Experimental Study on the Counterpart Test of LSTF 1% SBLOCA at Reactor Pressure Vessel Top with Accident Management Action

Yusun Park
Jongrok Kim, Byoung Uhn Bae, Jae Bong Lee,
Seok Cho, Nam Hyun Choi, Kyoung Ho Kang

2020.12.18.

Korea Atomic Energy Research Institute

CONTENTS

01 INTRODUCTION

02 SCALING METHOD

03 TEST CONDITIONS

04 TEST RESULTS

05 SUMMARY

01
INTRODUCTION

01 INTRODUCTION (1)

- **After the Fukushima accident, interest on the safety assessment of the existing nuclear power plant increased.**
  - Further demand for experiments which can give information related to the transient state of nuclear power plant.
  - To resolve key thermal-hydraulic safety issues related to multiple high risk failures highlighted from the Fukushima accident the importance of the integral effect test (IET) result is increasing.
- **As one of the test items performed under the OECD-ATLAS2 project, the B5.1 test was defined as a counterpart test with respect to the LSTF SB-PV-07 test.**
  - The target scenario for the SB-PV-07 test was a 1% small-break loss-of-coolant accident (SBLOCA) at reactor pressure vessel (RPV) top in a pressurized water reactor (PWR) under assumption of total failure of high pressure injection (HPI) system.

01 INTRODUCTION (2)

» Objectives

- **To investigate thermal-hydraulic phenomena during RPV upper head break accident**
  - Corresponds to a small break LOCA with cold leg injection (CLI) and accident management (AM) action
  - Investigation of key phenomena such as core heat-up, effect of AM actions
- **Counterpart test of LSTF SB-PV-07 test**
  - Comparison of the scale characteristics of the ATLAS with other facilities
  - To address the scaling issues of the IET facility

