Verification of STREAM/RAST-K Code against Yonggwang Unit 3 Cycle 1

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1. Introduction

Various code systems have been developed to analyze the commercial reactor core. Recently, Ulsan National Institute of Science and Technology (UNIST) developed STREAM, a lattice code, and RAST-K, a nodal code. STREAM/RAST-K (ST/R2) code systems analyzes the characteristic of the reactor core using a two-step method. Because newly developed code requires verification, this paper presents the result of ST/R2 code verification work in Yonggwang Unit 3 (YGN3) cycle 1 compared with the results using MCS of Monte Carlo (MC) code. MCS code verification work has already been conducted in various condition so ST/R2 verification results are compared with the MCS code calculation results [1].

To verify the ST/R2 code, ST/R2 and MCS were simulated under hot zero power (HZP) and hot full power (HFP) conditions and two codes were compared as a result of radial power distribution and axial power distribution and critical boron concentration (CBC).

2. Code Description

2.1 STREAM/RAST-K Code

The flowchart of ST/R2 code is shown in Fig. 1 [2]. ST/R2 code are two-step code used to solve whole core problems. The STREAM (Steady state and Transient Reactor Analysis code with Method of Characteristics) code, a neutron transport analysis code, was developed for LWR whole core calculations. STREAM calculates Fuel Assembly (FA) and reflector to solve the transport equation and generates two-group cross section and group constants data. STN file generated after the STREAM calculation stores the cross section data and group constants for FA and reflector. [3]

STORA (STREAM to RAST-K) is a linking code that converts a STN (STREAM to Nodal code) file to a XS file used by RAST-K code.

RAST-K code is a 3-dimensional (3D) diffusion code using a two-group unified nodal method to solve the neutron diffusion equation. RAST-K code, which simulates whole core model, has been developed for use with high accuracy and performance in core design calculations, load-following simulations, and transient analysis in neutrons point of view. [4]

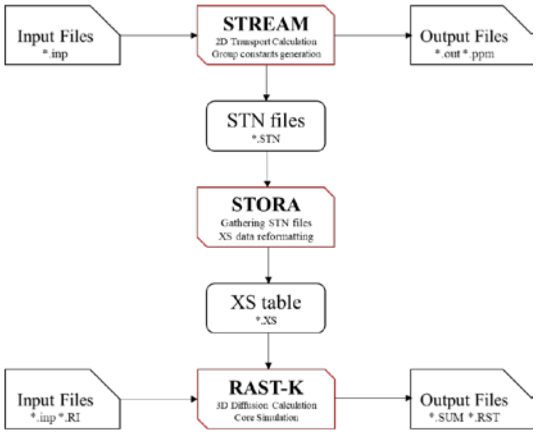

Fig. 1. Flowchart of STREAM/RAST-K code [2].

2.2 MCS Code

MCS code has been developed to analyze for the large scale reactor with accelerated Monte Carlo simulation. MCS uses continuous energy cross-section libraries and detailed geometrical data to estimate neutron design parameters of a nuclear reactor such as effective multiplication factor, neutron flux, and fission power [1].

3. Yonggwang Unit 3 Reactor Condition

The YGN3 reactor is PWR (pressurized light water reactor) type and use slightly enriched uranium dioxide (UO_2) pellets. This reactor is designed to produce thermal power of 2815MW for full power operation. The core was composed 177 assemblies (FA) of 16x16 array. Each assembly consists of 236 fuel rods and 5 guide tube. Table I shows the specification of each assembly used in YGN3 cycle1. The fuel enrichment of each assembly ranges from 1.3wt% to 3.36wt% and the enrichment of gadolinia is all 4wt%. [5]

Table I: Specification of fuel assemblies in YGN 3 cycle 1

Type	Fuel Enrichment (w/o U-235)	No. of Fuel Rods Per Assembly	No. of Gd Poison Rods Per Assembly
A0	1.30	236	-
B0	2.37	236	-
B1	2.36/1.30	176/52	8
B2	2.37	232	4
C0	2.87/2.35	184/52	-

