



# International Agreement Report

## Feedwater Line Break Analysis Using RELAP5/MOD3.3 for Steam Generator Blowdown Load Assessment

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## **ABSTRACT**

The RELAP5/MOD3.3 is generally used for best-estimate transient simulation of light water reactor coolant systems during postulated accidents in the Light Water Reactor (LWR). The RELAP5/MOD3.3 code is based on a non-homogeneous, and non-equilibrium model for a two phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients. This code is suitable for the analysis of transients and postulated accidents in LWR systems, including both large- and small-break loss of coolant accidents, as well as for the full range of operational transients.

For the evaluation of structural integrity for the steam generator in the Pressurized Water Reactor (PWR), the postulated accidents, such as the Feedwater Line Break (FLB) in the Advanced Power Reactor (APR1400) at the Korean domestic plants, are considered Design Basis Events (DBE). In order to evaluate the structural integrity of a steam generator during the FLB, the data for the thermo-hydraulic velocity, density and pressure are needed.

This study was performed to calculate thermal hydraulic parameters, such as thermo-hydraulic velocity, density and pressure, using the RELAP5/MOD3.3 code for the structural evaluation of the steam generator internals during the postulated FLB accidents.

The calculation results were verified by comparing with experimental data generated from the experimental facility ATLAS (Advanced Thermal-Hydraulic Test Loop for Accident Simulation).



# TABLE OF CONTENTS

<b>ABSTRACT .....</b>	<b>iii</b>
<b>LIST OF FIGURES .....</b>	<b>vii</b>
<b>LIST OF TABLES.....</b>	<b>vii</b>
<b>EXECUTIVE SUMMARY .....</b>	<b>ix</b>
<b>ABBREVIATIONS AND ACRONYMS .....</b>	<b>xi</b>
<b>1 INTRODUCTION.....</b>	<b>1</b>
<b>2 DESCRIPTION OF THE ATLAS SG FLB EXPERIMENT .....</b>	<b>3</b>
2.1 Experimental Facilities .....	3
2.2 Instrumentation .....	7
2.3 Experimental Procedure .....	10
2.4 Experimental Conditions.....	11
<b>3 RELAP5 INPUT MODEL .....</b>	<b>13</b>
3.1 ATLAS Facility Steam Generator RELAP5 Input Model .....	13
<b>4 RELAP5 ANALYSIS RESULTS .....</b>	<b>17</b>
4.1 Steady State Calculation .....	17
4.2 Transient Calculation .....	19
4.2.1 Flow Rate .....	20
4.2.2 Temperature.....	21
4.2.3 Pressure .....	22
4.2.4 Dynamic Pressure.....	23
4.3 Sensitivity Study.....	24
4.3.1 Critical Flow Model .....	24
4.3.2 Break Valve Opening Time.....	26
4.3.3 Time Step Size.....	27
4.3.4 Break Valve Discharge Coefficient .....	28
<b>5 CONCLUSIONS.....</b>	<b>29</b>
<b>6 REFERENCES.....</b>	<b>31</b>



## LIST OF FIGURES

Figure 2-1	Major Component of the ATLAS .....	4
Figure 2-2	Steam Generator of the ATLAS.....	5
Figure 2-3	Configuration of the Break System in the ATLAS .....	6
Figure 2-4	Configuration of the Double Rupture Disk Assembly .....	6
Figure 2-5	Locations of Measurement ID in the SG of the ATLAS.....	8
Figure 2-6	Detailed Locations of Dynamic Pressure Sensors Installed in the Steam Generator .....	9
Figure 2-7	Measurement Location of Dynamic Pressure in the Break System .....	9
Figure 3-1	MARS-KS Code ATLAS Nodalization .....	13
Figure 3-2	The ATLAS Steam Generator RELAP5/MOD3.3 Nodalization .....	15
Figure 4-1	Flow Rate at the Economizer Feedwater Line .....	20
Figure 4-2	Flow Rate at the Downcomer Feedwater Line .....	20
Figure 4-3	Temperature at the Steam Dome .....	21
Figure 4-4	Temperature at the Top of the Economizer.....	21
Figure 4-5	Temperature at the Top of the Hot Side Tubesheet.....	22
Figure 4-6	Pressure at the Steam Dome .....	22
Figure 4-7	Dynamic Pressure - 01 (the Economizer Box) .....	23
Figure 4-8	Dynamic Pressure - 02 (Top of the Economizer) .....	23
Figure 4-9	Dynamic Pressure - 01 for the Critical Flow Model .....	25
Figure 4-10	Dynamic Pressure - 01 for the Break Valve Opening Time .....	26
Figure 4-11	Dynamic Pressure - 01 for the Time Step Size .....	27
Figure 4-12	Dynamic Pressure - 01 for the Break Valve Discharge Coefficient .....	28

## LIST OF TABLES

Table 2-1	List of Measuring Locations and Parameters .....	7
Table 2-2	Uncertainty Level of Instruments .....	8
Table 2-3	Sequence of Major Events.....	10
Table 2-4	Actual Initial Parameters of the ATLAS Steady-State Condition.....	12
Table 4-1	Steady State Results.....	18
Table 4-2	Sequence of Events .....	19



## EXECUTIVE SUMMARY

The RELAP5/MOD3.3 is a computer code for best-estimate transient simulation of light water reactor systems during the postulated accidents. In this study, the possibility of the application of the postulated FLB accident analysis for a steam generator was investigated using the RELAP5/MOD3.3. For the verification and validation of the code analysis results, experimental tests were performed in the thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) at KEARI, located in Daejeon, Korea. The code analysis results for the thermal hydraulic response during the FLB accidents were compared to those of experimental tests. Some sensitivity studies were also performed.

From this study, major results of the analysis and experiments are summarized below.

The RELAP5/MOD3.3 predicts well the thermal hydraulic behaviors of the ATLAS FLB experimental test.

The dynamic pressure estimated with the RELAP5/MOD3.3 is conservative compared to that of the ATLAS FLB experimental test data.

The following conclusions are drawn from the results of the sensitivity studies.

- The Henry-Fauske and the Modified Henry-Moody critical flow model is recommended.
- The break valve opening time of 1.0 milli-sec is recommended.
- A maximum time-step-size less than or equal to  $10^{-4}$  sec is recommended.
- The break valve discharge coefficient of 1.0 is recommended.



## **ABBREVIATIONS AND ACRONYMS**

ATLAS	Advanced Thermal-Hydraulic Test Loop for Accident Simulation
APR1400	Advanced Power Reactor 1400 MWe
SG	Steam Generator
DAS	Data Acquisition System
FLB	Feedwater Line Break
KAERI	Korea Atomic Energy Research Institute
MARS-KS	Multi-dimensional Analysis of Reactor Safety
RCS	Reactor Coolant System
RELAP	Reactor Excursion and Leak Analysis Program
US NRC	United States Nuclear Regulatory Commission



# **1 INTRODUCTION**

The light water reactor (LWR) transient analysis code, RELAP5, was developed at the Idaho National Engineering Laboratory (INEL) for the U.S. Nuclear Regulatory Commission (NRC). Uses of code include analyses required to support rulemaking, licensing audit calculations, evaluation of accident mitigation strategies, evaluation of operator guidelines, and experiment planning analysis. RELAP5 has also been used as the basis for a nuclear plant analyzer.

The mission of the RELAP5/MOD3.3 development program was to develop a code version suitable for analysis of all transients and postulated accidents in LWR systems, including both large- and small-break loss-of-coolant accidents (LOCAs) as well as the full range of operational transients.

This study focuses on the applicability of the RELAP5/MOD3.3 for a guillotine break transient showing very sudden change of thermal hydraulic conditions in the system in a short period of time. That is, the code is analyzed to check whether or not it predicts well the rapid thermal hydraulic response in an FLB accident.

From a structural integrity point of view, the pressure difference between the internals of the steam generator is a critical parameter because the pressure difference is the only structural load during the guillotine break accidents. To verify the pressure difference inside the steam generator, the dynamic pressure near the break line was investigated and analyzed in relation to experimental test data.



## 2 DESCRIPTION OF THE ATLAS SG FLB EXPERIMENT

Experimental tests were performed to verify the RELAP5/MOD3.3 results. The tests were performed at a special facility for testing the thermal hydraulic integral effect. Transducers were installed to check accurately the dynamic pressure data. The experimental tests proceeded to reach a steady state condition and then the break was simulated with data logging. During the test, the major thermal-hydraulic parameters, such as dynamic and static pressures, local temperatures, and flow rates, were obtained in the course of an abrupt break of the steam generator feedwater line using the double rupture disk assembly. Also, the reproducibility of the test was checked by doing additional test cases observing the characteristics of the dynamic pressure during the tests. Details are shown in the following subsections.