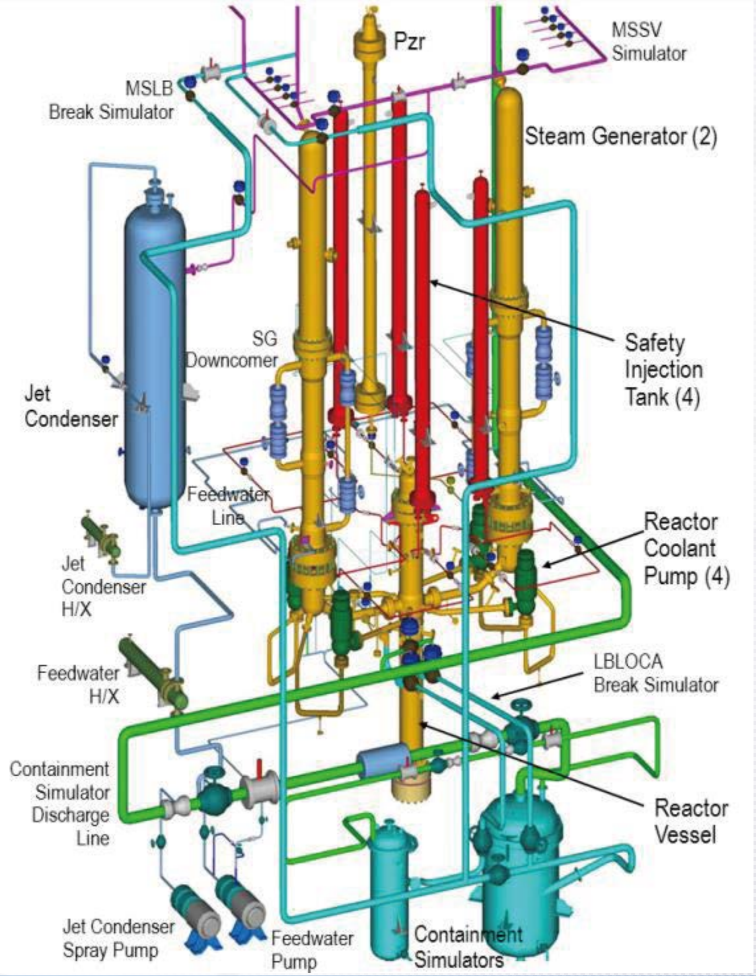
02

SCALING METHOD

02 SCALING METHOD (1)

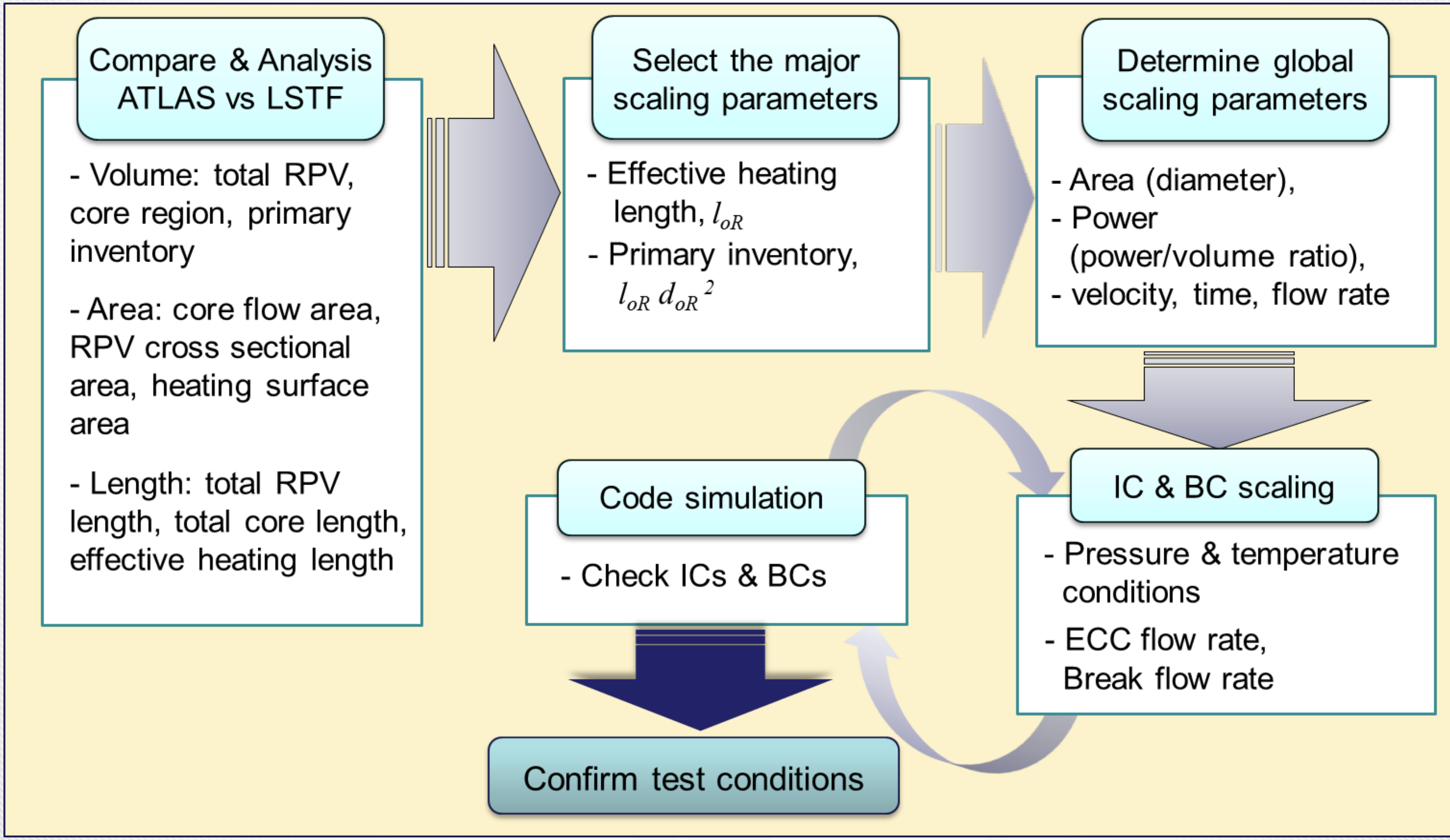
Description of ATLAS test facility

- **A Large-Scale TH Integral Effect Test (IET) Facility for APR1400 and OPR1000**
- **Scaling ratio(Based on APR1400)**
  - **1/2 Height & Length**
  - **1/12 Diameter**
  - **1/288 Volume**
- **Loop: 2(HL)x4(CL)**
- **Integrated Annular Downcomer**
- **ECCS: DVI & CLI**
- **Pressure: 18.7 MPa**
- **Temperature: 350 °C**
- **Core Power: 2 MW (10 %)**
- **Measurement: >1,600 pts**



02 SCALING METHOD (2)

Scaling Flow Chart



02 SCAILING METHOD (3)

Scaling Results – LSTF vs ATLAS

Parameter	Scaling Ratio	Description	LSTF (P)	ATLAS(M)	Ratio(M/P)
Length (height)	l_{oR}	Total RPV	10.9572(m)	5.9579(m)	0.54
		Effective heating length	**3.66(m)**	**1.905(m)**	**0.52**
Diameter	d_{oR}	RPV inner wall D	0.640(m)	0.4080(m)	0.64
		Core barrel inner D	0.514(m)	0.3175(m)	0.62
Area	d_{oR}^2	Calculation($V_{core,active}/L_{core,active}$)	0.1123(m^2)	0.0446(m^2)	0.39*
		Calculation($V_{RPV,Total}/L_{RPV,Total}$)	0.2883(m^2)	0.0945(m^2)	0.33**
		Core flow area(data)	0.1134(m^2)	0.0452(m^2)	0.40
Volume	$l_{oR}\, d_{oR}^2$	Total RPV	2.754(m^3)	0.5630(m^3)	0.20
		Core region	0.4477(m^3)	0.0849(m^3)	0.19
		Primary inventory	**8.14(m^3)**	**1.6366(m^3)**	**0.20**

Choose two major scaling parameters

Primary inventory ($l_{oR}\, d_{oR}^2 = 0.20$)

Effective heating length ($l_{oR} = 0.52$)

→ $d_{oR} = 0.62$

✓ Preserve equivalent pressure and temperature at the initial steady state

03
TEST CONDITIONS

03 TEST CONDITIONS (1)

» Summary of the LSTF SB-PV-07 Test

1) One whole CRDM penetration nozzle ejection
2) Loss of off-site power concurrently with the scram signal
3) Total failure of HPI system : manual inject of HPI system as the first AM action
4) SG secondary-side depressurization as the second AM action
5) AFW injection to both SGs simultaneously with an initiation of the second AM action
6) ACC system was actuated with Non-condensable gas inflow due to failure of the ACC system isolation

03 TEST CONDITIONS (2)

Set Points for ATLAS B5.1 Test

Event	Condition
Break	Time zero
Generation of scram signal	Primary pressure set value
Initiation of core power decay curve simulation	Generation of scram signal
Initiation of primary coolant pump coastdown	Generation of scram signal
Closure of SG main steam stop valve	Generation of scram signal
Manual closure of SG main steam isolation valve	Generation of scram signal
Termination of SG main feedwater	Generation of scram signal
Manual coolant injection from HPI system into cold legs in both loops as first AM action	Maximum core exit temperature set value
Initiation of ACC system in both loops	Primary pressure set value
SG secondary-side depressurization by fully opening RVs in both SGs as second AM action	Primary pressure set value
Initiation of AFW injection into secondary-side of both SGs	Initiation of second AM action
End of test	By the operator’s decision

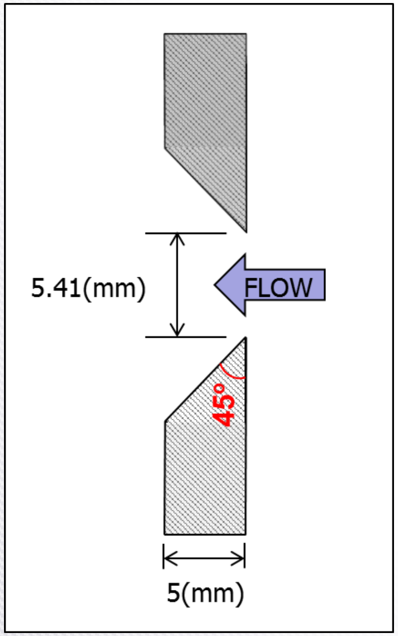
Core Power Simulation

LSTF SB-PV-07					
	Total	High	Medium	Low	Remark
Power (kW)	10011	5268	1750	2993	SB-PV-07 test result
Heat flux (kW/m^2)	-	**134.00**	88.74	58.57	
For ATLAS B5-1-S1					
	Total	Group1	Group2	Group3	Remark
Power (kW)	**1600**	**615.36**	**471.84**	**512.80**	Based on the 1.6 MW total core power
Heat flux (kW/m^2)	-	106.11	60.14	60.14	

