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Rapid Depressurization Capability of Monobloc Sebim Valves for KNGR Total Loss of Feedwater Event

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Abstract

The conceptual design of Korea Next Generation Reactor (KNGR), which is 3914 MWt PWR, includes the safety depressurization system (SDS) to comply with U.S. NRC's severe accident policy. In this analysis, it is assumed that three Monobloc Sebim valves are adopted for the SDS bleed valves of KNGR. The characteristic of Monobloc Sebim are modeled in the CE-FLASH-4AS/REM code for this analysis. The various feed and bleed (F&B) procedures with Sebim valves are investigated for total loss of feedwater (TLOFW) event. It is found that if operators open two out of three Sebim valves in conjunction with four HPSI pumps before hot leg temperature reaches saturation condition, the decay heat removal and core inventory make-up function can be successfully accomplished. Therefore, this F&B procedure can be used for mitigating the TLOFW event of the KNGR. This result also demonstrates the feasibility of adopting the Monobloc Sebim valves for the SDS of KNGR.

1. Introduction

Following the accident at Three Mile Island (TMI) in 1979, the potential ability of power-operated relief valves to provide an alternative method to remove decay heat from the reactor core was identified and considered to be beneficial in dealing with severe accidents. Recent studies[1-4] have concluded that the feed and bleed (F&B) can be a viable alternate means of decay heat removal. TMI accident showed that the pressurizer safety valves and power operated relief valves are very important for the safe and reliable operation of PWR power plants. FRAMATOME and EDF developed the Monobloc Sebim valves (simply, Sebim valve) for improved RCS overpressure protection concept because many problems were experienced with spring-loaded valves in the RCS and residual heat removal systems.

The conceptual design of KNGR includes SDS in conjunction with in-containment refueling water storage tank (IRSWT) to provide the F&B capability, which complies with the U.S. NRC's severe accident policy. In this analysis, it is assumed that the Sebim valve is adopted for the SDS bleed valve of KNGR. Since Sebim valves have been developed for the overpressure protection of the RCS, the adoption of these valves replaces the existing pressurizer safety valves (PSV) also. Therefore, Sebim valve is capable of both overpressure protection and bleed functions, which is competitive with the previous design in terms of design simplification and cost. Because 4200 MWt French N4 plant has three Monobloc Sebim vales. However, since the KNGR and N4 have different NSSS configuration, it may not be enough to have only three valves. The number of Sebim valves required is determined from the design base overpressure transients. Preliminary analysis performed for YGN 5&6 implies that more than three Monobloc Sebim valves are required for overpressure protection. Therefore, three Sebim valves are assumed for F&B function in a conservative sense. The SDS bleed paths are modeled by three assemblies of Sebim valve, where an assembly consists of two pilot-operated valves mounted back to back (called "tandem").

In French practice operator manually opens Sebim valves when the steam generators (SG) are unavailable (e.g., TLOFW), and SGs are partially available but hot leg temperature reaches saturation. Safety injection is manually or automatically actuated. In this analysis, the French F&B practices for the TLOFW event are investigated to find whether they are applicable to the KNGR.

2. Plant description and initial conditions

The SDS is a dedicated safety system designed to rapidly depressurize the reactor coolant system (RCS) to initiate a primary system F&B for the beyond design base accident (DBA) of the TLOFW. Adoption of Sebim valves for the bleed line of SDS is an option in the KNGR design. The KNGR is two loop 3914 MWt PWR employing several advanced design features. The SDS is assumed to consists of three separate lines connected to the top head of the pressurizer and the flow through Sebim valve discharges to the IRWST. The IRWST provides the volume for receiving the steam and liquid from discharge lines, and prevents the release of effluent to the containment. However, the IRWST is not modeled in this analysis. According to the experimental test results for the Sebim Monobloc valve [5], the minimum valve capacity is of 220 ton/hr steam under 172.3 absolute bar. The analytical bleed area corresponding to this flow capacity is determined as 0.0243 ft^2 based on the Murdock-Bauman correlation. The Sebim valves have staggered opening and closing setpoints to minimize hydraulic load induced by valve actuation during overpressure transients. The opening and closing characteristics of the Sebim valve are shown in Fig.1 and their setpoints are presented in Table 1. High setpoints considering uncertainty are used in the conservative manner for the analysis.