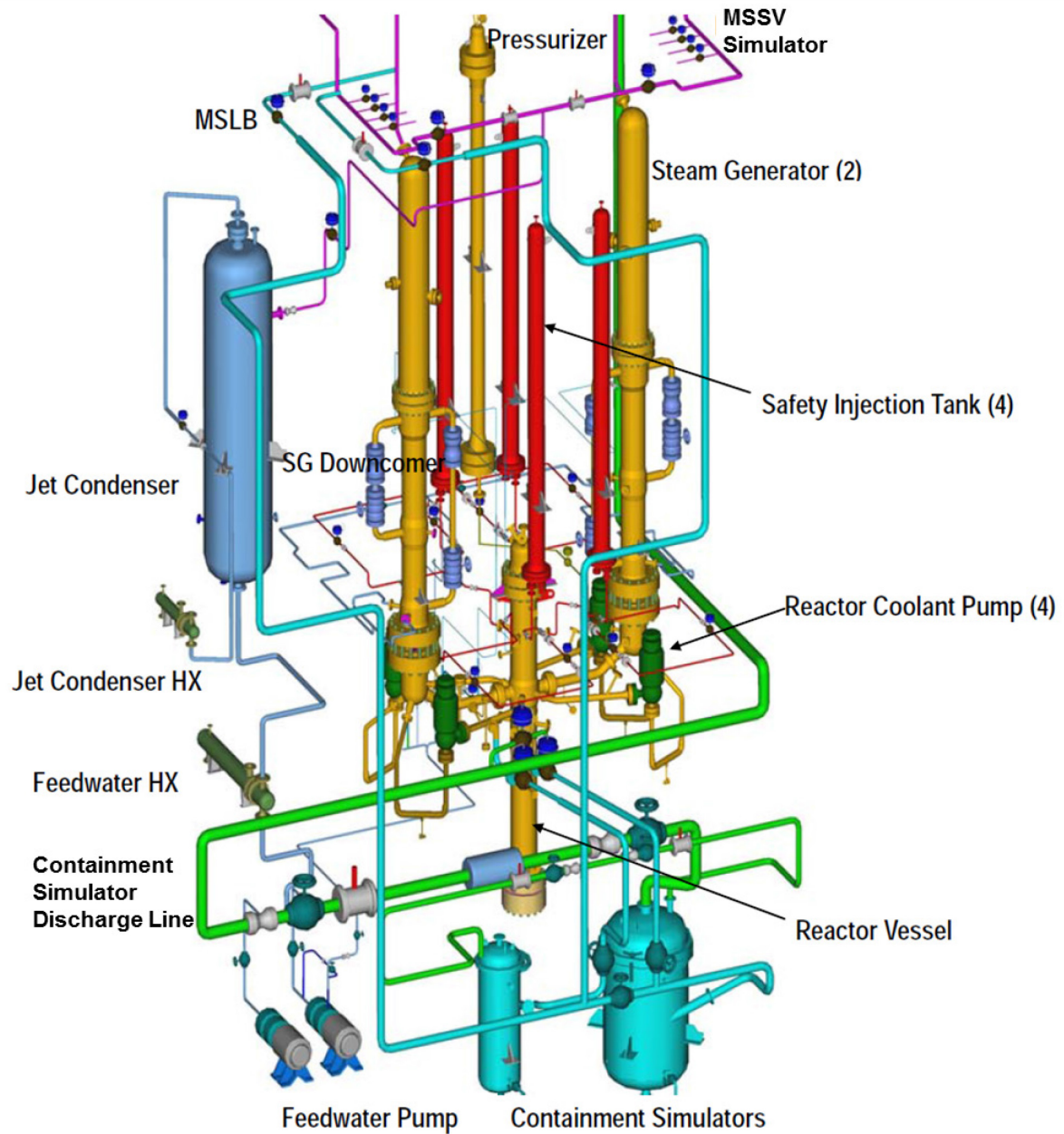
### 2.1 Experimental Facilities

A thermal-hydraulic integral effect test facility, ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation), was used to perform tests for a feedwater line break in the steam generator. ATLAS has the same two-loop features as the APR1400 (Advanced Power Reactor 1400 MWe); but is a half-height and 1/288-volume scaled test facility with respect to APR1400. The fluid system of the ATLAS consists of a primary system, a secondary system, a safety injection system, a break simulating system, a containment simulating system, and auxiliary systems. Figure 2-1 shows a 3-dimensional view of the ATLAS.

The ATLAS has two steam generators and each steam generator consists of a lower plenum, a U-tube assembly, middle and upper SG vessels, two downcomer pipes, and other internals as shown in Figure 2-2.

A feedwater line break was simulated by installing a break spool piece on the economizer feedwater line in SG-1. Figure 2-3 shows the configuration of a break simulation system for the feedwater line break of the ATLAS steam generator. The break opening time is the most crucial factor influencing a blowdown load during a feedwater line break, so it should be simulated appropriately in the test. In order to make the break opening time as short as possible, a double rupture disk assembly was used in the test. Figure 2-4 shows the configuration of the double rupture disk assembly, which consists of two rupture disks that have different cut off pressure for actuation.

The double rupture disk assembly works as follows: rupture disk-2 will be opened first, when the pressure in the “intermediate region” is increased to a specified actuation pressure by operators. Subsequently, rupture disk-1 will be opened within a very short period of time (approximately 1 milli-sec) by the driving force resulting from opening rupture disk-2.



