Preliminary Study for Validation and Verification of STREAM/RAST-K 2.0 Transient Calculation with DCRM Benchmark

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1. Introduction

This paper presents preliminary study for the validation and verification results of STREAM/RAST-K 2.0 dynamic control rod reactivity measurement (DCRM) calculation at the transient states. When there is a problem or serious accident occurring in the reactor, it is very important to analyze the reactor quickly and accurately. At that time, there are many unpredictable changes in the reactor, that is, the reactor experiences a series of transient states. Therefore, the verification and validation of the transient state calculation of the STREAM/RAST-K 2.0 code system developed by Computational Reactor Physics and Experiment laboratory (CORE) in Ulsan National Institute Science and Technology (UNIST) is required.

In this study, DCRM calculations for the OPR1000 cycles N and N+1 have been conducted using the STREAM/RAST-K 2.0 as a way to verify and validate its transient calculation ability. The results of dynamic and static reactivity at the transient states by STREAM/RAST-K 2.0 are compared with the proven code RAST-K 1.0 and measured data to evaluate its reliability for the transient calculation. The RAST-K 1.0 code is a licensed code, so it can be used as a reference.

2. Description of Core Design and Calculation Code System

2.1 OPR1000 core design

The reactor is composed of 177 fuel assemblies. The fuel assemblies are arranged to approximate a circular cylinder with the same fuel length of 381cm. Each fuel assembly consists of 16 by 16 array of water holes, normal fuel rods, lower enrichment fuel rods and gadolinia-bearing fuel rods. All components which affect the core nuclear design such as, fuel rods, control rods and other structures must be considered in the design. The core loading patterns for OPR1000 cycles N and N+1 are shown in Fig. 1. and Fig. 2. In addition, the general OPR1000 core parameters are listed in Table I.

In the reactor core, there are three types of assemblies for each cycle. In cycle N, type Q is new fuel, type P is once-burned fuel and type O is twice-burned fuel. While in cycle N+1, type R is new fuel, type Q is once-burned fuel and type P is twice-burned fuel. The enrichment of all fuel assemblies is 4.50 w/o.

Table I: Test model description

Reactor Model	OPR1000
Reactor Power [MW_{th}]	2,815
Fuel Assembly Model	16×16 GUARDIAN, PLUS7
Simulated Cycles	Cycles N and N+1

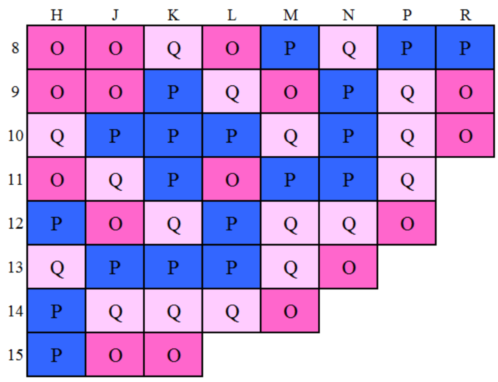

Fig. 1. Core loading pattern for OPR1000 cycle N.

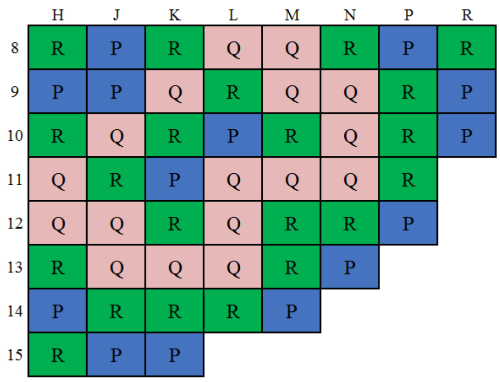

Fig. 2. Core loading pattern for OPR1000 cycle N+1.

2.2. Simulation code system of the STREAM/RAST-K 2.0

The STREAM/RAST-K 2.0 calculation procedure is shown in Fig. 3. The STREAM code generates stn files with 2D transport calculation of fuel assemblies. Next, the stn files are processed by the STORA code to reformat the cross-section data. Finally, the 3D whole core diffusion calculation is conducted by the RAST-K 2.0 code.

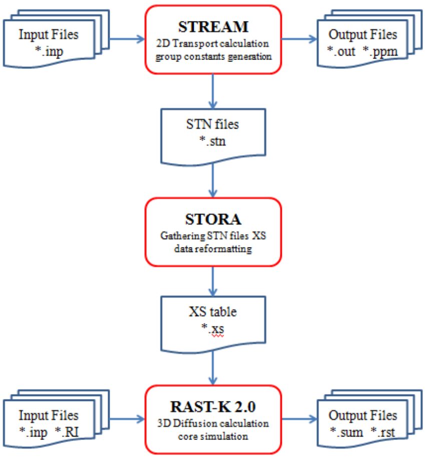

Fig. 3. STREAM/RAST-K 2.0 two-step approach.

