DEVELOPING THE CORE LOADING PATTERN FOR THE VVER-1200/V491

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3. Tran Vinh Thanh, Tran Viet Phu; A study on the core loading pattern of VVER-1200/V491; Accepted to be published in Nuclear Science and Technology journal.

Abstract: In this report we present the results of an investigation in developing the core loading pattern of the VVER-1200/V491. The loading pattern was developed in two ways: (1) Based on the core configuration of the VVER-1000/V392 and (2) Selected by the optimized method using in the LPO-V code. To estimate the developed core, several parameters such as the k_{eff}, power distribution, delayed neutron fraction, fuel and moderator temperature reactivity feedbacks are calculated by SRAC code.

Keywords: *Core configuration, Optimized method, VVER-1200/V491, VVER-1000/V392, LPO-V, SRAC.*

1. INTRODUCTION

The VVER-1200/V491 reactor was considered to be nomanee for the First Vietnam's Nuclear Power Plant (NPP) – NinhThuan I. Beacause of that reason, studying characteristics of these reactors is necessary. In order to understand the neutronic and thermal-hydraulic (TH) characteristics of these reactors, several studies have been performed in Nuclear Energy Center (NEC) in the Institute for Nuclear Science and Technology (INST) [1][2]. For the VVER-1000/V392, the team in NEC has finished the Ministerial Project and had good agreement results with the parameters in VVER-1000/V392's ISAR [2].

On the other hand, in the situation of the VVER-1200/V491, the Russian Vendor has provided specifications through the Fesibility Study Safety Analysis Report (FS-SAR). However, those parameters are not specified. In case of neutronic calculations, they lack of the core loading configurations for fuel cycles. To predict the tendencies of the VVER-1200's core, finding the fuel loading pattern is necessary.

According to the FS-SAR, there is only difference between the VVER-1200's fuel assemblies (FAs) and the VVER-1000's. That is, the VVER-1200's FAs are 20cm higher than the VVER-1000's [3][4].Thus we can conjecture that, if the arrangement of fuel rods in each VVER-1000's FA is the same as the VVER-1200's, the core loading pattern of the VVER-1000 can be applied for the VVER-1200.

On the other hand, using the criteria of effective multiplication factor (k_{eff}) and power peaking factor also lead us to use optimization algorithm to find out the core configuration of the VVER-1200.

II. CONTENTS

In this report, to find the fuel loading pattern of the VVER-1200 core, we did the following steps:

- Calculated the k_{eff} of fuel assemblies (FAs) of the VVER-1200 by SRAC code [4] and made the comparisions with the VVER-1000 FAs. Then the core configuration of the VVER-1000 was applied to the core loading pattern of the VVER-1200
- Used the optimized core loading pattern (LPO-V) to seek the applicable configurations of the VVER-1200
- Used SRAC code to calculate and compare the characteristics of configurations. After doing these calculations, we calculated the Fuel Temperature Coefficient (FTC) and the Moderator Temperature Coefficient (MTC) of the VVER-1200

II.1. The SRAC code and the LPO-V program

The SRAC code was developed by Japan Atomic Energy Agency (JAEA). This is the deterministic code which consists of 107 neutron energy groups. In this report we used two modules of the SRAC code:(i) The first one is PIJ module which uses the collision probability method (CPM). This module is usually used to calculate for fuel rod, fuel assembly and prepare the group constants. Then these constants are used in the second module: (ii) The CITATION module which import the Finite Difference Method (FDM) for core calculations [4]

The LPO-V program was developed by members of Nuclear Energy Center (NEC) – Institute for Nuclear Science and Technology (INST). This program consists of two parts:

- The neutronic core calculation part: In this part, LPO-V uses the FDM to solve the neutron transport equation. On the other hand, to decrease the calculation time, LPO-V skips several neutronic parameters. The results of LPO-V are k_{eff} and power peaking factor in reactor core.
- The optimized loading pattern part: the LPO-V uses the Simulated Annealing method (SA) in combine with the Tabu Search method (TS) to find the applicable loading pattern. The optimized core configuration has to satisfy two conditions: (a) the k_{eff} is highest and (b)the power peaking factor is under 1.5.