C1	2.87/2.36	176/52	8
D0	3.35/2.87	184/52	-
D1	3.36/2.85	176/52	8
D2	3.35/2.87	128/100	8

4. Results

STREAM solves neutron transport equations for two-dimensional assembly and reflector models. So STREAM and ST/R2 code verification work was conducted using MCS code. The core consisted of a loading pattern of YGN3 cycle 1. The height was 1cm in MCS and ST/R2. Fuel temperature is 850K and moderator temperature is 600K. When performing 2-dimensional (2D) calculations, equilibrium xenon and Thermal-Hydraulics (TH) feedback were not considered. Neutron XS library ENDF-B / VII.1 was used for the calculation. Exceptionally, however, the Pu-239 nuclide used the JENDL library. MCS calculations used 20 inactive cycles and 200 active cycles and a neutron history of 400000, and deviation of the $\boldsymbol{k_{eff}}$ value is about 11pcm. Fig. 2-3 shows the radial power distribution, and Table II shows $\boldsymbol{k_{eff}}$ in the absence xenon.

	8	9	10	11	12	13	14	15
H	0.941 0.931 -1.08	1.168 1.152 -1.34	1.355 1.339 -1.25	0.928 0.921 -0.75	1.259 1.248 -0.82	1.033 1.032 -0.11	1.118 1.126 0.70	0.892 0.911 2.18
J	1.168 1.152 -1.34	1.402 1.395 -0.45	0.955 0.949 -0.71	1.379 1.365 -1.06	0.878 0.875 -0.25	1.193 1.192 -0.05	1.079 1.086 0.66	0.759 0.772 1.71
K	1.355 1.339 -1.25	0.955 0.949 -0.71	1.283 1.269 -1.02	0.856 0.852 -0.40	1.189 1.186 -0.31	0.819 0.813 -0.73	1.032 1.042 0.96	0.509 0.516 1.42
L	0.928 0.921 -0.75	1.379 1.365 -1.06	0.856 0.852 -0.40	1.167 1.162 -0.41	0.805 0.806 0.22	1.161 1.168 0.54	0.910 0.925 1.68	
M	1.259 1.248 -0.82	0.878 0.875 -0.25	1.189 1.186 -0.31	0.805 0.806 0.22	1.078 1.083 0.54	0.978 0.985 0.75	0.510 0.518 1.52	
N	1.033 1.032 -0.11	1.193 1.192 -0.05	0.819 0.813 -0.73	1.161 1.168 0.54	0.978 0.985 0.75	0.600 0.608 1.35		
P	1.118 1.126 0.70	1.079 1.086 0.66	1.032 1.042 0.96	0.910 0.925 1.68	0.510 0.518 1.52		RMS 1.02% Max 2.18%	
R	0.892 0.911 2.18	0.759 0.771 1.69	0.509 0.516 1.42				RAST-K(A) MCS(B) Diff.(%)[(B-A)/A]	

Fig. 2. Assembly power distribution comparison by ST/R2 and MCS in 2D.

	8	9	10	11	12	13	14	15
H	0.936 0.931 -0.56	1.160 1.152 -0.67	1.350 1.339 -0.81	0.925 0.921 -0.43	1.255 1.248 -0.57	1.033 1.032 -0.16	1.122 1.126 0.37	0.896 0.911 1.71
J	1.160 1.152 -0.67	1.398 1.395 -0.19	0.953 0.949 -0.52	1.373 1.365 -0.61	0.877 0.875 -0.22	1.193 1.192 -0.04	1.082 1.086 0.37	0.764 0.772 0.96
K	1.350 1.339 -0.81	0.953 0.949 -0.52	1.276 1.269 -0.55	0.853 0.852 -0.13	1.188 1.186 -0.22	0.817 0.813 -0.49	1.038 1.042 0.40	0.511 0.516 0.86
L	0.925 0.921 -0.43	1.373 1.365 -0.61	0.853 0.852 -0.13	1.165 1.162 -0.26	0.805 0.806 0.14	1.163 1.168 0.35	0.918 0.925 0.81	
M	1.255 1.248 -0.57	0.877 0.875 -0.22	1.188 1.186 -0.22	0.805 0.806 0.14	1.080 1.083 0.31	0.981 0.985 0.40	0.513 0.518 0.80	
N	1.033 1.032 -0.16	1.193 1.192 -0.04	0.817 0.813 -0.49	1.163 1.168 0.35	0.981 0.985 0.40	0.603 0.608 0.77		
P	1.122 1.126 0.37	1.082 1.086 0.37	1.038 1.042 0.40	0.918 0.925 0.81	0.513 0.518 0.80		RMS 0.77% Max 1.71%	
R	0.896 0.911 1.71	0.764 0.771 0.95	0.511 0.516 0.86				STREAM 2D(A) MCS(B) Diff.(%)[(B-A)/A]	

Fig. 3. Assembly power distribution comparison by STREAM 2D and MCS in 2D.

