Verification of RAST-K hexagonal analysis module with SNR and VVER-440 benchmarks

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1. Introduction

This paper presents verification results of hexagonal geometry analysis module of our in-house nodal diffusion code RAST-K. Hexagonal geometry based code system has been recently implemented in RAST-K for the purpose of sodium-cooled fast reactor design and analysis [1][2][3]. As a nodal solver for hexagonal geometry, a triangle-based polynomial expansion nodal (TPEN) method was used. This method has been previously verified for MOX-3600, CAR-3600, MET-1000 and MOX-1000 fast reactors in steady state condition [1][2][3]. In this paper, verification of Liquid Metal-cooled Fast Breeder Reactor (LMFBR) and PWR are performed.

VVER is a Russian PWR that is using hexagonal shape fuel assemblies (FA). Currently, there are 128 VVER-type reactors under operation worldwide. In addition, 37 % of all reactors under construction worldwide are VVER reactors [4]. Therefore, development and validation of hexagonal geometry solver is necessary for improving the competitiveness of our in-house nodal code RAST-K. As part of that, this paper performs verification using benchmark problems such as SNR4g and VVER-440 [4][5].

2. Code system

In this study, RAST-K code was used for calculations. RAST-K is a nodal diffusion code system based on TPEN method for hexagonal geometry analysis [6]. TPEN solver implemented in RAST-K has been verified with sodium-cooled fast reactor and 33-group cross section data generated by SARAX based on ENDF/B-VII.0 [1]. In that paper, multiplication factor, control rod worth, fuel temperature coefficient, and sodium void worth were compared with PARCS nodal code showing the differences within 1 pcm [1]. In addition, RAST-K hexagonal geometry analysis solver had been verified using our in-house Monte-Carlo code MCS for MET-1000 and MOX-3600 fast reactors [2].

3. Specification of benchmark model

3.1. SNR 4g benchmark

SNR benchmark is a three-dimensional LMFBR benchmark problem which is a simplified model of MARK-I core design of SNR 300 prototype LMFBR [5]. This benchmark problem uses 4 group cross sections, and a total of 289 fuel assemblies are used to build the core as shown in Figure 1. Six different types of regions are used in the core. The axial composition of each FA is shown in Figure 2. The core consists of five different regions, and a total of 181 reflector elements are used. In Figures 1 and 2, FA03 is a reflector FA. Active fuel height of the core is 175 cm, and 8 axial nodes are used for simulation. Cross section data is described in reference [4]. FA pitch is 11.2003 cm.

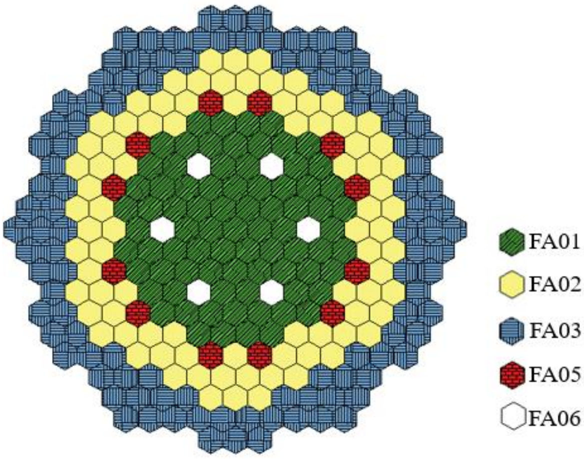


Figure 1 Loading pattern of SNR

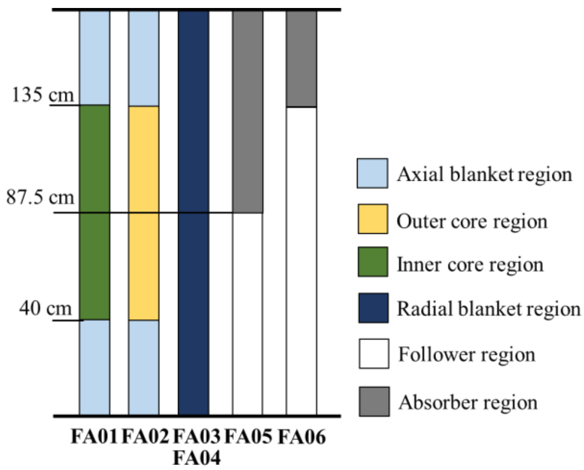


Figure 2 Axial composition of SNR

3.2. VVER-440 benchmark

The three-dimensional VVER-440 benchmark problem models a VVER-440 core with two-group diffusion approximation. The cross-section data for this benchmark problem is given in reference [5]. Active fuel height is 250 cm, 349 fuel assemblies, and 72 radial reflector assemblies are used in the reactor. Axially, 12 calculation nodes are used for verification. Each axial node height is set as 25 cm. The first and the last calculation nodes are chosen as the reflector region nodes. There are five different types of fuel assemblies as shown in Figure 3. FA03 is a reflector assembly.

