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NDR Data Generation Capabilities of STREAM/RAST-K 2.0 Code System

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1. Introduction

STREAM/RAST-K 2.0 is a two-step approach nuclear reactor analysis code system for the design and analysis of Light Water Reactors (LWRs) that is currently under development by the Computational Reactor Physics and Experiment Lab (CORE) at the Ulsan National Institute of Science and Technology (UNIST).

RAST-K 2.0 is a nodal diffusion reactor core analysis code for Pressurized Water Reactor (PWR) analysis. STREAM is a lattice physics code which solves the transport equation to generate the nuclear data of the fuel assemblies and reflector models which is to be used in RAST-K 2.0. STORA combines and formats the cross section and group constant data (output of STREAM) for use in RAST-K 2.0. The goal of the developers is to ensure that the code system is capable of generating extensive and accurate core analysis data. One of the most important nuclear analysis documents that is produced in the Korean nuclear industry is the Nuclear Design Report (NDR), prepared by Kepco Nuclear Fuel Co., Ltd. (KNF).

In this paper, the capabilities of the code system are explored by attempting to reproduce the data typically contained in the NDR. The target reactor is OPR1000, which is a PWR with thermal core power of 2815 MWth. It is designed to provide 13800 MWD/MTU energy extraction in the initial cycle. From this study, the shortcomings of the code can be identified, so that the additional required capabilities may be incorporated.

2. STREAM/RAST-K 2.0 capabilities

At the onset of the investigation the following set of NDR nuclear data, which is widely used in core design and analysis, could directly be reproduced by the STREAM/RAST-K 2.0 code system:

- Critical boron concentration
- Axial power distribution
- Radial power and burnup distributions
- Control rod worth
- Isotopic inventories for fuel assemblies

The pre-existing capabilities are demonstrated in section 2.1. The isotopic inventories are not presented in this paper.

Additional capabilities have already been incorporated in the code system during this investigation to assist in generating NDR data. The newly added capabilities are presented in section 2.2. These new capabilities are:

- Assembly wise pin peaking factor
- Boron worth
- Extension of branch calculation output parameters
- Average fuel temperature change
- Temperature coefficients
- Boron concentration requirements for target k_{eff}
- Shutdown margin

2.1. Pre-existing STREAM/RAST-K 2.0 capabilities

Fig.1 shows the critical boron concentration requirements for the depletion of the core. The results that were generated from STREAM/RAST-K 2.0 show a good correlation with the true NDR data (generated with DIT/ROCS), with a maximum absolute difference of 35ppm. There are two reasons for the difference in the results from STREAM/RAST-K 2.0 and DIT/ROCS. Firstly, STREAM/RAST-K 2.0 uses combined JENDLE4.0 and ENDF/B-VII.1 cross section data, while DIT/ROCS uses and older version of ENDF. Secondly, in DIT/ROCS, the top, bottom, and radial reflectors are not explicitly modeled as in STREAM/RAST-K 2.0.

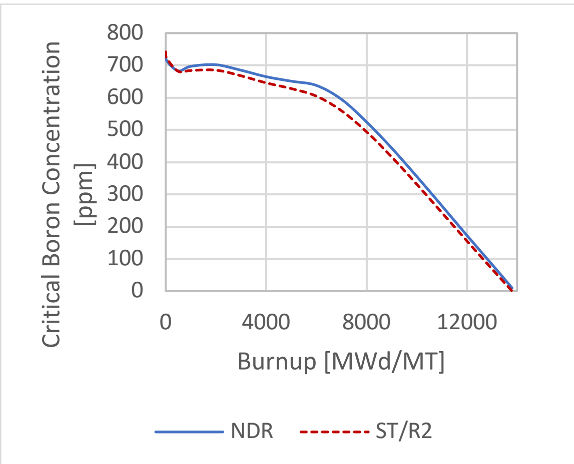

Fig. 1. Critical boron concentration vs. cycle burnup

The average axial power distributions at Beginning Of Cycle (BOC) and End Of Cycle (EOC) are shown in Fig. 2 and Fig. 3. At BOC and EOC the generated results agree very well with the data in the NDR.