Table II: Multiplication factors of 2D model

Code Type	$\boldsymbol{k_{eff}}$	Difference from MCS 2D (pcm)
MCS 2D	1.04456	-
STREAM/RAST-K	1.04484	28
STREAM 2D	1.04468	12

The assembly power difference between ST/R2 and MCS 2D is less than 2.18%. The RMS difference of assembly power is 1.02%. The assembly power difference between STREAM 2D and MCS 2D is less than 1.71%. The RMS difference of assembly power is 0.77%. Compared with MCS, the $\boldsymbol{k_{eff}}$ in the absence xenon difference are 28pcm, 12pcm in ST/R2 and STREAM, respectively.

When calculating the 3-dimensional (3D) model, the following conditions were set. In the STREAM calculation, the fuel pins were divided into three ring for the normal fuel pins and ten rings for Gd_2O_3 fuel pin. RAST-K divided into 2x2 subassemblies with 46 axial meshes for calculation. In the MCS calculation, the fuel pins were divided into one ring for the normal fuel pins and ten rings for Gd_2O_3 fuel pin. All fuel pins were divided into ten axial meshes is used for burnup calculation. Spacer grids were modeled homogeneously in moderator and the water reflector with a baffle is modeled in ST/R2 and MCS. The library used for calculations is the same as the library used for 2D calculations.

At HZP, Fuel and moderator temperature are 600K and equilibrium xenon and Thermal-Hydraulics (TH) feedback were not considered. The fuel and moderator temperatures in HFP are 850K and 584K, respectively, which are average temperatures. Equilibrium xenon and TH feedback is considered in the calculation. The power and pressure are same to 2815MW(t) and 158.18kg/cm^2, and all control rods are out.

Fig. 4. show assembly power distribution at HZP by ST/R2 and MCS. At HZP, the maximum radial power distribution difference is 2.24% compared between ST/R2 and MCS. The RMS difference of assembly power is 1.08%. Fig. 5-7. shows assembly wise power distribution at HFP BOC, MOC, EOC by ST/R2 and MCS. At HFP, the maximum radial power distribution difference is 2.71%, 1.98%, and 2.19%, respectively. The RMS difference of assembly power is 1.38%, 0.76%, and 0.82% at BOC, MOC, EOC, respectively. Fig. 8. show core average axial power distribution at HFP. The CBC is shown in Fig. 9. The maximum CBC difference in HFP is 26 pcm.

	8	9	10	11	12	13	14	15
	0.785	0.996	1.171	0.826	1.196	1.068	1.240	1.012
H	0.775	0.975	1.145	0.821	1.173	1.055	1.223	1.007
	-1.17	-2.18	-2.24	-0.58	-1.97	-1.20	-1.40	-0.49
	0.996	1.196	0.823	1.261	0.831	1.226	1.193	0.854
J	0.975	1.183	0.813	1.243	0.830	1.217	1.182	0.858
	-2.18	-1.04	-1.17	-1.44	-0.12	-0.74	-0.98	0.42
	1.171	0.823	1.148	0.786	1.167	0.842	1.141	0.566
K	1.145	0.813	1.134	0.789	1.161	0.843	1.130	0.570
	-2.24	-1.17	-1.19	0.47	-0.53	0.09	-0.95	0.72
	0.826	1.261	0.786	1.129	0.810	1.260	1.015	
L	0.821	1.243	0.789	1.127	0.812	1.250	1.021	
	-0.58	-1.44	0.47	-0.17	0.22	-0.75	0.60	
	1.196	0.831	1.167	0.810	1.159	1.097	0.569	
M	1.173	0.830	1.161	0.812	1.149	1.090	0.575	
	-1.97	-0.12	-0.53	0.22	-0.92	-0.68	1.05	
	1.068	1.226	0.842	1.260	1.097	0.675		
N	1.055	1.217	0.843	1.250	1.090	0.684		
	-1.20	-0.74	0.09	-0.75	-0.68	1.38		
	1.240	1.193	1.141	1.015	0.569			RMS 1.08%
P	1.223	1.182	1.130	1.021	0.575			Max 2.24%
	-1.40	-0.98	-0.95	0.60	1.05			
	1.012	0.854	0.566					RAST-K(A)
R	1.007	0.852	0.570					MCS(B)
	-0.49	-0.21	0.72					Diff.(%)[(B-A)/A]

Fig. 4. Assembly power distribution comparison at HZP by ST/R2 and MCS.