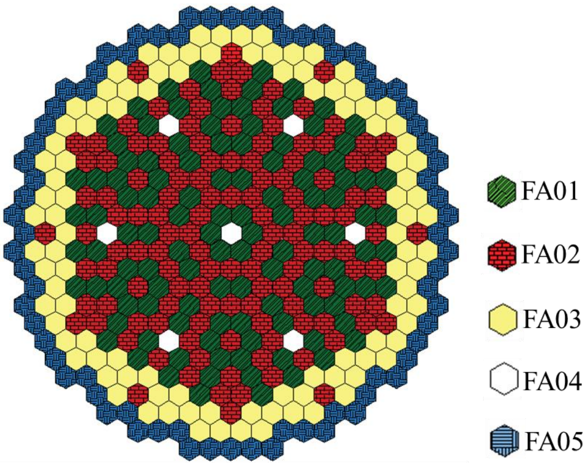


Figure 3 Loading pattern of VVER-440

4. Calculation results

This section presents the calculation results compared with DIF [4]. Multiplication factors and radial power distribution are compared in this section.

4.1. Multiplication factor

Table 1 presents the comparison data of RAST-K with DIF [4]. The target model is VVER-440. The calculation difference is 4 pcm, while simulation time of RAST-K is 0.880 seconds. Table 2 contains the specification of CPU used for calculation. Table 3 displays the multiplication factors calculated by RAST-K and DIF. In this case, SNR is used as the target model. RAST-K shows 5 pcm difference compared to DIF [4].

Table 1 Multiplication factor of VVER-440

Code system	keff	Difference [pcm]	CPU time [sec]
DIF[a]	1.01132	–	–
RAST-K	1.01136	4	0.880

a comes from Reference [5]

Table 2 Specification of CPU

Model	Processor	Memory [GB]	Storage
Intel(R) Xeon(R) CPU E5-2690 v2 @ 3.00GHz	2.92 GHz, 20 cores	252 GB	SSD 240 GB x 1ea

Table 3 Multiplication factor of SNR

Code system	keff	Difference [pcm]	CPU time [sec]
DIF*	1.00989	–	–
RAST-K	1.00994	5	0.555

* Reference [5]

4.2. Relative difference of power distribution

Relative power differences of VVER-440 are calculated and presented in this section. Figure 4 contains the FA index in VVER-440 which is used for comparison [4]. Figure 5 contains the power distribution of RAST-K and comparison results. Y-direction means the FA ID matched with FA ID displayed in Figure 4. X-direction is calculation node. In this comparison, only fuel assembly regions are considered. In total, 10 calculation nodes are compared for VVER-440 analysis. Subplot (a) presents a relative power distribution of 37 FAs. Subplot (b) contains the comparison data and relative differences. Relative differences are within ±2%.

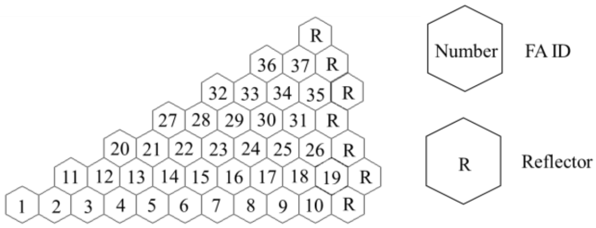
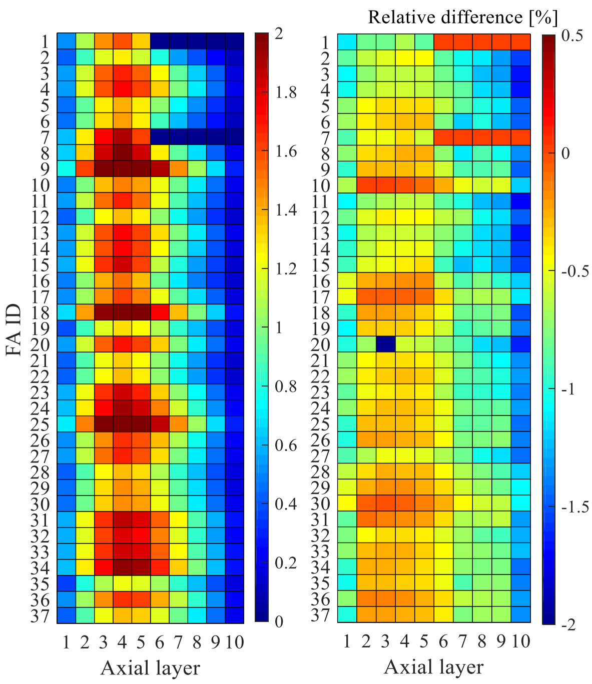


Figure 4 FA index in VVER-440



(a) Power distribution of RAST-K (b) Relative difference [%]

Figure 5 Relative power difference

Conclusion

This paper presents the benchmark calculation and comparison. Two benchmark problems are selected for analysis. One is SNR and the other one is VVER-440.

In terms of multiplication factor, RAST-K shows a difference within 5 pcm for both VVER-440 and SNR. As for the radial power differences, relative differences are found within ±2%. The reference code system is DIF, and a total of 370 nodes (*i.e.*, 37 FA positions with 10 axial nodes per FA) are compared. These comparisons show that the developed code system can provide reliable results for hexagonal geometry analysis. In conclusion, the hexagonal geometry analysis module implemented in RAST-K has been successfully verified based on the results shown in this paper.

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