II.2. The FAs of the VVER-1200/V491

According to the FS-SAR, there are three types of FAs in the first loading cycle of the VVER-1200/V491. The detail parameters of these FAs were listed in Table 1 [5]

Table 1: The FAs in 1st loading cycle of the VVER-1200/V491

First loading cycle					
FA type (Avarage Enrichment)	*No. of FAs in core*	*The fuel rods (enrichment)*		*FA pitch (cm)*	*FA length (cm)*
		Type I	Type II		

1.6	54	311 (1.6)	-	23.6	368
2.4	67	311 (2.4)	-	23.6	368
3.62	42	247 (3.7)	66 (3.3)	23.6	368

When doing this report, we had to look for several type of VVER-1000 to find the similar of the VVER-1000's FA and the VVER-1200's FA. Fortunately the VVER-1000/V446 used in the Iranian Bushere NPP has the same parameters of FA type with the VVER-1200/V491. Therefore we used the 1^{st} cycle core loading pattern of the VVER-1000/V446 to reference to the VVER-1200/V491 core.[6][7]

In Figure 1 we can easily find the similarities the two VVER's FA.

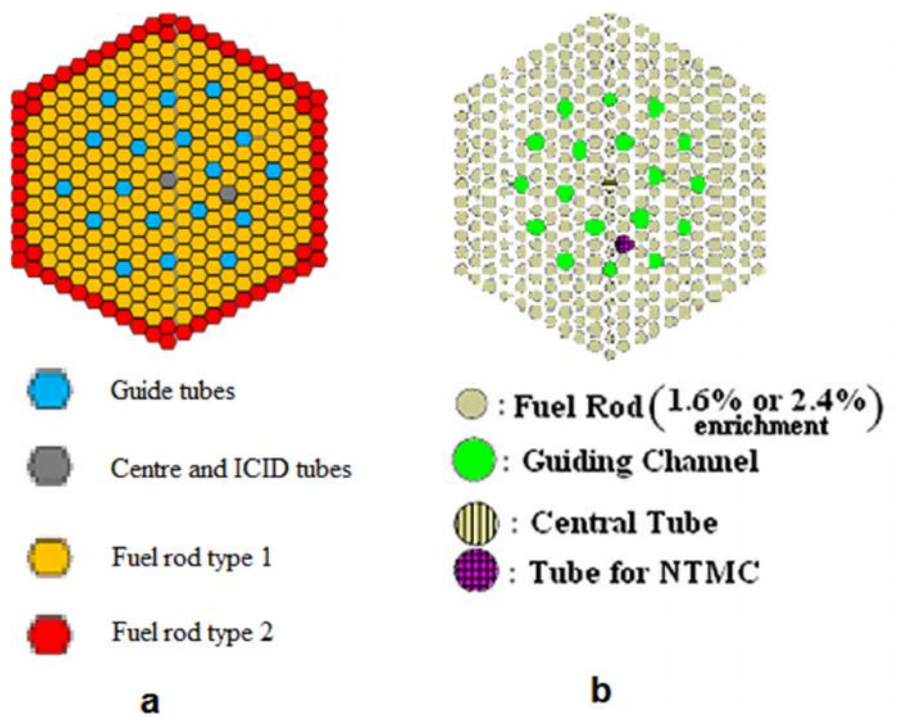

Figure1: The FA of VVER-1200/V491 (left) and the VVER-1000/V446 (right)

The Figure 1 presented two FAs used in VVER-1200/V491 (left) and VVER-1000/V446 (right). In these FAs, there are 312 rods, they are: 247 fuel rods type 1 and 66 fuel rods type 2. In each FA there are 18 guide tubes, 1 center tube filled by water and 1 tube for testing instrument.

The results of infinite neutronic multiplication factor (k_{inf}) of each VVER-1200/V491 FA were presented in Table 2.

Table 2: The k_{inf} of FA in VVER-1200/V491 at 1^{st} cycle

FA	Type of FA	k_{inf}
1.6	1	1.16007
2.4	2	1.27508
3.62	3	1.37141

In the Table 2, the values of k_{inf} of VVER-1200/V491 were presented. From these results, we could predict a core loading pattern.

Normally in a reactor, the FA with higher enrichment will be arranged at the outside of the core and the lower enrichment FA inside. From the results above, we made an assumption that the 3.62% w/o FAs were outside the core, and the 1.6% w/o and 2.4% w/o FAs were inside.

