3D Multicycle Core Burnup Calculation of 1000MWe PWR

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The great leader Comrade **Kim Jong Il** said as follows.

"Along with this any scientific and technological problems relating to the construction of hydroelectric- and thermal-power stations and atomic power plants that are suited to the conditions in our country should be solved." ("ON THE FURTHER DEVELOPMENT OF SCIENCE AND TECHNOLOGY" p.2)

In nuclear power reactors, the core undergoes several transient cycles from the initial fuel loading to the equilibrium cycle, so multicycle burnup analysis for the core is necessary.

We have performed 3D multicycle burnup calculation for the core of 1 000MWe class PWR by using the PWR physics calculation system "BuHung" [1-3].

1. Core Configuration of 1 000MWe class PWR

The core of 1000MWe class PWR consists of 177 of fuel assemblies. For 1 to 4 cycles, fuel

D	C	B					
C_1	C_1	D_2	D	B			
B_1	B_2	A	D_2	D_1	C		
B_2	A	C_1	A	C_1	D_1	B	
A	D_2	A	C_1	A	D_2	D	
B_2	A	C_1	A	C_1	A	D_2	B
B_1	B	A	D_2	A	B_2	C_1	C
A	B_1	B_2	A	B_2	B_1	C_1	D

a) the case of cycle 1

B_2	E	D_1					
E_2	B	D_2	E	D_2			
B_1	D_2	E_3	B_2	E_1	B		
B_2	B	C	D	C_1	E_1	D_2	
E_3	C_1	C_1	B_1	D	B_2	E	
C_1	C_1	E_3	C_1	C	E_3	D_2	D_1
D	C	C_1	C_1	B	D_2	B	E
A	D	C_1	E_3	B_2	B_1	E_2	B_2

b) the case of cycle 2

D	F	D_2					
F_1	D_2	F_1	F	D_1			
C_1	E	B	D	F_1	C		
E_3	C	E_1	E	B	F_1	D_1	
C_1	F_2	B	C_1	E	D	F	
E_3	D_2	E_3	B	E_1	B	F_1	D_2
E_2	E_3	D_2	F_2	C	E	D_2	F
C_1	E_2	E_3	C_1	E_3	C_1	F_1	D

c) the case of cycle 3

E_2	G	D_2					
G_1	E	G_1	F	D_1			
E_3	F_1	C	F	G_1	C		
F_1	D	G_2	E	E_3	G_1	D_1	
D	F_1	D_2	E_2	E	F	F	
G_2	F_1	F_2	D_2	G_2	C	G_1	D_2
E_3	E_3	F_1	F_1	D	F_1	E	G
C_1	E_3	G_2	D	F_1	E_3	G_1	E_2

d) the case of cycle 4

Fig. 1. 1/4 configuration of the core in every clcye

Table 1. Specifications of fuel assembies loaded in each cycle

cycle	Assembly	Number of assemblies in the core	Fuel enrichment (%)	Number of fuel cells in the assembly	Number of burnable poison rods in the assembly	Gd_2O_3 concentration, wt %
1	A	45	1.28	236		
	B	20	2.34	236		
	B1	8	2.34/1.28	176/52	8	4
	B2	16	2.34	232	4	4
	C	12	2.84/2.34	184/52		
	C1	32	2.84/2.34	176/52	8	4
	D	12	3.34/2.84	184/52		
	D1	8	3.34/2.84	176/52	8	4
	D2	24	3.34/2.84	128/100	8	4
2	E	16	4.6/4.1	184/52		
	E1	8	4.6/4.1	176/52	8	6
	E2	4	4.1/3.5	176/52	8	6
	E3	16	4.1/3.5	172/52	12	6
3	F	16	4.3/3.8	184/52		
	F1	20	4.3/3.8	176/52	8	6
	F2	8	4.3/3.8	172/52	12	6
4	G	8	3.9/3.4	184/52		
	G1	20	3.9/3.4	176/52	8	6
	G2	12	3.9/3.4	172/52	12	6

assemblies within the core are shown in Table 1 and the core configurations are shown in Fig.1.

2. Calculation Results

We have performed 3D burnup calculations on the above mentioned four cycles. For the first cycle, the multiplication factors of the core consisting of nine types of assembies at the several operating states have been calculated in the beginning of the cycle (BOC) as shown in Table 2.

Table 2. The effective multiplication factor of the core at serveral operating states in the beginning of first cycle

State	Reference value	Calculation result	Derivation (%)
The cold state(20℃), 0ppm	1.215	1.219	0.33
The heat zero power state(296℃), 0ppm	1.161	1.165	0.34

The heat full power state(312℃), 0ppm	1.138	1.141	0.26

As shown in Table 2, the deviations of calculation results for the effective multipilication factor from those of the reference [4] are only 0.26~0.34%.