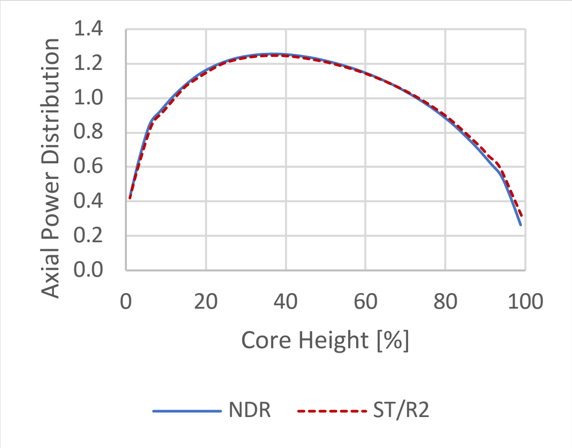

Fig. 2. Average axial power distribution at BOC

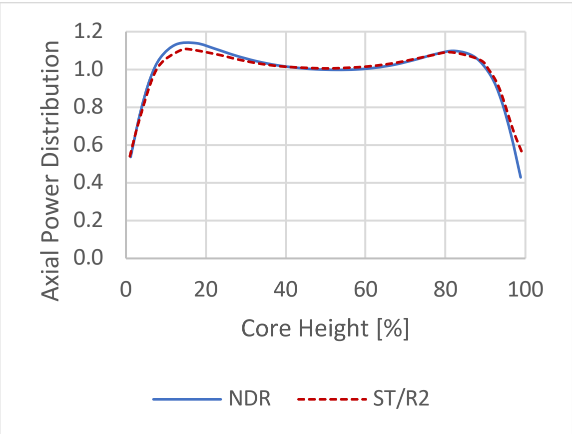

Fig. 3. Average axial power distribution at EOC

Fig. 4 shows the STREAM/RAST-K 2.0 generated radial power and burnup distribution at EOC. Relative to the NDR values, the power and burnup distributions both have maximum absolute errors less than 5% and RMS values of 1.9 and 1.72, respectively.

				FA Power	0.64	0.80	0.88
				FA Burnup	8462	11081	12525
			0.63	0.92	1.09	1.18	1.14
			8263	12741	14781	16266	16007
		0.77	1.07	0.92	1.15	0.96	0.95
		10155	14310	12443	16299	13127	12959
	0.63	1.07	1.18	1.17	0.97	1.23	0.96
	8263	14310	16521	16840	13478	17495	13161
	0.92	0.92	1.17	0.98	1.19	0.98	1.19
	12741	12443	16840	13711	17251	13457	16944
0.64	1.09	1.15	0.97	1.19	0.98	1.23	0.95
8462	14781	16299	13478	17251	13429	17030	12639
0.80	1.18	0.96	1.23	0.98	1.23	0.91	0.88
11081	16266	13127	17495	13457	17030	11938	11348
0.88	1.14	0.95	0.96	1.19	0.95	0.88	0.84
12525	16007	12959	13161	16944	12639	11348	10657

Fig. 4. Radial power and burnup distribution

Table I below shows a summary of the control rod group worths and accumulated control rod worths, as generated by the code system. The control rod group worths were assessed at BOC and EOC while the core was at Hot Full Power (HFP), and again at BOC and EOC while the core was at Hot Zero Power (HZP). A maximum absolute error of 7.2% was obtained for the accumulated rod worth in comparison to the data contained in the NDR.

Table I. Summary of control rod group worths

Group	BOC HFP, Eq.Xe		EOC HFP, Eq.Xe	
	Group Worth (pcm)	Accumulated Worth (pcm)	Group Worth (pcm)	Accumulated Worth (pcm)
5	435	435	442	442
4	567	1002	613	1055
3	654	1656	657	1711
2	751	2407	864	2576
1	1449	3856	1598	4174
B	5164	9019	5757	9931
A	8973	17993	8775	18706
Group	BOC HZP, No Xe		EOC HZP, HFP Eq.Xe	
	Group Worth (pcm)	Accumulated Worth (pcm)	Group Worth (pcm)	Accumulated Worth (pcm)
5	360	360	376	376
4	497	857	544	920
3	672	1529	580	1500
2	621	2150	570	2070
1	1239	3388	1418	3488
B	3693	7081	3651	7139
A	8565	15646	9532	16671

2.2. Newly implemented STREAM/RAST-K 2.0 capabilities

Some additional capabilities have already been implemented in the code system during this study. In this section, these new capabilities are demonstrated.

Assembly wise pin peaking factors are presented in the NDR. Therefore, this capability has been added to the STREAM/RAST-K 2.0 code system. Fig. 5 shows the assembly wise pin peaking factors that were generated by the code system.

