Effect of Core Bypass Flow during 6 inch Cold Leg SBLOCA Test with the ATLAS

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1. Introduction

Two cold leg SBLOCA experiments, SB-CL-02 and SB-CL-09, were performed to investigate an effect of the core bypass flow during the transient. These integral effect tests for the design basis accident of the APR1400 simulates a 152.4 mm (6 inch) equivalent break (4% of the cold-leg area) at the bottom of a cold-leg with a single failure assumption of the high pressure safety injection system. The only difference between the SB-CL-02 and the SB-CL-09 is whether the core bypass flow was simulated or not. In the SB-CL-02, relatively low core bypass flow was simulated. On the other hand, in the SB-CL-09, the scaled core bypass flow was simulated during the transient. The post-test calculation, performed using the best-estimate thermal hydraulic safety analysis code, MARS 3.1, reasonably predicts the major thermal hydraulic parameters measured during the present experiment. Table 1 compares the actual test conditions of the present experiments and the calculated steady-state conditions.

Table 1 Calculated geometric volume data of the ATLAS steam generator

Parameter	Unit	Calculated Value (MARS)	SB-CL-02	SB-CL-09
Core Power	MW	1.64	1.64	1.64
Primary Pressure	MPa	15.5	15.5	15.5
Hot-Leg Temperature	°C	323.8	324.1	325.5
Cold-Leg Temperature	°C	289.9	290.7	291.9
Cold-Leg Flow Rate	kg/s	1.99	2.16	2.17
Secondary Pressure	MPa	7.83	7.78	7.82
Steam Dome Temperature	°C	293.5	292	293.6
SG 2nd Water Level	m	2	2.5	1.98
Feed Water Flow Rate /SG	kg/s	0.44	0.42	0.42
Feed Water Temperature	°C	232.2	236	233.2
SIT Pressure	MPa	4.2	4.26	4.23
SIT Tempeartture	°C	50	50.1	50
Opening Degree (OD) of FCV-RV-37	%	74	0	79.3
OD of FCV-RV-38	%	65	95.2	57.5
OD of FCV-RV-95	%	81	0	91.3
OD of FCV-RV-96	%	97	0	98.5

2. Experimental conditions

In the ATLAS, four bypass flow control valves were installed at the reactor pressure vessel to simulate the downcomer-upper head and downcomer-hot leg bypass flow. Two bypass valves, FCV-RV-37 and -38, are for the simulation of the downcomer to upper head bypass, and the other two bypass valves, FCV-RV-95 and -96, are for the downcomer to hot leg bypass simulation. The bypass flow fractions of the downcomer-upper head and the downcomer-hot leg are 0.5 % and 1.4 % of rated primary flow, respectively. Considering that the primary flow rate at the scaled full flow condition, calculated from the pre-analysis, is up to 97 kg/s, the bypass flow rates of the downcomer-upper head and the downcomer-hot leg at the 100 % of the scaled full flow condition are 0.49 kg/s and 1.36 kg/s for the ATLAS, respectively.

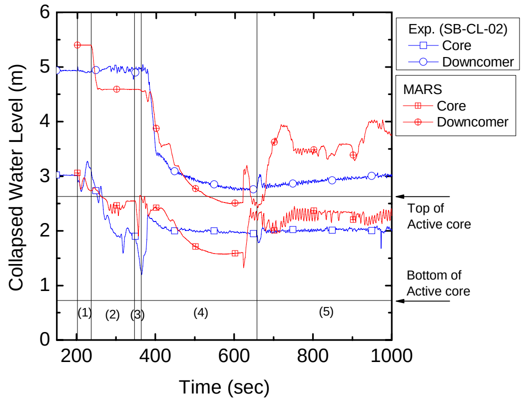
The opening degrees of these four bypass flow control valves to simulate the rated condition were calibrated during the commissioning test performed in 2006. The opening degrees for the rated flow condition can be found in Table 1. In the SB-CL-02, all the bypass valves except for FCV-RV-38 were closed: therefore, the bypass flow rates are relatively smaller than those of the SB-CL-09. In the SB-CL-09, however, the opening degree of the bypass valves was set to the corresponding values as shown in Table 1. The total bypass flow rates at the 100 % of the scaled full flow condition are estimated at 0.42 kg/s and 1.92 kg/s for the SB-CL-02 and -09, respectively.

In the present experiments the SB LOCA was assumed to occur at a cold leg-1A piping located between the outlet of the RCP-1A and the corresponding RV inlet nozzle. In addition, the single-failure of a loss of a diesel generator, resulting in the minimum safety injection flow to the reactor pressure vessel, was assumed to occur in concurrence with the reactor trip.

