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Analysis of Impact of Power Uprate on Loss of RHR Events during Mid-loop Operation for Kori 3&4

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1. Introduction

Pressurized Water Reactor (PWR) plants can be operated for inspection and maintenance of certain components after reactor shutdown. The reduced inventory condition is when Reactor Vessel (RV) water level is lower than 3 feet below the RV flange. The mid-loop operation when RCS water level is below the top of hot leg flow area at the junction with the RV is a specific kind of the reduced inventory operation.

In order to enhance safety during reduced inventory operation, Nuclear Regulatory Commission (NRC) issued a Generic Letter (GL) 88-17 [1] including recommendations to all holders of operating licensee or construction permit of PWRs to implement certain "expeditious action items" before operating their plants in a reduced inventory condition and to implement, as soon as practical, "program enhancement items" concerning operations during shutdown cooling. To resolve the safety action items of the GL 88-17 for Yonggwang Nuclear Power Plant Units 1&2 (YGN 1&2) and Kori Nuclear Power Plant Units 3&4 (Kori 3&4), the analyses of the loss of Residual Heat Removal (RHR) events during mid-loop operation before power uprate had performed by using the RELAP5/MOD3 code version 2.2.β [2] in 2001 [3] and in 2003 [4], respectively.

On the other hand, the power uprate program will be implemented for Kori 3&4 and YGN 1&2. These plants were designed by Westinghouse Electric Company (WH) and the licensed core power for all four units is 2775 MWt. The target of power uprate is approximately 4.5 % for each unit (core power of 2900 MWt).

In order to address the safety action items of the GL 88-17 for the Kori 3&4 power uprate, the analyses of loss of RHR events during reduced inventory or mid-loop operation with various plant configurations were performed by using the RELAP5/MOD3 code version 2.1.2 utilized since Ulchin Nuclear Power Plant Units 3&4 (UCN 3&4). Besides the RELAP5/MOD3 code version change and core power uprate of 4.5%, the decay heat data of WH used in this analysis was calculated more conservatively than that before Kori 3&4 power uprate. Therefore, the safety analyses for the Kori 3&4 power uprate were newly performed in this study as recommended in the GL 88-17.

2. Methods and Results

A safety analysis methodology in Figure 1 had been developed and verified since UCN 3&4 and was applied to the Kori 3&4. The hand calculations were used to obtain the conservative parameters necessary to prepare the operation guidelines. The RELAP5 code was utilized to understand major thermal-hydraulic phenomena following loss of RHR events for typical plant configurations of Kori 3&4 as shown in Table 1. Since operator of Kori 3&4 preferred the pressurizer manway opening, the RELAP5/MOD3 analyses for seven plant configurations with pressurizer manway opened were performed in detail.

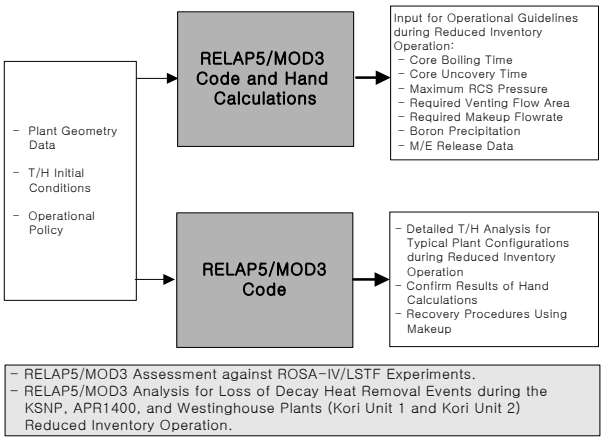

Figure 1. Analysis methodology for GL 88-17 action items.

Table 1. RELAP5 analysis cases of Kori 3&4.

Plant Configuration	Case 1 (PRO)	Case 2 (CLO)	Case 3 (HLOND)	Case 4 (SIMO)	Case 5 (SOMO)	Case 6 (ND)	Case 7 (NDR)+
Pressurizer manway	Open	Open	Open	Open	Open	Open	Open
1 check v/v removed in 12" CL accu. SI line	Close	Yes	Close	Close	Close	Close	Close
1 check v/v removed in 6" HL SI line	Close	Close	Yes	Close	Close	Close	Close
1 SG manway (inlet nozzle)	Close	Close	Close	Open	Close	Close	Close
1 SG manway (outlet nozzle)	Close	Close	Close	Close	Open	Close	Close
Nozzle dams installed	No	No	Yes	No	No	Yes	Yes
Number of active SGs	0	0	0	0	0	0	0

+) initial RCS water level = 3 feet below the RV flange.

The initial conditions and RELAP5 nodalization used in the analysis are shown in Table 2 and Figure 2, respectively.

Table 2. Initial conditions for Kori 3&4.