3. Validation and Verification of Transient Calculation

3.1. Introduction of DCRM

DCRM is one of the zero power physics tests that measures the control rod reactivity. The current method for the control rod worth measurement consists of rod swap and boron dilution. This method inserts the control bank and measure the static reactivity after the reactor reaches steady state by steps. It has the disadvantages that it takes too long time and generates the liquid waste, boron. However, DCRM method inserts the control bank without waiting, measures the dynamic reactivity and converts the dynamic reactivity directly into the static reactivity. It can save time compared to the current method, improve the economic efficiency of the nuclear power plant and reduce the liquid waste.

In this paper, the dynamic reactivity, static worth and dynamic to static worth conversion factor (DSCF) are calculated by the STREAM/RAST-K 2.0. DSCF is a factor used to convert the dynamic reactivity to the static reactivity and it is obtained as shown in Eq. (1). The STREAM/RAST-K 2.0 results are verified and validated with the measured data and RAST-K 1.0 results.

The procedures of the verification and validation are as follows and shown in Fig. 4. First, the dynamic reactivity is calculated by the STREAM/RAST-K 2.0 and compared with the measured data and the RAST-K 1.0 result. At the same time, DSCF and the static reactivity are calculated by the STREAM/RAST-K 2.0 are compared with the RAST-K 1.0 results. Finally, the dynamic reactivity from RAST-K 1.0 calculation and measurement are converted to the static reactivity using the DSCF calculated by RAST-K 1.0 and compared with the static reactivity calculated by STREAM/RAST-K 2.0.

$$\mathrm{DSCF} = \frac{\rho^{static}}{\rho^{dynamic}} \qquad (1)$$

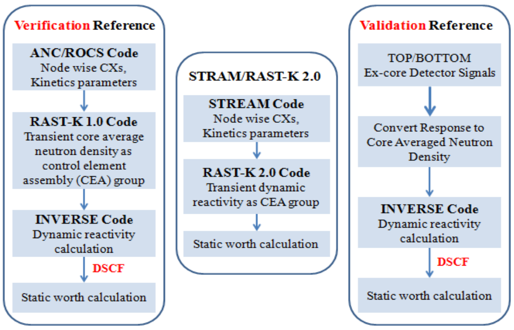

Fig. 4. Validation and Verification of the STREAM/RAST-K 2.0.

3.2. DCRM calculation for OPR1000 cycles N and N+1

There are control rod banks from RG1 to RG5 in the OPR1000 cycles N and N+1. The dynamic reactivity, DSCF and static reactivity are calculated for the control bank from RG1 to RG5 rod group and results for RG2 and RG4 rod groups are plotted.

3.2.1. Validation and verification results for RG2 and RG4 rod groups of cycle N

Validation and verification results of dynamic reactivity for RG2 and RG4 rod groups of cycle N are shown in Fig. 6. and Fig. 8. Also, verification results of DSCF for RG2 and RG4 rod groups of cycle N are shown in Fig. 5. and Fig. 7.

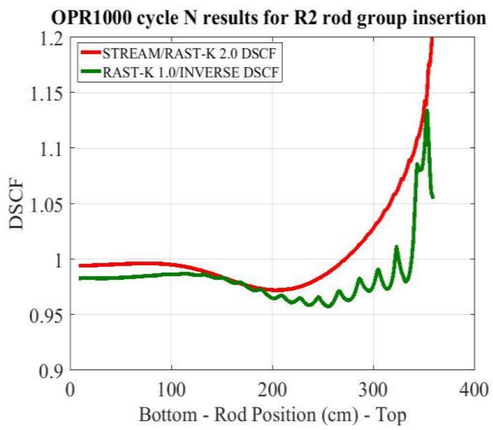

Fig. 5. DSCF for OPR1000 cycle N RG2 rod group.

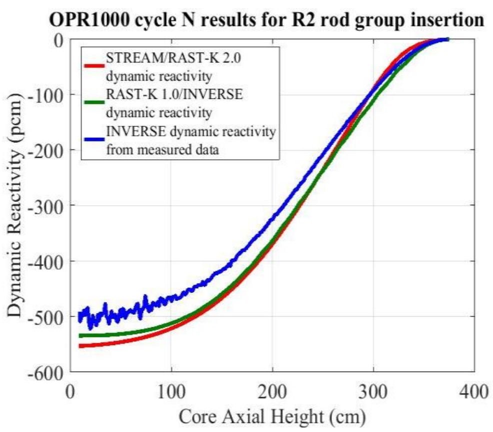

Fig. 6. Dynamic reactivity for OPR1000 cycle N RG2 rod group.