II.3. The core loading pattern of VVER-1200/V491

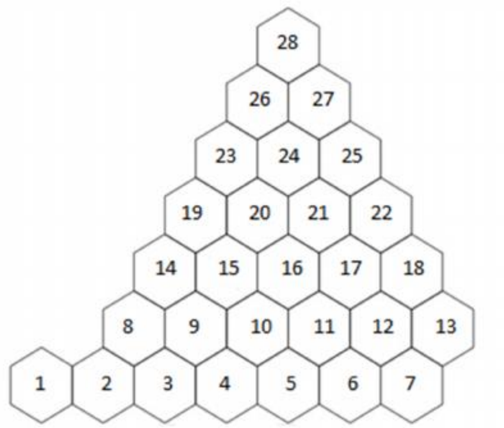

Figure 2: The number of each FA in 1/6 VVER-1200's core

Figure 3 presented the number of 28 FAs in 1/6 VVER-1200's core. From the assumption, the reference from VVER-1000/V446 and calculation by LPO-V, we suggested 6 configurations of VVER-1200/V491's core. The arrangements of 6 loading patterns were presented in Table 3.

Table 3: The k_{eff}s and core configurations of 6 loading patterns.

Core	**VVER-1000/V392**	**VVER-1000/V446**	**LPO-V1**	**LPO-V2**	**LPO-V3**	**LPO-V4**
k_{eff}	*1.213683*	*1.213262*	*1.25572*	*1.25603*	*1.25571*	*1.25652*
No. of FA	Type	Type	Type	Type	Type	Type
1	2	2	2	2	2	2
2	1	1	1	1	1	1
3	2	2	1	1	1	2
4	1	1	2	2	2	2
5	1	2	2	2	2	2
6	2	1	3	3	3	1
7	3	3	1	1	1	1
8	2	2	1	3	1	2
9	1	1	2	2	2	2
10	2	2	2	2	2	2
11	1	1	2	2	2	3
12	2	2	3	3	3	1
13	3	3	1	1	1	1

14	1	1	3	2	3	2
15	2	2	2	2	2	2
16	1	1	2	2	2	2
17	2	2	3	3	3	3
18	3	3	1	1	1	1
19	2	2	2	2	2	2
20	1	1	2	2	2	2
21	2	2	3	3	3	3
22	3	3	1	1	2	3
23	1	1	2	2	2	3
24	2	2	3	3	3	3
25	3	3	2	1	1	3
26	2	2	3	3	3	1
27	3	3	1	1	1	1
28	3	3	1	1	1	1

The results from Table 3 showed the noticeable differences between the loading patterns referenced and calculated by LPO-V. The k_{eff} when using assumption and applied from VVER-1000/V446 configurations showed good agreement with deviation is ~42pcm.

Otherwise the k_{eff}s of the 4 loading pattern found by LPO-V also had small differences (~30 – 60 pcm). However when comparing with referenced configurations, k_{eff}s of 4 loading patterns calculated by LPO-V had large values. The differences of them were ~400pcm. There is an explaination for these deviations. That is the LPO-V' objectives are finding the highest k_{eff} and limiting the power peaking factor under 1.5. That means the results from LPO-V can provide higher k_{eff} than referenced loading patterns but the power distribution will be not equalized.

II.4. Power distribution and delayed neutron fraction of the VVER-1200/V491's core

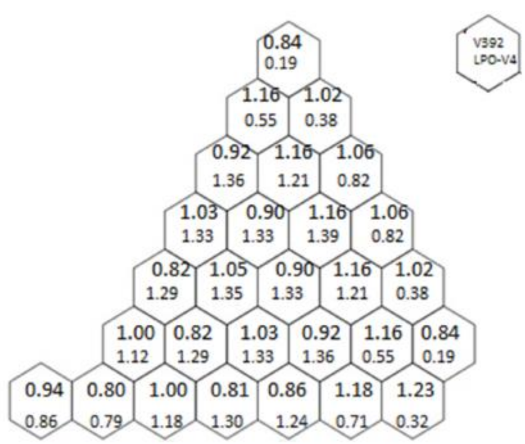

Figure 3: Power distribution of the VVER-1200/V491's core

Figure 4 showed the power distributions in the 2 configurations: V392 and LPO-V4. In each hexagon, the aboved number is power distribution in V392 and the lowered is LPO-V4.

From the results in Table 3 and Figure 4, it is easily to relize that in the 2 cases there were considerable differences of the power distributions. For the V392, the power distribution was almost stable, the fluctuation from 1.0 in each position was around 0.2. The power peaking factor is 1.23 at FA no.7, the lowest power distribution is 0.80 at position no.2.