Analysis Parameter	Value
Initiation of Loss of RHR event	4 days after shutdown
RCS pressure	0.101325 MPa
RCS hot leg temperature	330.37 K (= 135 °F)
RCS cold leg temperature	300.164 K (= 80.625 °F)
RCS liquid level	Centerline of the hot leg
Secondary pressure	0.101325 MPa
Secondary temperature	322.04 K (= 120 °F)
Containment pressure	0.101325 MPa
RWST temperature	322.04 K (= 120 °F)

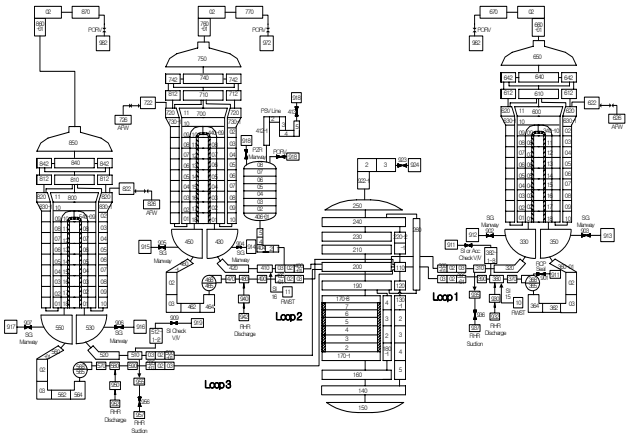

Figure 2. RELAP5/MOD3 nodalization for Kori 3&4 analysis.

The RELAP5/MOD3 analysis results to understand the detailed thermal-hydraulic behavior are summarized in Table 3 and were drawn from loss of RHR events initiated at seven plant configurations with additional openings at cold leg, hot leg, and SG inlet or outlet plenum and initial conditions such as a decay heat at 4 days after reactor shutdown, opening of pressurizer manway, initial RHR pump operation before the loss of RHR event, and initial levels of the hot leg centerline or 3 feet below reactor vessel flange.

Table 3. Summary of RELAP5/MOD3 analysis results.

	Case 1 (PRO)	Case 2 (CLO)	Case 3 (HLOND)	Case 4 (SIMO)	Case 5 (SOMO)	Case 6 (ND)	Case 7 (NDR)+
Core incipient boiling time (s)	670	670	690	650	650	**650**	670
Core bulk boiling time (s)	880	970	820	950	**820**	910	1100
Time to max. RCS press. (s)	8080	11990	5870	1900	2550	7650	3190
Max. RCS press. (MPa)	0.165	0.137	0.124	0.119	0.128	0.161	**0.192**
Max. PZR liquid level (m)	5.14	1.85	1.06	0.59	2.03	4.56	**7.53**
Core uncovery Time (s)	8030	7940	**5970**	**6330**	7630	7080	9300

+) initial RCS water level = 3 feet below the RV flange.
Nozzle dam design press. = 0.258525 MPa (= 22.8 psig).

The important operation guidelines for reduced inventory operation developed from the hand calculation and RELAP5/MOD3 analyses under the conservative assumption without initial RHR pump operation before the loss of RHR event are summarized in Table 4.

Table 4. Recommended guidelines for Kori 3&4 mid-loop operational procedure.

Analysis Parameter	Analysis Result before Power Uprate [4]	Analysis Result after Power Uprate
Min. core boiling time	710 s	500 s
Min. core uncovery time	4920 s for CLOND case	5250 s for HLOND case
Min. RCS vent path to prevent nozzle dam failure	2 PSVs removed	1 PSV and 1 PORV removed
Min. makeup flow to prevent core uncovery	4.5 kg/s	5.53 kg/s
RHR pump recovery time to prevent boron precipitation	within 13.7 hours	within 7.23 hours
Min. gravity makeup time (RWST level)	9.46 hours (97.1%)	9.13 hours (95%)
Analysis conditions: Loss of RHR event initiates 4 days after shutdown, Initial RCS temperature = 135 °F (= 330.37 K), Initial RCS level = hot leg centerline.		

3. Conclusion

In order to address the GL 88-17 recommendations for the Kori 3&4 power uprate condition, analyses of loss of RHR events were performed by using the RELAP5/MOD3 code and hand calculation. For the Kori 3&4 with power uprate, the minimum RCS vent flow area should be larger than the opening of 1 PSV and 1 PORV removed in order to prevent the nozzle dam from failure. The minimum core boiling time and the minimum makeup flow were earlier and greater than those before power uprate due to the increased decay heat, respectively. The minimum core uncovery time was slightly longer than that before power uprate. The detailed analysis results for the GL 88-17 action items will be used to provide the operation guidelines for Kori 3&4 reduced inventory or mid-loop operation.

ACKNOWNEDGMENTS

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