				Fxy	1.59	1.36	1.33
			1.58	1.38	1.19	1.11	1.12
		1.50	1.21	1.10	1.08	1.08	1.07
	1.58	1.21	1.07	1.08	1.08	1.08	1.08
	1.38	1.10	1.08	1.07	1.08	1.08	1.08
1.59	1.19	1.08	1.08	1.08	1.08	1.08	1.09
1.36	1.11	1.08	1.08	1.08	1.08	1.11	1.08
1.33	1.12	1.07	1.08	1.08	1.09	1.08	1.05

Fig. 5. Assembly wise pin peaking factors

Another new capability that was implemented in the code system enables the calculation of the boron worth. The boron worth as a function of cycle burnup which was calculated from STREAM/RAST-K 2.0 is shown in Fig. 6. The boron worth calculated from the code system has a maximum absolute error of 1.32% relative to the original NDR boron worth.

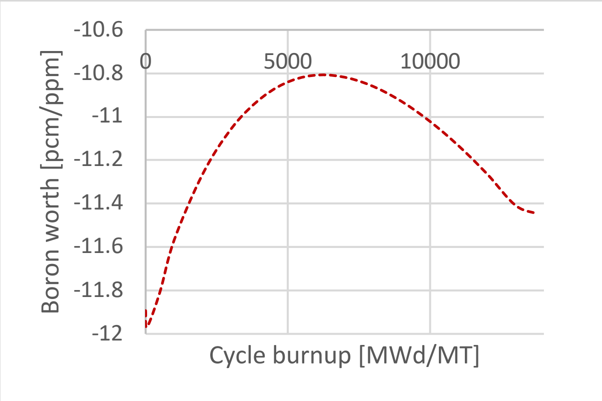

Fig. 6. Boron worth vs. cycle burnup

Originally the output of a STREAM/RAST-K 2.0 branch calculation only displayed the case number, case name, and effective multiplication factor (k_{eff}). The branch calculation output was expanded to also include the average fuel temperature, average moderator temperature, and boron concentration. Adding these parameters to the branch output has enabled the calculation of the average fuel temperature as a function of power level (demonstrated in Fig. 7) and the manual calculation of temperature coefficients.

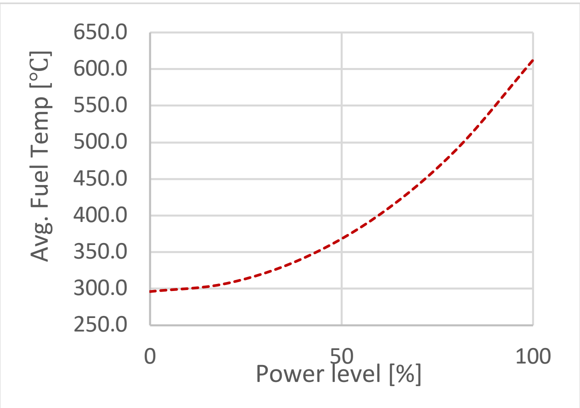

Fig. 7. Average fuel temperature as a function of power

Additionally, a new option card was created which would let the code system automatically calculate the Moderator Temperature Coefficient (MTC), Fuel Temperature Coefficient (FTC), and Isothermal Temperature Coefficient (ITC), as a function of cycle burnup. The results generated when specifying this card are presented in Fig. 8 to Fig.10.

