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Analysis on the safety verification tests of the ECCS driven by the electrically 4 trains during LBLOCA

Yusun Park [a*], Hyun-sik Park [a], Kyoung-ho Kang [a], Nam-hyun Choi [a], Kyoung-ho Min [a], Ki-yong Choi[a]
[a] *Thermal Hydraulics Safety Research Division, Korea Atomic Energy Research Institute*
989-111 Daedeok-daero, Yuseong-gu, Daejeon, 305-333, Republic of Korea
[*]*Corresponding author: yusunpark@kaeri.re.k.r*

1. Introduction

The APR1400 design has been changed such that the safety injection pumps are driven by four emergency diesel generators in the design certification process from the U.S. NRC. Owing to the design change, the total amount of water injected from three SIPs to the reactor pressure vessel is expected to increase compared with the case of a two train ECC system. The bypass ratio will also be different depending on the different combinations of three available SIPs, and might have different influences on the thermal hydraulic characteristics during the reflood phase of the LBLOCA.

After the SIT injection is terminated, the nitrogen gas remaining in the SITs can flow into the reactor coolant system (RCS). It can be expected that the nitrogen gas injection has a positive effect from the view point of the core cooling performance. However, there is no available experimental data to confirm this expectation at the moment.

Thus, the verification experiments of the reflood phase during a large break LOCA were performed to evaluate the core cooling performance of the four trains ECCS with the assumption of a single failure.

2. Description of the ATLAS

2.1 General Description of the ATLAS

The ATLAS facility includes a reactor pressure vessel, two steam generators, four reactor coolant pumps, a pressurizer, and four safety injection tanks. Arrangement and labeling of the primary legs including the break simulation lines are also shown together. The detailed ATLAS design and description of the ATLAS development program can be found in the literature [1, 2]. The number of instruments is up to 1,300 at present, and the detailed description of the signal processing system and control system of the ATLAS can be found in the literature [3, 4].

2.2 Break Simulation System for the LBLOCA Test

The configuration of the break simulation system and containment simulation system used for the LBLOCA reflood tests were described in detail in the literature [5].

For the present LBLOCA test, four control valves were installed to simulate the discharge through the DVI and additional thermocouples were also installed on the outer surface of the RPV down-comer wall to achieve the initial conditions for the reflood phase of the LBLOCA.

3. Experimental Conditions and Procedure

Before the test, a heat-up of the whole system and an initialization process was carried out to obtain the steady state of the whole system. The overall procedures to achieve the initial steady state are explained in the literature [6]. About 10 minutes after the steady-state conditions were achieved, both in the primary and secondary system, the water inventory in the reactor pressure vessel was discharged using the four FCV valves (FCV-DVI-01~04), which were newly installed valves on the DVI lines. This new endeavor lowered the overall RPV wall temperatures about 20^{o}C than that of the former LBLOCA test. The initial and boundary conditions for the LBLOCA test were explained in the literature [7] in detail.

The sequence of events of the LBLOCA test is summarized in Table 1. The decay heat was simulated from the start time for the reflood phase of a LBLOCA along the ANS-73 decay curve and the scaled ECC water flow rates from the four safety injection tanks and three high pressure safety injection pumps were injected as the designed flow rates. The different combinations of three SIPs were conducted as a sensitivity study. , The nitrogen gas was injected to the primary system through the stand pipes which were installed in the SITs after the SIT injection was terminated. The amount of the nitrogen gas injected to the primary system was estimated using the ideal gas equation. The amount of the injected nitrogen gas was a little different for each tank and the total amount from the four SITs was calculated as 5.18 kg. The test matrix is shown in Table 2.

Table 1: Sequence of Event

Event	Time (DAS)	Description
Test Start	0	Data recording start
Heating End	301	Core/RCP Trip, SS Isolation, Heater off
Vent/Drain	364	FCV-DVI-01~04 Open
BS Open	1260	FCV-BS-02, OV-BS-01 Open
IL Drain	Manual	Intermediate lines are emptied.
Power Restart	1408	Linear increase during 20

		seconds
SIT Injection	1463	Max T>450℃(target : 456℃)
Reflood Start	1465	2.0 s after SIT Injection
SIP Injection	1479	12.7 s after Reflood start
PCT	1563	Peak Heater rod surface temperature, 624.74 °C
Quenching	1855	TH-CO-Gi-MAX

Table 2: Test Matrix

Test ID	SIP Injection	Nitrogen gas	Remarks
LB-SI-01R	HPSI-01,02,03	No injection	Standard case
LB-SI-02	HPSI-01,03,04	No injection	Sensitivity study case
LB-SI-03	HPSI-02,03,04	No injection	Sensitivity study case
LB-SI-04	HPSI-01,03	No injection	2 train case comparison
LB-SI-05	HPSI-01,02,03	Inject	N_2 gas effect test

4. Results

The overall experimental results revealed the typical thermal-hydraulic trends expected to occur during the reflood phase of a large-break LOCA scenario for the APR1400.

