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Evaluation of Transient Natural Circulation Behavior during Accident in Low Power/Shutdown Condition of YGN Units 3/4

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Abstract

A transient natural circulation behavior during a LOCA at hot-standby operation is evaluated for YGN Units 3/4. The plant initial condition is determined within the EOP limitation as suitable to hot-standby mode and the transient scenario is prepared as relevant to evaluation of transient natural circulation. A 0.4 % cold leg break with loss of off-site power is calculated with RELAP5/MOD3.2, whose predictability has been verified for SBLOCA natural circulation test, S-NC-8B. Through one hour transient analysis, it is found that the plant has its own decay heat removal capability by natural circulation following a LOCA at hot-standby mode. Additional calculation is performed to investigate an effect of HPSI flow on natural circulation.

I. Introduction

An accident during low power or shutdown condition (LPSD) has been emphasized due to its potential to severe accident [1]. To confirm the safety in preventing the accident occurrence and mitigating the accident consequence during LPSD operation, it is necessary to evaluate plant-specific capabilities in decay heat removal (DHR), reactor coolant inventory control, reactivity control, and containment isolation [1]. Also the plant-specific emergency operation procedure (EOP) should be evaluated considering the various plant configurations during LPSD condition. All the design basis accidents at full power operation should be considered during LPSD condition

The natural circulation was one of the important DHR mechanism for the events initiated from loss of offsite power during LPSD condition. It is known that the natural circulation behavior should be evaluated to determine the available time for the operator to cooldown and depressurize of reactor coolant system (RCS) and to identify the plant thermal-hydraulic status for operator decision on safety equipment activation following such a event [1].

This study aims at supporting the best-estimate safety evaluation of LPSD operation. A loss-of-coolant-accident (LOCA) at hot standby operation mode of YGN Units 3/4 was analyzed for the evaluation of plant-specific natural circulation behavior through RCS loops as a part of LPSD safety study in regulatory viewpoint

Also, additional calculation was attempted for the case without HPSI, which was to investigate an effect of high pressure safety injection (HPSI) flow on natural circulation The present analysis was based on RELAP5/MOD3.2 [2]. The predictability of the code has been extensively studied for SBLOCA and related thermal-hydraulic phenomena, which indicated that the code had a capability in natural circulation phenomena with proper modeling scheme [3].

II. Modeling and Assumption

The present study describes an analysis of a small break LOCA at one of discharge leg of YGN Units 3/4. The YGN Units 3/4 were 1000 MWe Combustion Engineering type PWR, which has been operated since 1995. For the purpose of this study, the plant was modeled with RELAP5 standard noding scheme. Figure 1 shows a nodalization diagram used in the present study. The whole plant was modeled with 189 hydrodynamic volumes, 207 hydrodynamic junctions, and 212 heat structures. The reactor vessel core was modeled with two parallel channels with 12 volumes each.

The predictability of RELAP5/MOD3.2 on the SBLOCA and the associated natural circulation phenomena has been extensively evaluated through the effort of code development and assessment. Author's report [3] on Semiscale test, S-NC-8B was one of the relevant verification.

The accident was assumed to be initiated at a hot-standby mode operation. The RELAP5 calculated initial condition was listed in Table 1, compared with EOP condition [4].