**Figure 2-1 Major Component of the ATLAS**

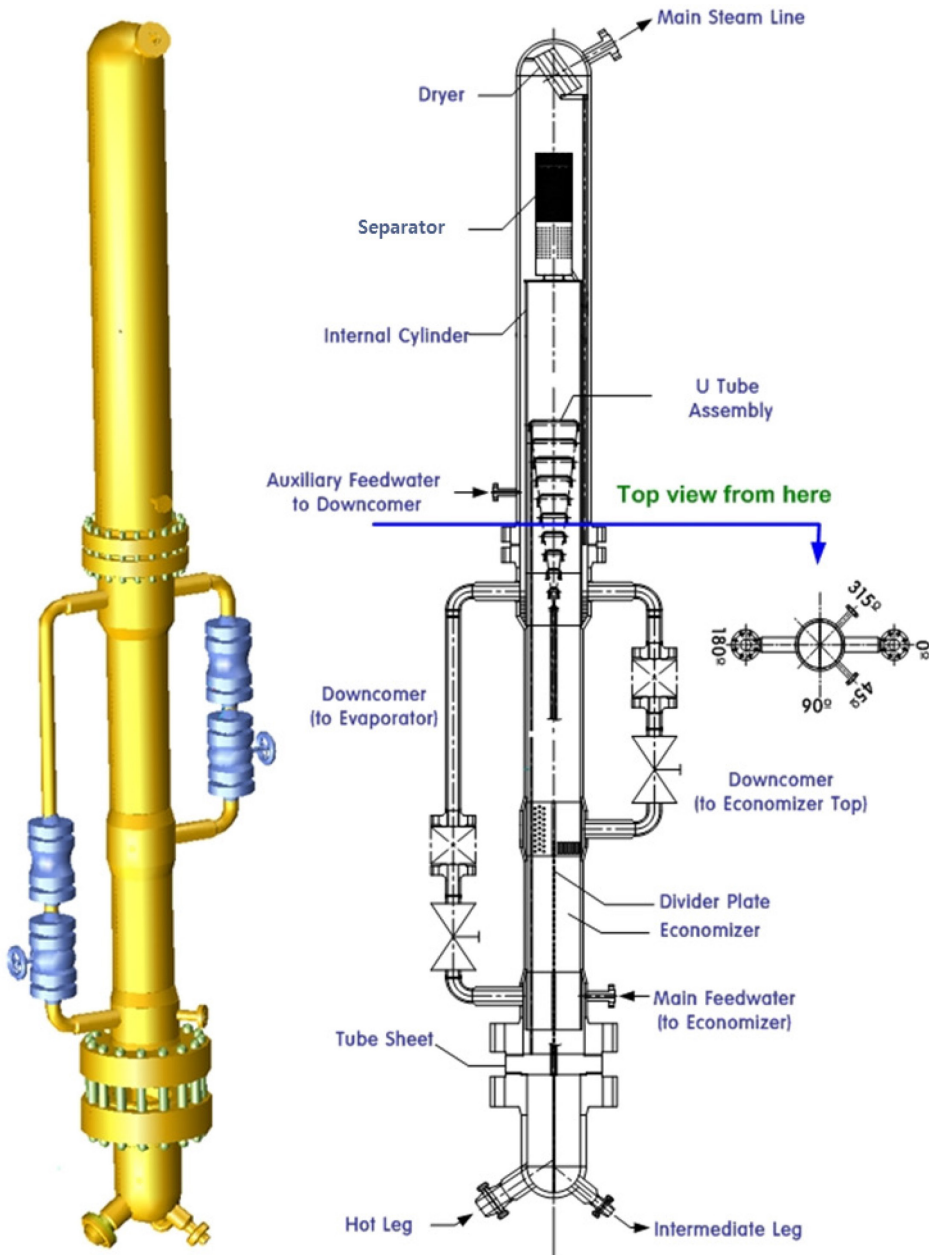


Figure 2-2 Steam Generator of the ATLAS

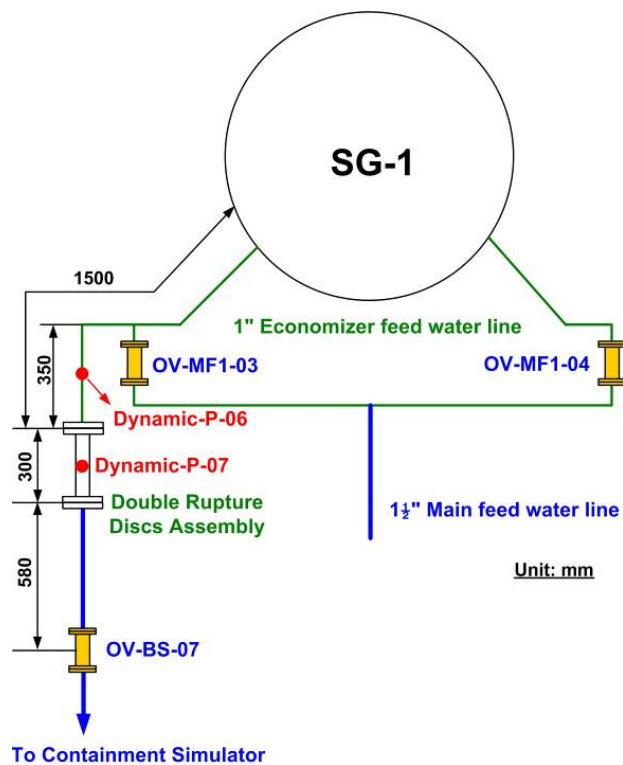


Figure 2-3 Configuration of the Break System in the ATLAS

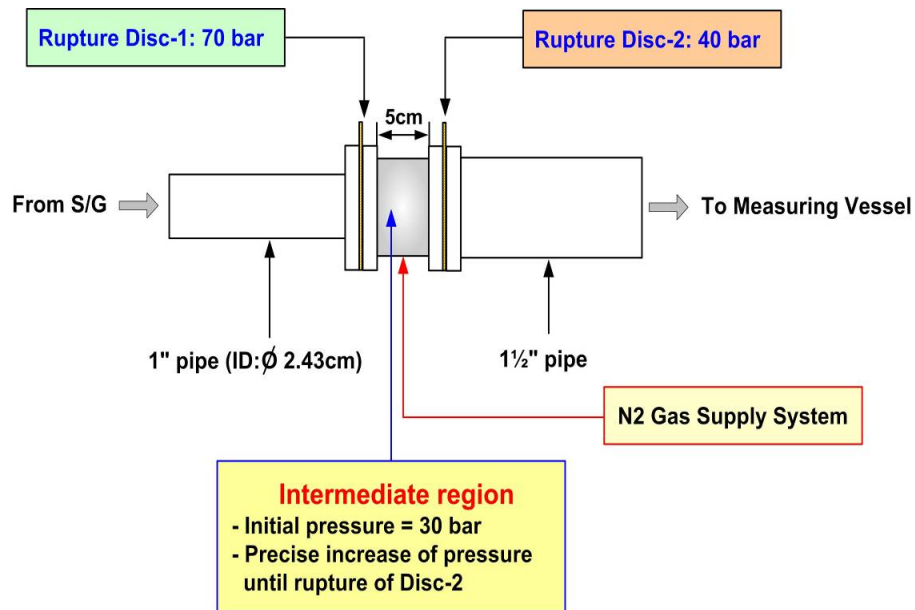


Figure 2-4 Configuration of the Double Rupture Disk Assembly

## 2.2 Instrumentation

In the ATLAS test facility, 1,236 instrument were installed for the measurement of several thermal-hydraulic parameters in the components. The measuring locations that would be affected most after the break were selected. Table 2-1 shows a list of the measuring locations, parameters, and tag name of sensors. Figure 2-5 shows the locations of measurement ID in the ATLAS steam generator.

The dynamic pressure was measured using Kistler dynamic pressure transducers with a measurement frequency of 2000 Hz. In order to precisely estimate the rupture time of the disks, additional dynamic pressure transducers (Dynamic-P-06 and Dynamic-P-07) were installed in the pipe line of the break simulation system as shown in Figure 2-3. The detailed location of dynamic pressure sensors installed in the steam generator is shown in Figure 2-6 and Figure 2-7.

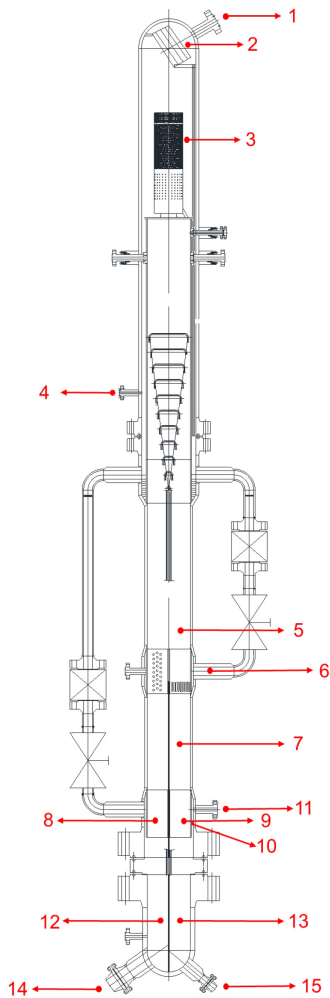
Table 2-2 shows the analysis uncertainty levels of each group of instruments.

**Table 2-1 List of Measuring Locations and Parameters**

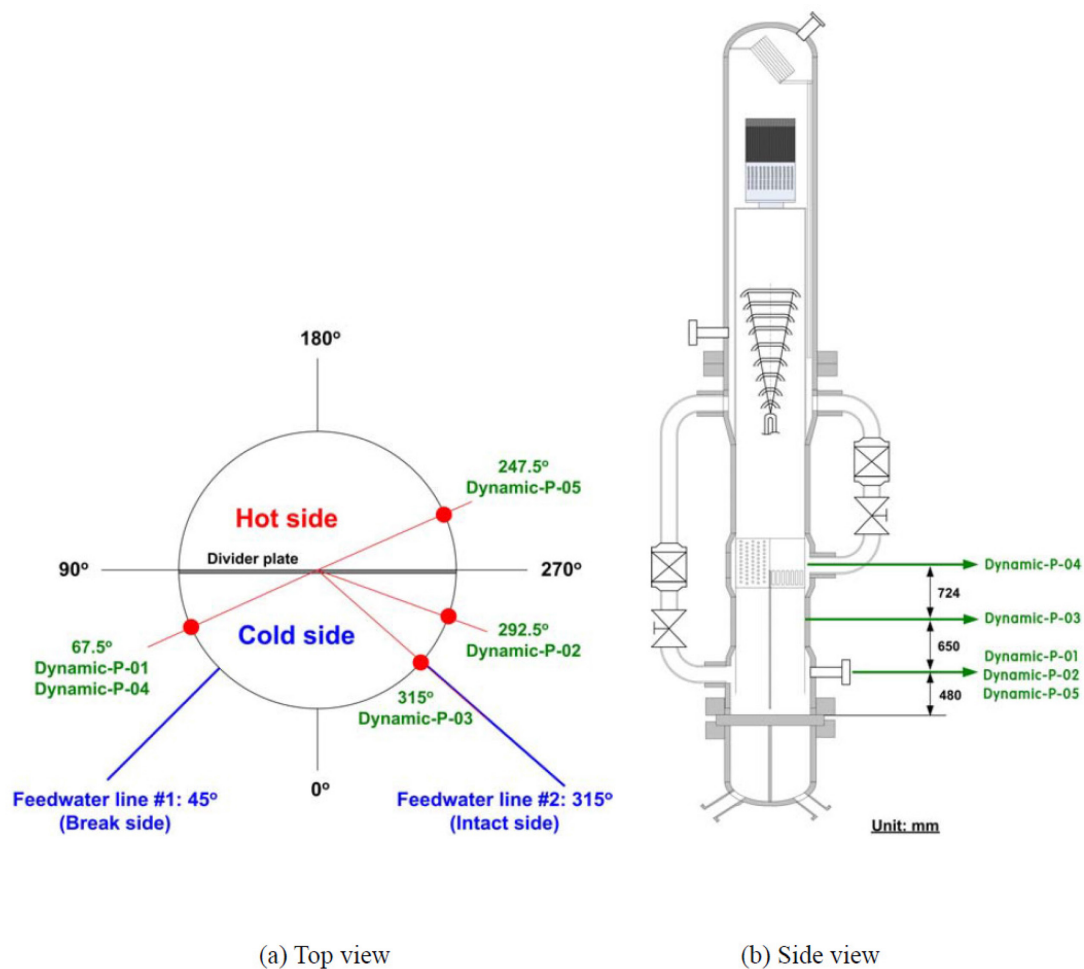
ID	Location	Dynamic Pressure	Static Pressure	Fluid Temperature	Mass Flowrate
1	Outside of main steam line				QV-MS1-01
2	Top of steam dome		PT-SGSD1-01		
3	Outlet region of steam separator			TF-SGSD1-03	
4	Downcomer feedwater line			TF-MF1-02	QV-MF1-02
5	Top of economizer			TF-SGRS1-03b	
6	Bottom of downcomer region at cold side	Dynamic-P-04			
7	Economizer (wall side)	Dynamic-P-03			
8	Top of tubesheet on hot side	Dynamic-P-05		TF-SGRS1-01a	
9	Top of flow distribution plate (wall side)	Dynamic-P-02			
10	Inside of feedwater box	Dynamic-P-01			
11	Economizer feedwater line			TF-MF1-01	QV-MF1-01
12	Inside of lower plenum from hot leg			TF-SGP1-01	
13	Inside of lower plenum to cold leg			TF-SGP1-02	
14	Hot leg side		PT-HL1-01		QV-HL1-01B
15	Cold leg side				QV-CL1A-01B QV-CL1B-01B

**Table 2-2 Uncertainty Level of Instruments**

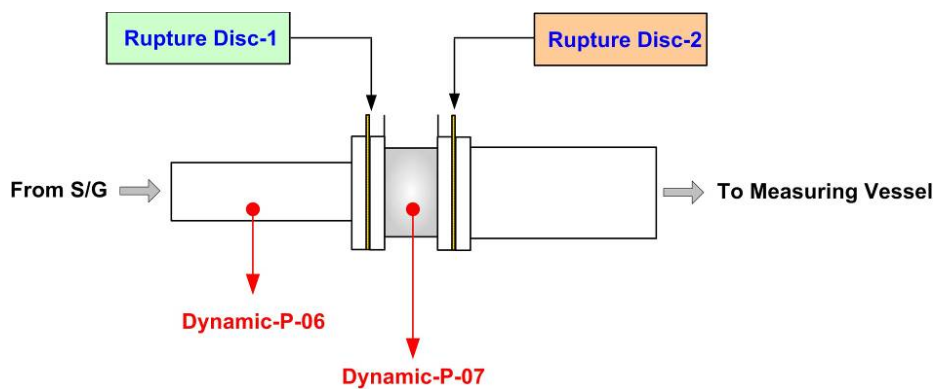
Items	Unit	Uncertainty
Static Pressure	MPa	0.039 %
Dynamic Pressure	bar	1.02 %
Differential Pressure	kPa	0.23 %
Collapsed Water Level	m	0.17 %
Temperature	°C	maximum 2.4 °C
Flow rate	kg/s	0.053 %



**Figure 2-5 Locations of Measurement ID in the SG of the ATLAS**



**Figure 2-6 Detailed Locations of Dynamic Pressure Sensors Installed in the Steam Generator**



**Figure 2-7 Measurement Location of Dynamic Pressure in the Break System**

### 2.3 Experimental Procedure

After a steady state condition was achieved in both primary and secondary systems, a break in the steam generator feedwater line was simulated according to the following procedures:

- The ATLAS main data is logged.
- After approximately 10 minutes from start of the ATLAS data logging, sub-DAS is started to acquire the dynamic pressure data in the steam generator.
- After several sec from start of the sub-DAS data logging, OV-MF1-03 and OV-MF1-04 valves are closed to prevent break flow rate distortion from the feedwater line during the break simulation.
- After several sec from closing of the OV-MF1-03 and OV-MF1-04 valves, nitrogen gas is supplied into the "Intermediate region" to rupture disk-2. Subsequently, disk-1 is opened by the driving force resulting from rupture of disk-2.

