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Scoping Analyses for the Safety Injection System Configuration for Korean Next Generation Reactor

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Abstract

Scoping analyses for the Safety Injection System (SIS) configuration for Korean Next Generation Reactor (KNGR) are performed in this study. The KNGR SIS consists of four mechanically separated hydraulic trains. Each hydraulic train consisting of a High Pressure Safety Injection (HPSI) pump and a Safety Injection Tank (SIT) is connected to the Direct Vessel Injection (DVI) nozzle located above the elevation of cold leg and thus injects water into the upper portion of reactor vessel annulus. Also, the KNGR is going to adopt the advanced design feature of passive fluidic device which will be installed in the discharge line of SIT to allow more effective use of borated water during the transient of large break LOCA. To determine the feasible configuration and capacity of SIT and HPSI pump with the elimination of the Low Pressure Safety Injection (LPSI) pump for KNGR, licensing design basis evaluations are performed for the limiting large break LOCA. The study shows that the DVI injection with the fluidic device SIT enhances the SIS performance by allowing more effective use of borated water for an extended period of time during the large break LOCA.

I. Introduction

The purpose of this study is to determine the feasible configuration of Safety Injection System (SIS) for Korean Next Generation Reactor (KNGR). The KNGR is an Advanced Light Water Reactor (ALWR), whose design belongs to the same category as ABB-CE's System 80$^+$ and European Power Reactor (EPR). Table 1 summarizes the major design data of KNGR. As seen in the Table, the SIS of KNGR consists of four mechanically separated hydraulic trains. They are also electrically separated by two division (i.e., each emergency diesel generator powers two hydraulic trains). Each hydraulic train consisting of a High Pressure Safety Injection (HPSI) pump and a Safety Injection Tank (SIT) is connected to the Direct Vessel Injection (DVI) nozzle located above the cold leg and thus injects water into the upper region of reactor vessel annulus. During the large break LOCA, SITs are used for the initial quick reflooding of core and HPSI pumps are used for the continued reflooding after the SITs are emptied. Different from System 80$^+$ SIS, the KNGR is going to adopt passive fluidic device[4] which will be installed in the discharge line of SIT. This device delivers SIT water into the reactor coolant system by controlling its injection flow from a high flow rate to a low flow rate by utilizing the confined vortex flows. This allows more effective use of borated water for an extended period of time during the large break LOCA. The excessive large injection of SIT is not beneficial for the current large break LOCA evaluation model (EM) analysis, because the safety injection water exceeding the amount of core reflooding spills out the break. The larger amount of spillage minimizes the containment pressure which in turn minimizes the core reflood rate and maximizes the Peak Cladding Temperature (PCT). Thus, the optimum SIS capacity is determined as the minimum flow enough to maintain the dowmcomer water level at the elevation of the cold leg nozzle throughout the transient, and it is determined by evaluating the safety injection configurations such as injection location and flow capacities of SIT and HPSI pump with the elimination of the LPSI pump. The water supply of HPSI pumps is from the incontainment refueling water supply tank (IRWST) designed with the cylindrical type of double containment.

II. Scope of Analysis

To determine the feasible safety injection configuration and to define the optimum flow rate requirements of SIT and HPSI pump for KNGR, licensing design basis evaluations are performed. As a licensing design basis approach, this study performs analyses for the limiting large break, the 1.0 Double-Ended Guillotine break in the Pump Discharge leg (1.0 DEG/PD), using the NRC approved, 1985 version of the C-E large break LOCA evaluation model[1]. For the analysis presented, the CEFLASH-4A[2] and COMPERC-II[3] codes are used. The CEFLASH-4A computer program calculates the thermal hydraulic response of a pressurized water reactor (PWR) during the blowdown period of large break LOCA. The COMPERC-II computer program determines the hydraulic response of a PWR during the refill and reflood period of a LBLOCA. In addition, it calculates the containment pressure during both the blowdown and refill/reflood periods of the transients.

The analysis assumes loss of off-site power simultaneously with the break and the worst single failure as a loss of a diesel generator which results in the minimum Emergency Core Cooling System (ECCS) flow to the core. For containment pressure considerations, no ECCS failure is considered as an additional conservatism. Table 2 summarizes the SIS flows used for core cooling and spilled into the containment in the discharge leg break analysis for each injection configuration.

The study includes the comparison of four DVI injection configuration (hereafter it will be called as DVI4) of KNGR with the other configurations of safety injection. One configuration of SIS considered is the Yonggwang 3 & 4 (YGN 3 & 4) which adopts the cold leg injection with two HPSI pumps, two LPSI pumps, and four SITs (hereafter it will be called as CLI2). Another configuration considered in this study is the one with four HPSI pumps and four SITs connected to each cold leg without the LPSI pumps (hereafter it will be called as CLI4). For CLI4 configuration, two case runs are performed for the 100 % and 200 % of the KNGR HPSI pump capacity . Finally, DVI4 configuration with the current SIT and with the fluidic device SIT are analyzed.