The Sebim valves have operational advantages in view of F&B operation. The valves ensure stable operation without the risk of valve chatter for any type of discharge flow condition encountered: steam, saturated or under saturated water, while maintaining specified operating and closing characteristics. During F&B operation, the flow condition through the bleed path changes from pure steam to single phase water or two-phase mixture. Such phase transients of discharge flow are dependent on the F&B procedure. The Sebim valves ensure maintaining adequate reliability of valve re-closing; thus providing the control of bleed flow through throttling of flow area as well as reliable isolation of the RCS in case of a stuck open valve. The SEBIM valves provide the capability for remote manual opening and closing (F&B) operation under post-accident conditions using fully qualified equipment.

As for the feed system, the KNGR has four trains of high pressure safety injection (HPSI) pump which are mechanically independent. Two diesel generators supply power to each train of HPSI pump. The HPSI flow is injected into upper downcomer through four direct vessel injection (DVI) nozzles. Table 1 provides major plant parameters and initial conditions used for the analysis. The plant initial conditions are assumed at full power steady state nominal conditions.

3. Analyses methodology

The EPRI URD [6] for advanced PWR requires two SDS performance criteria: 1) A single SDS bleed path, in conjunction with two of four safety injection pumps, shall have a sufficient capacity to prevent core uncovery following a TLOFW if F&B is initiated immediately following the opening of primary safety valves, 2) The SDS bleed paths shall have sufficient total flow capacity with all safety injection pumps operating to prevent core uncovery following a TLOFW if F&B is delayed up to 60 minutes from the time primary safety valves lift. For both conditions, analyses shall show a margin to core uncovery of at least two feet, using best estimate methods.

Since the bleed capacity of the Sebim valve is known from the experimental test, the operator's F&B initiation time required to prevent core uncovery is investigated by varying the number of valve opening in conjunction with available HPSI pump. The CEFLASH-4AS/REM computer code [7] developed by ABB-CE is used for the realistic analysis of TLOFW event. Ref.[8] provides the validation of the CEFLASH-4AS/REM against experimental data to verify the capability of the code for use in the analysis of a TLOFW event with F&B. The CEFLASH-4AS/REM is modified to incorporate Sebim valve characteristics shown in Fig.1 for this analysis. The nodalization scheme for the representation of the RCS and detail methodology for determination of the bleed capacity for the YGN 3&4 is presented in Ref.[4].

4. Analysis results and discussions

The assumptions used in the simulation of these transients are: 1) The plant initial conditions are at steady state full power condition. 2) A reactor trip occurs due to low steam generator level at 30 seconds after event initiation. 3) The Reactor Coolant Pumps (RCPs) are tripped 10 minutes after the reactor trip per Emergency Procedure Guidelines [9]. The 10 minutes operator action time is based on the fact that the operator should trip the all RCPs in the Optimal Recovery Guideline (ORG) for the loss of all feedwater. 4) The operator actions are considered according to the design criteria discussed in section 3.

Table 2 provides major chronology of the event for both TLOFW cases without recover action and with F&B. The major plant parameters for typical cases are presented in Fig.2 through Fig.6.

