NUREG/IA-0540

International Agreement Report

Assessment of TRACE5.0 Code Against ATLAS Test A5.2. Counterpart Test to LSTF

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ABSTRACT

The purpose of this work is to overview the results provided by the simulation of a counterpart experiment reproducing an Intermediate Break Loss-Of-Coolant Accident (IBLOCA) at the ATLAS and LSTF integral test facilities, using the thermal-hydraulic code TRACE5 patch 5 and the Symbolic Nuclear Analysis Packages software (SNAP) version 2.6.8.

The scenario simulates a 13% cold leg IBLOCA under the assumption of the full High-Pressure and Low-Pressure Injections, and the total failure of the Auxiliary Feedwater.

The simulation results are compared with the available data of the A5.2 and IB-CL-05 tests, in the OECD-ATLAS and OECD/NEA ROSA-2 projects, respectively, to evaluate the prediction capabilities of TRACE5 and clarify the causes of the major differences between the transients. Furthermore, these results represent a contribution to assess the predictability of computer codes such as TRACE5.

FOREWORD

Thermalhydraulic studies play a key role in nuclear safety. Important areas where the significance and relevance of TH knowledge, data bases, methods and tools maintain an essential prominence, are among others:

- Assessments of plant modifications (e.g., Technical Specifications, power uprates, etc.);
- Analysis of actual transients, incidents and/or start-up tests;
- Development and verification of Emergency Operating Procedures;
- Analytical information in support of some elements for the Probabilistic Safety Assessments (e.g., success criteria and available time for manual actions, and sequence delineation) and its applications within the risk informed regulation framework;
- Training personnel (e.g., full scope and engineering simulators); and/or
- Assessments of new designs.

For that reason, the history of the involvement in Thermalhydraulics of CSN, nuclear Spanish Industry as well as Spanish universities, is long. It dates back to mid 80's and comes to current days through several periods of USNRC CAMP programs. During this long history, CSN has promoted coordinated joint efforts with Spanish organizations through different periods of the so-called CAMP-España, the associated national program.

From the CSN perspective, we have largely achieved the objectives. Good models of our plants are in place, and a reliable infrastructure of national TH experts, models, complementary tools, just as an ample set of applications, have been created. The main task now is to maintain the expertise, to consolidate it and to update the experience. We at the CSN are aware on the need of maintaining key infrastructures and expertise, and see CAMP program as a good and well consolidated example of international collaborative action implementing this goal.

Many experimental facilities have contributed to the today's availability of a large thermal-hydraulic database (both separated and integral effect tests). However there is a continuous need for additional experimental work and code development and verification, in areas where no emphasis have been made along the past. On the basis of the SESAR/ SFEAR[1] reports "Nuclear Safety Research in OECD Countries: Major Facilities and Programmes at Risk" (SESAR/FAP, 2001), "Support Facilities for Existing and Advanced Reactors (SFEAR) NEA/CSNI/R(2007)6", and the 2019 updated SESAR/SFEAR2 report, CSNI is promoting since the beginning of this century several collaborative international actions in the area of experimental TH research. These reports presented some findings and recommendations to the CSNI, to sustain an adequate level of research, identifying a number of experimental facilities and programmes of potential interest for present or future international collaboration within the nuclear safety community during the coming decade. The different series of PKL, ROSA, ATLAS and RBHT projects are under these premises.

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[1] SESAR/SFEAR is the *Senior Expert Group on Safety Research / Support Facilities for Existing and Advanced Reactors* of NEA Committee on the Safety of Nuclear Installations (CSNI).

CSN, as Spanish representative in CSNI, is involved in some of these research activities, helping in this international support of facilities and in the establishment of a large network of international collaborations. In the TH framework, most of these actions are either covering not enough investigated safety issues and phenomena (e.g., boron dilution, low power and shutdown conditions, beyond design accidents), or enlarging code validation and qualification data bases incorporating new information (e.g., multi-dimensional aspects, non-condensable gas effects, passive components).

This NUREG/IA report is part of the Spanish contribution to CAMP focused on:

- The analysis, simulation and investigation of specific safety aspects of PKL/OECD and ATLAS/OECD experiments.
- The analysis of applicability and/or extension of the results of these projects to the safety, operation or availability of the Spanish nuclear power plants.

Both objectives are carried out by simulating the experiments and conducting the plant application with the last available versions of NRC TH codes (RELAP5, TRACE and/or PARCS).

Additional goal of CSN is to assure and to maintain the capability of the national groups with experience in the thermalhydraulics analysis of accidents in the Spanish nuclear power plants. Nuclear safety needs have not decreased as the nuclear share of the nation's grid for the next coming years is expected to be maintained with plants of extended life and/or higher power. This is the challenge that will require a continued effort.

