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Source Term Sensitivity Studies for Primary Feed & Bleed Operation

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1. Introduction

Accident source term is evaluated for primary feed & bleed operation under a hypothetical high-pressure severe accident in Korean standard nuclear plant (OPR-1000) using MIDAS code system [1]. Both the rapid depressurization and coolant injection processes are made using SDS (safety depressurization system) and HPSI (high pressure safety injection), respectively. The analysis is limited to in-reactor vessel source term, until the vessel failure time (or accident termination time).

The SDS is composed of 2 small capacity (= 9/32") discharge lines draining to reactor drain tank and 1 large capacity (= 4") discharge line draining to containment atmosphere. The operator is assumed to fully open the large capacity discharge line at particular timings for a bleed operation. The HPSI is injected into 4 cold legs using 2 HPSI pumps which are initiated by SIAS (safety injection actuation signal: the pressurizer low pressure or the containment high pressure). One HPSI pump with 75% design flow rate (= maximum 80 kg/sec) and pump characteristic curve[2] are used in the analysis for a feed operation. The water inventory source is the refueling water tank (RWT) at first and is converted to sump after RAS (recirculation actuation signal) occurs when RWT water inventory decreases to 10% of initial inventory.

2. Methods and Results

2.1 Analyzing Scenarios

The selected accident for a base high-pressure sequence is a total loss of feedwater (TLOFW) accident. Following total loss of feedwater including main and auxiliary feedwater, reactor scram occurs at 37 seconds into the accident by steam generator (S/G) low water level (< 42.9%, mass inventory < 45,000 kg) and core power decreases to decay power.

For a basic case of feed & bleed operation (TLOFW1), the SDS is opened by an operator when the collapsed water level is 30 cm above the reactor vessel floor (at 4200 seconds into the accident corresponding to 70 seconds before the coolant depletion in a reactor vessel).

2.2 Base Accident Progression

Table 1 shows the major accident progression for base (TLOFW) and sensitivity (TLOFW1) cases.

Event	Time [sec]	
	TLOFW	TLOFW1
Accident initiation	0	0
Reactor Trip	37	37
SG1/2 dryout	734/751	734/751
PSV opening start	841	841
RCP stop	1519	1519
TAF uncover	2559	2559
BAF uncover	3328	3328
Gap Release initiation (cladding T. ≥ 1173K)	3487	3487
SDS opening start	N/A	4200
PSV final close	N/A (after RV failure)	4208
RV coolant depletion	4270	N/A
HPSI start	N/A	4446
SIT start	N/A (after RV failure)	4680
Fuel Release initiation (UO_2 melt starts)	5424	N/A
Reactor Vessel failure	6621	N/A (end=7500)

Table 1 Comparison of major accident progression

The primary pressure decreases to 125-130 bar after reactor trip but starts to increase after S/G dryout. At 840 seconds, primary pressure reaches at PSV (pressurizer safety valve) open setpoint (= 172.4 bar) and coolant is released showing maximum flow rate (=170 kg/sec) at 170 bar (see Fig.1) which is very similar with FSAR results (Main feed line break accident in FSAR [2] shows a maximum critical flow rate of 160 kg/sec at 173 bar)

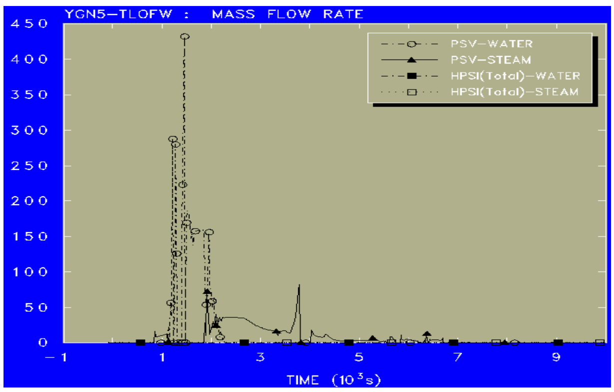

Figure 1 PSV flow rate [kg/sec] : TLOFW

As shown in Fig.1, the discharge flow through the PSVs is made by saturated liquid located in the upper part of the vessel at the early stage and is changed to saturated steam (resulting in higher energy discharge rate) after 2000 seconds into the accident when the collapsed liquid level reaches near the vessel center line. The primary pressure increasing even after PSV opening reaches the maximum pressure of 180 bars at 2000 seconds and then decreases to 170 bars for 300 seconds which is kept until reactor vessel failure. The reactor coolant pumps trip due to the cavitation occurred first in the intermediate leg between 1450 and 1540 seconds and undergo the coast down process for 300 seconds.