	8	9	10	11	12	13	14	15
	0.808	1.014	1.187	0.842	1.193	1.053	1.212	0.999
H	0.824	1.007	1.178	0.853	1.175	1.043	1.194	1.002
	1.95	-0.62	-0.78	1.33	-1.47	-0.94	-1.47	0.39
	1.014	1.215	0.844	1.263	0.840	1.211	1.171	0.849
J	1.010	1.227	0.860	1.252	0.853	1.198	1.156	0.857
	-0.35	1.03	1.85	-0.88	1.47	-1.06	-1.32	0.95
	1.187	0.844	1.159	0.801	1.165	0.847	1.127	0.569
K	1.182	0.858	1.157	0.818	1.160	0.857	1.113	0.581
	-0.39	1.72	-0.15	2.02	-0.45	1.14	-1.27	2.24
	0.842	1.263	0.801	1.133	0.819	1.247	1.010	
L	0.854	1.252	0.817	1.130	0.834	1.233	1.020	
	1.41	-0.83	2.01	-0.25	1.75	-1.16	1.07	
	1.193	0.840	1.165	0.819	1.152	1.090	0.575	
M	1.179	0.852	1.159	0.834	1.147	1.088	0.591	
	-1.20	1.42	-0.52	1.83	-0.45	-0.21	2.71	
	1.053	1.211	0.847	1.247	1.090	0.679		
N	1.038	1.192	0.853	1.238	1.090	0.697		
	-1.40	-1.54	0.76	-0.75	0.01	2.69		
	1.212	1.171	1.127	1.010	0.575			RMS 1.38%
P	1.184	1.150	1.113	1.019	0.590			Max 2.71%
	-2.26	-1.79	-1.27	0.98	2.70			
	0.999	0.849	0.569					RAST-K(A)
R	0.998	0.853	0.577					MCS(B)
	-0.05	0.49	1.54					Diff.(%)[(B-A)/A]

Fig. 5. Assembly power distribution comparison at HFP BOC by ST/R2 and MCS.

	8	9	10	11	12	13	14	15
	0.855	1.034	1.101	0.885	1.144	1.136	1.216	0.869
H	0.853	1.030	1.102	0.882	1.150	1.146	1.235	0.886
	-0.24	-0.38	0.11	-0.29	0.55	0.91	1.56	1.98
	1.034	1.101	0.875	1.254	0.904	1.172	1.169	0.756
J	1.039	1.105	0.871	1.251	0.902	1.183	1.180	0.770
	0.48	0.39	-0.51	-0.31	-0.22	0.95	0.98	1.82
	1.101	0.875	1.180	0.896	1.206	0.902	1.094	0.527
K	1.109	0.876	1.182	0.892	1.204	0.902	1.096	0.538
	0.71	0.12	0.17	-0.53	-0.18	0.05	0.18	1.96
	0.885	1.254	0.896	1.207	0.919	1.243	0.919	
L	0.887	1.255	0.891	1.206	0.913	1.236	0.920	
	0.24	0.08	-0.62	-0.09	-0.63	-0.59	0.17	
	1.144	0.904	1.206	0.919	1.221	1.113	0.549	
M	1.150	0.904	1.204	0.909	1.212	1.098	0.545	
	0.55	0.08	-0.16	-1.10	-0.68	-1.35	-0.59	
	1.136	1.172	0.902	1.243	1.113	0.670		
N	1.144	1.179	0.898	1.236	1.102	0.666		
	0.66	0.61	-0.41	-0.63	-1.04	-0.65		
	1.216	1.169	1.094	0.919	0.549			RMS 0.76%
P	1.212	1.162	1.078	0.915	0.550			Max 1.98%
	-0.30	-0.55	-1.44	-0.41	0.19			
	0.869	0.756	0.527					RAST-K(A)
R	0.864	0.754	0.526					MCS(B)
	-0.60	-0.32	-0.35					Diff.(%)[(B-A)/A]

Fig. 6. Assembly power distribution comparison at HFP MOC by ST/R2 and MCS.