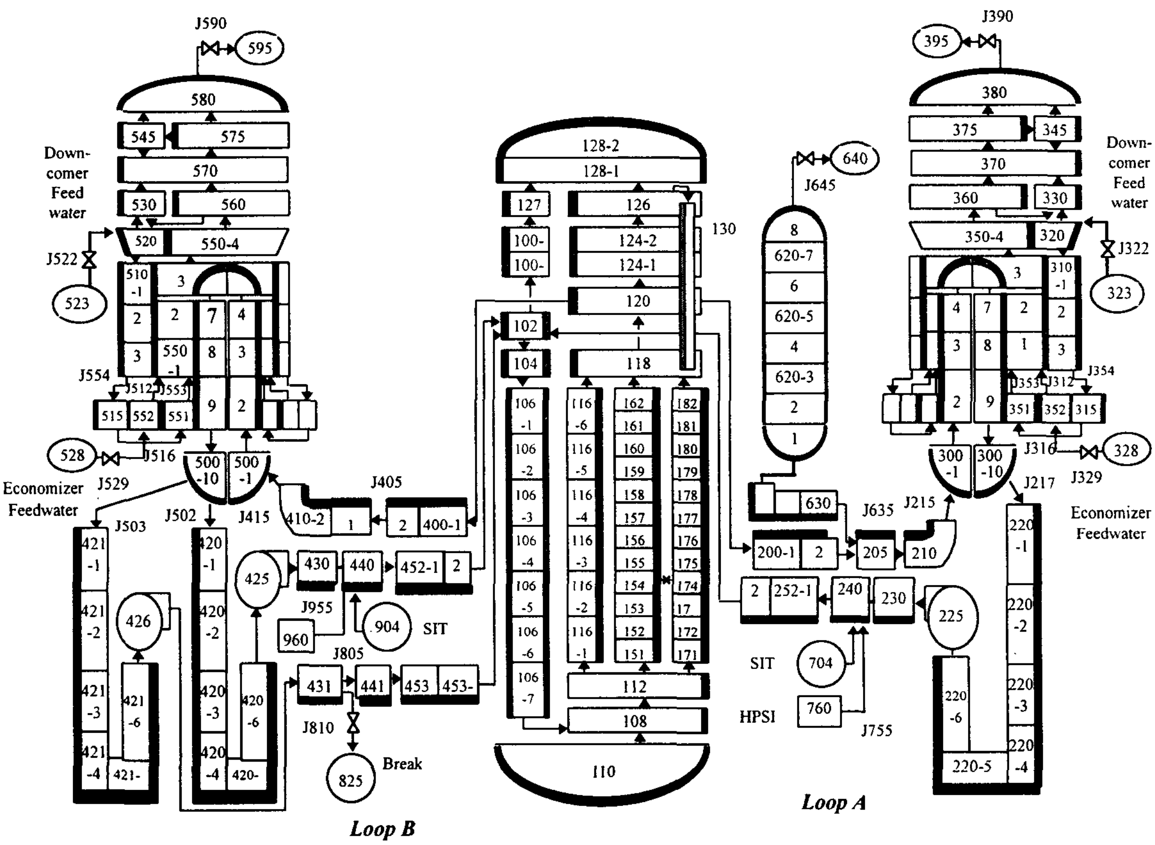

Fig. 1 RELAP5 Nodalization for Natural Circulation Analysis of YGN Units 3/4

Table 1. Initial Condition of Transient of YGN Units 3/4

Items	RELAP5 Cal.	EOP
Reactor Power Level, % (not included decay heat)	0	0
Pressurizer Pressure, psia	2150	1950 ~ 2350
RCS Hot Leg Coolant Temp. T_{hot}, °F	554.42	N/A
RCS Cold Leg Coolant Temp. T_{cold}, °F	552.36	>350
Delta T ($T_{hot} - T_{cold}$), °F	2.06	<18
RCS Average Temp. $T_{average}$, °F	553.39	558 ~ 570
RCS Subcooling, $T_{hot} - T_{sat}$, °F	92.26	>27 °F
Loop Mass Flow Rate, lbm/sec	17355	N/A
Pressurizer Liquid Level, %	33	15 ~ 70
Steam Generator Level, % (wide range)	44	23.4 ~ 90
Steam Generator Pressure, psia	1101	1100 ~ 1220
Steam Generator Feedwater Flow Rate, lbm/sec	80	>77.1
Steam Flow, lbm/sec	24.5	N/A

The calculated initial condition was relevant to EOP initial condition limit. The RCS average temperature was calculated slightly lower than the EOP limit, however, its effect on natural circulation behavior can be neglected.

The assumptions used in transient analysis was as follows

1. 0.4 % cold leg break was assumed, which simulated a RCP (reactor coolant pump) seal damage, and was relevant to figure out two-phase natural circulation and reflux condensation.
2. A loss of offsite power coincident with LOCA was assumed to establish a RCS natural circulation condition. The RCP speed was assumed to be dropped to zero in 5 seconds
3. Single failure assumption was applied to all safety related systems, i.e. a failure of one train diesel generator, etc.).
4. No operator action in one hour was assumed, which was to maintain natural circulation mode.

As previously mentioned, two cases of transient were calculated; a base case with HPSI and a case without HPSI. By comparing both results directly, an effect of HPSI on the natural circulation and the related thermal-hydraulic behavior can be identified.