In case of the LPO-V4 configuration, there were large differences between FAs' position, the outside-core FAs at positions: 7, 12, 13, 18, 26, 27, 28 had low value, high power distribution positions were FAs no.10, 11, 15, 16, 19, 20, 21. The power peaking factor at FA no.21 is 1.39 and the lowest power distribution is 0.19 at FAs no.13 and no.28. In this loading pattern, the maximum difference between the higest and lowest power distribution is 1.2.

The results described above let us to an implementation that the LPO-V's objectives are searching for the cores which have high $k_{eff}$and power peaking factor limit under 1.4, so the cores found by LPO-V may have non-uniform power distribution. This means that the LPO-V is still in developing and it needs to be verified and improved.

From the results presented in Table 3 and Figure 4, thisis not easy to affirm which configuration is better. The LPO-V4 showed higherk_{eff} but the V392 had more stable power distribution.

To estimate the operation period of the reactor, the neutronic – TH coupling and burn-up calculating are needed. However, in the scope of this paper, those calculations were not carried out.

Table 4 presented the delayed neutron fraction (DNF) and calculated by SRAC in the 2 loading configurations: V392 and LPO-V4. In these cases, the DNF were closed to 0.007. These DNFs can be accepted when comparing with the standards from 0.0058 to 0.0078 in the VVER-1200's FS-SAR[5]

Table 4: Delayed neutron fraction (DNF) of VVER-1200's core in 2 cases V392 and LPO-V4

LPO-V4			**V392**		
Group	*Delayed neutron fraction*	*Decay constant*	*Group*	*Delayed neutron fraction*	*Decay constant*
^{87}Br	2.05E-04	1.25E-02	^{87}Br	2.05E-04	1.25E-02
^{137}I	1.12E-03	3.17E-02	^{137}I	1.12E-03	3.17E-02
^{89}Br	1.10E-03	1.10E-01	^{89}Br	1.11E-03	1.10E-0 1
^{139}I	3.23E-03	3.20E-01	^{139}I	3.23E-03	3.20E-01
^{85}As	1.03E-03	1.35E+00	^{85}As	1.04E-03	1.35E+00
^{9}Li	3.46E-04	8.83E+00	^{9}Li	3.47E-04	8.84E+00
Delayed neutron fraction: 0.0070			Delayed neutron fraction: 0.0071		
Delayed neutron mean lifetime: 13.11s			Delayed neutron mean lifetime: 13.12s		

II.5. The fuel and moderator temperature reactivity feedbacks

To calculate the fuel temperature feedbacks, the temperature of moderator was fixed at 579K, the temperature of fuel was increased gradually from 580K to 1400K with 41 steps, each step is 20K.

Figure 5 showed the FTC in 2 configurations V392 and LPO-V4. When fuel temperature increased from 580K to 1400K, the reactivity feedbacks of V392 increased steadily from -2.54 pcm/K to -1.8pcm/K, the feedbacks of LP3 were from -2.44 pcm/K to -1.73pcm/K. The average difference between the 2 curves is 0.2 pcm/K and can be neglected.

Because of the VVER-1200/V491's FS-SAR does not provide information on criteria of the FTC, the results in this study had been to compare with standards in the VVER-1000/V392 ISAR.

In the ISAR, the limits for FTC vary from -3.3 pcm/K to -1.7 pcm/K at the Beginning Of Cycle (BOC) .Thus when comparing with standards in the ISAR, the FTC in the 2 configurations V392 and LPO-V4 were satisfied.

