Development Status of Monte Carlo Code at UNIST

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1. Introduction

A Monte Carlo code MCS has being developed at Ulsan National Institute of Science and Technology (UNIST) since 2013. The target of MCS is to solve complex whole core problems like BEAVRS [1-3]. MCS can treat the 3D whole core geometry with universe and lattice, and the neutron physics with probability-table, free-gas treatment, S(a,b) and Doppler Broadening Rejection Correction. The collision kernel and transport kernel of MCS has been verified and validated with various benchmarks: ICSBEP, H-M, VENUS-2, BEAVRS, and etc. In addition, the adjoint weight tally function has been implemented to calculate the adjoint-weighted parameters [4]. UNIST is now working on the On-The-Fly Doppler Broadening, depletion and TH-coupling to get the solutions at real core operation conditions. Currently, those modules work fine independently [5-6]. On the other hands, the acceleration techniques are under development to reduce the computing costs: Coarse Mesh Finite Difference Method (CMFD), and Modified Power Method (MPM) [7-8]. Both CMFD and MPM can accelerate the source convergence very efficiently and the performance in active cycles is under investigation. In this paper, the results of depletion, OTF-DB module and TH solver will be presented.

2. Overview

MCS was written in FORTRAN 2003 language. It is capable of 3D whole core calculation with ACE format ENDF data library. To model the neutron physics properly, free-gas treatment module, resonance upscattering treatment module, probability table and S(a,b) module were implemented. For the TH-feedback, simple 1D TH solver from nTRACER was adopted and two types of On-The-Fly Doppler Broadening modules, SIGMA1 and multipole representation, were implemented. The depletion module was implemented with Matrix Exponential Method (MEM).

2.1 Benchmark Results

MCS has been verified and validated with several benchmarks, among which 5 reactor core benchmark results are summarized in Table I. MCS was compared with other well recognized Monte Carlo codes. As shown in the table, MCS shows good agreement with measured data and other codes. Fig. 1 shows several mesh tally results of BEAVR core by MCS.

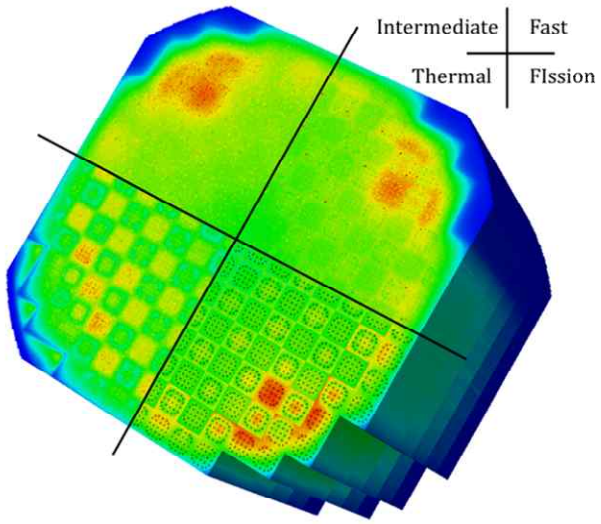

Fig. 1. BEAVRS flux distribution by MCS.

Table I: Benchmark Results

Benchmarks	k_{eff}	SD	Diff. [pcm]
C5G7	1.18647	0.00003	-8*1)
MHTGR-350 Ph-1 ex 1	1.06884	0.00004	-5*2)
VENUS-2 (2D core)	1.08526	0.00011	-25*1)
H-M	1.00090	0.00010	67*1)
BEAVRS	0.99819	0.00007	-101*3)

*1) compared with MCNP6
*2) compared with McCARD
*3) compared with OpenMC

2.2 OTF-DB

The multipole representation (MPR), proposed by Hwang, was implemented to calculate microscopic cross sections during the simulation [11-16]. The multipole representation with implemented energy window concept was tested with the BEAVRS single fuel assembly of 1.6% enrichment. All the simulations were done with 50 inactive cycles, 1000 active cycles and 10,000 neutron histories per cycle. The given problems were computed using 20 cores of a parallel Linux cluster. As shown in Table II, it was possible to have statistically same solution with multipole. However, it cost 5 more times than the pointwise method. It is

natural that slow simulation time for multipole since the multipole method have to calculate complex equation to get cross section while pointwise method needs simple interpolation. However, Josey got much better performance by adopting high order polynomials which can reduce the number of poles to calculate [20]. The time ratio between multipole and pointwise was 1.15 with BEAVRS core problem. The next step would be development of OTF module with same strategy as in Josey's paper.

