Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Application of MCS Code to Yonggwang Unit 3 Cycle 1 BOC Analysis

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1. Introduction

Application of the Monte-Carlo (MC) code, MCS, to Yonggwang Unit 3 Cycle 1 (YGN3C1) at beginning of cycle (BOC) is presented and analyzed. The growth of computing power computing has led to a sustainable increase of the share of Monte Carlo codes in the nuclear reactor research and development industry. Many Monte Carlo (MC) codes have been developed and are widely used to perform reactor designs and fuel cycle analysis. These can provide the most accurate locally dependent neutron characteristics in realistic three-dimensional (3D) geometries of any complexities. The computational reactor physics and experiment laboratory (CORE) at the Ulsan National Institute of Science and Technology (UNIST) has developed the 3D continuous-energy neutron/photon transport code MCS for large-scale reactor application [1].

In this paper, the capability of MCS solving large-scale reactor was demonstrated against commercial pressurized water reactor Yonggwang unit 3 cycle 1. The Beginning of Cycle (BOC) for hot zero power (HZP) and hot full power (HFP) conditions were simulated, and it was compared with the in-house two-step code system STREAM/RAST-K 2.0 (ST/R2) [2].

2. Yonggwang Unit 3 Reactor Core Design

YGN3 is a Pressurized Water Reactor (PWR) reactor, which produces 2815 MW of thermal power. YGN3 is a Combustion Engineering (C-E) System 80 plants with major components and construction handled domestically under a technology transfer agreement [3]. The core consists of 177 fuel assemblies (FA) with 16x16 arrays of 236 fuel rods and 5 guide tubes. In this reactor, the burnable absorber is comprised of gadolinia (Gd_2O_3) admixed in natural uranium (UO_2) and the Gd_2O_3 contents are 4 wt.%. The fuel rod axial cutback regions contain no gadolinium (Gd) and this represent the top and bottom 5% of the burnable absorber rods. The loading pattern for YGN3C1 is shown in Fig. 1.

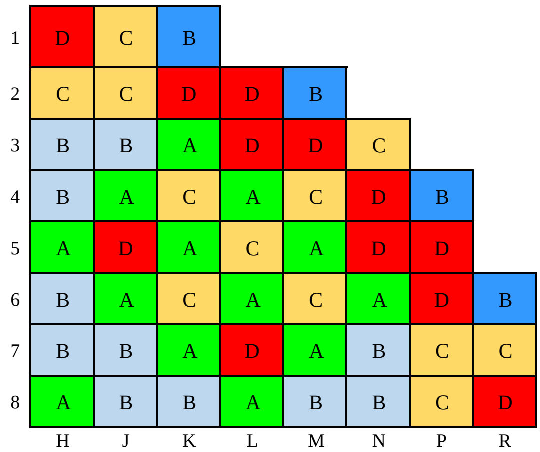

Fig. 1. Loading pattern for YGN3C1.

3. Code Description

3.1 STREAM/RAST-K Code

Steady state and Transient REactor Analysis code with Method of Characteristics (STREAM), a neutron transport analysis code, has been developed to perform a whole LWR core calculation with the direct transport analysis method and the two-step method. STREAM calculates FA and reflector models using 2D MOC to solve the transport equation and generates 2-group cross section and group constants data. [4].

RAST-K 2.0 has been developed to be used with high accuracy and performance in core design calculations, load follow simulation and transient analysis in neutronics. RAST-K 2.0 simulates whole core models and solves the two-group 3D neutron diffusion equation in eigenvalue or fixed source modes by using the unified nodal method [4].

STORA (STREAM To RAST-K 2.0) is a file transformation code. STN file stores cross section data and group constants for all FAs and reflectors generated by STREAM. STORA reformats cross-section data for RAST-K 2.0 [4]. The flowchart of ST/R2 code is shown in Fig. 2 [5].