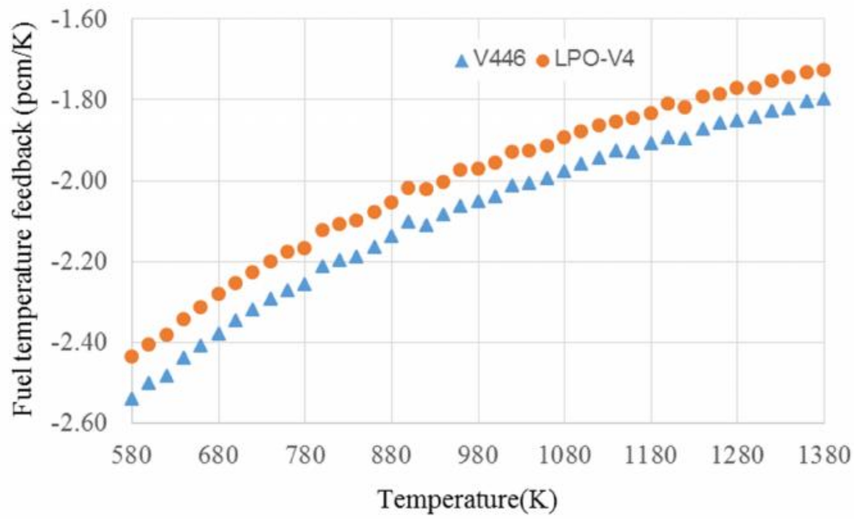

Figure 4: Fuel temperature feedbacks

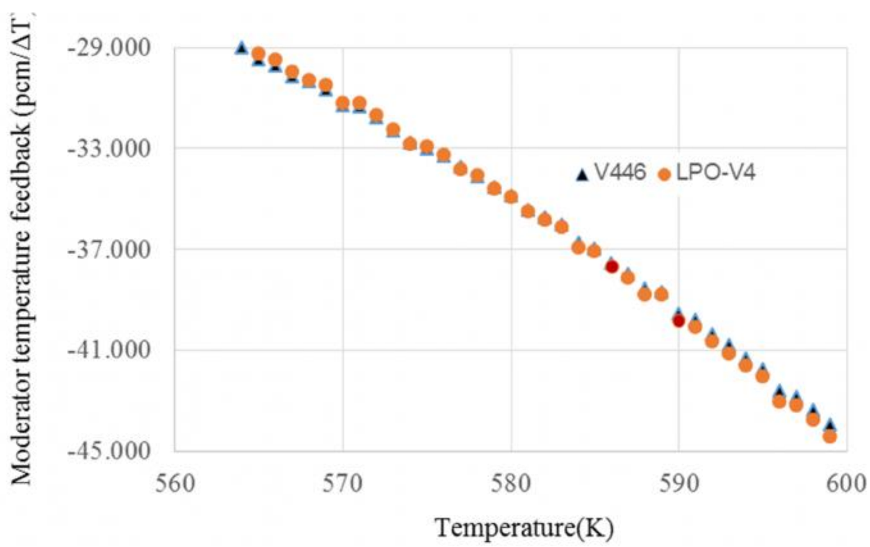

Figure 5: Moderator temperature feedback

Figure 6 presented the dependence of reactivity of the V392 and LPO-V4 loading pattern on moderator temperature. In this calculation, the fuel temperature was fixed at 580K when moderator temperature was devided to 37 steps from 564K to 600K. It is not difficult to relize that the MTC of V392 and LPO-V4 had the agreement. Figure 6 also showed that when increasing the moderator temperature, the reactivity curves tent to move down from -29 pcm/K to -45pcm/K. This outcome confirms the key influence of the moderator temperature reactivity feedback.

The results of MTCs in this report were also compared with the criteria in the FS-SAR of VVER-1200/V491 and can be regarded as acceptable when the standards in FS-SAR range from -54.8 pcm/K to -26.7 pcm/K.[5]

III. CONCLUSION

In this study, 6 fuel loading configurations were suggested for the VVER-1200/V491's core: the applied from the VVER-1000/V446 in the Iranian Bushehr NPP,the assumption and the 4 calculated by core optimization code LPO-V. Several neutronic characteristics in those loading patterns were performed, they are: the k_{eff}, power distribution, delayed neutron fraction, fuel and moderator temperature coefficient.

For the V392 configuration, the k_{eff} was 1.21326, the power distribution was almost uniform with fluctuation from 1.0 is 0.2; the peaking factor was 1.23; the delayed neutron fraction was 0.0071; the fuel temperature coefficient raised from -2.54 pcm/K to -1.8 pcm/K; the moderator temperature coefficientmoved down from -29.03 pcm/K to -43.96 pcm/K.

In case of the LPO-V4 loading pattern, k_{eff} was 1.25652, the power distribution was not uneven with the lowest was 0.19 and the highest was 1.39; the delayed neutron fractionwas0.0070; the fuel temperature coefficientvariedfrom -2.44 pcm/K to -1.73 pcm/K; the moderator temperature coefficientdecreased from -28.85 pcm/K to -44.43 pcm/K.

Basically, that can be found that the configurations had power distribution, delayed neutron fraction, the fuel temperature coefficientandmoderator temperature coefficientsatisfied the criteria in the VVER-1000's ISAR and the VVER-1200's FS-SAR. However, there are still some points to note, they are: (a) the power distribution in the loading pattern calculated by LPO-V was not uniform and (b) the fuel cycle operation needs to be estimated by burn-up and neutronic – TH coupling calculations. That is also our next objectives: verify the LPO-V and do those mentioned calculations.

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