4.1 TLOFW without recovery action

In this case the bleed paths are not available, i.e., no operator action is assumed. Following the TLOFW event, the reactor trip occurs due to low SG secondary liquid level at 30 seconds. Following reactor trip the RCS pressure drops due to a sudden decrease in heat generation from the core as shown in Fig.2. After a short time period, the RCS pressure starts to rise in response to the power-to-flow mismatch and reaches to a new steady state. After the RCP trip at 630 seconds, the pressurizer pressure increases more rapidly due to RCP coast down. When both steam generators dry out at about 1250 seconds the RCS volume expansion and pressurization is accelerated. Then the pressurizer pressure reaches the safety valve's opening setpoint at 1270 seconds and cycles following the characteristics of the Sebim valve. The first stage Sebim valve has almost enough capacity to accommodate the increased volumetric expansion during the entire transient. However, the second stage Sebim valve opens from around 3300 seconds to 3400 seconds. Pressurizer goes solid at about 2000 seconds as shown in Fig.3, and the discharge flow becomes single phase liquid. After the hot leg reaches saturation condition around 2700 seconds, steam generated in the core due to decay heat flows from the core to pressurizer via hot leg and surge line. Core uncovery begins at around 4900 seconds into the transient. The duration between the safety valve's lift and core uncovery is the maximum theoretical allowable time for the operator to open the bleed paths to prevent the core uncovery. It is worth noting that the SG inventory dryout of the KNGR occurs earlier than the YGN 3&4 (1360 seconds; refer to Ref.[4]) because the ratio of SG secondary water mass to unit power of the KNGR is lower than that of the YGN 3&4.

4.2 TLOFW with F&B

The F&B operation is utilized to attempt to cool the core and make up the RCS inventory. Analyzed in this study are the F&B cases with varying the number of bleed valve opening and HPSI pump operating, where the operator action times required to prevent core uncovery with

2 feet margin are investigated. The F&B cases considered are as follows: 1) the case for one bleed valve opening (0.0243 ft^2 analytical area) with two HPSI pumps, 2) the case for two bleed valves opening (0.0486 ft^2) with two HPSI pumps, 3) the case for three bleed valves opening (0.0729 ft^2) with four HPSI pumps. To evaluate the effects of HPSI flow for core covering, the case with four HPSI pumps operating are additionally analyzed for the first two cases. Fig.6 shows the summary of the analysis results where operator action times required to prevent core uncovery is presented for the various F&B cases.

The system parameters presented in the figures are for the F&B case in which two bleed valve opens with four HPSI pumps when the hot leg reaches saturation condition around 2700 seconds. This F&B procedure is the French practice discussed in the introduction. The transients of system is identical to the TLOFW without recovery case until the safety valve (Sebim valves) lift. Soon after the bleed path is opened the RCS pressure decreases rapidly as shown in Fig.2, and hence HPSI injection flow is initiated at 2746 seconds. Fig.4 shows the bleed flow rates through two Sebim valves. The core mixture level increases again as shown in Fig.5 when the injected HPSI flow rate becomes higher than bleed flow rate. Eventually, the continued decrease in RCS pressure results in increased HPSI flow which causes the RCS inventory to rise. The CEFLASH-4AS/REM prediction in this case shows that core mixture level is always maintained above the top of the core.

Based on the analysis results, the French F&B practice is applicable to the KNGR adopting three sebim valves for the SDS. For the initiation of the F&B, monitoring both hot leg saturation and SG inventory would be more reliable rather than relying on the opening of primary safety valve to secure inadvertent opening of the bleed valves. According to YGN 3&4 EPG, the F&B initiates at the time of PSV lift when SGs are unavailable. This analysis indicates that the KNGR SDS adopting Sebim valves has enough capacity to extend the operator's action time to the time of hot leg saturation for initiating the F&B.

As shown in Fig.6, the F&B is a trade-off between allowable time before operator action and the bleed capacity of the system. The first performance criterion required by EPRI URD is satisfied because one bleed valve opening with two HPSI pumps at 1290 seconds succeeds. The second EPRI requirement for a 60 minute time delay after safety valve opening for initiation of the F&B can not be satisfied for the KNGR. Because at 4870 seconds (safety valve lift time is 1270 seconds) the core level is already lowered below two feet from the top of the core as shown in Fig.5.

5. Summary and conclusions

The TLOFW events are simulated by CEFLASH-4AS/REM computer code for the cases without operator recovery and with F&B, where the Monobloc Sebim valves are adopted for the bleed valves of KNGR SDS. The operator action times required to prevent core uncovery are investigated by varying the number of bleed valve opening in conjunction with available HPSI pumps. It is found that if operators open two of three Sebim valves in conjunction with four HPSI pumps before hot leg temperature reaches saturation condition, the decay heat removal and core inventory make-up function can be successfully accomplished by F&B operation. Therefore, this F&B procedure can be used for mitigating the TLOFW event of the KNGR. This result also demonstrates the feasibility of adopting the Monobloc Sebim valves for the SDS of KNGR.

