Cold Leg SBLOCA Simulation Test with the ATLAS

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1. Introduction

A series of cold leg small break LOCA simulation tests were carried out using the ATLAS facility. Main objectives of these experimental tests are not only to provide physical insight into the system response of the APR1400 reactor during the transient situation but also to present integral effect data for validation of the safety analysis code such as the MARS and SPACE. This paper briefly introduces the outline of a cold leg SBLOCA test series and presents preliminary test results. Table 1 shows a test matrix on the cold leg SBLOCA test series.

Table 1 Calculated geometric volume data of the ATLAS steam generator

No.	Test I.D.	Break Size (APR1400) (inch)	Break Size (ATLAS) (mm / %)	Break Location Orientation	Bypass Rate DC-UH (%)	Bypass Rate DC-HL (%)	SI Injection	Comment
1	SB-CL-01	4	7.12 /1.25	CL Bottom	0.5	1.4	DVI(2/4)	Standard case
2	SB-CL-02	6	10.68 /2.82	"	0	0	"	SPACE Test-1*
3	SB-CL-03	8	14.24 /5.03	"	0.5	1.4	"	Standard case
4	SB-CL-04	8.5	15.13 /5.68	"	"	"	DVI(2/4)	DVI 100% CPT
5	SB-CL-05	4	7.12 /1.25	"	"	"	"	Redundancy Test
6	SB-CL-06	6	10.68 /2.82	"	"	"	DVI(1/3)	DVI 50% CPT
7	SB-CL-07	2	3.56 /0.31	"	"	"	DVI(2/4)	Standard case
8	SB-CL-08	3.5	6.12/-	POSRV	"	"	"	SPACE Test-2*
9	SB-CL-09	6	10.68 /2.82	CL	"	"	CLI	LSTF CPT

2. Major thermal-hydraulic phenomena during cold-leg SBLOCA

A SBLOCA is characterized by relatively slow RCS depressurization rates and relatively slow mass loss from the RCS, compared to the design basis LBLOCA [1]. Because of the slow depressurization rates and the low primary flow rates (after RCPs are tripped), the steam and liquid phase in the RCS can be easily separated. The amount and nature of phase separation depend upon the location within the RCS and the time during the transient.

These phase separation has a significant effect on both the hydraulic and heat transfer characteristics of a SBLOCA. The detailed response of the RCS parameters during a SBLOCA depends on several PWR design characteristics: an initial core power, a core power distribution, a fuel burn-up, a RCS inventory, a relative volumetric distribution of major RCS components, a steam generator type, and an emergency core cooling system (ECCS) design.

The real safety issue associated with a SBLOCA is the possibility of severe voiding of vessel liquid before primary pressure decreases to a set point for safety injection. Semiscale studies [2] indicated that a 5% SBLOCA produced the most severe core liquid depressions and that the core bypass flow significantly affected the accident.

3. Experimental conditions and procedures

The initial and boundary conditions were determined by a pre-test calculation with a best-estimate thermal hydraulic code, MARS 3.1. First of all, a transient calculation was performed for the APR1400 to obtain the reference conditions. A single failure assumption for a safety injection system was assumed in the MARS calculation; four SITs and two of the SIPs were utilized during the test period. The initial and boundary conditions were obtained by applying the scaling ratios to the MARS calculation results for the APR1400 [3].

The decay heat was simulated to be 1.2 times of the ANS-73 decay curve for the conservative condition. The initial heater power was controlled to maintain at 1.637 MW, which is equal to the sum of the scaled-down core power (1.567 MW) and the heat loss rate of the primary system (about 70 kW), and then the heater power was controlled to follow the specified decay curve after pre-determined time delay from the opening of the break valve. For all of the test cases in Table 1, the uniform radial power distribution was applied. However, axial power profile is chopped cosine with peaking factor 1.466.

After keeping the steady-state conditions of the primary and secondary system for more than 30 minutes, the main test was started by the opening of the break simulation valve, OV-BS-06, for a cold leg break case. With the start of the test, a pressure of the primary system is decreased rapidly below 10.7 MPa, which is the set-point of the low-pressurizer pressure (LPP) signal. When the LPP signal occurs, the RCP and pressurizer heater are stopped, and the main feed water isolation valves and the SIP are actuated with a specified delay time. Further decreasing of the primary pressure, below 4.03 MPa, results in a passive actuation of the SIT injection. The detailed technical descriptions on the ATLAS facility can be found in the literature [4].