III. Result and Discussion

RCS Pressure

Figure 2 show a RCS pressure transient. For both case, the RCS experiences a rapid subcooled blowdown following a LOCA. Such a fast depressurization was due to low power level even in this ultra-small break, which resulted in HPSI flow at 60 seconds in the base case. A slight pressure increase before 200 seconds was due RCS volume expansion by void formation at hot leg. A re-decrease in pressure at 600 seconds may resulted from saturated blowdown caused by cold leg voiding and the resultant a transition from subcooled-phase to saturated-phase in break flow. After that, both results show a similar trend until 2100 seconds, which indicated the RCS was thermally balanced by break flow, natural circulation, and decay heat. The comparison showed that the RCS was further cooled down by continuing HPSI flow, while not in the case without HPSI, after 2100 seconds.

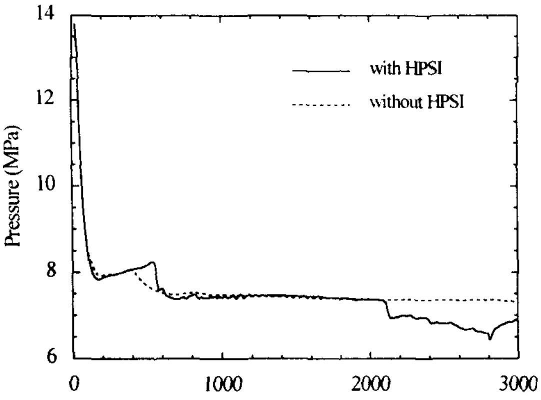

Fig. 2 Primary System Pressure

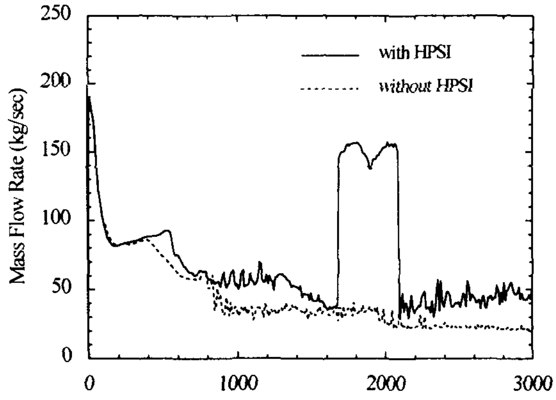

Fig. 3 Break Flow

Break Flow

Figure 3 shows a break flow transient. The overall behavior was similar to the pressure response. The break flow initially amounted to 190 kg/sec, and then reduced to 80 kg/sec, showing a similar trend to the pressure response. A sudden peak during 1700 to 2100 seconds in the case with HPSI was considered as a result from loop seal clearing (LSC), which will be discussed at the next section.

For the base case, the total primary system inventory was initially 375475 kg (834390 lbm). The discharged mass through the break amounted to 160000 kg during the one hour transient, i.e. 42 % of the initial inventory. The comparison between two cases shows that the break flow in the case with HPSI was greater than that in the case without HPSI. It implies that large amount of HPSI water was bypassed out due to high RCS pressure.

Inventory Re-distribution

Figures 4 and 5 show transient behaviors of hot leg liquid fraction and cold leg liquid fraction of the intact loop, respectively. Following the transient, hot leg inventory was reduced by break, however it was recovered by HPSI water until 600 seconds. After that, void was gradually expanded under stratified regime. During 2100 to 2200 seconds, the intact loop hot leg was suddenly emptied, and then recovered, which was due to LSC. The cold leg was filled with water until 2100 seconds, emptied by LSC, and then gradually recovered by the continuous HPSI in the base case.