Figure 1 shows the maximum heater rod surface temperatures of the five test cases. Three lines with different symbols refer to the maximum temperature of the heater group1, group2, and group3 respectively. The LB-SI-04 test, in which two SIPs were injected, took the longest time interval (650 sec) from the power restart to the quenching. Other cases, LB-SI-01R, 02, and 03, took a relatively short time (around 450 sec) for quenching. This result comes from the different amount of injected ECC water. The injection of ECC water from three SIPs delivered 1.5 times much water to the RPV core, and thus the water level increased faster than that of the LB-SI-04 case.

As shown in Figure 2, the case of LB-SI-04, which two SIPs were injected in, showed a higher direct ECC bypass ratio, i.e., around 0.52, than the other cases. The direct bypass ratios were 0.50, 0.44, and 0.41 in the LB-SI-01R, LB-SI-02, and LB-SI-03 cases, respectively. The difference between each case might be from the different SIP combination. From this result, we can conclude that the injection of three SIPs decreased the direct bypass ratio, causing positive effect on the RPV core cooling.

5. Conclusions

Verification experiments of the reflood phase during a large break LOCA were performed to evaluate the core cooling performance of the four train ECCS with the assumption of a single failure.

The design change of the safety injection pump as the electrically 4 trains resulted in a shorter quenching time than that of the two train case. There was no significant difference owing to the different SIP combinations. The nitrogen gas injected into the system affected on the higher water level in the RPV and the shorter quenching time than those of the other cases, which were performed without the nitrogen gas injection. Thus, the nitrogen gas injection into the RPV has a positive effect from the view point of safety.

From these series of experiments, we can conclude that the design change of the safety injection pump as the electrically 4 train improves the safety during the LBLOCA reflood phase.

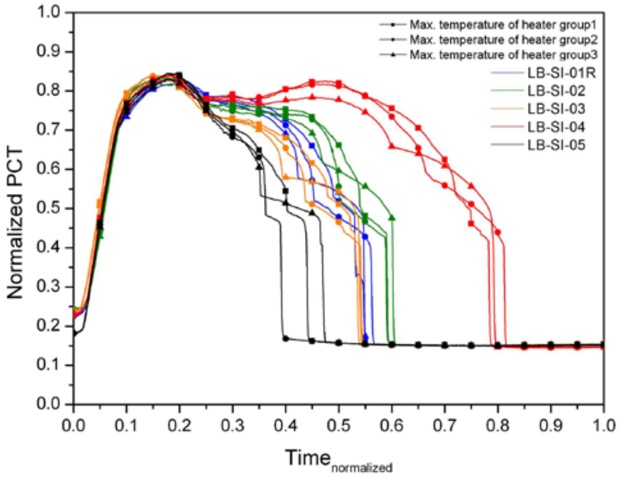

Fig.1. Comparison of the peak cladding temperatures.

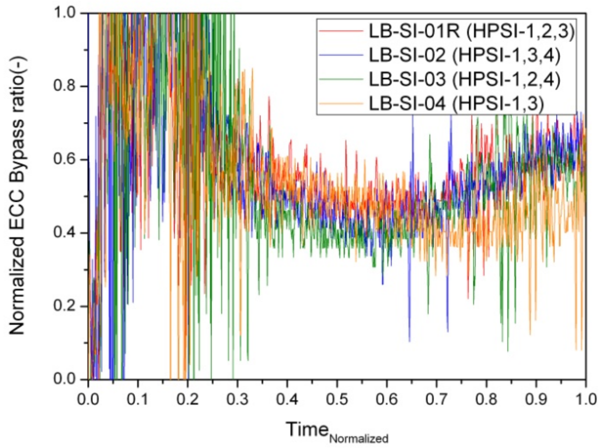

Fig.2. Direct ECC bypass ration during the reflood phase.

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