After acquiring experimental data over approximately 30 sec, Sub-DAS and the ATLAS logging are stopped.

The major events of the tests are listed in Table 2-3.

**Table 2-3 Sequence of Major Events**

Events	Time (sec)	Description
Heat Up	about 18,000	Heating up process
Test Standby	about 600	Steady state condition
Test Start	0.0	ATLAS main DAS data logging start
	600.0	Sub-DAS data logging start (Dynamic Pressure)
	603.0	OV-MF1-03, 04 closing
Break	605.0	SG-1 feed line break 100% open
Test End	630.0	Data recording stop

## **2.4 Experimental Conditions**

The tests aimed to obtain major thermal-hydraulic parameters, such as dynamic and static pressures near the break location, local temperatures, and flow rates during the feedwater line break of the steam generator. Three tests, named FLB-DS-01, FLB-DS-02 and FLB-DS-03, were performed using the double rupture disk assembly in order to simulate a sudden break of the steam generator feedwater line. The reason for performing FLB-DS-02 and FLB-DS-03 was to confirm the reproducibility of the FLB tests, and the reproducibility of the tests was confirmed by comparing the FLB test results. Therefore, only the FLB-DS-01 data was used to compare with the RELAP5/MOD3.3 calculation results.

Table 2-4 presents the actual initial conditions measured in these three tests. In Table 2-4, STDEV stands for standard deviations of each designated values. Even though there are some discrepancies between the target values and the measured values, the measured initial conditions of the primary and secondary systems are acceptable considering the standard deviations of each value, and the characteristics of the integral effect test.

**Table 2-4 Actual Initial Parameters of the ATLAS Steady-State Condition**

Design Parameter	Target Value	Measured Value			Remark (Sensor ID)
		FLB-DS-01 (Value <sup>(1)</sup> /STDEV <sup>(2)</sup> )	FLB-DS-02 (Value <sup>(1)</sup> /STDEV <sup>(2)</sup> )	FLB-DS-03 (Value <sup>(1)</sup> /STDEV <sup>(2)</sup> )	
Reactor Pressure Vessel					
Normal Power (MW)	1.56	1.631 / 0.0006	1.628 / 0.0005	1.631 / 0.0005	Heat loss: 85 kW
Pressurizer Pressure (MPa)	15.5	15.51 / 0.034	15.56 / 0.014	15.55 / 0.002	(PT-PZR-01)
Core Inlet Temperature (°C)	290.7	289.01 / 0.23	290.25 / 0.19	290.15 / 0.23	(TF-LP-02G18)
Core Outlet Temperature (°C)	324.2	324.22 / 0.43	325.61 / 0.37	325.51 / 0.38	(TF-CO-07G14,18,21,25)
Steam Generator					
Net Thermal Power (MWt)	0.78	0.743	0.743	0.736	Heat loss: 30 kW
Steam Flow Rate (kg/s)	0.444	0.400 / 0.001 0.430 / 0.001	0.400 / 0.001 0.430 / 0.001	0.400 / 0.004 0.427 / 0.003	SG-1 (QV-MS1-01) SG-2 (QV-MS2-01)
Feed Water Flow Rate (kg/s)	0.444	0.421 / 0.007 0.422 / 0.004	0.419 / 0.003 0.424 / 0.003	0.415 / 0.006 0.419 / 0.007	SG-1 (QV-MF1-01,2) SG-2 (QV-MF2-01,2)
Feed Water Temperature (°C)	232.2	234.55 / 0.16 233.91 / 0.16	234.75 / 0.12 233.95 / 0.12	234.40 / 0.15 233.57 / 0.15	SG-1 (TF-MF1-01) SG-2 (TF-MF2-01)
Steam Pressure (MPa)	7.83	7.69 / 0.003 7.69 / 0.003	7.83 / 0.003 7.83 / 0.003	7.83 / 0.015 7.82 / 0.009	SG-1 (PT-SGSD1-01) SG-2 (PT-SGSD2-01)
Steam Temperature (°C)	293.5	294.24 / 0.09 294.32 / 0.08	295.42 / 0.09 295.67 / 0.07	295.35 / 0.16 295.56 / 0.10	SG-1 (TF-SGSD1-03) SG-2 (TF-SGSD2-03)
Primary Piping					
Cold Leg Flow (kg/s)	2.0	2.19 / 0.08	2.21 / 0.09	2.20 / 0.09	Cold leg average (QV-CL1A,1B,2A,2B-01B)
Hot Leg Temperature (°C)	323.8	324.24 / 0.61	325.32 / 0.66	325.27 / 0.70	Hot leg average (TF-HL1,2-03A)
Cold Leg Temperature (°C)	289.9	290.92 / 0.68	292.13 / 0.61	292.09 / 0.65	Cold leg average (TF-CL1A,B-04A, TF-CL2A,B-04A)

Notes)

(1) Average Value at -10 to 600 sec

(2) STDEV: Standard Deviation at -10 to 600 sec

### 3 RELAP5 INPUT MODEL

#### 3.1 ATLAS Facility Steam Generator RELAP5 Input Model

The RELAP5/MOD3.3 input model was prepared from the MARS-KS code input model originally created at KAERI. The MARS-KS code input model consists of a reactor pressure vessel, primary piping, steam generators, a pressurizer, steam lines, a safety injection system, feedwater and the turbine system, and reactor coolant pumps. Figure 3-1 shows the MARS-KS code ATLAS nodalization.