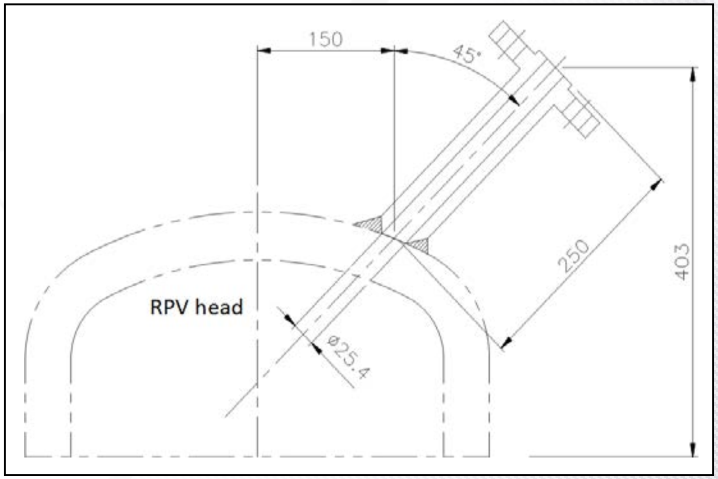
- ✓ **Supplied power for G1 is determined to preserve the maximum heat flux of a fuel rod.**
- ✓ **The rest of the power is distributed into the G2 and G3 by the constant heat flux per rod.**

» Break Simulation – Orifice Design

Conditions	LSTF SB-PV-07	ATLAS B5-1-S1
Location	Pressure vessel upper-head	Pressure vessel upper-head
Type	Sharp-edge orifice	Sharp-edge orifice
Inner-diameter of orifice	10.1 mm	5.41 mm



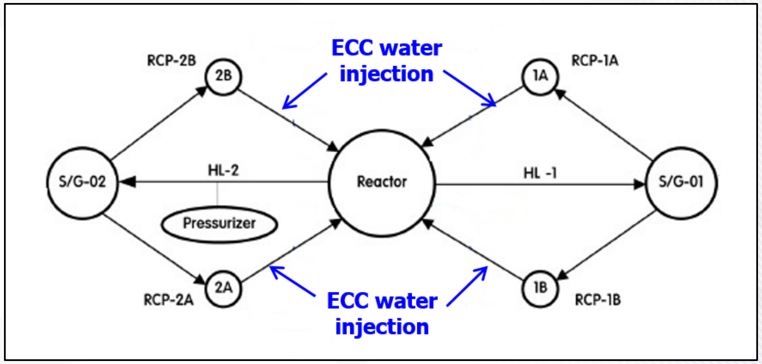
- ✓ **The thickness of an orifice plate was determined as 5 mm by considering the break unit pipe inner diameter.**
- ✓ **The orifice was mounted in the nozzle which was installed at the RPV top.**



03 TEST CONDITIONS (5)

ECCS Injection

- **Accumulator**
  - Total injected inventory of one accumulator in the SB-PV-07 test was divided and delivered by two SITs in the ATLAS.
  - Injected according to the primary system pressure variation
- **HPI (1st AM action) and Auxiliary feedwater**
  - Scaled flow rate of LSTF test was supplied with the same injection condition.



SG Depressurization (2nd AM Action)

- **Initiated with the same primary system pressure of LSTF test condition**
- **The criterion : Initial peak flow rate through the relief valves at the opening time**