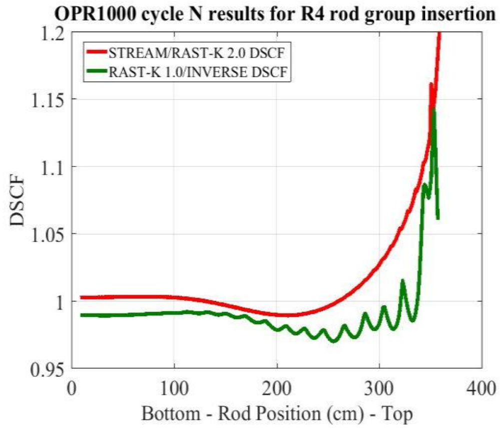

Fig. 7. DSCF for OPR1000 cycle N RG4 rod group.

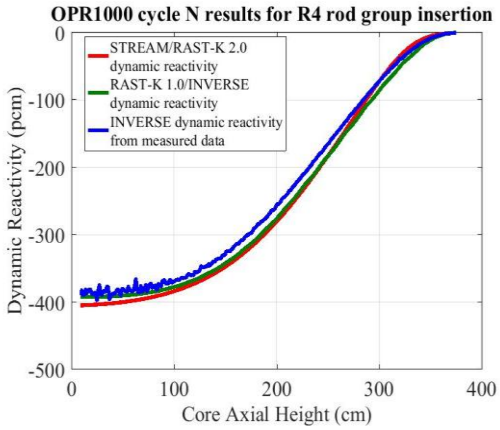

Fig. 8. Dynamic reactivity for OPR1000 cycle N RG4 rod group.

Using DSCF calculated by RAST-K 1.0, the measured dynamic reactivity and dynamic reactivity calculated by RAST-K 1.0 are converted into a static worth. Also, the dynamic reactivity calculated by STREAM/RAST-K 2.0 is converted into a static worth using DSCF calculated by STREAM/RAST-K 2.0. Next, they are validated and verified. Verification and validation results are shown in table II.

Table II: Verification and validation of the STREAM/RAST-K 2.0 with RAST-K 1.0 and measured data for OPR1000 cycle N

	ST/R2 (pcm)	R1 (pcm)	Error (%)	INVERSE (pcm)	Error (%)
RG1	-575.9	-550.3	4.7	-543.5	5.9
RG2	-549.7	-525.0	4.7	-482.9	13.8
RG3	-328.9	-316.9	3.8	-311.4	5.6
RG4	-405.9	-388.3	4.5	-385.1	5.4
RG5	-298.8	-281.8	6.0	-301.4	0.9

In the table II, STREAM/RAST-K 2.0 is written by ST/R2 as abbreviation and that of RAST-K 1.0 is shown as R1.

Verification of the STREAM/RAST-K 2.0 and the proven code RAST-K 1.0 results for OPR1000 cycle N is satisfactory because they are below acceptance criteria. The acceptance criterion is less than 10 percent. In addition, in the validation of the results of STREAM/RAST-K 2.0 and measured data, the error for the RG2 rod group is 13.8% in the cycle N. Except for the RG2 rod group results, results for the other rod groups are satisfactory. Especially, all results using STREAM/RAST-K 2.0 are similar to results using the proven code RAST-K 1.0.

3.2.2. Validation and verification results for RG2 and RG4 rod groups of cycle N+1

Validation and verification results of dynamic reactivity for RG2 and RG4 rod groups of cycle N+1 are shown in Fig. 10. and Fig. 12. Also, verification results of DSCF for RG2 and RG4 rod groups of cycle N+1 are shown in Fig. 9. and Fig. 11.

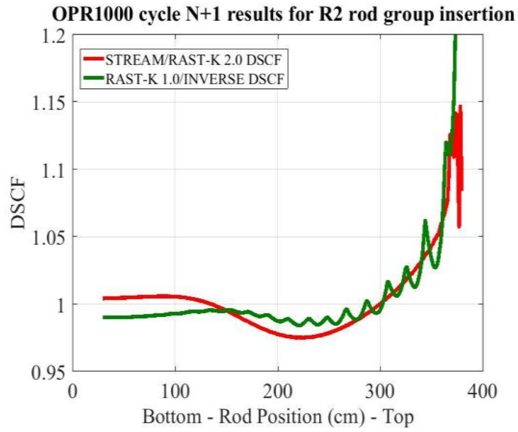

Fig. 9. DSCF for OPR1000 cycle N+1 RG2 rod group.