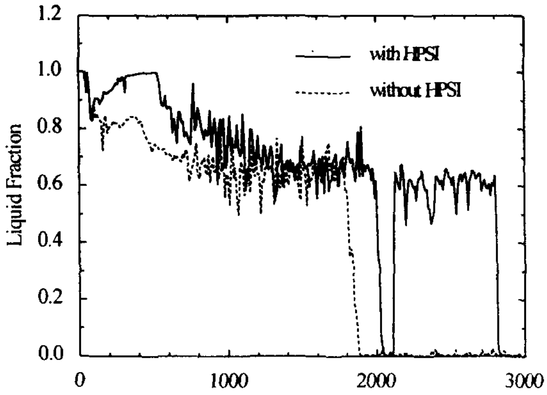

Fig. 4 Intact Loop Hot Leg Liquid Fraction

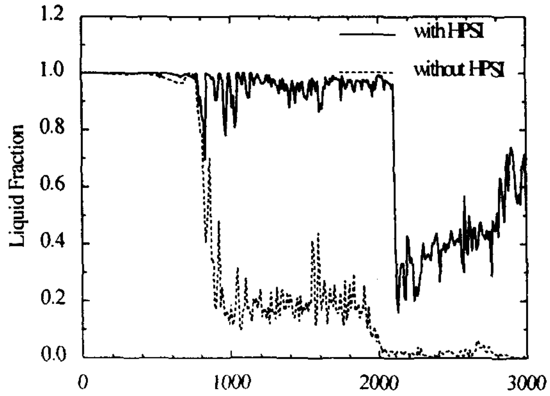

Fig. 5 Intact Loop Cold Leg Liquid Fraction

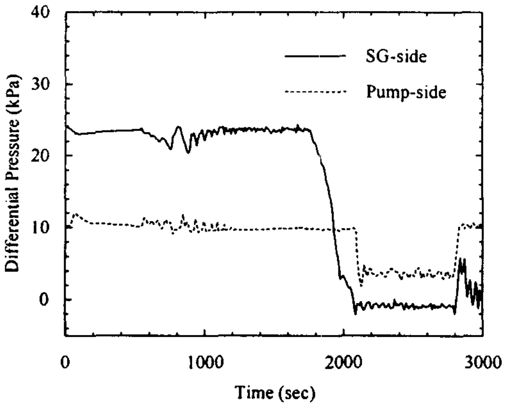

Fig.6 Differential Pressures at Intact Loop Crossover Leg (A)

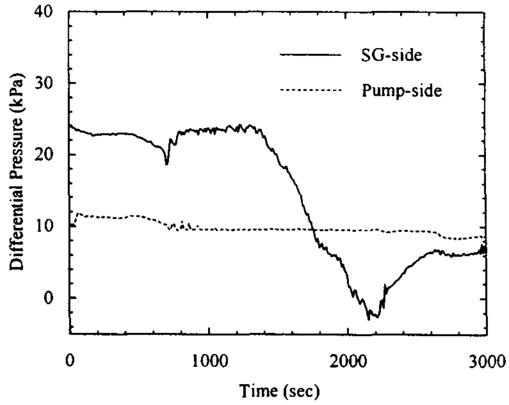

Fig.7 Differential Pressures at Intact Loop Crossover Leg (B)

In the case without HPSI, hot leg inventory was also decreased at 1800 seconds, after then, it, however, was not recovered. The cold leg water was depleted earlier (800 seconds), however, it was not recovered. It indicated that there still existed a water seal in pump side crossover leg in the case without HPSI.

Figures 6 and 7 show comparisons of differential pressure in SG-side crossover leg and pump-side crossover leg at the intact loop for the case with and without HPSI, respectively. Difference in loop seal behavior between two cases can be clearly shown in these figures.

The inventory behavior at the broken loop was quite similar to that at the intact loop.

Transient Natural Circulation

Figure 8 shows a comparison of hot leg mass flow. The loop flow, which was initially 7809 kg/sec, dropped to 200 kg/sec in 5 seconds into transient, due to a sudden RCP stop. And then, it was increased to 800 kg/sec, which was a peak two-phase natural circulation (NC) driven by the maximum density gradient through the RCS. However, the NC flow in the base case was decreased by void reduction due to HPSI, which was clearly identified at hot leg liquid fraction behavior (Figure 4). From 600 seconds, this NC behavior was reduced with some oscillatory manner as the same way as hot leg voiding expanded. As a result, flow direction at hot leg was reversed at 800 seconds, i.e., reflux condensation for both cases. In this situation, vapor in the SG U-tube was condensed and moved into the hot leg. Such a negative flow was stopped by the continuous steam flow from the reactor vessel core, and those behavior was repeated in several times.

At 2000 seconds, the hot leg was completely voided, such a reflux flow was also diminished in the case without HPSI, while it existed in the case with HPSI, The comparison between two cases indicated that HPSI has an effect in reducing the initial two-phase NC flow in the early phase of transient and enhancing the reflux condensation during low inventory period.

Core Behavior

Figure 9 show a liquid level in the reactor vessel core. As discussed previously, core level was continuously decreased by LOCA. For the base case, top of the core was slightly uncovered, heatup was not predicted due to low heat flux. For the case without HPSI, one half of the core was uncovered with significant heatup (Figure 10). This result indicated that the HPSI was effective in maintaining a core cooling within one hour, however, additional cooldown action such as a SG feed-and-bleed was required to continue further RCS cooldown.