04
TEST RESULTS

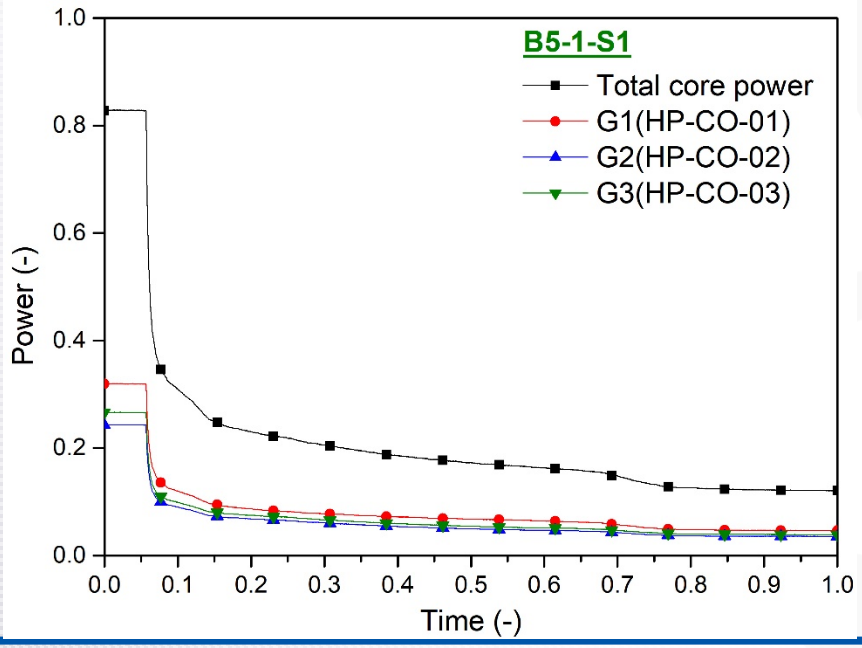
Sequence of Events

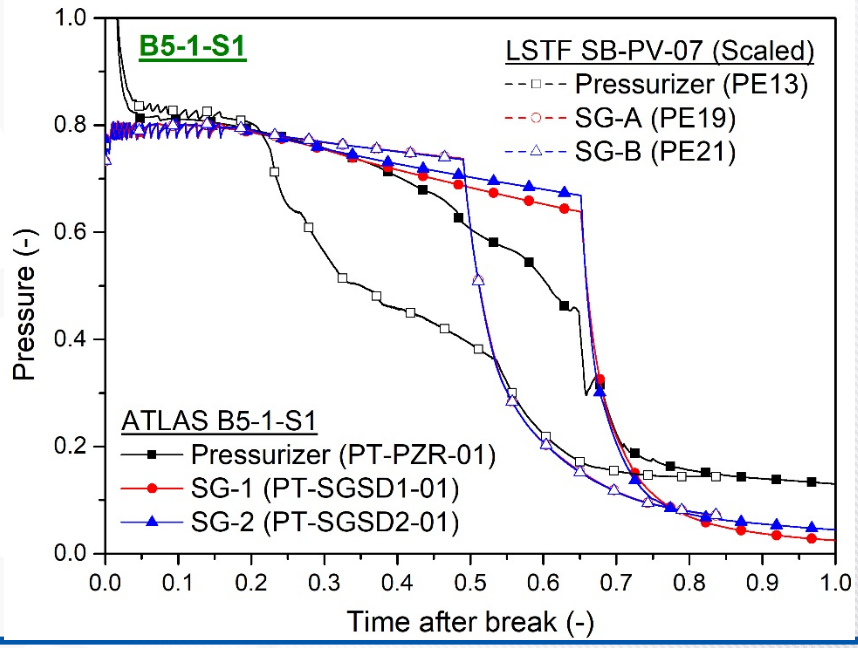
No	Description	Remark (Set-point)	LSTF SB-PV-07	ATLASB5.1-S1
1	Break Valve Open	Manual Open	0.0000	0.0000
2	Reactor Scram	Primary system pressure	0.0058	0.0068
3	Core power decay	Generation of scram signal	0.0085	0.0108
4	Turbine Trip	Generation of scram signal	0.0060	0.0068
5	MFIV Close	Generation of scram signal	0.0063	0.0068
6	MSIV Close	Generation of scram signal	0.0082	0.0068
7	Manual injection of HPI (First AM action)	Maximum core exit temperature	0.2317	0.6285
8	Initiation of ACC	Primary system pressure	0.3817	0.6703
9	SG 2^{nd} depressurization (Second AM action)	Primary system pressure	0.5068	0.6733
10	Aux Injection into SG1/2	Primary system pressure, Simultaneously with the second AM action	0.5112	0.6733
11	End of the test	By operator’s decision	0.8693	1.0328

04 TEST RESULTS (2)

Core Power Decay & System Pressure

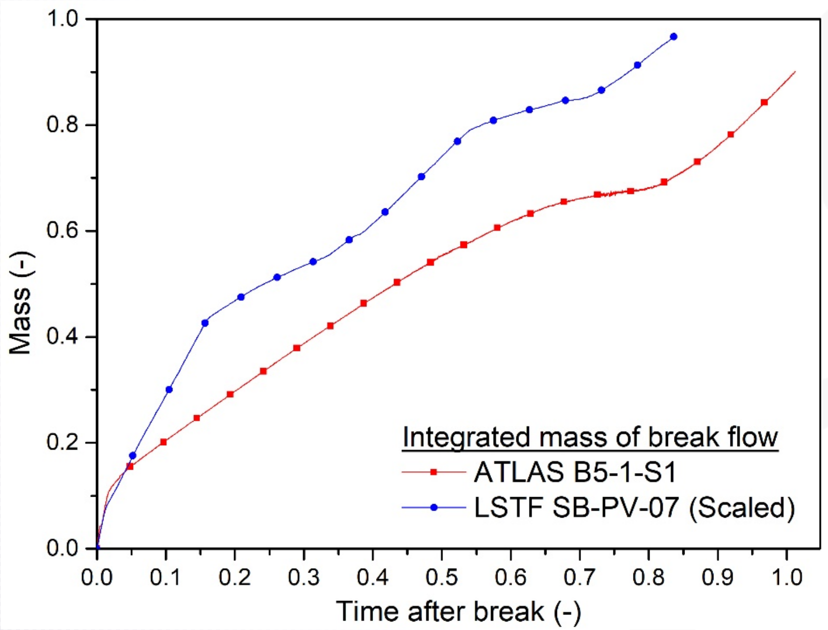
- **The core power started to decay after the scram signal to follow the same decay fraction as the scaled decay power of the SB-PV-07 test.**
- **The decreasing rate of the primary system pressure increased slightly with the first AM action.**
- **With the ACCs injection and the 2nd AM action, the primary system pressure decreased significantly.**

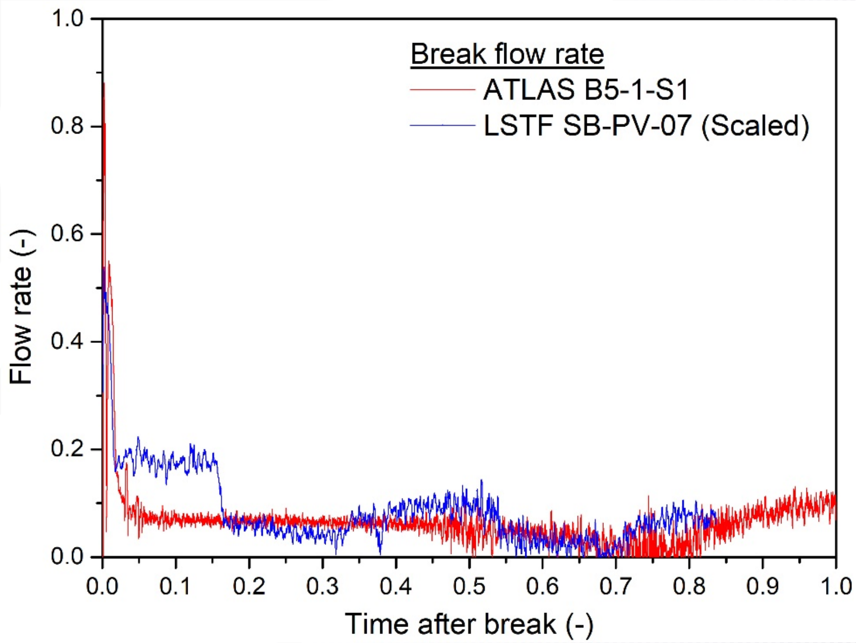




Break Flow

- After the high peak flow rate at the initiation of the transient, the break flow rate of the B5.1 test was smaller than that of the SB-PV-07 test.