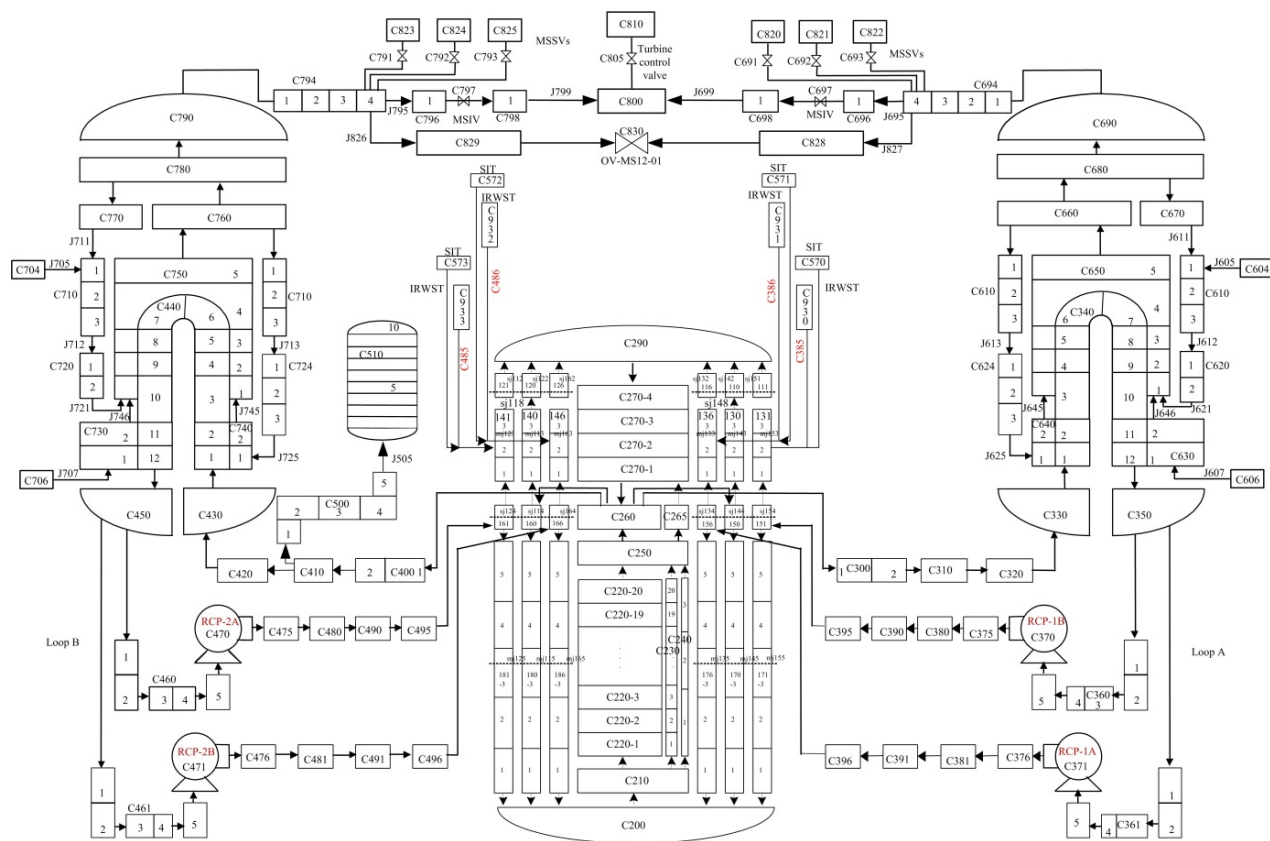


Figure 3-1 MARS-KS Code ATLAS Nodalization

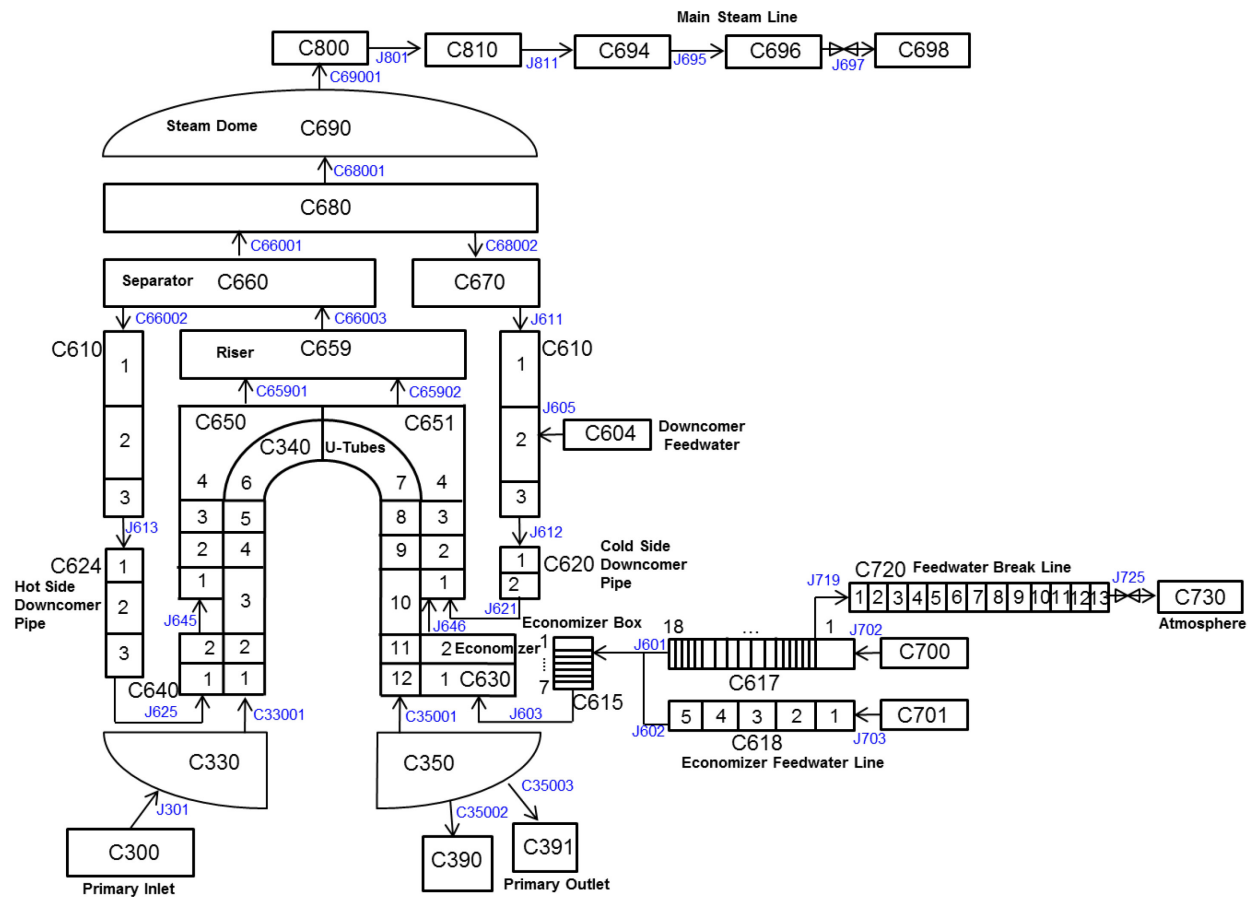
To simulate the feedwater line break test, the RELAP5/MOD3.3 input model took one steam generator from the MARS-KS code input model and modified it accordingly for analysis. Nodalization of the RELAP5/MOD3.3 input model for the ATLAS feedwater line break is shown in Figure 3-2. The model is based on 95 volumes connected by 36 junctions and 15 heat structures.

The primary side of the steam generator consists of primary inlet/outlet plenum and U-tubes.

- The primary inlet/outlet plenums (C330/C350) are modeled as BRANCH components and are connected to RCS loops (C300/C390/C391) and the primary side of the U-tubes (C340). RCS loop are modeled as TIME DEPENDENT VOLUME components and used as the boundary condition in the primary side of the steam generator.
- The U-tubes consist of 12 volumes in a PIPE component.

The secondary side of the steam generator consists of economizer, evaporator, riser, downcomer, hot and cold side downcomer pipe, separator, bypass, steam dome, economizer feedwater line, downcomer feedwater, main steam line and feedwater break line.

- The economizer (C630) is modeled as a PIPE component and has 2 volumes.
- The evaporator is divided into the hot side evaporator (C640/C650) and the cold side evaporator (C651). The hot side evaporator is modeled as a PIPE component and has 6 volumes and the cold side evaporator is also modeled as a PIPE component and has 4 volumes. The hot/cold side evaporators (C650/C651) are also connected by cross flow which is modeled as a MULTIPLE JUNCTION component.
- The riser (C659) is modeled as a BRANCH component connected to the evaporator and the separator.
- The downcomer (C610) is modeled as an ANNULUS component and has 3 volumes.
- The hot/cold side downcomer pipes (C624/C620) are modeled as PIPE components and have 3 and 2 volumes, respectively.
- The separator (C660) is modeled as a SEPARATOR component.
- The bypass (C670) is modeled as a SINGLE VOLUME component.
- The steam dome (C680/C690) is modeled as BRANCH components.
- The economizer feedwater line consists of an economizer box (C615) and economizer feedwater pipes (C617/C618). The economizer box and the economizer feedwater pipes are modeled as PIPE components and consists of 32 volumes. The economizer feedwater pipes are connected to TIME DEPENDENT VOLUME components (C700/C701) used as boundary condition to the economizer feedwater line.
- The downcomer feedwater (C604) is modeled as a TIME DEPENDENT VOLUME component used as boundary condition to the downcomer feedwater and connected to the downcomer by a TIME DEPENDENT JUNCTION component (J605).
- The main steam line (C800/C810/C694/C696/C698) is modeled as SINGLE VOLUME components and a TIME DEPENDENT VOLUME component used as boundary condition to the main steam line connected by a VALVE component. The main steam line consists of 5 volumes.
- The feedwater break line (C720/C730) is modeled as a PIPE component, and a TIME DEPENDENT VOLUME component and has 14 volumes. A TIME DEPENDENT VOLUME component provides the boundary condition as the atmosphere and is connected by a VALVE component (J725).



**Figure 3-2 The ATLAS Steam Generator RELAP5/MOD3.3 Nodalization**



## 4 RELAP5 ANALYSIS RESULTS

### 4.1 Steady State Calculation

In order to achieve a stable initial condition, the steady state calculation was performed for 3000 sec. The following controllers were used for the first 3000 sec:

- The downcomer feedwater flow rate proportional controller
- The economizer feedwater flow rate proportional controller
- The steam dome pressure proportional controller

The other controlled parameters (feedwater temperature, primary coolant temperature, primary coolant pressure, and primary coolant flow rate) were entered as boundary conditions.

Table 4-1 shows the calculated parameters compared to the experiment. The calculated RCS flow rate was a little different from that of experimental value. If we do a thermal power calculation using the measured inlet and outlet plenum temperatures, the RCS flow rate assuming 0.744 MW thermal power is 1.9 kg/sec, which is the same as the value predicted by the code. The calculated steam dome pressure was a little different from that of the experimental value. Because the measured steam dome pressure was lower than the saturation pressure at the given steam dome temperature, the saturation pressure at that given steam dome temperature was used as the steam dome pressure in the steady state calculation. The calculated steam flow rate was also a little different from that of the experimental value. Although the calculated steam and feedwater flow rates were equal, their measured values were not equal. It is noted that the instrument used for the water flow rate is more accurate than for the steam flow rate. Therefore, the calculated steam and feedwater flow rates were adjusted to the experimentally measured feedwater flow rate.

Once a stable condition was obtained, the downcomer, economizer feedwater and steam dome pressure controllers were de-activated and replaced by a relevant boundary condition for the transient analysis.

**Table 4-1 Steady State Results**

Parameters	Measured <sup>(1)</sup>	Calculated
Primary system		
Hot leg pressure (MPa)	15.582±0.006	15.582
Inlet plenum temperature (K)	598.3±2.4	598.1
Outlet plenum temperature (K)	564.1±2.4	563.5
Cold leg flow rate (kg/s) <sup>(2)</sup>	2.1365±0.001	1.9
Secondary system		
Thermal power (MW)	0.744	0.745
Steam dome pressure (MPa)	7.697±0.003	7.915
Steam dome temperature (K)	567.4±2.4	567.4
Steam flow rate (kg/s)	0.401±0.0002	0.42622
Economizer feedwater temperature (K)	507.7±2.4	507.7
Downcomer feedwater temperature (K)	506.8±2.4	506.8
Economizer feedwater flow rate (kg/s)	0.389±0.0002	0.3892
Downcomer feedwater flow rate (kg/s)	0.037±0.00002	0.037

Notes)

- (1) Average value during 300 to 600 sec
- (2) Average of cold legs A and B

## 4.2 Transient Calculation

In the FLB experiment (FLB-DS-01), after an initial steady-state condition was reached, this condition was maintain for about 600 sec. The feedwater line break test was initiated by isolation of the main feedwater line at 602.6 sec and opening the break line valve at 604.04 sec.

The RELPA5/MOD3.3 calculation was also conducted for null transient analysis during 600 sec. The break was initiated by isolation of the 702 and 703 TIME DEPENDENT JUNCTION components at 602.6 sec and opening the 725 valve at 604.04 sec as in the FLB experiment (FLB-DS-01). Table 4-2 shows the sequence of events in both the calculation and the ATLAS experiment.