III. Analysis Results and Discussions

The purpose of this study is to determine the feasible configuration of the SIS for KNGR, therefore, the thermal hydraulic differences of various SIS configuration as calculated by the ABB-CE's large break LOCA evaluation model are described. The discussion is divided into two parts. The first one is concerned with the blowdown portion of the transient and the second one pertains to the refill and reflood period.

Blowdown Period

The limiting large break LOCA with the SIS configurations of DVI4 for KNGR, CLI2 adopted for YGN 3 & 4, and the additionally considered CLI4 are analyzed. As seen in Table 2, for the CLI2 and CLI4 configurations one SIT is assumed to spill directly into the containment. In the KNGR design, since four tanks inject directly into the reactor vessel, no spillage out of the break is assumed. This would tend to lead to an earlier end of blowdown because the downcomer fills up more quickly and the ECC water is delivered to the core sooner. However, as seen in Figure 1, there is insignificant differences between the various SIS configuration during the blowdown period. This is most likely a consequence of the methodology and is not necessarily true. In large-scale tests in the 2D/3D program such as UPTF[5] have shown that DVI injection resulted in strong ECC bypass throughout the end of blowdown due to the high velocity injection jets which cause the ECC water to be more finely distributed in the upper portion of the downcomer.

Refill/Reflood Period

The refill period starts when the ECC water in the annulus flows down to the lower plenum. The reflood period starts when the ECC water fills to the bottom of active core. During these refill and early reflood periods, sufficient amount of injection from SITs is required to make the downcomer water level rapidly reach the inlet nozzle elevation. From this time on, the water column in the downcomer provides the driving force to reflood the core. Once the downcomer is filled to that elevation, all safety injection water in excess of that which refloods the core is assumed to be spilled out the break. Thus, the optimum SIS capacity is to provide the minimum flow enough to maintain the dowmcomer water level at the elevation of the inlet nozzle throughout the transient, and it is determined by evaluating the safety injection configurations such as injection location and flow capacities of SIT and HPSI pump with the elimination of the LPSI pump.

Figures 2 and 3 compare the downcomer water level and the integrated reflood liquid mass added to the core for the various SIS configurations. It shows that the downcomer remains full and the mass is added to the core at approximately the same rate for all of the configurations except for the CLI4 with 100 % of HPSI capacity. These figures along with Figure 1, however indicate that the DVI4 SIS with fluidic device SIT case shows the best performance among the considered SIS configurations. This implies that more ECC is being spilled into the containment for other SIS configurations. Based on these results, the PCT for the DVI4 injection with fluidic device SIT would be lower than 2045 °F which is the value calculated from the case of DVI4 injection with the current SIT.

Figure 4 shows the comparison of the total SIS flow rates for the DVI4 with the current SIT and with the fluidic device SIT. With the reduced SIT flow rate from the time when the downcomer water level reaches the inlet nozzle, the safety injection water of SIT would be available for an extended period of time. It is calculated from this analysis that the SIS empty time can be extended to approximately 300 seconds after the break. This will contribute to the significantly less stringent requirements for the startup time of emergency power source and the capacity of SIS.

IV. Conclusions

The KNGR ECCS configuration of four train DVI injection with the fluidic device SIT allows more effective use of borated water for an extended period of time during the large break LOCA. This SIS configuration produces the least spillage into the containment which enhances ECCS performance and thus increases the safety margin. It also leads to the less stringent requirements for the startup time of emergency power source and the capacity of SIS. However, since there is still a issue of 2D/3D effect of strong ECC bypass for DVI configuration, further study is required to draw final conclusion.

References

1. CENPD-132P, Supplements 1, 2P,and 3-P, "Calculative Methods for the C-E Large Break LOCA Evaluation Model", June, 1985.
2. CENPD-133P, Supplements 2, 4-P,and 5-P, "CEFLASH-4A A FORTRAN IV Digital Computer Program for Reactor Blowdown Analysis", June, 1985.
3. CENPD-134P, Supplements 1, 2, "COMPERC-II, A Program for Emergency Refill-Reflood of the Core", June, 1985.
4. T. Shiraishi, H. Watakabe, "Development of the flow controller accumulator", Int'l Conference on Design and Safety of Advanced Nuclear Power Plants, vol. IV, 1992.
5. NUREG/IA-0127, "Reactor Safety Issues Resolved by the 2D/3D Program", USNRC, July, 1993.