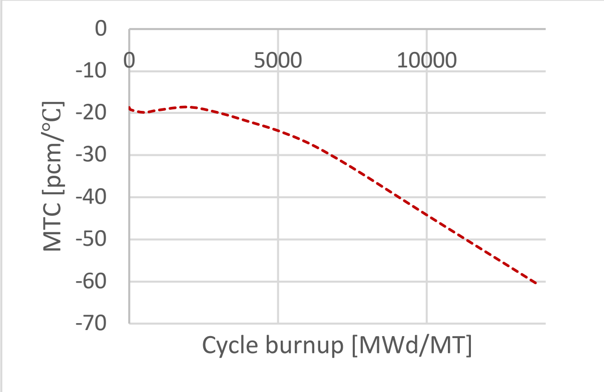

Fig. 8. MTC vs. cycle burnup

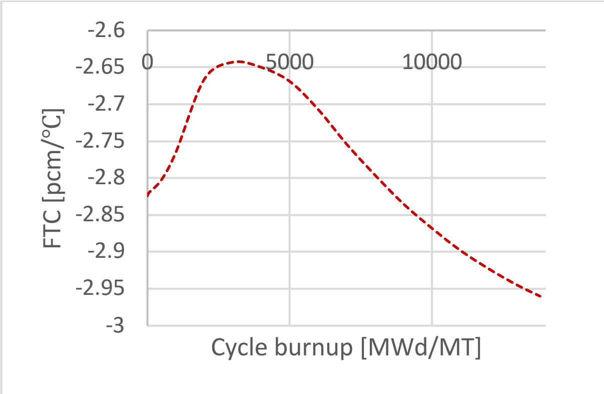

Fig. 9. FTC vs. cycle burnup

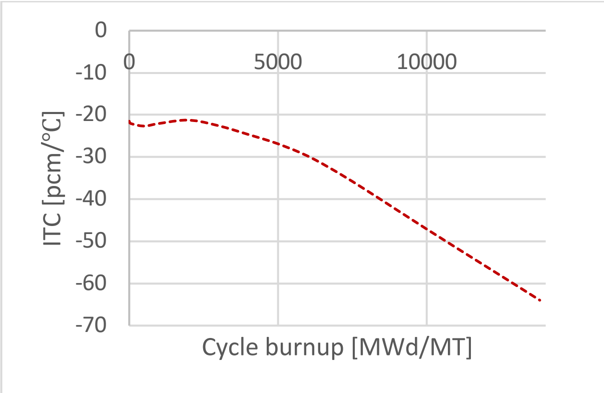

Fig. 10. ITC vs. cycle burnup

Another additional capability that has already been implemented in the code system during this investigation is the option to calculate the required boron worth to achieve a desired k_{eff} value. For this new capability, the output shown in Fig. 11 is obtained when specifying a target k_{eff} value of 0.95 at BOC and HZP conditions. This boron concentration value has less than 0.7% difference from the value provided in the NDR.

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  CYC-BU      P(%)      PPM     K-EFF     REACTIVITY
----------------------------------------------------
  0.0000     0.0001  1540.40  0.950000   -0.052632
```

Fig. 11. Boron concentration for target k_{eff}

The final additional capability that was recently implemented in STREAM/RAST-K 2.0 is the ability to calculate shutdown margin. The shutdown margin that was calculated with STREAM/RAST-K 2.0 is presented in Table II. The STREAM/RAST-K 2.0 calculated shutdown margin value is within 2.5% of the shutdown margin provided in the NDR.

Table II. Shutdown margin

	HFP	HZP
A. Control Rod Requirements (pcm)		
Power Defect	2193.21	0
Doppler		
Moderator Temperature		
Redistribution		
Rod Insertion Allowance	270	1660
Total Requirements	2463	1660
Largest Total	2463	
B. Control Rod Worth (pcm)		
Scram (N-1) Worth	11409	
Uncertainty Allowance (2.15%)	245	
Remaining Worth	11164	
C. Shutdown Margin (pcm)		
Calculated Shutdown Margin (B-A)	8701	
Required Shutdown Margin	6500	

3. Conclusion

As shown in this study, the STREAM/RAST-K 2.0 code system has the capabilities required to generate many of the desired NDR data. As demonstrated in section 2.1, at the onset of the investigation the code system was already capable of generating some of the data contained in the NDR. During the investigation, some additional capabilities were implemented in the code system. The newly implemented capabilities were demonstrated in section 2.2.

Table III. STREAM/RAST-K 2.0 NDR data generation capability status

Data contained in NDR	Y/N
Critical Boron Concentration	Y
Core Average Axial Power Distributions	Y
Isotopic Inventories for Assembly Types	Y
Isotopic Inventory for Gadolinia Fuel Pin	N
Radial Power and Burnup Distributions	Y
Burnable Absorber Worth vs. Cycle Burnup	N
Core Average Fuel Temperature vs. Power Level	Y
Temperature Coefficients	Y
Temperature Defects	N
Boron Worth	Y
Boron Concentration Requirements	Y
Summary of Control Rod Worths	Y
Shutdown Margin	Y

Table III summarizes all the data contained in the NDR and the current status of the STREAM/RAST-K 2.0 code system capabilities. The code system is still being revised further to include the remaining capabilities required to accurately reproduce the complete set of data contained in the NDR.

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