	8	9	10	11	12	13	14	15
	0.934	1.075	1.123	0.945	1.122	1.087	1.131	0.849
H	0.933	1.076	1.112	0.941	1.113	1.078	1.113	0.837
	-0.15	0.06	-0.93	-0.46	-0.83	-0.83	-1.60	-1.42
	1.075	1.126	0.945	1.244	0.944	1.120	1.106	0.759
J	1.074	1.118	0.946	1.232	0.939	1.108	1.094	0.755
	-0.07	-0.66	0.10	-0.93	-0.46	-1.03	-1.07	-0.59
	1.123	0.945	1.187	0.952	1.180	0.928	1.066	0.561
K	1.123	0.950	1.190	0.954	1.171	0.924	1.058	0.565
	0.06	0.55	0.29	0.14	-0.84	-0.38	-0.77	0.78
	0.945	1.244	0.952	1.188	0.951	1.190	0.912	
L	0.956	1.249	0.961	1.187	0.951	1.179	0.910	
	1.16	0.43	0.90	-0.09	0.05	-0.95	-0.27	
	1.122	0.944	1.180	0.951	1.168	1.083	0.580	
M	1.134	0.956	1.188	0.956	1.165	1.079	0.587	
	1.12	1.26	0.61	0.54	-0.28	-0.34	1.25	
	1.087	1.120	0.928	1.190	1.083	0.692		
N	1.096	1.124	0.932	1.187	1.084	0.699		
	0.79	0.33	0.49	-0.24	0.09	1.09		
	1.131	1.106	1.066	0.912	0.580			RMS 0.82%
P	1.135	1.111	1.070	0.918	0.592			Max 2.19%
	0.34	0.49	0.38	0.63	2.08			
	0.849	0.759	0.561					RAST-K(A)
R	0.852	0.765	0.573					MCS(B)
	0.34	0.69	2.19					Diff.(%)[(B-A)/A]

Fig. 7. Assembly power distribution comparison at HFP EOC by ST/R2 and MCS.

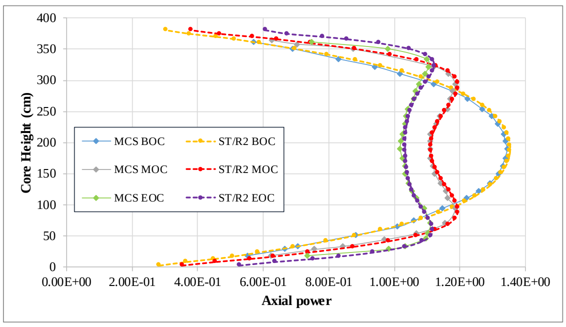

Fig. 8. The core average axial power distribution at HFP by ST/R2 and MCS.

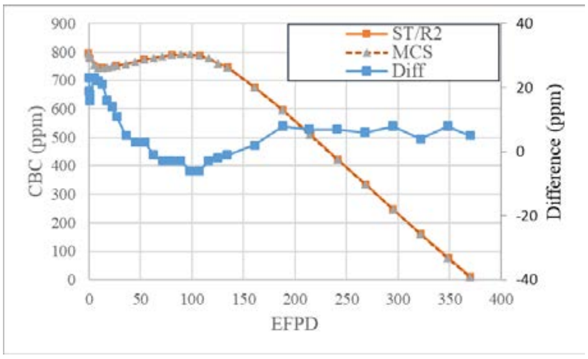

Fig. 9. Comparison of the CBC at HFP by ST/R2 and MCS.

5. Conclusions

This paper presents comparison of ST/R2 code and MCS code for YGN3 cycle 1. Radial power distribution, axial power distribution and CBC at HFP were compared by two codes.

Compared to MCS, RMS of radial power distribution is 1.02, 0.77 by ST/R2 and STREAM 2D in 2D calculation, respectively. The maximum assembly power difference is 2.71%, and maximum RMS is 1.38%. The shape of the axial is similar at BOC, MOC, EOC by ST/R2 and MCS. At HFP, the maximum difference of CBC is 26pcm by ST/R2 and MCS. In conclusion, the ST/R2 code can be utilized as a commercial light-water reactor core analysis code when compared with the already verified MCS code, and verification of various types of reactors should be performed in the future.

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