Javier Dies Llovera, Commissioner

Nuclear Safety Council (CSN) of Spain

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EXECUTIVE SUMMARY

The present work offers an overview of a counterpart experiment in the ATLAS and LSTF facilities and the simulations with the TRACE5 code. The tests deal with an IBLOCA scenario based on a 13% break in a cold leg, followed by the actuation of the Emergency Core Cooling Systems (ECCS) and under the assumption of the total failure of the Auxiliary Feedwater system. The results are compared with the available data of the A5.2 and IB-CL-05 tests, in the OECD-ATLAS and OECD/NEA ROSA-2 Projects, respectively, to evaluate the prediction capabilities of the code.

The comparison between ATLAS and LSTF tests reveals that thermal-hydraulic phenomena and the overall sequence of major events are equivalent, except for the PCT behavior. This discloses the possibility to extrapolate some thermal-hydraulic variables between both facilities to predict phenomena under this type of scenario.

The simulation results have been contrasted with the experimental data in different graphs, including primary and secondary pressures, discharged inventory, collapsed liquid levels (in the U-tubes and the core) and ECCS mass flow rates. Thus, the TRACE5 calculations show a close agreement with the test data. Especially, the cooling progress and the peak cladding temperature are correctly reproduced and prove the code to be a suitable tool to simulate the thermal-hydraulic phenomena of the analyzed scenario.

ACRONYMS AND ABBREVIATIONS

ATLAS	Advanced Thermal-Hydraulic Test Loop for Accident
CCFL	Counter Current Flow Limitation
DBA	Design Basis Accident
DEC	Design Extension Conditions
DEGB	Double-Ended Guillotine Break
ECCS	Emergency Core Cooling System
HPIS	High-Pressure Injection System
IBLOCA	Intermediate Break LOCA
LBLOCA	Large Break LOCA
LOCA	Loss Of Coolant Accident
LPIS	Low-Pressure Injection System
LSC	Loop Seal Clearing
LSTF	Large Scale Test Facility
LWR	Light Water Reactor
RPV	Reactor Pressure Vessel
SBLOCA	Small Break LOCA
SNAP	Symbolic Nuclear Analysis Package
PCT	Peak Cladding Temperature

1 INTRODUCTION

Thermal hydraulic codes have proven to be an effective tool for simulating experiments performed in reduced-scale test facilities if proper models are available. Nevertheless, this capability does not ensure that the level of accuracy on a different scale or in a plant model is maintained. Given this fact, counterpart experiments between two or more integral test facilities constitute a significant means to address the scaling methodology and enhance confidence in extrapolating results from the facilities to their reference power plants.

Loss Of Coolant Accidents (LOCA) are analyzed in the risk assessment of Light Water Reactors (LWR) as one of the main design basis events. Small Break and Large Break LOCAs (SBLOCA and LBLOCA) were extensively analyzed in the past using experiments in the integral test facilities, however, data about Intermediate Breaks (IBLOCA) have been very limited despite during these scenarios the thermal-hydraulic responses can differ significantly from the other types of breaks. Thus, the USNRC proposed to consider, in 2005, the intermediate break for the assessment of the effectiveness of emergency core cooling systems. Given this, although this proposal was not carried out, LSTF was one of the pioneer facilities in the IBLOCA accident simulation. Subsequently, facilities such as ATLAS have included in their experimental programs several experiments related to intermediate breaks, aimed at researching the influence of the type, location, size and accident management measures on the accidental effects.

The purpose of this work is to test the capability of the thermal-hydraulic code TRACE5 patch 5 [1, 2] in the simulation of a 13% cold leg IBLOCA in the ATLAS and LSTF facilities and analyze the major phenomena of the counterpart experiment. For this goal, two TRACE5 models have been developed to reproduce test A5.2 [3] and Test 7 [4] in the frame of OECD/NEA ATLAS and OECD/NEA ROSA-2 Projects.