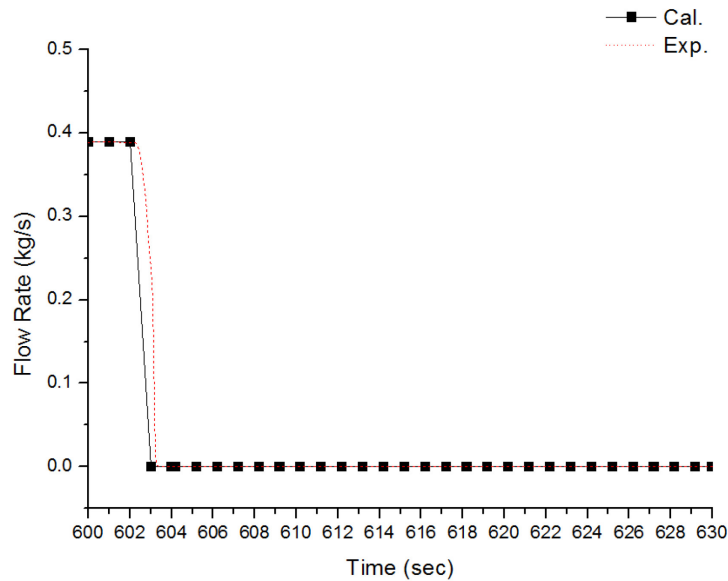
**Table 4-2 Sequence of Events**

Events	ATLAS FLB Test [FLB-DS- 01] (sec)	RELAP5/MOD3.3 Calculation (sec)	Remark
Steady state condition	0.0 to 600.0	0.0 to 600.0	null transient
Isolation of main feedwater line	602.6	602.6	702,703 junction isolation
SG-1 feedwater line break open	604.04	604.04	725 valve open
Test end	630.0	630.0	

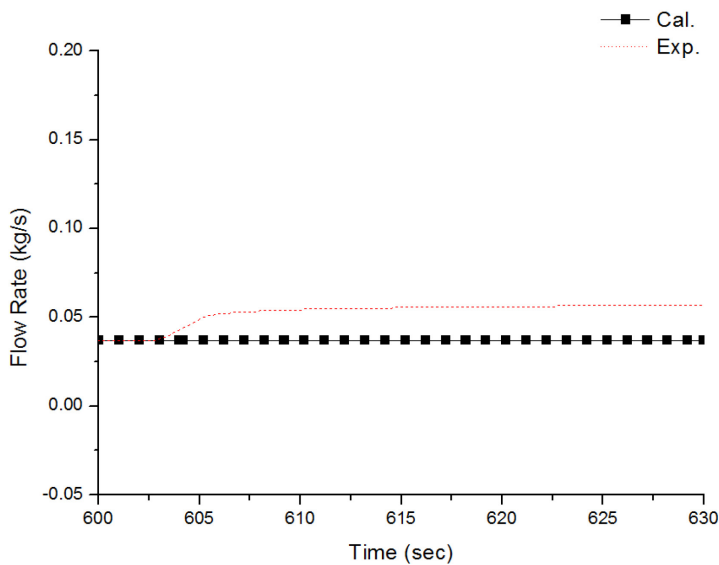
In the transient calculation, the Henry-Fauske critical flow model was used and the maximum time step size was 0.000001 sec during the period from 604.0 to 604.2 sec. The RELAP5/MOD3.3 calculation data were compared with experimental data as shown in Figure 4-1 through Figure 4-8. The experiment data are labeled "Exp.", and the RELAP5/MOD3.3 calculation data as "Cal.".

#### 4.2.1 Flow Rate

The economizer feedwater lines were isolated in the RELAP5/MOD3.3 calculation and the experiment at 602.6 sec as presented in Figure 4-1. The downcomer feedwater flow rate in the experiment increased after isolation of the economizer feedwater lines as presented in Figure 4-2. Because, the meaningful thermal hydraulic parameters were acquired experimentally during a short period of time (approximately 0.1 to 0.2 sec), this difference is immaterial.



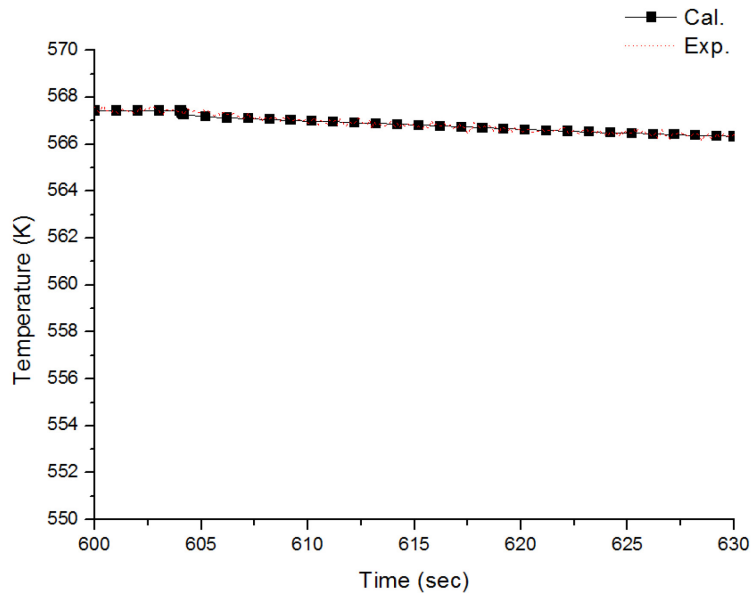
**Figure 4-1 Flow Rate at the Economizer Feedwater Line**



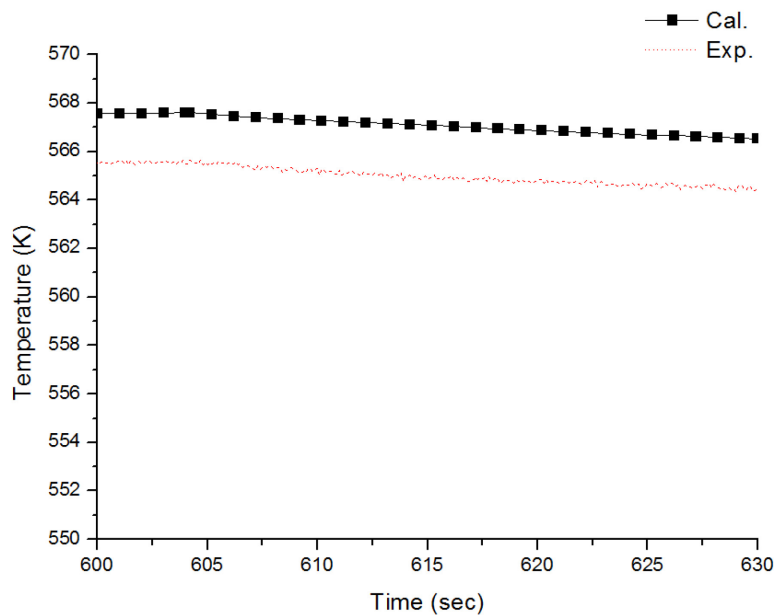
**Figure 4-2 Flow Rate at the Downcomer Feedwater Line**

## 4.2.2 Temperature

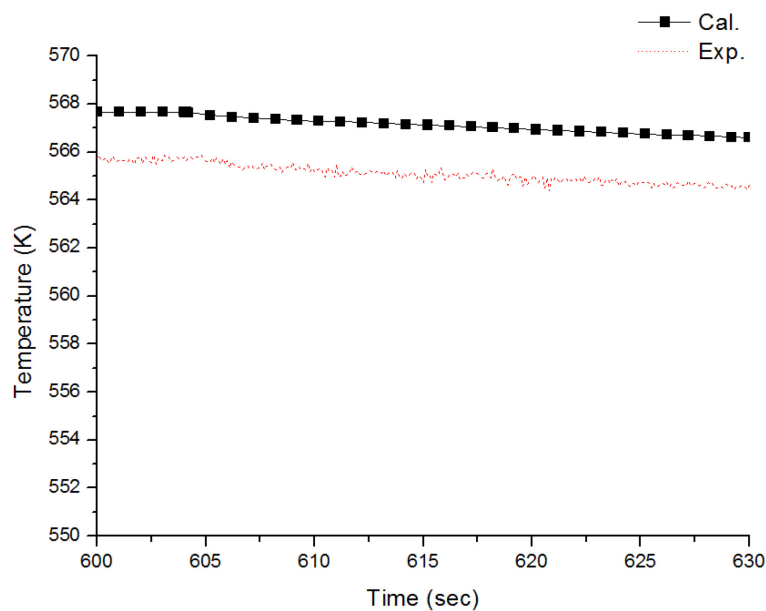
The temperature at the steam dome calculated by the RELAP5/MOD3.3 was in good agreement with experimental data, as presented in Figure 4-3. The temperature at the top of the economizer and the top of the tubesheet at the hot side section was slightly over-predicted, as presented in Figure 4-4 and Figure 4-5. However, these differences were within the uncertainty band shown in Table 2-2.



**Figure 4-3 Temperature at the Steam Dome**



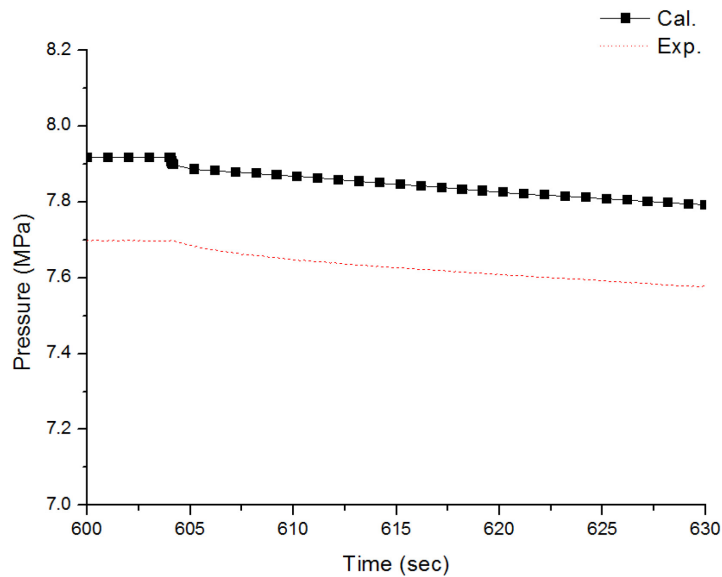
**Figure 4-4 Temperature at the Top of the Economizer**



