission and Surface Source Iteration Method Applied to a Fast Reactor Core Configuration

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1. Introduction

The Monte Carlo method becomes popular in nuclear reactor design and analysis due to the increase of computing power. There have been several studies [1-4] on the domain decomposition method for whole-core Monte Carlo calculation to overcome the limitation of computer memory due to the demanding cross section data, geometry description, and tally requirements.

Recently, the fission and surface source (FSS) iteration method [3,4] which banks fission and surface sources for the next iteration (i.e., cycle) was proposed based on domain decomposition and combined with a source splitting scheme to reduce the load-imbalance problem and achieve global variance reduction. The FSS iteration method has been tested on two-dimensional continuous-energy thermal reactor problems.

In this paper, the FSS iteration method is applied to the fast reactor where the neutron mean-free-path is around 10 times longer than that in the thermal reactor [5]. The FSS iteration method with domain-based parallelism is tested on a two-dimensional continuous-energy fast reactor test problem. The multiplication factor and the pinwise fission-rate distributions of the FSS iteration method show good agreements with those of the conventional power method.

2. FSS Iteration Method for Fast Reactor Core Analysis

In the previous study [4], a local domain was chosen as a single assembly for thermal reactor analysis. In this study, a local domain for fast reactor analysis is chosen as a "cluster" of 19 hexagonal assemblies, as shown in Fig. 1. The reason for the larger local domain size in the fast reactor analysis is to have not too large number of surface sources compared to the number of fission sources.

For each local domain, the fixed-k (also known as fixed-source) problem with incoming angular flux boundary condition can be solved independently by using the FSS iteration method which uses both fission and surface sources from the previous iteration. At the end of each FSS iteration, neutron angular fluxes entering local domain *i* from neighboring local domains should be transmitted and they will be used as surface sources of local domain *i* in the next FSS iteration. During tracking fission sources, surface source data can be transmitted to neighboring local domains by using asynchronous, non-blocking communication with message-passage interface (MPI) parallelism.

While domain-based parallelism is easily achieved by using the FSS iteration method, the computing times for the local problems will be different, depending on the specific local problems. This may cause idle times of the processors to wait for the results from other local problems. To reduce the idle times, two means are considered. One is to apply a source splitting scheme [4]. The other is to assign different numbers of processors to local problems.

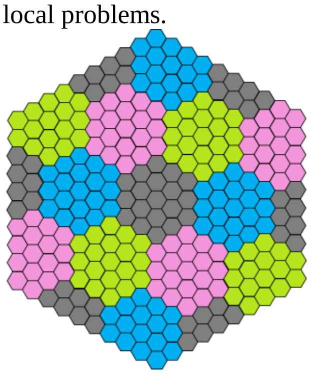

Fig. 1. Local domain denoted by the same color on a cluster of hexagonal assemblies in FSS iteration method for fast reactor core analysis

3. Test Problem

The FSS iteration method with domain-based parallelism is tested on a two-dimensional, continuous-energy fast reactor test problem. The problem is based on the Phénix fast reactor used in [6]. The geometry and specifications of the test problem are shown in Fig. 2 and Table I, respectively. Material compositions are shown in Table II. For the convenience of problem modeling in this study, the hexagons in the last ring of the core is filled with sodium coolant and the boundary condition is assumed vacuum.

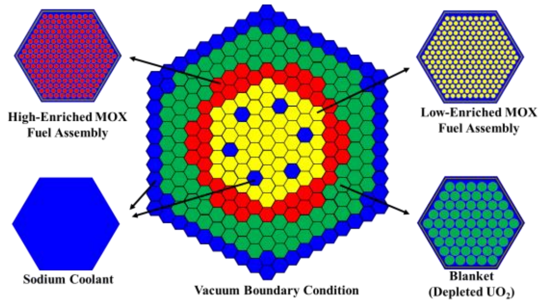

Fig. 2. Geometry of the fast reactor test problem

Table I: Specifications of the fast reactor test problem

Reactor Parameter	Value
Assembly Pitch	12.5 cm
Duct (SS304)	
Outer Hexagon Pitch	12.2 cm
Inner Hexagon Pitch	11.7 cm
MOX Fuel Pin	
Pellet Diameter	5.5 mm
Cladding (SS304) Outer Diameter	5.65 mm
Cladding (SS304) Inner Diameter	6.55 mm
Pin Pitch	7.8 mm
Blanket Pin	
Pellet Diameter	12.5 mm
Cladding (SS304) Inner Diameter	12.5 mm
Cladding (SS304) Outer Diameter	13.4 mm
Pin Pitch	14.5 mm