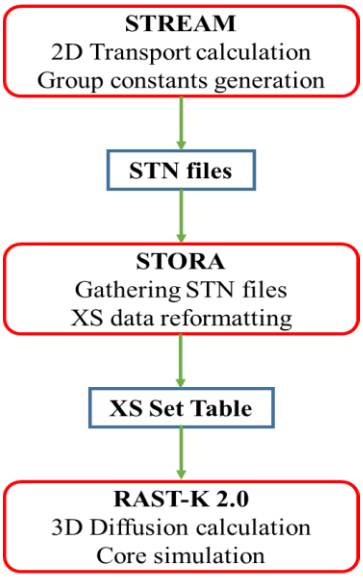

Fig. 2. The flowchart of STREAM/RAST-K 2.0 [4].

3.2 MCS Code

A MCS code has been developed with the purpose of large scale reactor analysis with accelerated Monte Carlo simulation. To be used for large scale reactor analysis, MCS code considers various feedbacks as xenon equilibrium, thermal hydraulics (TH), depletion, critical boron concentration (CBC) and On-The-Fly cross-section reconstruction (OTF) [5]. The feedbacks on MCS is updated at every cycle depending on the parameters tallied during each cycle.

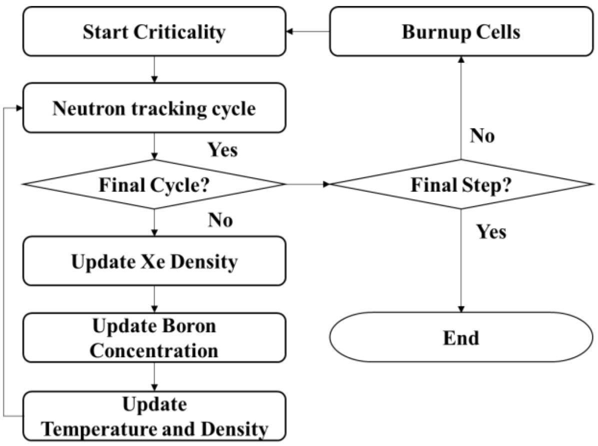

Fig. 3. The flowchart of MCS [5].

The one-dimensional TH module is applied to obtain the pin-wise power distribution from MCS and feedback again the temperature and density distribution to MCS [5].

The OTF cross section generation is applied by using the OpenW module developed at MIT CRPG. The OpenW module is used to consider the Doppler broadened cross-section feedbacks [5].

The equilibrium xenon feedback is considered by updating number density of ^{135}Xe based on the cycle tallied quantities during depletion. The depletion capability tracks 1,374 nuclides and uses the Chebyshev Rational Approximation Method to solve the burnup equations [5].

4. Results

The accuracy of the MCS code for commercial PWR analysis is evaluated. The BOC calculation for cycle 1 of YGN3 is performed. The MCS and ST/R2 simulation were based on a 3D quarter core geometry.

In the MCS simulation, the fuel pins were divided into ten rings for Gd_2O_3 fuel and one ring for the normal fuel pins. All fuel pins were divided into ten axial meshes are used for TH feedback, neutronics, and burnup calculation. Power was tallied by mesh tally function with one-hundred axial meshes. Ten spacer grids are distributed from bottom to top fuel assemblies. In the STREAM calculation, the radial rings for Gd_2O_3 fuel pins and normal fuel pins are divided into ten and three, respectively. The spacer grids were smeared into coolant. RAST-K 2.0 divides 2x2 subassemblies with 46 axial meshes for calculation. The water reflector with a baffle is modeled in both MCS and ST/R2. The neutron XS library ENDF-B/VII.1 was used in the calculation for MCS and ST/R2.

At HZP, all materials are at 600K and all options (TH, Xe,) are turned off. For the HFP at the BOC, all options are turned on, and the inlet temperature set at 569.26K. The modeled conditions in MCS at HZP and HFP are shown in Table I.

Table I: The Summary of MCS Simulation.