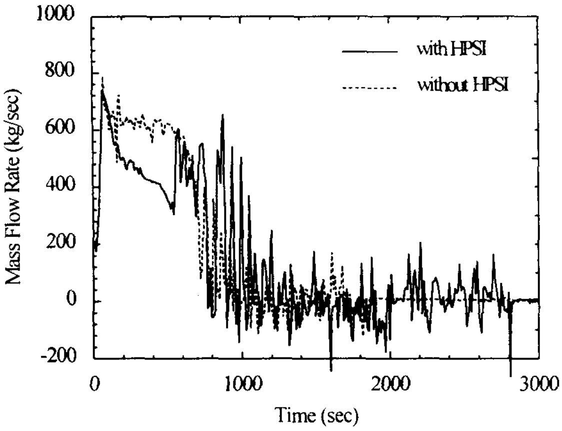

Fig. 8 Intact Loop Mass Flow Rate

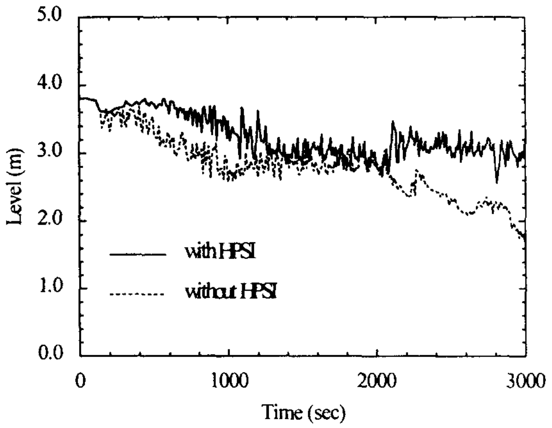

Fig. 9 Reactor Vessel Water Level

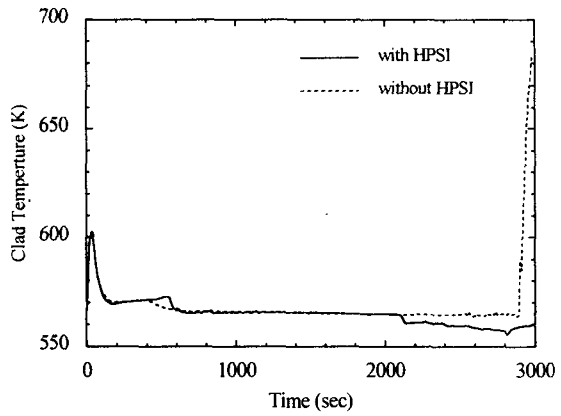

Fig.10 Hot Spot Clad Temperature

IV. Summary and Conclusion

A transient natural circulation behavior during a LOCA at hot-standby operation was evaluated for YGN Units 3/4. The plant initial condition was determined within the EOP limitation as suitable to hot-standby mode and the transient scenario was prepared as relevant to evaluation of transient natural circulation. The RELAP5/MOD3.2, which was verified through an assessment of the code with Semiscale S-NC-8B experiment, was used in the present analysis The following conclusions are obtained :

1. A single-phase and two phase natural circulation, reflux condensation were clearly identified in LOCA at hot-standby mode of YGN Units 3/4. The plant calculation result shows the YGN Units 3/4 has a plant-specific DHR capability by natural circulation within one hour after LOCA at hot-standby mode.
2. The HPSI has an effect on the whole thermal-hydraulic behavior during a hot-standby LOCA, especially on enhancement of reflux condensation.
3. The HPSI was effective in maintaining a core cooling within one hour, however, additional action such as a SG feed-and-bleed was required to continue further RCS cooldown.

References

[1] USNRC, *Regulatory Approach to Shutdown and Low-Power Operations*, SECY-93-190, July 1993

[2] The RELAP5 Development Team, *RELAP5/MOD3 Code Manual*, NUREG/CR-5535, Aug. 1995.

[3] Young S.Bang, et. al., *Assessment of RELAP5/MOD3.2 with the Semiscale Natural Circulation Experiment, S-NC-8B*, KINS/GR-121, January 1997.

[4] KEPCO, *Emergency Operation Procedure for YGN Units 3/4*, June 1994 (*In Korean*)