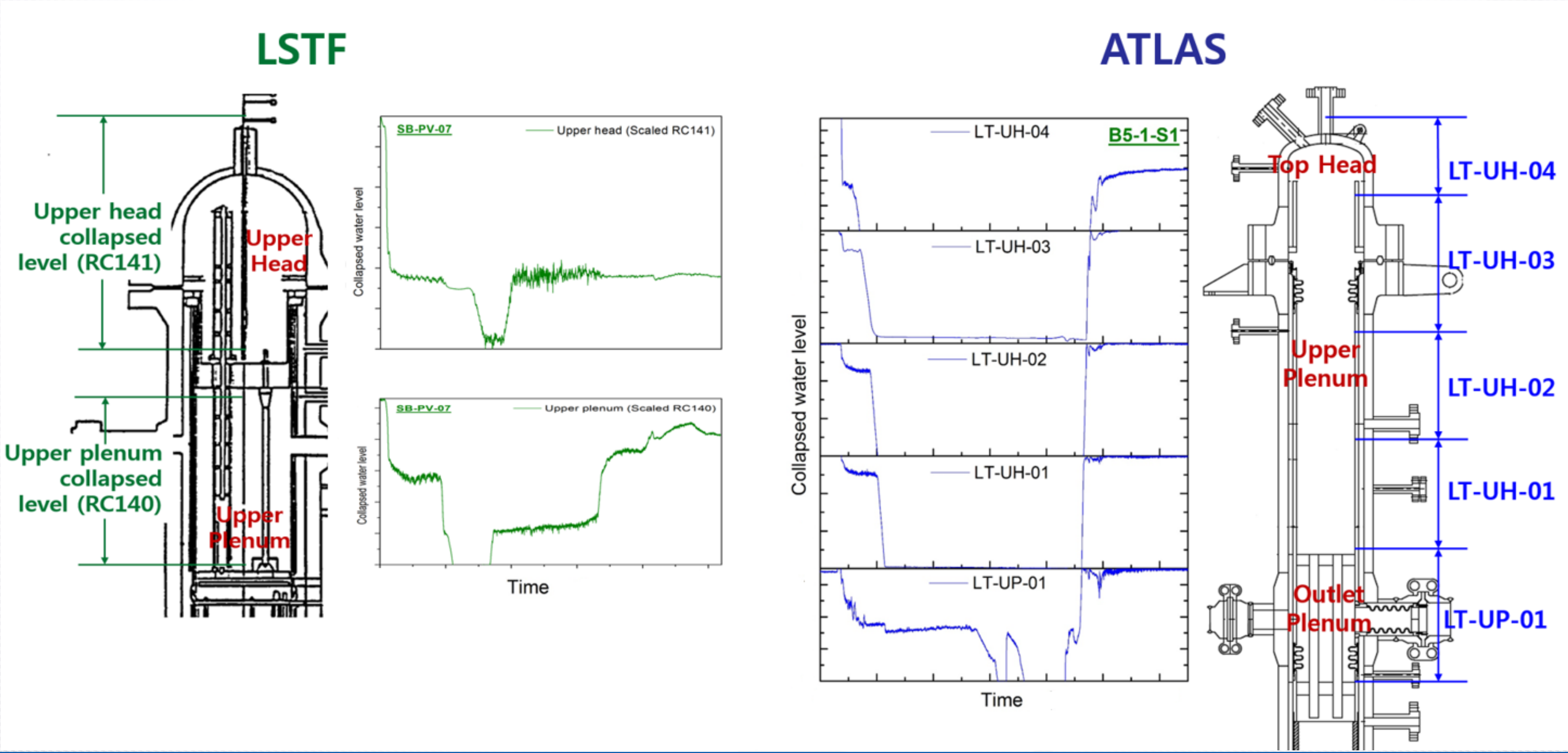




04 TEST RESULTS (4)

Collapsed Water Level in the Upper Head

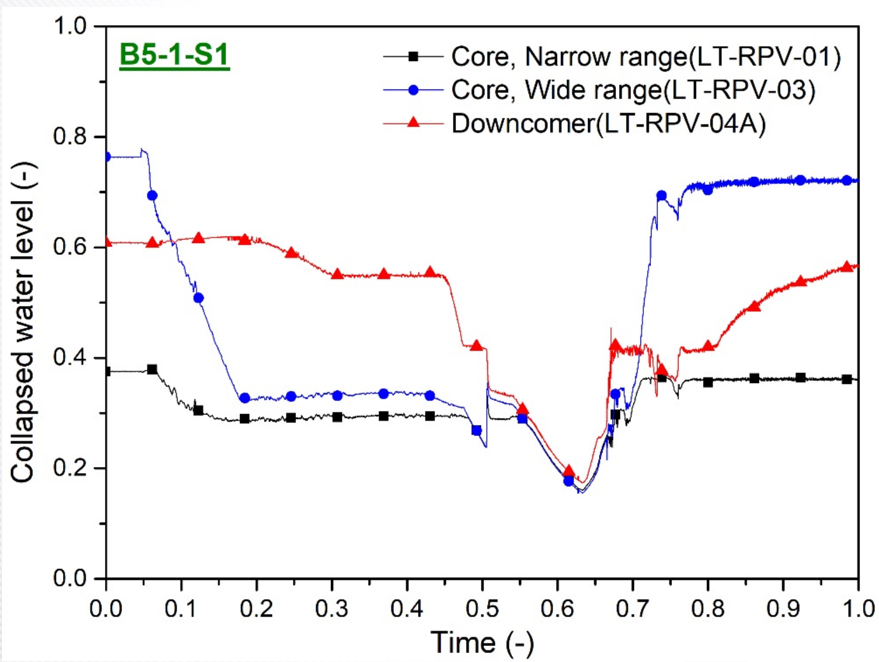
- Upper head region of ATLAS RPV has no inner structure that can hold a liquid level during transient.
- With opening of the break valve, the collapsed water levels in the upper plenum of RPV started to decrease from the upper head.