**Figure 4-5 Temperature at the Top of the Hot Side Tubesheet**

### 4.2.3 Pressure

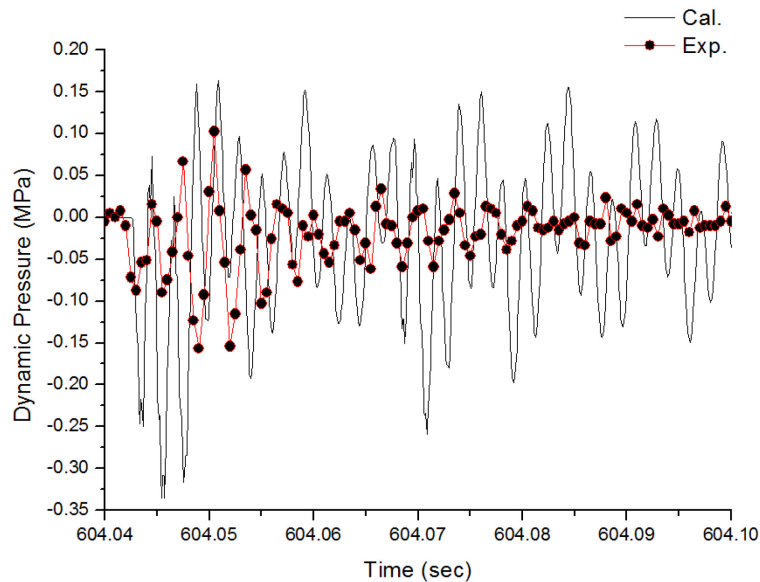
The steam dome pressure in the RELAP5/MOD3.3 calculation was determined from the table of TIME DEPENDENT JUNCTION. As shown in Figure 4-6, there is a difference between the RELAP5/MOD3.3 calculation and the experimental results. This is because the saturation pressure at the steam dome temperature was used as the steam dome pressure, as described in section 4.1.



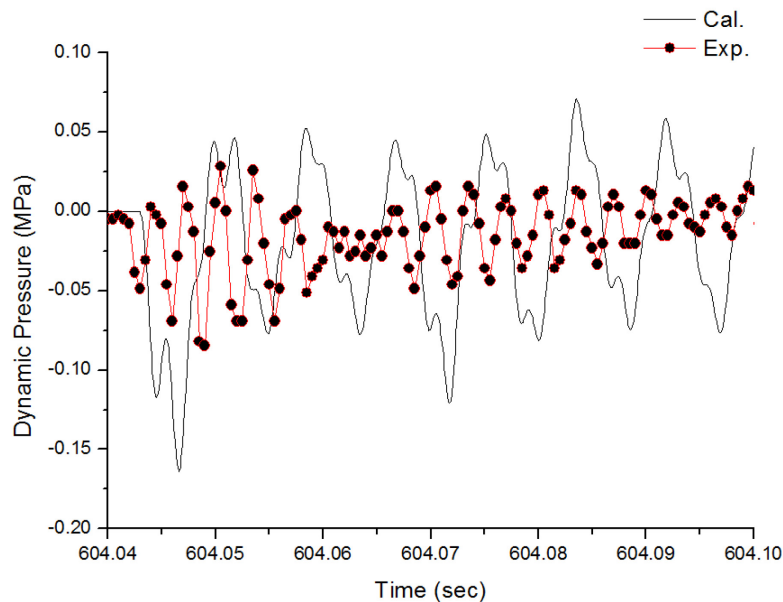
**Figure 4-6 Pressure at the Steam Dome**

#### 4.2.4 Dynamic Pressure

The RELAP5/MOD3.3 calculation conservatively predicted the dynamic pressure for the feedwater line break of the steam generator. Locations for the dynamic pressure measurements are shown in Figure 2-6. The maximum dynamic pressure was observed at dynamic pressure - 01 (Economizer Box) which was 0.157 MPa in experiment and 0.335 MPa in the RELAP5/MOD3.3 calculation, as presented in Figure 4-7. The dynamic pressure - 02 (Top of Economizer) was 0.085 MPa in experiment and 0.164 MPa in the REALP5/MOD3.3 calculation, as presented in Figure 4-8.



**Figure 4-7 Dynamic Pressure - 01 (the Economizer Box)**



**Figure 4-8 Dynamic Pressure - 02 (Top of the Economizer)**

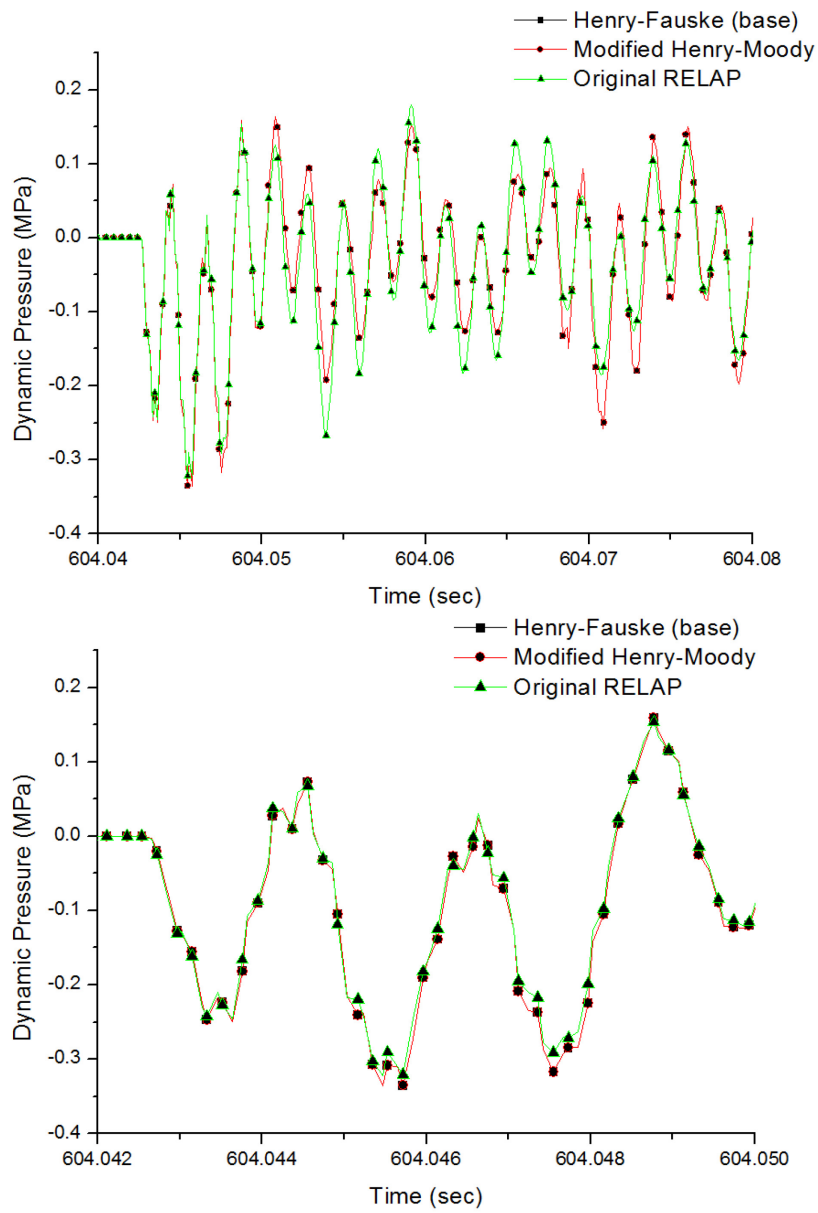
### **4.3 Sensitivity Study**

Sensitivity studies were performed to investigate the important factors affecting the dynamic pressure. The important factors are the critical flow model, the break valve opening time, the time step size, and the break valve discharge coefficient. Detailed results are presented in the following sub-sections.

#### **4.3.1 Critical Flow Model**

The critical flow model is an important factor in the feedwater line break analysis. Thus, a sensitivity analysis of the critical flow model was performed. The critical flow models used for this sensitivity analysis were the Henry-Fauske critical flow model, the Modified Henry-Moody critical flow model and the Original RELAP choked flow model.

Figure 4-9 shows the behavior of the dynamic pressure depending on the critical flow model. The dynamic pressure used the Henry-Fauske and the Modified Henry-Moody critical flow model were shown to be about the same and were more conservative than the Original RELAP critical flow model. Therefore, use of the Henry-Fauske and the Modified Henry-Moody critical flow model is recommended to obtain the most conservative maximum dynamic pressure for the feedwater line break of the steam generator.

