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A Study on Thimble Plug Removal for PWR Plants

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ABSTRACT

The thermal-hydraulic effects of removing the RCC guide thimble plugs are evaluated for 8 Westinghouse type PWR plants in Korea as a part of feasibility study: core outlet loss coefficient, thimble bypass flow, and best estimate flow. It is resulted that the best estimate thimble bypass flow increases about by 2% and the best estimate flow increases approximately by 1.2%. The resulting DNBR penalties can be covered with the current DNBR margin. Accident analyses are also investigated that the dropped rod transient is shown to be limiting and relatively sensitive to bypass flow variation.

I. INTRODUCTION

Thimble plugging devices are used to minimize the core bypass flow through the fuel assembly thimble tubes. Typically, all guide thimble tubes that are not under RCC locations or are not equipped with sources or burnable absorbers currently have thimble plugs inserted in them. The removal of the thimble plugs reduces the active core flow since the hydraulic resistance through the bypass region decreases, thereby increasing the bypass flow.

As it is known, thimble plug removal offers various advantages. First, it is not required to purchase a new set of thimble plugging devices because of fuel design change. Second, there is a time savings of refueling. Third, the potential for a time loss of few hours due to bent or damaged thimble plugs is eliminated. Fourth, ALARA considerations are improved because of reduced fuel shuffle time. Fifth, the potential for generation of loose parts due to cracked plugging device springs is reduced, and so on.

As a part of feasibility study on the thimble plug removal, the thermal-hydraulic characteristics will be investigated in terms of the core outlet loss coefficient calculation, thimble bypass flow calculation, and the change of best estimate flow for PWR plants in Korea. As an evaluation of thermal effect due to thimble plug removal, the DNB margin is examined for the plants. In addition, the effect of thimble plug removal is also evaluated in several accident conditions.

2. THE EVALUATION OF HYDRAULIC EFFECT

2.1 Evaluation of Outlet Loss Coefficient (PFO) for Fuel Assembly

Removal of thimble plugging devices causes a reduction in outlet loss coefficient (PFO) for the fuel assembly. This PFO reduction for fuel assembly also causes a reduction in PFO for the overall core. The effect of these changes should be evaluated by the hydraulic points of view. Fuel assembly outlet loss coefficient effects the fuel assembly lift force, DNB and fuel rod fretting wear, etc.

Because of the increase in bypass flow and the reduction in fuel assembly loss coefficient caused by the thimble plug removal, fuel assembly lift forces decreases. Therefore, the integrity of fuel assembly hold-down spring and reactor vessel internal are valid despite thimble plug removal. In general, PFO mismatch due to thimble plug removal has a negligible impact on DNB and fuel rod fretting wear.

The change of loss coefficients due to elimination of the thimble plugs are investigated and are summarized in Table 1 before and after thimble plug removal. The revised top nozzle and upper core plate loss coefficients are calculated by preserving the pre-K(TN)/K(UCP) ratio.

2.2 Core Bypass Flow Calculation

Core bypass flow is defined as the portion of the reactor vessel flow which is assumed to be ineffective for core heat removal. Generally, core bypass flow paths include outlet nozzle leakage, baffle-barrel cooling, head cooling, cavity flow, and thimble cooling. Among these bypass flow paths, typical core bypass flow through the thimble cooling is fractioned as much as 1.9% ~ 2.0% of total RCS flow[2].

In this study, the generic bypass flow calculation is used to evaluate the thimble bypass flow. This method is based on the fact that thimble flow per tube can be obtained from the appropriate table for each core component type in the core design, adjusted for the difference in core pressure drop between the specific and generic designs, and summed for all of the thimble locations in the core.

Based on the calculated outlet loss coefficient without thimble plug, new fuel assembly pressure drop is calculated using by CALOPR code[4]. The flow field of CALOPR code for all core and fuel assembly pressure drops is assumed to be one dimensional, incompressible, turbulent, and single phase. With new fuel assembly pressure drops from CALOPR code, the thimble bypass flow calculation are carried out before and after thimble plug removal for Westinghouse type PWR plants and results are shown in Table 2.

2.3 The change of Best Estimate Flow

The Best Estimate Flow (BEF) means the maximum flow in the primary loop. The BEF is calculated through the balance between pressure loss of primary loop and reactor coolant pump (RCP) head, considering the steam generator tube plugging level.

And the performance of RCP is obtained from the homologeous curve provided by manufacturer. By balancing between head loss and RCP head, the following formula is obtained:

$$\sum_{loop} \text{Pressure Loss} = \text{RCP Head}$$

The BEF is the flow at the operating point that satisfies the above condition. From the above condition, the decrease of head loss by the thimble plug removal makes the BEF increase. According to the table 1, by the removal of thimble plug, the head loss of the core decreases approximately by 5% in the case of 17×17 V5H fuel assembly. Therfore, the vessel head loss decreases approximately by 3%. This makes the BEF increase about by 1.2%.

As a result, the removal of thimble plug does not make a large impact on the BEF and the thermal design flow, which is used for safety analysis, can be maintained without change.

3. THE EVALUATION OF THERMAL EFFECT

As the thimble plug removal is being performed based on an evaluation to an existing safety analysis, the DNB margin that has to be allocated to cover thimble plug removal should be calculated based on a maximum value of sensitivity of DNBR to bypass flow.