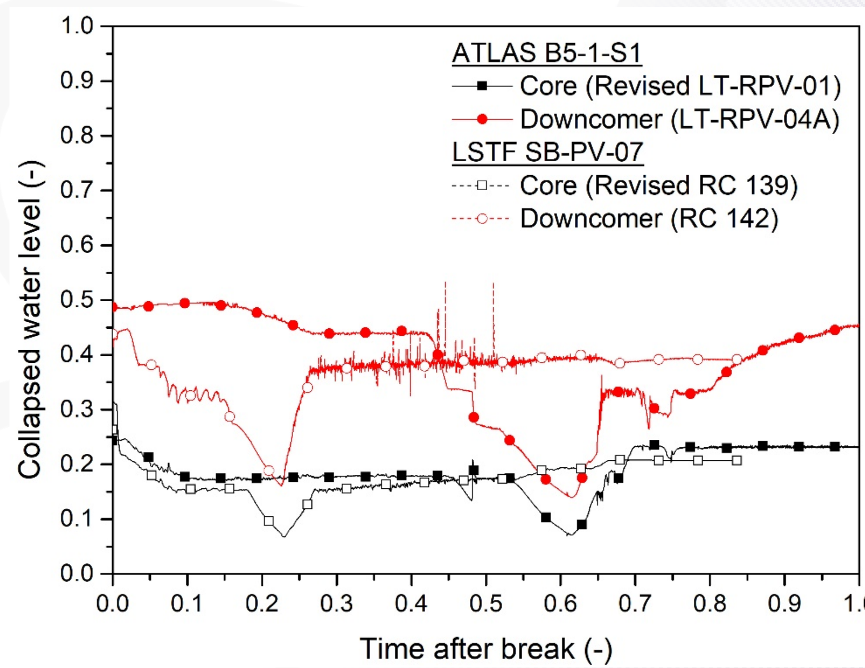


04 TEST RESULTS (5)

» Collapsed Water Levels in the Primary System

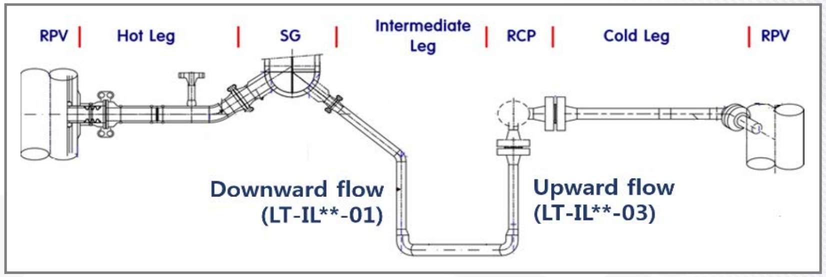
- **The collapsed water level of the core increased near the top of the active core due to the loop seal clearing.**
- **They were recovered by the ECCS water injection.**

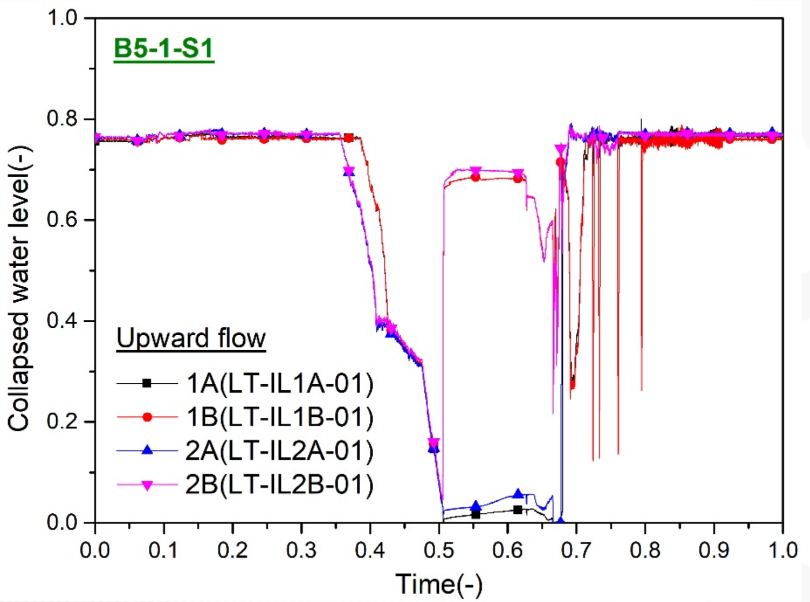


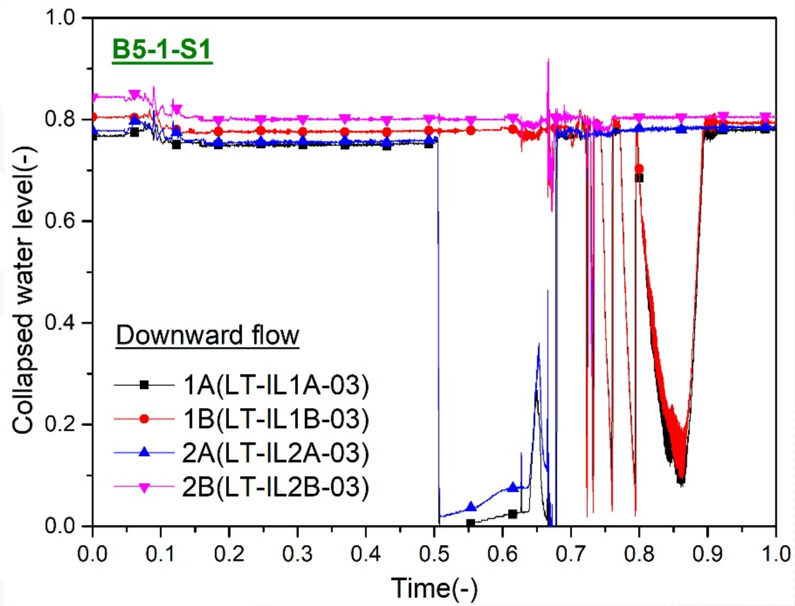


Collapsed Water Level in the Intermediate Legs

- The loop seal clearing was occurred at loop 1A and 2A.
- It affected the collapsed water level of the core region and the loop flow rates.