Table II: Material compositions of the fast reactor test problem

Material	Isotope	Weight Fraction
MOX (Low-Enriched) [10.97 g/cc]	8016	1.18366E-01
	92235	4.95722E-03
	92238	7.17246E-01
	94238	5.54909E-03
	94239	8.26140E-02
	94240	3.78574E-02
	94241	2.06929E-02
	94242	1.27181E-02
MOX (High-Enriched) [10.98 g/cc]	8016	1.18312E-01
	92235	4.69419E-03
	92238	7.13132E-03
	94238	1.05564E-01
	94239	4.83613E-02
	94240	2.64785E-02
	94241	1.62933E-02
	94242	1.18312E-01
SS304 [8.01 g/cc]	6000	7.98372E-04
	14028	9.18370E-03
	14029	4.83201E-04
	14030	3.29899E-04
	15031	4.49865E-04
	24050	7.92947E-03
	24052	1.59028E-01
	24053	1.83793E-02
	24054	4.66132E-03
	25055	1.99996E-02
	26054	3.86004E-02
	26056	6.28387E-01
	26057	1.47713E-02
	26058	2.00028E-03
	28058	6.38358E-02
	28060	2.54373E-02
	28061	1.12417E-03
	28062	3.64311E-03
	28064	9.57723E-04
Depleted Uranium [10.5 g/cc]	8016	1.18522E-01
	92235	2.61120E-03
	92238	8.78866E-01
Sodium [0.968 g/cc]	11023	1.00000 E+00

4. Numerical Results

To use the FSS iteration method, the whole-core problem is divided into 19 local problems, as shown in Fig. 1. For each local problem, 4 processors are assigned for particle-based parallelization. Thus, the total number of processors used in this calculation is 76.

The FSS iteration method is compared with the conventional power method on the whole core with 76 processors for particle-based parallelization. Calculational conditions are shown in Table III. The Monte Carlo calculations are performed by the in-house code [7] with ENDF/B-VII.0 continuous-energy cross section library at room temperature (293 K). Note that the number of surface sources is around 3 times larger than that of fission sources when FSS iteration has converged.

Table III: Calculational conditions

	FSS Iteration Method	Conventional Power Method
No. of Inactive Iterations	60	30
No. of Active Iterations	150	150
No. of Fission Sources/Iteration	400,000	400,000

Table IV compares the multiplication factors obtained from the FSS iteration method and the conventional power method. The difference between the multiplication factors obtained with the two methods is 5 pcm. However, the figure of merit (FOM) in the multiplication factor of the FSS iteration is 3.6 times smaller than that of the conventional power method due to load-imbalance. This could be improved when load balancing features (e.g., by assigning more processors on heavy-load local problems) are implemented.

Table IV: Comparison of the conventional power method and FSS iteration method

	FSS Iteration Method	Conventional Power Method
k_{eff}	1.16323	1.16328
Standard Deviation	6 pcm	6 pcm
Time for Active Iterations	11,192 sec	3,550 sec
FOM (k_{eff})	31,452	113,320

Figs. 3 and 4 show the pinwise fission-rate distributions of the FSS iteration method and the conventional power method, respectively. The relative difference between the maximum pinwise fission-rates is around 0.26 %.

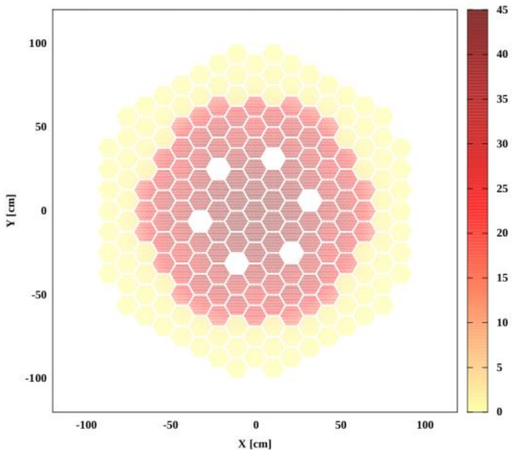

Fig. 3. Pinwise fission-rate distributions of the FSS iteration method (unit not normalized)

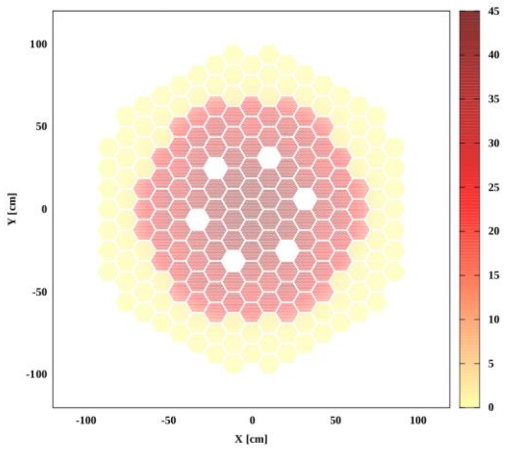

Fig. 4. Pinwise fission-rate distributions of the conventional power method (unit not normalized)

5. Summary and Conclusions

The FSS iteration method with domain-based parallelism has been tested on a two-dimensional, continuous-energy fast reactor test problem. A local domain is chosen as a cluster of 19 assemblies, taking into account the longer neutron mean-free-path. In the future, another type of local domain can be defined to take into account reflector assemblies and shield assemblies with appropriate boundary conditions.

In the test problem, the multiplication factor and the pinwise fission-rate distributions of the FSS iteration method show good agreements with those of the conventional power method.

Although the domain decomposition is easily achieved by the FSS iteration method, load-imbalance of local problems causes idle times in the processors. Applying the source splitting scheme and assigning different numbers of processors to local problems will reduce this problem.

However, the preliminary results in this study indicate that the FSS iteration method is less attractive in fast reactors than in thermal reactors [3,4]. This is because a local problem should consist of several (e.g., 19) fuel assemblies and there need not be many local problems in a fast reactor.

References

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