4. Experimental results and discussions

Compared with the large break LOCA, the phases of the small break LOCA prior to recovery occur over a long period. In order to identify various phenomena, the small break LOCA can be divided into five phases such as blowdown, natural circulation, loop seal clearance, boil-off, and core recovery. The duration of each phase depends on the break size and the performance of the

ECCS. For the test cases indicated in Table 1, the characteristic five phases are identified, and they are compared with the characteristic parameters such as the primary pressure (PT-PZR-01), the SG secondary pressure (PT-SGSD1-01), and the collapsed water level of the core (LT-RPV-01) and the downcomer (LT-RPV-04A) as shown in Fig. 1.

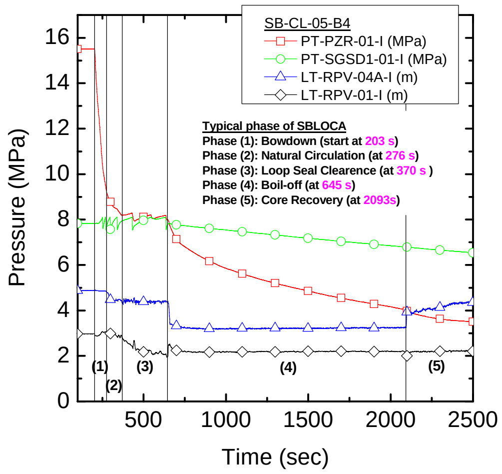

Fig. 1 Cold leg SBLOCA characteristic phase separation of SB-CL-05

The natural circulation phase might continue until there was insufficient driving head on the cold leg side of the loops, due to the accumulation of steam in loops between the top of the steam generator tubes and the loop seals. Figure 2 shows collapsed water levels in the U-tube of the SG-01. In the SB-CL-05, the natural circulation period (phase-2) was assumed to continue from the 276 seconds to the 370 seconds as indicated in the Fig. 1.

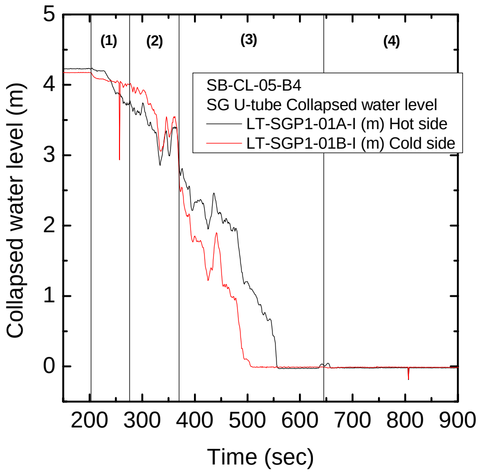

Fig. 2 Collapsed water levels in the SG U-tube in case of SB-CL-05

The RCS water inventory continued to decrease and steam volume in the RCS increased. The relative pressure in the core increased, which caused the liquid levels in the core and the SG to continue to decrease. When the differential pressure between the downcomer and the upper head reached its maximum value, the loop seals were cleared as indicated in Fig. 3 and steam in the RCS was vented to the broken cold legs. Break flow changed from a low quality mixture to primarily steam.

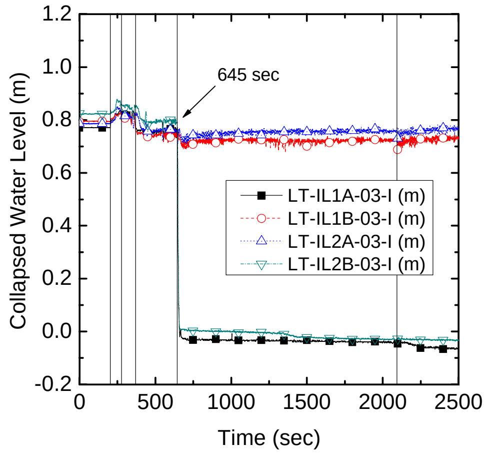

Fig. 3 Cold leg SBLOCA characteristic phase separation of the SB-CL-05

4. Conclusions

Several SBLOCA experimental tests using the ATLAS were performed to simulate a cold-leg-bottom break and a inadvertent opening of POSRV of the APR1400. Main objectives of this experimental test are not only to provide physical insight into the system response of the APR1400 reactor to adverse situations but also to present experimental data for validation of safety analysis code. In the present paper, the major thermal hydraulic phenomena such as the system pressure, the loop seal behaviour in the primary coolant system, the collapsed water levels in the core and the downcomer region, and the resultant trends of the cladding temperatures were presented and discussed along with the identified SBLOCA sub-phases. This integral effect data will be used to evaluate the prediction capability of the existing safety analysis codes. Furthermore this data will be utilized to identify any code deficiency for small break LOCA simulation, especially for the DVI-adapted plants.

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