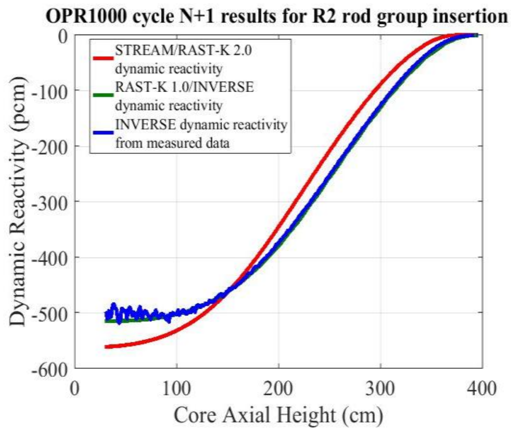

Fig. 10. Dynamic reactivity for OPR1000 cycle N+1 RG2 rod group.

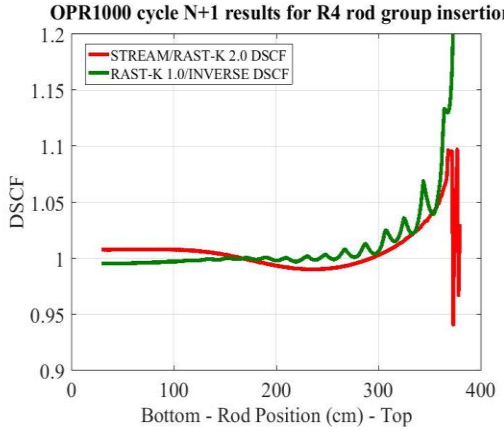

Fig. 11. DSCF for OPR1000 cycle N+1 RG4 rod group.

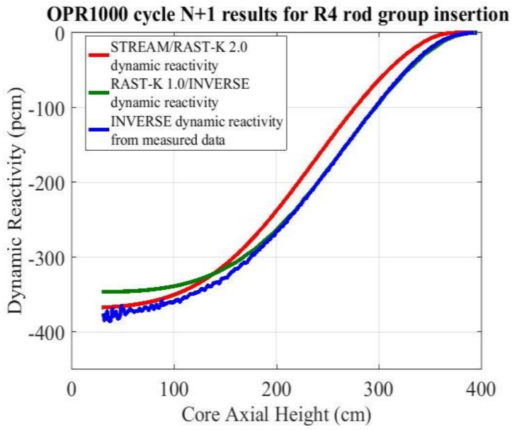

Fig. 12. Dynamic reactivity for OPR1000 cycle N+1 RG4 rod group.

Like cycle N, Using DSCF calculated by RAST-K 1.0, the measured dynamic reactivity and dynamic reactivity calculated by RAST-K 1.0 are converted into a static worth. Also, the dynamic reactivity calculated by STREAM/RAST-K 2.0 is converted into a static worth using DSCF calculated by STREAM/RAST-K 2.0. Next, they are validated and verified. Verification and validation results are shown in table III.

Table III: Verification and validation of the STREAM/RAST-K 2.0 with RAST-K 1.0 and measured data for OPR1000 cycle N+1

	ST/R2 (pcm)	R1 (pcm)	Error (%)	INVERSE (pcm)	Error (%)
RG1	-430.8	-435.9	1.2	-415.9	3.6
RG2	-563.4	-509.4	10.6	-492.3	14.4
RG3	-302.6	-283.1	6.9	-284.5	6.4
RG4	-370.0	-344.7	7.3	-373.3	0.9
RG5	-409.6	-427.7	4.2	-442.6	7.5

In the table III, STREAM/RAST-K 2.0 is written by ST/R2 as abbreviation and that of RAST-K 1.0 is shown as R1.

Verification of the STREAM/RAST-K 2.0 and the proven code RAST-K 1.0 results for OPR1000 cycle N+1 is satisfactory because they are below acceptance criteria. The acceptance criterion is less than 10 percent. In addition, in the validation of the results of STREAM/RAST-K 2.0 and measured data, the error for the RG2 rod group is 14.4% in the cycle N+1. Except for the RG2 rod group results, results for the other rod groups are satisfactory.

4. Conclusions

In this paper, OPR1000 cycles N and N+1 have been verified and validated at the transient states of DCRM by STREAM/RAST-K 2.0 code system. Dynamic reactivity, DSCF and static worth calculated by the STREAM/RAST-K 2.0 are compared with the RAST-K 1.0 results and measured data. Most of the results using the STREAM/RAST-K 2.0 are similar to results using the licensed code RAST-K 1.0. Future work will be proceeded with for additional validation and verification of the transient calculation of the STREAM/RAST-K 2.0.

Acknowledgement

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