2 INTEGRAL TEST FACILITIES

ATLAS (Advanced Thermal-hydraulic Test Loop for Accident Simulation) is an integral effect test facility destined to recreate the major Design Basis Accidents (DBAs) and Design Extension Conditions (DEC) in reactors APR1400 and OPR1000. The facility adopts a Reduced-Height, Full-Pressure concept and the geometric design was established according to the three-level scaling methodology of Ishii and Kataoka, being its geometrical scaling ratios ½ height, 1/144 area and 1/288 volume [5,6]. Thus, the design allows preserving the transient response of major thermal-hydraulic parameters, specifically, under natural circulation conditions. As a result of the reduced height criterion, the time scale ratio is 1/√2 and the duration of the experiments is √2 faster than expected on the APR1400, but the maximum design pressure and temperature may be preserved to 18.7 MPa and 643 K, respectively. The facility includes most of the features of Generation IV nuclear reactors distributed along a primary system with a loop configuration equal to that of the APR1400, and a secondary system. The primary system comprises a Reactor Pressure Vessel (RPV) surrounded by an annular downcomer, a pressurizer and two loops composed of a hot leg, a steam generator U-tube bundle, two loop seals and cold legs and two pumps, each one. The secondary system consists of two steam generators, their steam lines, a feedwater system, and one condensation and refrigeration loop. Concerning the thermal power, the 396 electrical heater rods located in the core can supply a maximum of 2.15 MW, limiting the scaled power to 11% of the reference reactor. Figure 2-1 shows an ATLAS scheme.

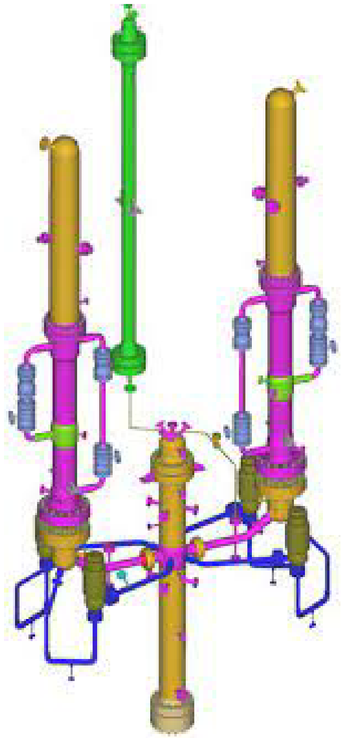


Figure 2-1 ATLAS Facility Scheme

LSTF (Large Scale Test Facility) [7] replicates a four-loop Westinghouse type reactor with 3423 MW thermal power. The facility is designed based on a Full-Height, Full-Pressure configuration so that it preserves the same height and operating pressure as its reference power plant. For the geometric design, the scaling approach follows the Power to Volume methodology with a scaling factor of 1/48 for both parameters. Thus, its components are scaled 1/1 in height and 1/48 in areas and volumes, except the hot and cold legs. Since the four primary loops of the reference reactor are lumped into two equal volume loops, these pipes are scaled by a factor of 1/24 in area to conserve the volumetric scale, as well as the relation of the length to the diameter square-root ($L/\sqrt{D}$). The facility consists of a pressure vessel, a pressurizer, two symmetric primary loops, full Emergency Core Cooling System (ECCS) and two steam generators. Each loop includes a hot leg, a U-tube bundle, a loop seal, a coolant pump and a cold leg. The core power is generated utilizing 1008 heated rods able to supply 10 MW (14% of the reference scaled power). To fulfill its mission of simulating accidents, the facility is equipped with a full Emergency Core Cooling System (ECCS), made up of active and passive sub-systems. Figure 2-2 shows a scheme of LSTF.

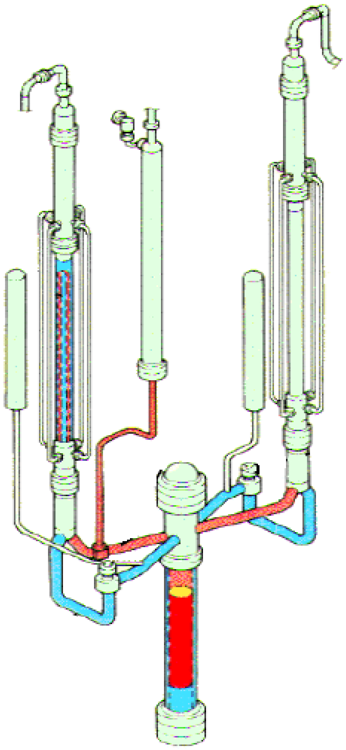


Figure 2-2 LSTF Scheme

3 13% IBLOCA EXPERIMENT

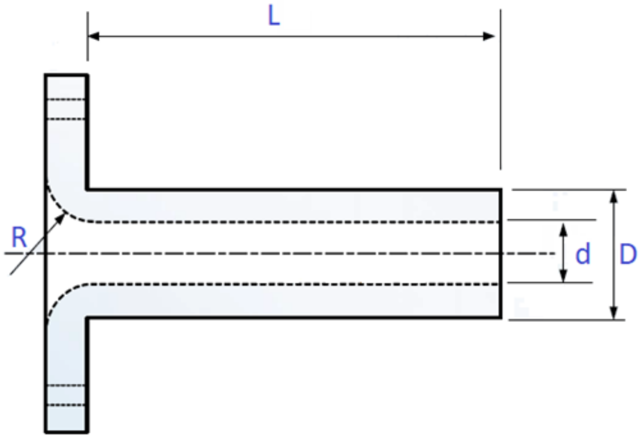
The counterpart scenario deals with a 13% cold leg IBLOCA under the assumption of full injection of High-Pressure Injection and Low-Pressure Injection systems, and total failure of the Auxiliary Feedwater. It is based on the IB-CL-05 experiment (OECD/NEA ROSA-2 Project) in LSTF [4], conducted on June 14, 2012, and from those test boundary conditions, the test A5.2 conditions [3] (OECD-ATLAS Project) were established to carry out, in 2016, the relevant experiment to perform a counterpart test.