The RCS (reactor coolant system) water level decreases after PSV opening and core starts to uncover at 2500 seconds. The RCS water reaches to the level of core bottom at 3300 seconds and even is depleted at 4270 seconds into the accident. Gap release starts at 3480 seconds when cladding temperature becomes 1173 K while fuel release starts at 5400 seconds when fuel temperature reaches UO_2 melting temperature. Melted fuel relocates into the reactor vessel bottom head which results in vessel failure at about 6600 seconds.

2.3 Primary Feed & Bleed Operation

The RCS pressure decreases to PSV closing setpoint (=163.8 bar) and HPSI injection point (= 108.8 bar) at 8 and 146 seconds after SDS opening, respectively. As shown in Fig.2, the discharge flow through the SDS shows maximum rates of 110 (steam) and 140 kg/sec (liquid) before and after the HPSI starts, respectively.

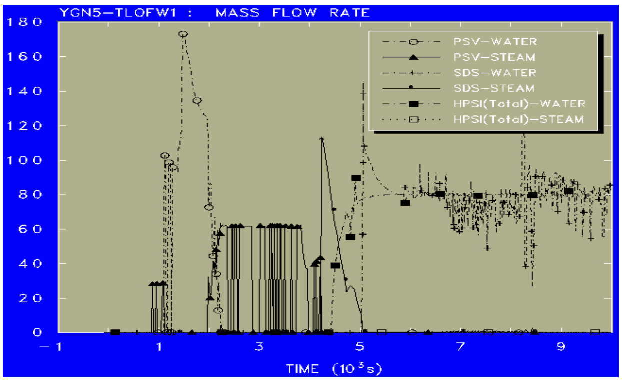

Figure 2 PSV/SDS flow rate [kg/sec] : TLOFW1

The RCS pressure decreases rapidly while the water level is recovered from the feed & bleed operation, and none of fuel melt and reactor vessel failure occur. Meanwhile, core damage (which means the maximum fuel temperature is over 1000 K) depends on the SDS opening timing. According to the sensitivity studies (see Table 2), SDS is needed to open at least before 20 minutes and 105 minutes to protect the core damage and reactor vessel failure, respectively.

Case	SDS opening	Core uncover	HPSI start	Core recovered	[sec]
1 **Shortest**	1200 (=20min)	1856	1791	2402	**Core intact** (= max.. fuel Temp. < 850K)
2	1500 (=25min)	2032	2058	2638	Core damage (= max.. fuel Temp. > 1000K)
3 TLOFW1	4200 (=70min)	2559	4446	4862	Core damage
4	5700 (=95min)	“	6300	6765	Fuel melt
5 **Longest**	6300 (=105min)	“	6602	7140	Fuel melt, **Rx intact**
TLOFW	N/A	"	N/A	N/A	Rx failure = 6621

Table 2 Sensitivity Results by the SDS opening time

2.4 In-Vessel Source Term

The table below shows the in-vessel source term for Cases 3/4/5/6 (Cases 1/2 show negligible source term due to negligible core damage) that is compared with typical value of early in-vessel release in NUREG-1465 [3]. Case 3 shows very small source term because core recovery is made before fuel melt time (=5424) and Case 5 shows larger source term than Case 4 (in which recovery is faster) and is almost same with Case 6 where reactor failure occurs. The similarity with the NUREG-1465 source term is the highest in Case 4 except inert gas release rate and fuel release duration. The difference is caused by the accident progression speed of TLOFW which is faster than that of the N-1465 typical scenario.

Case	3	4	5	6	N-1465
Xe	0.04	0.49	0.70	0.79	1.0
CsI	0.04	0.485	0.70	0.79	0.4
Cs	0.037	0.45	0.65	0.73	0.3
Te	3.68E-7	0.032	0.076	0.073	0.05
La	7.44E-9	3.4E-5	1.61E-4	1.5E-4	2.0E-4
Sr	1.66E-6	0.029	0.082	0.08	0.02
Ba	1.66E-6	0.029	0.082	0.08	0.02
Ru	2.58E-6	0.012	0.027	0.027	0.0025
Ce	2.30E-8	2.5E-5	7.1E-5	6.7E-5	5.0E-4
Gap release duration	23min	32min	32min	32min	30min
Fuel release duration	N/A	22min	29min	20min	80min

3. Conclusion

This study analyzes the source term using primary feed & bleed operation for the most conservative severe accident scenario of TLOFW. The results show similar source term with NUREG-1465 when the feed & bleed operation is made after 95 minutes into the accident. The evaluation is made using the MIDAS 1.0 code system based on the MELCOR code and will contribute to the construction of a domestic source term table.

REFERENCES

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[3] USNRC, “Accident Source Terms for Light Water Nuclear Power Plants,” NUREG-1465, 1995.