For statistical thermal design plants, the maximum value of sensitivity of DNBR to bypass flow[5,6] is used to set the DNB penalty due to thimble plug removal. To evaluate the DNB penalty resulted from the thimble plug removal, the increased best estimate bypass flow rate(%) of total RCS flow and maximum sensitivities are conservatively used. DNBR sensitivities, DNBR penalties and current DNB margins are listed in Table 4.

4. ACCIDENT ANALYSES

To evaluate the effect of thimble plug removal in accident analysis, the flow reduction transient (loss of flow) and the transients involving Rod Control Cluster Assemblies(RCCA) malfunction are investigated. As a Condition IV event, locked rotor are also examined against the thimble plug removal. The DNB design basis for these accidents is satisfied if the minimum DNBR is not less than the limit DNBR.

Table 3 shows the total core bypass flow before and after thimble plug removal and accident analysis performed using those values for a plant. The results of these accident analyses with the change of best estimate bypass flow are shown in Table 5 in terms of the DNBR change. The analyses of these transients are performed by the THINC IV code[7] and based on Reload Transition Safety Report.[8]

As a result of analyses, the dropped rod transient is found to be the limiting transient and the most sensitive transient according as the total core bypass flow increase. The minimum DNBR violates the safety analysis limit DNBR of the plants and the net remaining DNBR margin is allocated to cover this DNBR penalty as shown in Table 5.

5. CONCLUSIONS

From the results of core thermal-hydraulic characteristic evaluations, the thimble plug removal results in an increase of the core bypass flow and an increase of the total RCS flow (BEF). The following conclusions are obtained.

- The calculation shows that the core loss coefficients decrease approximatly by 5% due to the elimination of the thimble plugs.
- It is shown that the best estimate thimble bypass flow increases approximately by 2%.
- The best estimate primary system flow rate is estimated that there will be a slight increase in best estimate flow (approximately 1.2%).
- It is turned out that the current net DNBR margin is sufficient to cover the DNBR penalties. However the thermal design method is needed to accomodate DNBR martion reduction for plant using standard type fuel.
- According to the accident analyses, the dropped rod transient is found to be the limiting transient and the most sensitive transient.

REFERENCES

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Table 1. The change of loss coefficient before and after thimble plug for fuel type

Component Loss Coefficient	14x14 OFA		16x16 STD		17x17 V5H	
	w/ TP	w/o TP	w/TP	w/o TP	w/TP	w/o TP
△PFO	-	-0.69	-	-1.0*	-	-1.0
PFO	3.61	2.92	2.80	1.80	2.80	1.80
K(Top Nozzle)	1.34	1.08	0.65	0.42	0.73	0.47
K(Upper Core Plate)	2.27	1.84	2.15	1.38	2.07	1.33
K(TN)/K(UCP)	0.590	0.590	0.302	0.302	0.353	0.353
K(FA)	17.45	17.19	15.52	15.29	17.4	17.14
C1	73.91	72.81	65.73	64.76	73.69	72.59
K(core)	22.32	21.63	18.68	17.68	20.00	19.00
C2	94.53	91.61	79.11	74.88	84.71	80.47

PFO = K(Top Nozzle) + K(Upper Core Plate)

K(FA) = C1*Re$^{-0.11}$, K(core) = C2*Re$^{-0.11}$, Re=500,000

* 16x16 STD △PFO is not available (17x17 V5H △PFO is used).

Table 2. The change of pressure drops and best estimate thimble bypass flows

Plants	BE Thimble BP(w/ TP) (%)	$\triangle P_{FA}$ (w/ TP)	BE Thimble BP(w/o TP) (%)	$\triangle P_{FA}$ (w/o TP)	Changed BEBP rate(%)	$\triangle P_{w/\ TP}$ - $\triangle P_{w/o\ TP}$
14×14 OFA	0.927	17.625	2.615	17.349	1.688	0.276
16×16 STD	1.673	22.527	3.405	22.173	1.732	0.354
17×17 V5H	1.564	21.800	3.415	21.455	1.851	0.345

Table 3. The change of total core bypass flow for a 3-Loop Plant

Plant	Total Core Bypass Flow (w/ TP) (%)	Total Core Bypass Flow (w/o TP) (%)
3-Loop Plant (V5H Fuel)	5.6	7.59

Table 4. The DNBR sensitivities and current DNB margins

Plants \ Sensitivity	Max. DNBR Sensitivities to Bypass Flow	Increased Thimble BEBF rate(%)	DNBR Penalties	Current Net DNBR Margin(%)	Estimated Net DNBR Margin(%)
14×14 OFA	1.338	1.69	2.26	5.5	3.24
16×16 STD	1.200	1.73	2.08	2.8	0.72
17×17 V5H	1.530	1.85	2.83	5.1	2.27

Table 5. The results of accident analysis by total core bypass flow change (3-Loop Plant)

Accident \ Min. DNBR	Min. DNBR (typ/thm) w/ TP	Min. DNBR (typ/thm) w/o TP	△DNBR(%)	DNBR Penalties
Loss of Flow	1.879/1.850	1.838/1.813	2.18	Min DNBR> S.A.L DNBR
Static Rod Misalignment	1.764/1.712	1.721/1.674	2.44	2.1
Dropped Rod	1.769/1.711	1.724/1.670	2.54	2.3
Rod Withdrawal from Subcritical	1.736/1.716	1.708/1.691	1.61	Min DNBR> W-3 DNBR
Locked Rotor	1.740/1.740	1.716/1.719	1.38	1.4

Safety Analysis Limit DNBR for the Plant : 1.74/1.71 (TYP/THM)