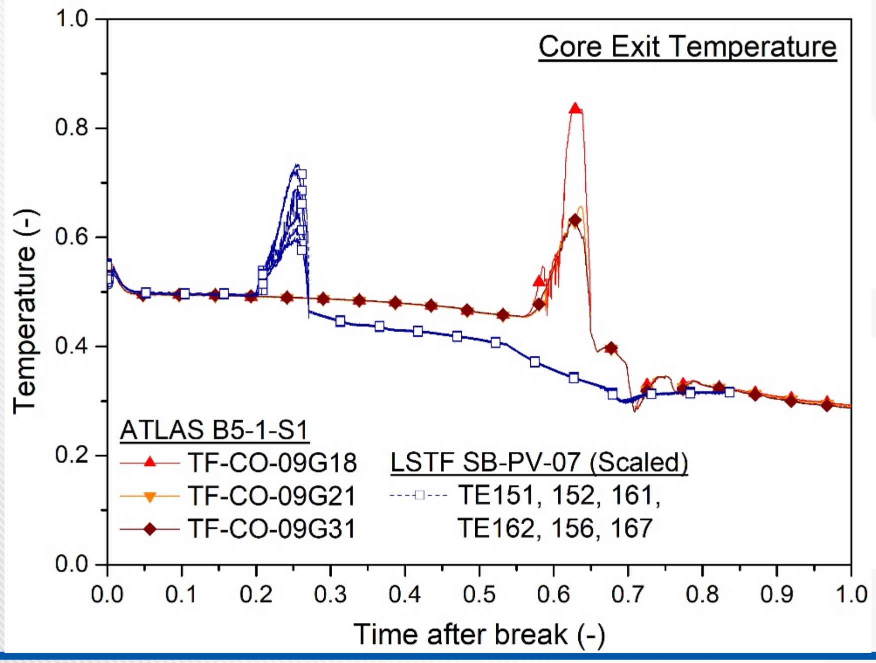


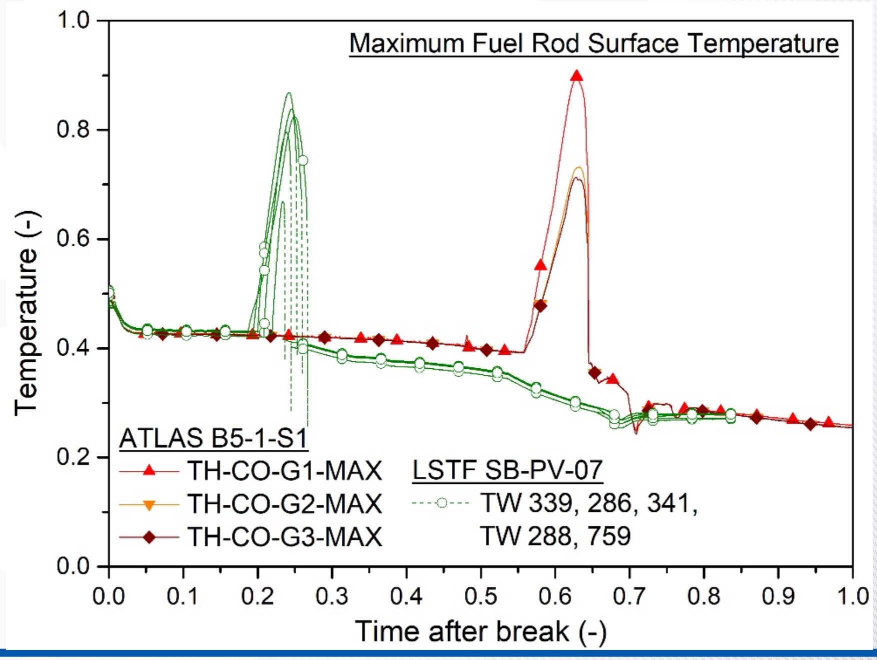


04 TEST RESULTS (7)

» CET and PCT Behaviors

- **After loop seal clearing occurred, the collapsed water level in the core decreased rapidly under the top of the active core.**
- **The maximum fuel rod surface temperature was measured in Group1**
- **Core heaters were quenched by HPI system actuation.**