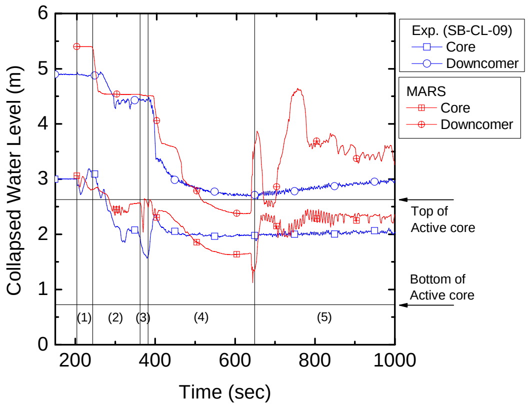
3. Experimental results and discussions

Behavior of collapsed water levels of the downcomer and the core region for the present experiments can be observed in Fig. 1, which compares the experimental results to those of the MARS post calculation. For the SB-CL-02 presented in Fig. 1(a), the core collapsed water level dropped severely below the top of the active core, and the cladding temperature experienced a temporary excursion as shown in Fig. 2(a). The maximum cladding temperature was observed at the 1.52 m higher position than the bottom of the active core, measured by TH-CL-10G33b1. The cladding temperatures are closed related to the two-phase mixture level [1]. In the experiments, the two-phase mixture levels are not measured.

In the present experiments, the minimum collapsed water levels were observed during the loop seal clearance phase as shown in Fig. 1. The observed minimum levels are 0.48 m and 0.85 m above the bottom of the active core for the SB-CL-02 and -09, respectively. Considering the total height of the active core is about 1.905 m, the volume averaged void fractions in the active core region can be estimated up to 0.75 and 0.55 for the SB-CL-02 and -09, respectively. Because of this water level difference, however, the cladding temperatures show a different trend in the SB-CL-02 and -09. In the SB-CL-09, the cladding temperature excursion was not observed. The water level difference between the present two experiments is also due to the effect of the core bypass flow.



(a) SB-CL-02

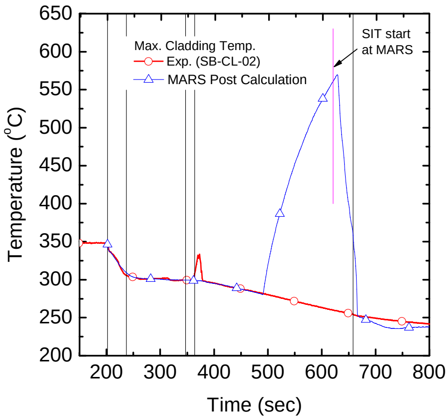


(b) SB-CL-09

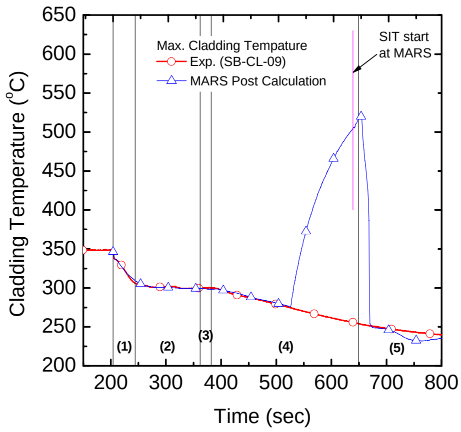
Fig. 1 Collapsed water levels of the downcomer and the core region

In the MARS analysis, the collapsed water levels during the loop seal clearance phase show a relatively higher value than those of the experiments. The minimum water level, however, was observed during the boil-off phase. This difference in the water level trend in the MARS analysis resultantly affects the cladding temperature behavior shown in Fig. 2 which shows relatively large cladding temperature excursion during the boil-off phase, not during the loop seal clearance phase. This temperature rising was turned down with the initiation of the SIT injection as noted in Fig. 2. From this observation, it can be understood that the MARS has a limited capability to predict the water level during the transient.

The maximum differential pressure between these two regions was observed up to 31.4 kPa and 24.2 kPa for the SB-CL-02 and -09, respectively, due to the higher upper head pressure for the SB-CL-02 performed with a relatively low core bypass flow than that of the SB-CL-09. When the liquid level of the downhill side of the SG was depressed to the elevation of the loop seals, the loop seals were cleared and steam in the RCS was vented to the cold legs. Break flow changed from a low quality mixture to primarily steam. This relieves the back-pressure in the core and the core liquid level was restored by incoming flow from the downcomer region as indicated in Fig. 1. With the restoring of the core water level, the downcomer water level started to decrease to the cold leg level.



(a) SB-CL-02



(b) SB-CL-09

Fig. 2 Cladding temperature trends at the 1.52m above the bottom level of the active core

4. Conclusions

Two integral effect tests were performed to investigate the effect of the core bypass rate during the 6 inch cold leg SBLOCA. The core bypass rate can affects the differential pressure between the core and the downcomer side, which has a noticeable effect on the core water level. The MARS post analysis results on the system pressure show a good agreement with those of the experiments, but the calculated collapsed water levels in the core and the downcomer show a different trend. This water level difference results in the difference in the calculated cladding temperature trend.

REFERENCES

[1] M.G.Ortiz, L.S.Ghan, “Uncertainty analysis of minimum vessel liquid inventory during a SBLOCA in a B&W plant,” NUREG/CR-5818, 1992.