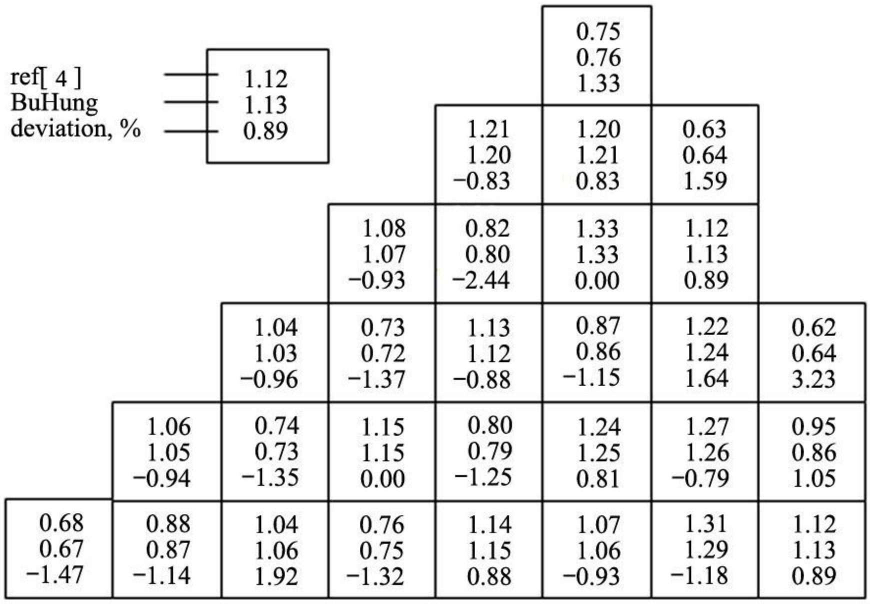

Fig. 2. Comparison of assembly power distribution at the beginning of first cycle(critical boron concentration 0.105 4%)

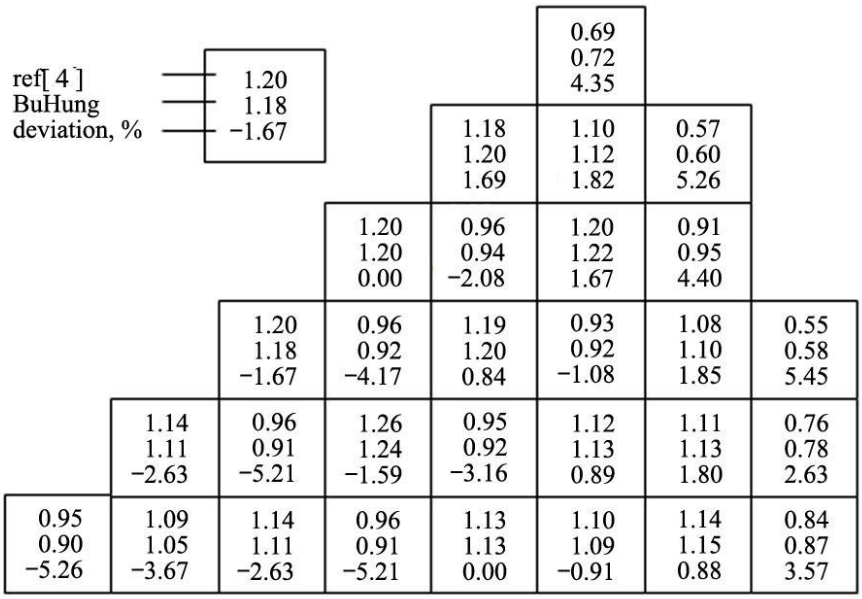

Fig. 3. Comparison of assembly power distribution of fuel assemblies at the end of first cycle(cycle burnup13.75GW · d/tU, critical boron concentration 1.19 · 10^{-3}%)

Average power distribution of assemblies at the beginning and the end of the first cycle in the heat full power state are shown in Fig. 2 and Fig. 3. In two cases, maximum deviations in the power distribution are 3.23% and 5.45%, respectively. The cycle length corresponding to the cycle burnup 13.75GW d/tU is 371 days, which is only 3 days longer than 368 days (cycle burnup 13.65GW d/tU) of reference [4].

ref[4] BuHung deviation, %		1.01 1.02 0.99			0.52 0.52 0.00		
				0.99 0.97 −2.02	1.25 1.20 −4.00	0.51 0.53 3.92	
			0.90 0.90 0.00	1.12 1.11 −0.89	0.96 0.96 0.00	1.07 1.10 2.80	
		1.40 1.34 −4.29	0.99 1.00 1.01	1.10 1.09 −0.91	1.43 1.39 −2.80	0.94 0.96 2.13	0.51 0.55 7.84
	1.07 1.05 −1.87	0.99 1.01 2.02	1.01 1.02 0.99	1.05 1.05 0.00	1.05 1.08 2.86	1.01 1.00 −0.99	0.94 0.97 3.55
0.82 0.78 −4.88	1.09 1.08 −0.92	0.99 0.99 0.00	1.41 1.35 −4.26	0.94 0.96 2.13	0.91 0.92 1.10	1.34 1.32 −1.49	0.63 0.65 3.17