References

1. Y.M. KWON, J.H. SONG, and T.S. RO, "Decay Heat removal Capability of Safety Depressurization System for Total Loss of feedwater Event," *Proc. of NURETH-5*, Salt Lake City, Vol.6 (1992)
2. Y.S. BANG, K.W. SEOL, and H.J. KIM "Evaluation of Total Loss of Feedwater Accident/Recovery

Phase and Investigation of the Associated EOP," *J. Korean Nucl. Soc.* Vol.**25**. (Mar. 1993)
3. B.E. BOYACK, R.J. HENNINGER, and etc., "Los Alamos PWR Decay Heat removal Studies Summary Results and Conclusions," NUREG/CR-4471, LANL (1985)
4. Y.M. KWON, J.H. SONG, and T.S. RO, "Analysis of Total Loss of feedwater Event for the Determination of Safety Depressurization Bleed Capacity," *J. Korean Nucl. Soc.* Vol.**27**. (Mar. 1995)
5. Dherissard C., Leduc. R., Lyonnet G., "Hot Protection Against Overpressure in the Main Primary System of Model N4 PWR. Testing of the Solution Termed Sebim Monobloc with Upstream Cold Water Trap," HT-21/88-12B, EDF
6. EPRI Utility Requirement Documents for the advanced light water reactor, Chap. 5.
7. C-E Power Systems, Realistic Small Break LOCA Evaluation Model, CEN-373-P, 1987.
8. C-E Nuclear Power Systems, Software Verification and Validation Report for CEFLASH-4AS/REM, VV-FE-0063, (1992)
9. C-E Power Systems, Combustion Engineering Emergency Procedure Guidelines, CEN-152, 1987.

Table 1. Major Plant Parameters and Initial Conditions

Parameter	Design Value
Core power (MWt)	3914
RCS pressure (psia)	2250
RCS flowrate (lbm/sec)	$165.8*10^6$
Cold leg temperature (^oF)	555.8
Hot leg temperature (^oF)	615
SG pressure (psia)	1000
RCS Inventory (lbm)	624930
Primary side volume (ft^3)	15450
Pressurizer volume, liquid/total (ft^3)	1200/2400
Low SG level reactor trip setpoint (% WR)	40.7
Safety Injection Actuation Signal setpoint (psia)	1825
HPSI pump shutoff head (psia)	1834.7
Number of Sebims	4
Sebim opening/blowdown setpoint (psia)	
first stage valve	2489.5/2406.5
second stage valve	2519.5/2436.5
third stage valve	2549.5/2466.5
Analytical bleed area of Sebim valve(ft^2)	0.024319

Table 2. Chronology of the TLOFW Event

	TLOFW w/o Recovery	TLOFW with F&B			
Bleed Area (m2)	0	1 valve	2 valves	3 valves	2valves
Feed flow	No HPSI	2 HPSI	2 HPSIs	4 HPSIs	4 HPSIs
Event		Time (seconds)			
Total loss of feedwate	0	0	0	0	0
Reactor trip	30	30	30	30	30
RCP trip, manua	630	630	630	630	630
Steam generator dryout	1245	1245	1245	1245	1245
Safety valve open	1270	1270	1270	1270	1270
SDS bleed path(s) opens	N/A	1290	2200	4200	2700
HPSI flow on	N/A	1378	3382	4543	2746
Hot leg saturation	2704	1400	2210	2704	2700
Core uncovery begins	4894	N/A	N/A	N/A	N/A
or					
Minimum RV inventory, kg		144100	120600	107200	101400
occurred at, sec		4200	3720	4600	2835