Table 1

List of Major Design Data for KNGR Large Break Analysis

Nominal full core power	3914 Mwt
Secondary side pressure	1000 psia
RCS flow rate	165.8×10^6 lbm/hr
Core flow rate	160.8×10^6 lbm/hr
RCS hot leg temperature	615 °F
No. of Hydraulic/ emergency power trains of ECCS	4/2
No. of DVI nozzles, SITs, HPSI pumps	4,4,4
Delay time for HPSI pumps to be at full delivery	40 sec.
Minimum SIT gas pressure (Min./Max.)	570/632 psia
SIT line K-factor (Based on 0.6827 ft^3)	4.5 to 30
SIT total volume per tank	2406 ft^3
SIT liquid volume (Min./Max.)	1600/1927 ft^3

Table 2

Summary of SIS flow characteristics during the Pump Discharge Leg Break

	Blowdown		Refill & Early Reflood		Late Reflood	
	Core Cooling	Direct Spillage	Core Cooling	Direct Spillage	Core Cooling	Direct Spillage
DVI4	4 SITs (Bypass)	No	4 SITs	No	Fraction of (4 SITs + 2 HPSIP)*	No
CLI4	3 SITs (Bypass)	1 SIT	3 SITs	1 SIT	Fraction of (3 SITs + 1 HPSIP)*	1 SIT + 1 HPSIP
CLI2	3 SITs (Bypass)	1 SIT	3 SITs	1 SIT	Fraction of (3 SITs + 3/4 HPSIP + 1/2 LPSIP)*	1 SIT + 1/4 HPSIP + 1/2 LPSIP

* Remainder will spill to the containment

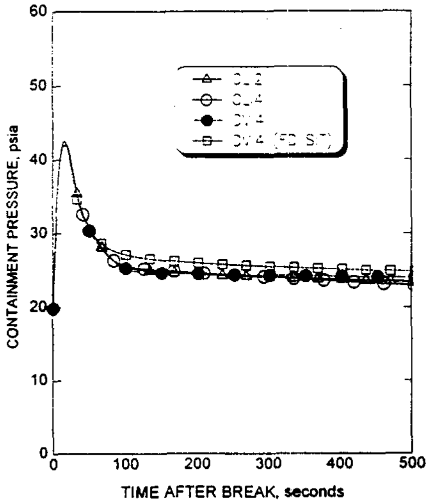

Fig. 1 Comparison of Containment Pressure (1.0 DEG/PD)

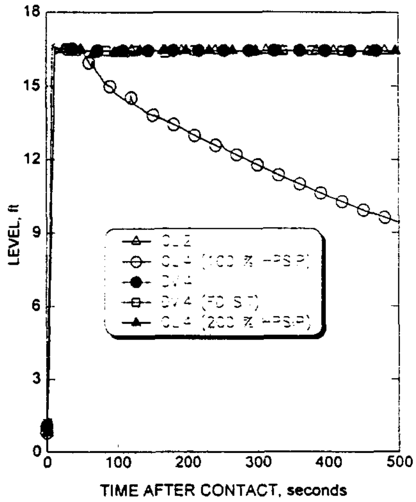

Fig. 2 Comparison of Downcomer Level (1.0 DEG/PD)

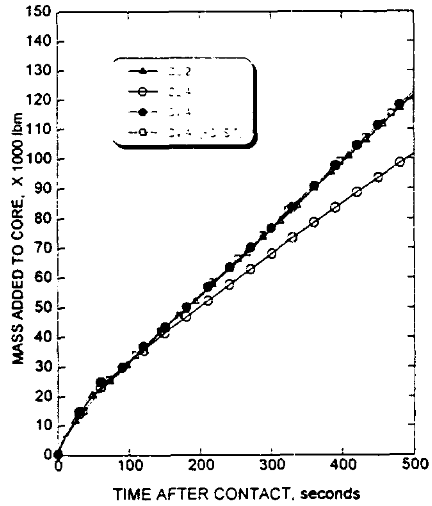

Fig. 3 Comparison of Reflood Liquid Mass Added to Core (1.0 DEG/PD)

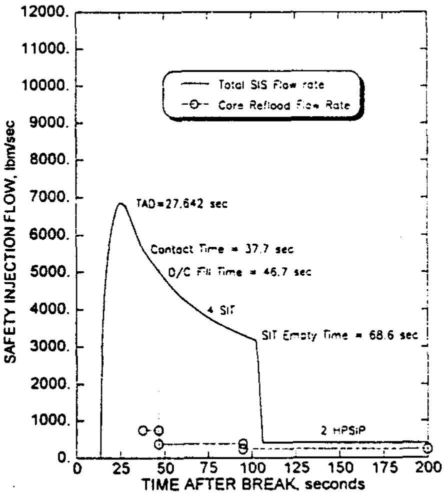

Fig. 4 Safety Injection Flow into Reactor Vessel (1.0 DEG/PD)