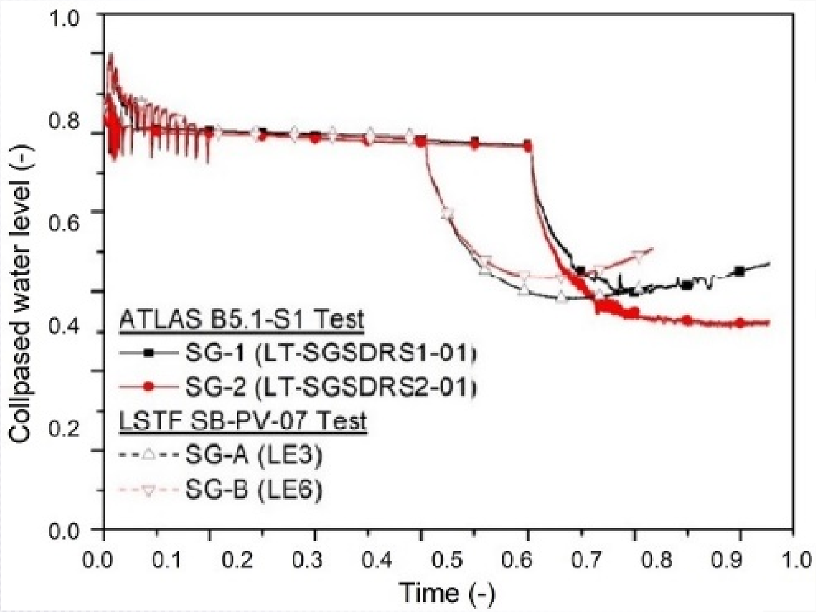


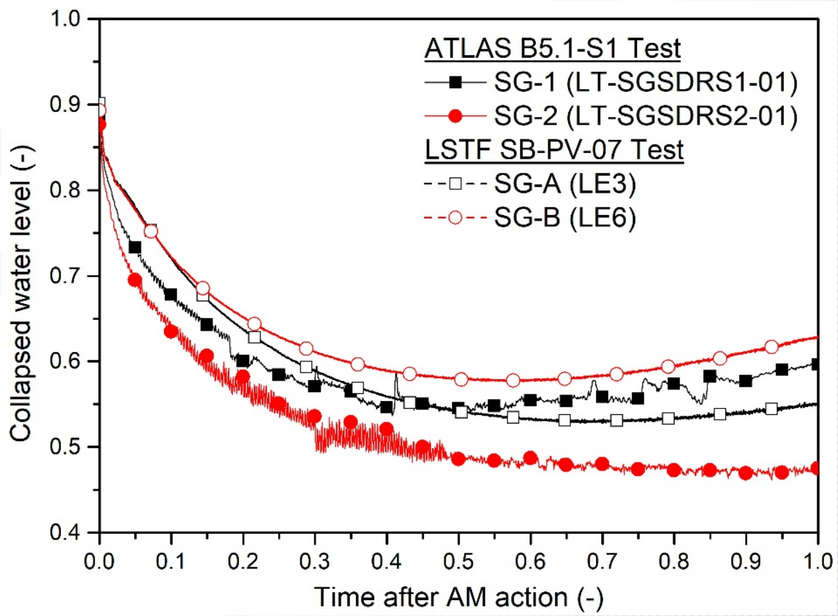


04 TEST RESULTS (8)

Collapsed Water Levels in the SGs

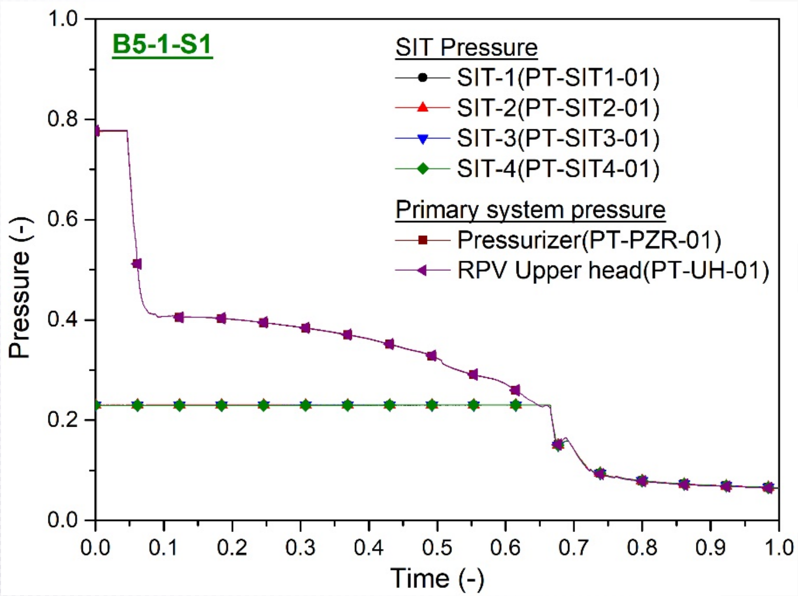
- With the second AM action, the collapsed water levels decreased rapidly and were recovered by auxiliary feedwater injection.
- The difference of water level behavior between two steam generators could be resulted from the different auxiliary feedwater flowrates and different heat removal rate.

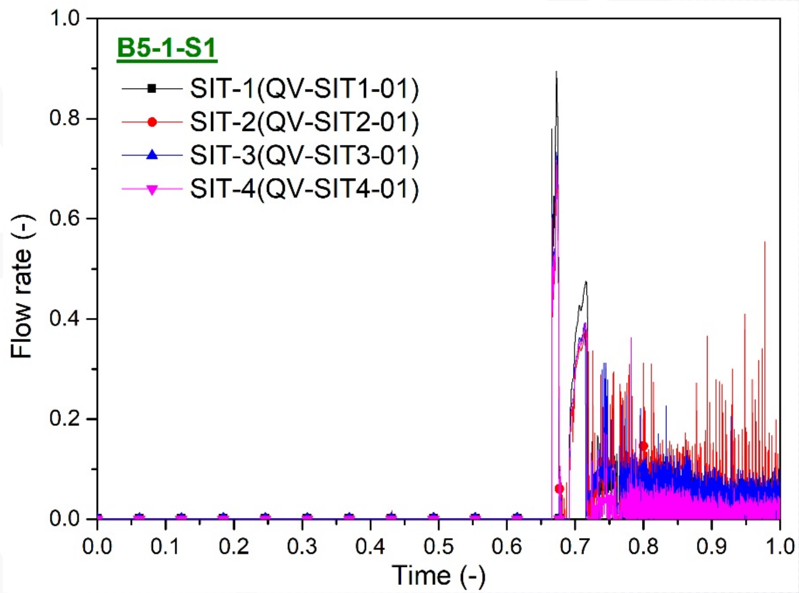




Accumulator (SITs) Injection

- **Accumulators were injected according to the system pressure variation of primary system pressure.**
- **The coolant injection from SITs was terminated when the collapsed water level in the tank reached at the top of the stand pipe.**





05 SUMMARY

05 SUMMARY

- An SBLOCA at RPV top was successfully simulated as a counterpart test of LSTF SB-PV-07 test.
- The overall sequences of transient scenario progressed later in the ATLAS test than those in the LSTF test.
- Major Findings as the Counterpart Test :
  - The break flow rate and collapse water level in the RPV showed different behaviours between two tests.
    - The upper head design of RPV is different.
  - Loop seal clearing phenomenon was clearly occurred in the B5.1 test.
    - Attributed to the different design of intermediate-leg and the location of the active core between two facilities.
  - These differences were the result of a different prototype power plant being used for each facility design.
- Essentially ATLAS and LSTF has different design, the test result is meaningful as the counterpart test in the view point of the characterization of ATLAS as a well designed IET facility.

THANK YOU