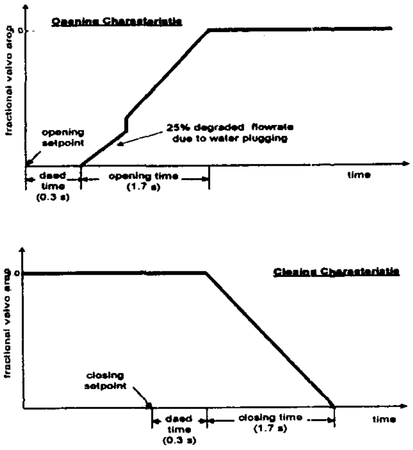

Fig.1 Characteristics of Sebim valve

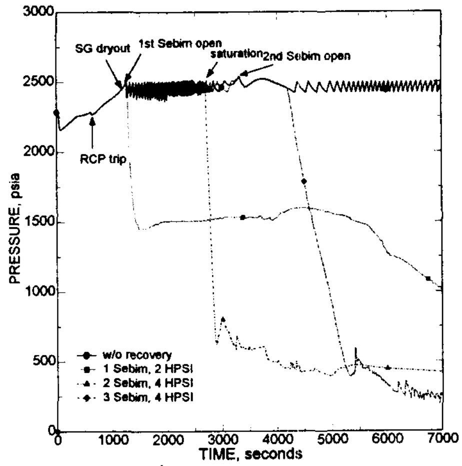

Fig.2 RCS Pressure

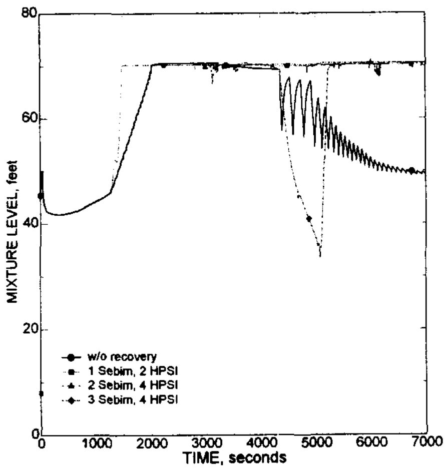

Fig.3 Pressurizer Level

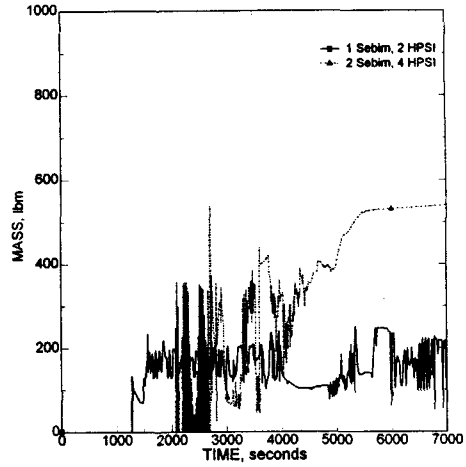

Fig.4 Bleed Flow Rates through Sebim valves

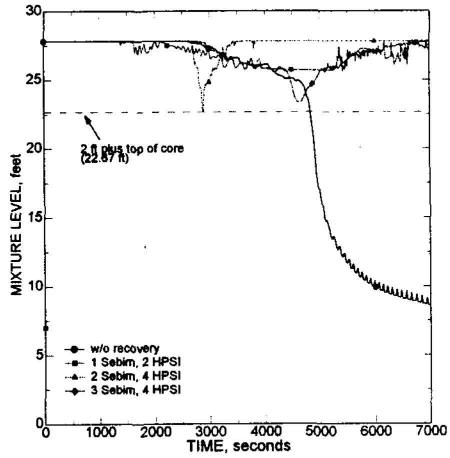

Fig.5 Core Level

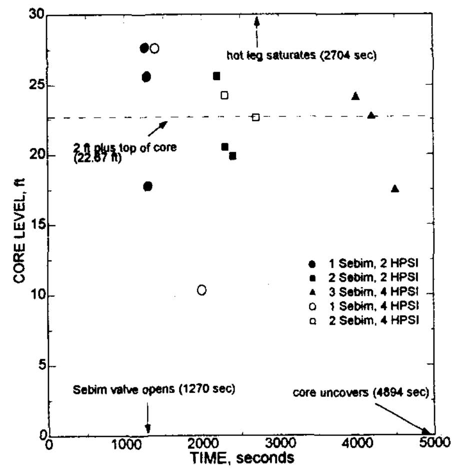

Fig.6 Operator's Action Delay Time to Prevent Core Uncovery