	HZP	HFP
Power	2815 MW(t)	2815 MW(t)
Power Rating	0 %	100 %
Pressure	158.18 kg/cm^2	158.18 kg/cm^2
Inlet temperature	600K	569.26 K
Control rods	All rods out	All rods out
TH feedback	Off	On
Equi-Xenon	Off	On
OpenW library	Off	On

Table II shows the CBC comparison at HZP and HFP condition. The assembly wise power distributions are shown in Figs. 4 and 5. The core average axial power distribution are shown in Figs. 6 and 7. The nuclear design report (NDR) data is also used for comparison.

Table II: Comparison of the CBC at HZP, BOC HFP by MCS and ST/R2.

Core status	Critical Boron Concentration (ppm)			Differences (ppm)	
	NDR	ST/R2	MCS	MCS-NDR	MCS-ST/R2
HZP	1154	1115	1114±1.44	-39	-1
HFP	802	790	796±0.96	-6	6

ST/R2
MCS
Rel. Error(%)

	RMS	1.106
	Min	0.142
	Max	2.269

	H	J	K	L	M	N	P	R
1	1.022	0.862	0.571					
	1.016	0.866	0.575					
	-0.556	0.487	0.627					
2	1.249	1.202	1.149	1.023	0.574			
	1.231	1.190	1.138	1.029	0.580			
	-1.509	-0.982	-0.974	0.596	0.989			
3	1.076	1.235	0.850	1.268	1.105	0.680		
	1.063	1.224	0.851	1.258	1.097	0.689		
	-1.215	-0.915	0.152	-0.839	-0.656	1.250		
4	1.205	0.839	1.176	0.817	1.167	1.105	0.574	
	1.181	0.838	1.169	0.818	1.156	1.097	0.580	
	-2.011	-0.151	-0.593	0.142	-1.004	-0.656	0.989	
5	0.834	1.270	0.793	1.138	0.817	1.268	1.023	
	0.829	1.251	0.796	1.136	0.818	1.258	1.029	
	-0.544	-1.487	0.341	-0.195	0.142	-0.839	0.596	
6	1.181	0.831	1.157	0.793	1.176	0.850	1.149	0.571
	1.154	0.821	1.143	0.796	1.169	0.851	1.138	0.575
	-2.269	-1.151	-1.211	0.341	-0.593	0.152	-0.974	0.627
7	1.005	1.207	0.831	1.270	0.839	1.235	1.202	0.862
	0.983	1.194	0.821	1.251	0.838	1.224	1.190	0.859
	-2.241	-1.081	-1.151	-1.487	-0.151	-0.915	-0.982	-0.391
8	0.793	1.005	1.181	0.834	1.205	1.076	1.249	1.022
	0.783	0.983	1.154	0.829	1.181	1.063	1.231	1.016
	-1.202	-2.241	-2.269	-0.544	-2.011	-1.215	-1.509	-0.556

Fig. 4. The assembly wise power distribution comparison at HZP by MCS and ST/R2.

ST/R2
MCS
Rel. Error(%)