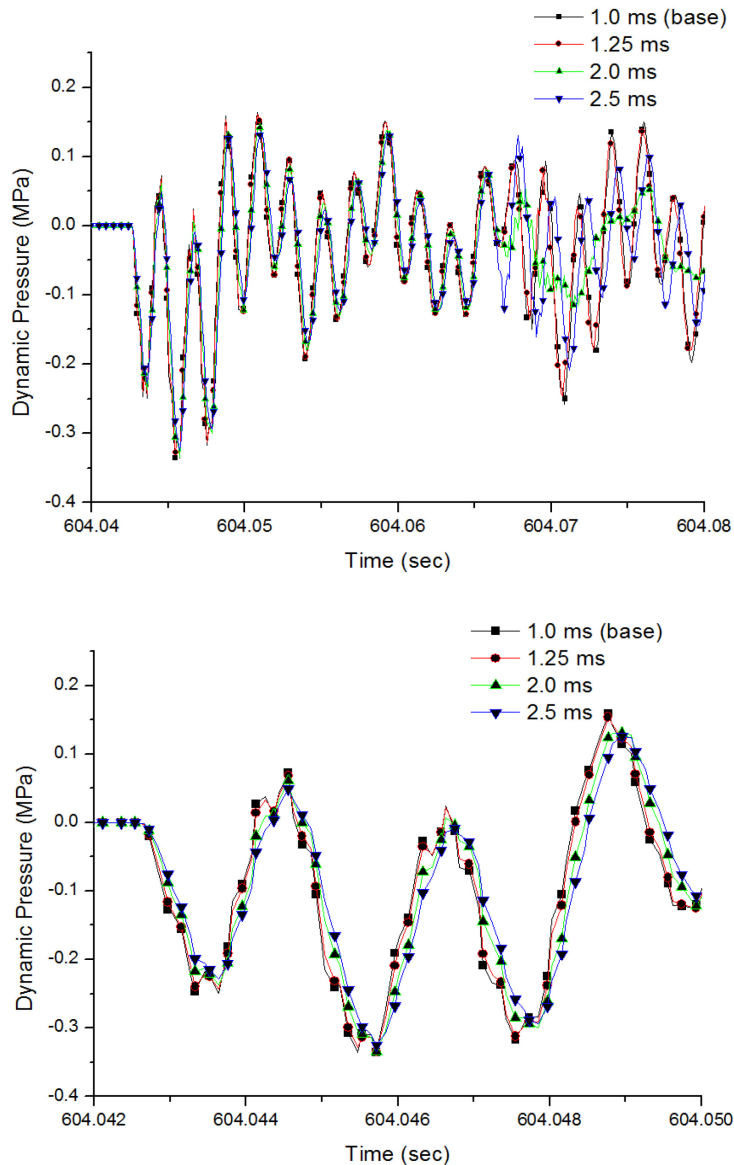


**Figure 4-9 Dynamic Pressure - 01 for the Critical Flow Model**

### 4.3.2 Break Valve Opening Time

The break valve opening time of 1.0 milli-sec is required for the feedwater line break analysis by the Korea Institute of Nuclear Safety. In the test, the maximum break valve opening time was less than 1.5 milli-sec. Thus, a sensitivity analysis was performed to find out the effect of changes in the break valve opening time. The analysis ranged from 1.0 to 2.5 milli-sec.

Figure 4-10 shows the behavior of the dynamic pressure depending on the break valve opening time. The maximum dynamic pressure increased as the break valve opening time decreased to 1.0 milli-sec. When the break valve opening time was 1.0 and 2.5 milli-sec, the maximum dynamic pressure was 0.335 and 0.325 MPa, respectively.



**Figure 4-10 Dynamic Pressure - 01 for the Break Valve Opening Time**

### 4.3.3 Time Step Size

After opening of the feedwater line break valve, the maximum dynamic pressure was reached within 0.005 sec. Thus, the time step size is an important factor in stem line break analysis and a sensitivity study for time step size was performed. The analysis for the maximum time step size ranged from  $10^{-8}$  to  $10^{-3}$  sec.

Figure 4-11 shows that the maximum dynamic pressure increased as the maximum time step size decreased to  $10^{-7}$  sec, and that the dynamic pressure was almost the same, below that value. A maximum time step size less than or equal to  $10^{-4}$  sec is recommended to obtain a most conservative maximum dynamic pressure. When the maximum time step size was  $10^{-4}$  sec, the calculated maximum dynamic pressure was 0.192 MPa (0.157 MPa in the experiment).

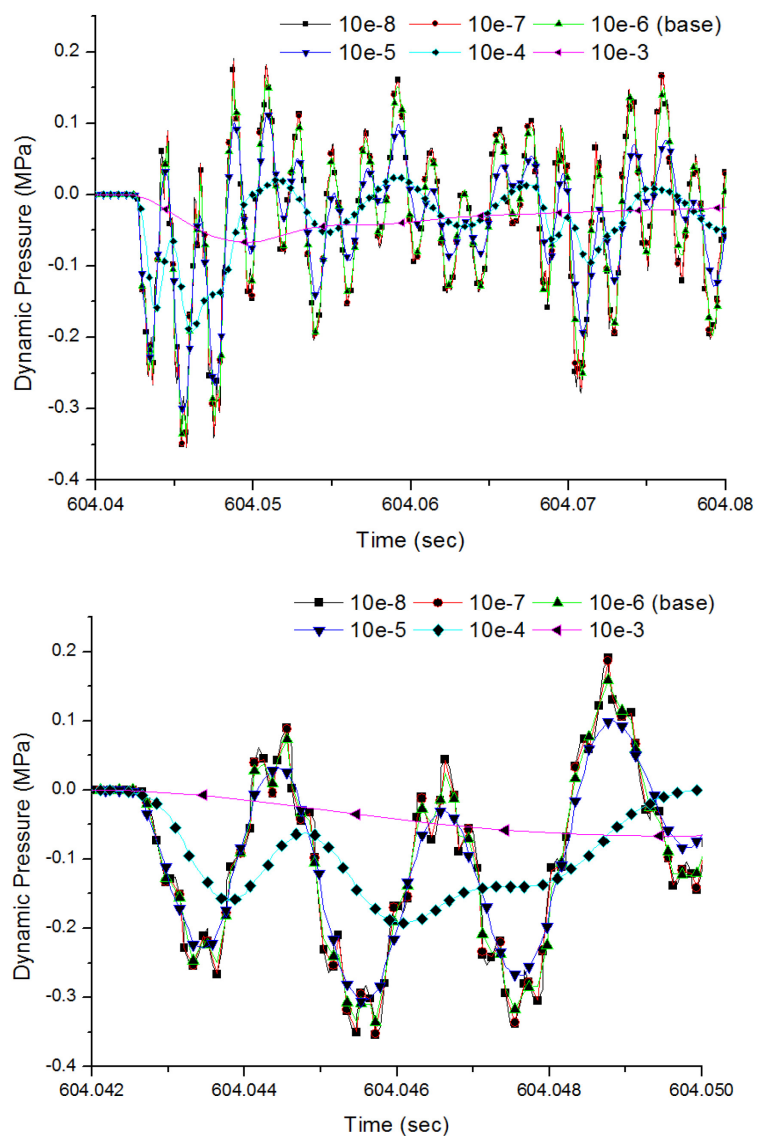


Figure 4-11 Dynamic Pressure - 01 for the Time Step Size

#### 4.3.4 Break Valve Discharge Coefficient

The break valve discharge coefficient is an important factor in the feedwater line break analysis. Thus, a sensitivity analysis of the break valve discharge coefficient was performed. The analysis ranged from 0.4 to 1.0.

Figure 4-12 shows the behavior of the dynamic pressure depending on the break valve discharge coefficient. The maximum dynamic pressure increased as break valve discharge coefficient increased. The break valve discharge coefficient of 1.0 is recommended to obtain the most conservative maximum dynamic pressure.

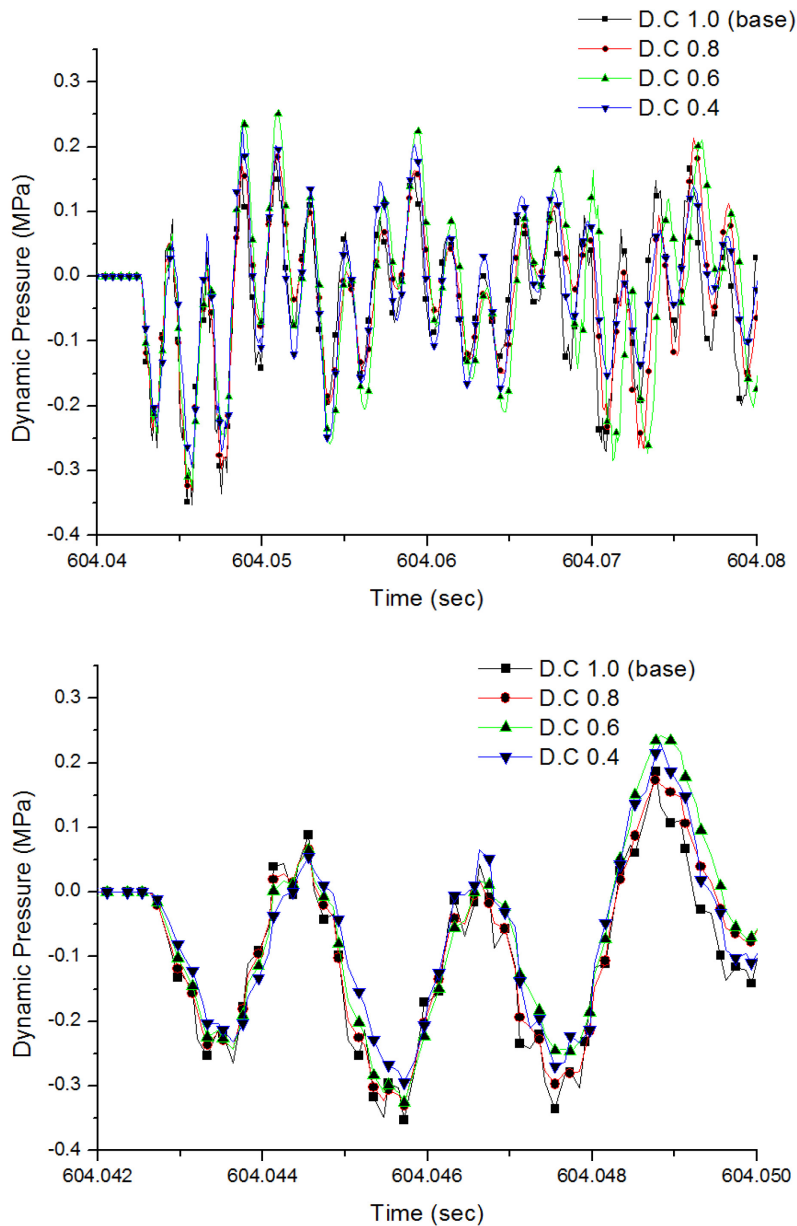


Figure 4-12 Dynamic Pressure - 01 for the Break Valve Discharge Coefficient

## **5 CONCLUSIONS**

The feedwater line break accident was simulated using RELAP5/MOD3.3. The calculation results were compared to the experimental data. As a result, the pressure and temperature behaviors were found to be well predicted, and the maximum dynamic pressure was predicted conservatively. Thus, it is concluded that use of the RELAP5/MOD3.3 should be acceptable for calculation of the steam generator blowdown load from feedwater line break accident.



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