Fig. 4. Power distribution of fuel assemblies at the end of second cycle

ref[4] BuHung deviation, %		1.04 1.02 0.92			0.49 0.48 −2.04		
				0.90 0.87 −2.14	1.17 1.09 −6.84	0.48 0.48 0.00	
			0.88 0.89 1.14	1.30 1.27 −2.31	0.95 0.95 0.00	1.04 1.02 −1.92	
		1.11 1.14 2.70	0.93 0.93 0.00	1.28 1.29 0.78	0.94 0.94 0.00	1.25 1.20 −4.00	0.46 0.49 6.52
	1.11 1.16 4.50	0.89 0.94 5.62	1.40 1.36 −2.86	0.98 0.98 0.00	1.31 1.31 0.00	0.91 0.92 1.10	0.88 0.90 2.27
0.85 0.91 −7.05	1.13 1.18 4.42	1.13 1.16 2.65	0.91 0.93 2.20	1.17 1.18 0.85	0.91 0.93 2.65	1.34 1.29 −3.73	0.63 0.65 3.17

Fig. 5. Power distribution of fuel assemblies at the end of third cycle

According to the fuel reloading patterns shown in Fig.1, burnup calculations for 2 to 4 cycles were performed. Average power distributions of assemblies at the end of second and third cycles are shown in Fig. 4 and Fig. 5. Maximum deviations are 7.84% and 7.05%, respectively, as shown in Fig. 4 and 5. These results describe that the calculations were performed with the full accuracies.

Critical boron concentration changes according to burnup in each cycle are shown in Fig. 6.

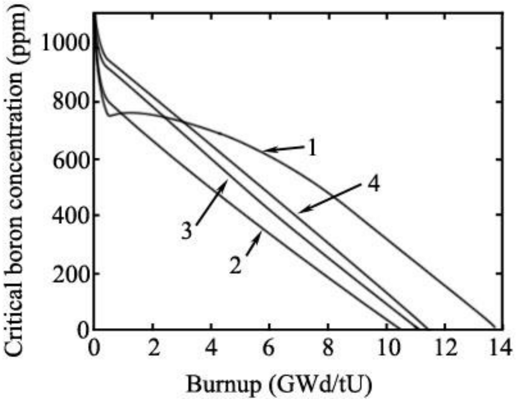

Fig. 6. Critical boron concentration changes according to burnup in each cycle

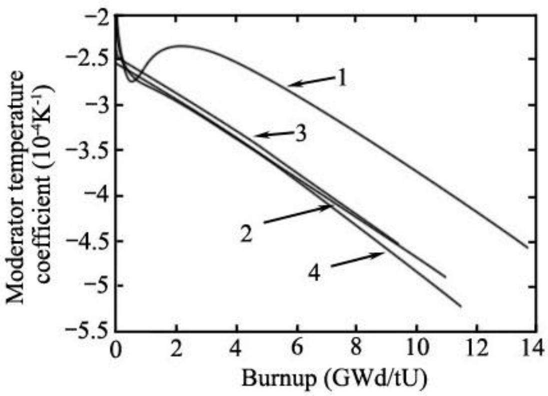

Fig. 7. Moderator temperature coefficient changes according to burnup in each cycle

As for the first cycle, after xenon concentration builds up to the equilibrium value, the critical boron concentration has increased somewhat because of the burning of Gd, and then decreased slowly with the increasing of burnup. The critical boron concentration has decreased almost linearly with the consuming of Gd. In the other cycles, critical boron concentrations have decreased almost linearly from the beginning. In general, if the types of fresh fuel assemblies loaded into the core in every cycle are same, the equilibrium cycle is achieved after 3 and 4 cycles. However, in these calculations, because the fresh assembly types are different in each cycle, the result curves are not confirmed.

Moderator temperature coefficient changes according to burnup have the similar tendency with the changes of critical boron concenstration (Fig. 7). It is because the temperature coefficient is closely related to the boron concentration in the moderator (coolant). The higher the boron concentration in the moderator is, the lower the absolute value of the temperature coefficient of moderator is. The temperature of moderator is positive even above a limit boron concentration.[5] The critical boron concentration for the compensation of the excess reactivity is decreased with the burnup progress; therefore, the absolute value of the moderator temperature coefficient is also increased accordingly.

The burnup step was choosen as 250MW·d/tU in these calculations. The calculation time from 1 to 4 cycles is 3 287s when used a PC with a 3.4GHz Intel Core i3.

Conclusion

By using the PWR physics calculation system "BuHung" with capabilities of 3D burnup analysis, thermal hydraulic feedback and criticality search, we performed 3D core burnup calculation for 1 to 4 cycles of 1000MWe class PWR. The calculation results were all in good agreement with those of the reference.

References

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Keywords : pressurized-water reactor, multicycle burnup calculation