Table II: Multiplication Factor Comparison

Method	Isotope	k (STD)	Time ratio
Pointwise	-	1.02477 (0.00018)	1
Multipole	U^{235}	1.02476 (0.00018)	3.98
Multipole	U^{238}	1.02448 (0.00018)	2.96
Multipole	U^{235}, U^{238}	1.02450 (0.00018)	5.08

2.3 TH Coupling

A simple 1D TH solver from nTRACER has been implemented in MCS. The TH coupling calculation capability was demonstrated with a pin cell problem with the length of 4m. The pin cell was divided into 20 equal size axial nodes for the TH coupling. The inlet density and temperature of coolant are 700kg/m3 and 293.6K, respectively. TH simulation is performed after every 1 neutron transport cycle. This strategy might be unstable for assembly or core simulation. However, it was fine for pincell calculation. The temperature and density distribution is accumulated just like MC tally result. The Fig. 2 shows the converged coolant density and temperature distribution. Fig. 3 shows the axial power profile convergence behavior. The iteration scheme for TH coupling will be studied with assembly and core problem.

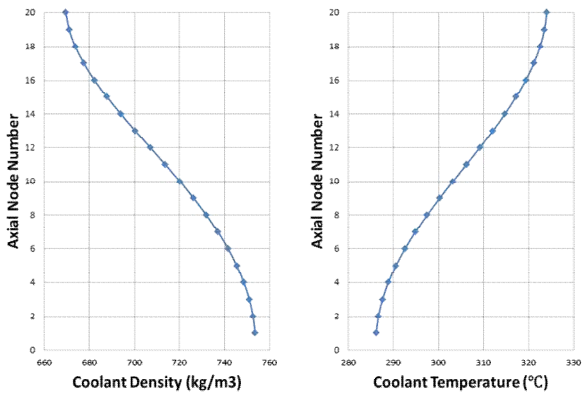

Fig. 2. Converged density and temperature distribution.

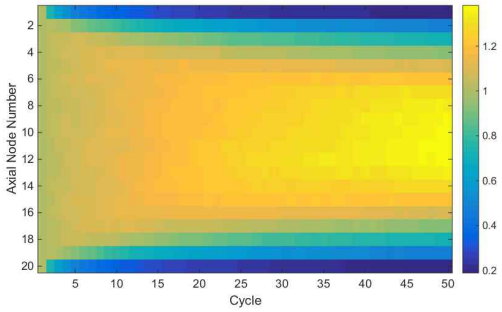

Fig. 3. Axial profile convergence behavior.

2.4 Depletion

Depletion module, one of the basic features in full range of reactor analysis, was implemented in MCS. It can simulate the change of fuel composition by solving burnup equation with MEM solver [17-19]. MCS is capable of cell-wise depletion calculation, different from the material-wise depletion as in some codes. The depletion module was tested with one of the pin cell problems in VERA benchmark by comparing McCARD which uses MEM method same as MCS. The statistical error is about 70 pcm for MCS and McCARD during all steps. Fig. 4 shows multiplication factor profiles and difference between two codes. As a next step, the memory requirement and simulation time for whole-core pinwise depletion calculation will be studied.

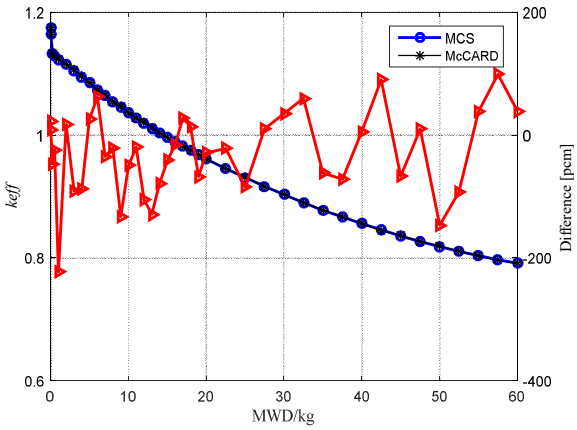

Fig. 4. Multiplication factor profiles with burnup

3. Conclusions

The Monte Carlo code MCS has being developed at UNIST. MCS is capable of 3D whole core simulation with continuous energy library and the accuracy has been verified and validated with various benchmark problems. In order to solve PWR whole core problems, depletion, On-The-Fly Doppler Broadening and TH-solver are being studied.

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