	RMS	1.571
	Min	0.004
	Max	3.344

	H	J	K	L	M	N	P	R
1	1.008	0.862	0.582					
	0.989	0.847	0.575					
	-1.842	-1.720	-1.149					
2	1.214	1.175	1.133	1.016	0.587			
	1.192	1.153	1.108	1.005	0.581			
	-1.791	-1.901	-2.194	-1.105	-1.050			
3	1.061	1.215	0.858	1.247	1.096	0.691		
	1.046	1.197	0.851	1.223	1.071	0.686		
	-1.436	-1.435	-0.791	-1.867	-2.307	-0.679		
4	1.199	0.852	1.171	0.831	1.156	1.096	0.587	
	1.183	0.851	1.165	0.831	1.139	1.076	0.580	
	-1.323	-0.111	-0.471	0.004	-1.491	-1.828	-1.209	
5	0.854	1.266	0.813	1.139	0.831	1.247	1.016	
	0.859	1.263	0.819	1.137	0.829	1.223	1.001	
	0.520	-0.186	0.675	-0.176	-0.193	-1.918	-1.498	
6	1.194	0.856	1.165	0.813	1.171	0.858	1.133	0.582
	1.201	0.869	1.174	0.821	1.164	0.851	1.103	0.573
	0.600	1.498	0.707	0.901	-0.602	-0.880	-2.609	-1.583
7	1.024	1.219	0.856	1.266	0.852	1.215	1.175	0.862
	1.034	1.250	0.872	1.270	0.854	1.192	1.143	0.839
	0.977	2.506	1.798	0.377	0.177	-1.914	-2.758	-2.700
8	0.822	1.024	1.194	0.854	1.199	1.061	1.214	1.008
	0.840	1.033	1.204	0.862	1.182	1.038	1.173	0.979
	2.208	0.838	0.869	0.932	-1.453	-2.194	-3.344	-2.834

Fig. 5. The assembly wise power distribution comparison at BOC by MCS and ST/R2.

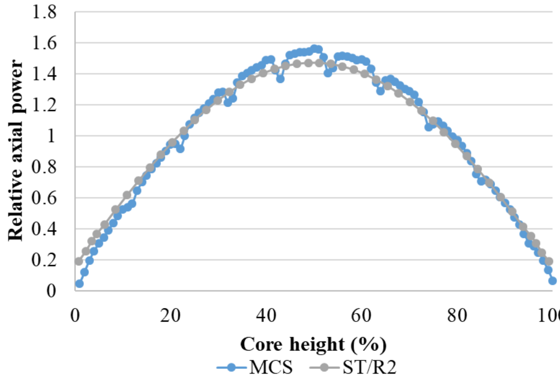

Fig. 6. The core average axial power distribution at HZP by MCS and ST/R2.

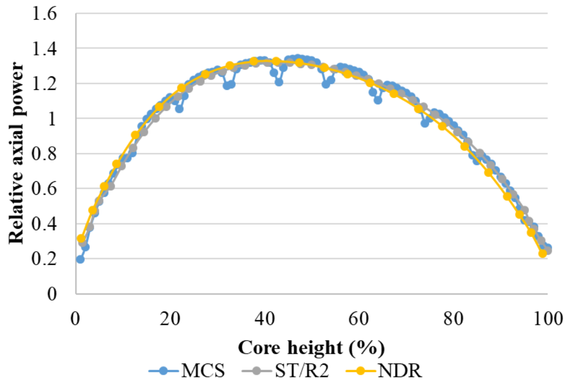

Fig. 7. The core average axial power distribution at BOC by MCS and ST/R2.

At HZP, the difference in CBC between MCS and ST/R2 is less than 1 ppm. The maximum radial power distribution difference is 2.269% compared between MCS and ST/R2. The RMS difference of assembly power is 1.106%. At the HFP, the CBC differences are 5.84 ppm between MCS and ST/R2, and -6.42ppm between MCS and NDR. The assembly wise power difference between MCS and ST/R2 is lower than 3.4%. The RMS difference of assembly power is 1.571%.

5. Conclusions

The Yonggwang unit 3 core cycle 1 was simulated by MCS. The critical boron concentration, core average axial power distribution and assembly wise power distribution at BOC, HZP and HFP were obtained by MCS and ST/R2. The comparison between MCS and ST/R2 results shows good agreement. The MCS and ST/R2 results were also compared to the NDR data and this shows good agreement. The maximum CBC difference between MCS and NDR is 39 ppm, between MCS and ST/R2 is 6 ppm. The assembly wise power difference between MCS and ST/R2 is less than 3.4%. In the future, the whole core depletion analysis for Yonggwang unit 3 multi-cycle will be conducted for further analysis of MCS.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT). (No.NRF2016M2B2A9A029452 05)

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