In particular, the experiments simulate an accident initiated by the Double-Ended Guillotine Break (DEGB) of one of the ECCS piping connected to a cold leg. Figure 3-1 shows a scheme of the nozzle upwardly mounted on the cold leg in the loop without a pressurizer for simulating the break conditions.

The experiments start at time 0 with the break valve opening and the consequent loss of a large quantity of coolant. Then, the safety systems are activated successively and based on the primary system pressure, to lead the facilities to stable conditions. To this end, the High-Pressure Injection System (HPIS), the accumulators and the Low-Pressure Injection System (LPIS) compensate, only from the loop with pressure, the lost inventory. The tests finish with the break valve closure when primary and secondary pressures are stabilized. The sequence of major events and the complete control logic of the transient are listed in Table 3-1.

Table 3-1 Control Logic in 13% IBLOCA

Event	Signal
Start of test - Break	T=0 s
SCRAM signal	Primary pressure < 12.97 MPa
Initiation of core power decay	SCRAM
Primary Coolant Pump coastdown.	SCRAM
Closure of Main Steam Isolation Valves (SG)	SCRAM
Main Feedwater termination (SG)	SCRAM
HPI initiation	Primary pressure < 12.27 MPa
Accumulators injection	Primary pressure < 4.51 MPa
LPI initiation	Primary pressure < 1.24 MPa
End of test	T_{ATLAS}=800 s and T_{LSTF}=1200 s



	ATLAS	LSTF
L (mm)	240	432
d (mm)	19	36
D (mm)	39	82
R(mm)	10	23

Figure 3-1 Break Nozzle Scheme

4 TRACE5 MODELS

The ATLAS and LSTF models developed with the TRACE5 code patch5 deal to faithfully reproduce the thermal-hydraulic behavior of the facilities [1, 2]. To this end, their technical specifications are adapted to the modeling code options, paying special attention to the nodalization of the models and the relevant thermal-hydraulic phenomena during the IBLOCA scenario. The ATLAS model consists of 76 hydraulic components (1 VESSEL, 53 PIPE, 1 PRIZER, 4 PUMP, 2 SEPARATOR, 2 TEE, 7 VALVE, 3 FILL and 5 BREAK). For its part, the LSTF model consists of 81 hydraulic components (1 VESSEL, 23 PIPE, 1 PRIZER, 2 PUMP, 22 TEE, 14 VALVE, 11 FILL and 7 BREAK).

The modeling techniques are equivalent in both models. VESSEL-3D components represent the reactor pressure vessels, allowing the simulation of multidimensional phenomena. As the facilities, both models include an annular downcomer, lower plenum, a core, upper plenum, and upper head, however, their nodalization differs between them. Likewise, the VESSEL-3D component enables the modeling of the fuel alignment plates and upper core plates, whereas the control rod guide tubes are simulated with PIPE components.

The whole loops, including the hot, intermediate and cold legs and the U-tube bundles of the steam generators are modeled with PIPE components. In the facilities, the U-tube bundles are made up of 176 tubes in ATLAS and 141 tubes in LSTF, distributed among different levels, so to simplify the models, the bundles are merged into one and three PIPE components, respectively. These PIPEs preserve the inlet and outlet temperature, the pressure drop and the heat transfer through the wall of the original ones. These nodalizations have been previously verified in [8][9][10].

The secondary systems are also mainly made up of PIPE components, which represent the riser and downcomer of the steam generators and the respective steam lines, while a SEPARATOR component has been used to model the steam separators in ATLAS.

The pressurizer is the only component for which the modeling techniques differ. In ATLAS, it is represented by a PIPE while in LSTF a PRIZER is used to model the device. This fact is not significant in the simulation of the IBLOCA test and the evaluation of discrepancies between both facilities since the major phenomena during the IBLOCA are not related to the characteristics and operation of the pressurizer. From its lower part, it is connected to a hot leg through a surge line represented by a PIPE. In the upper region, there is a relief and safety valve, modeled with a VALVE component, to control the pressure of the primary system.

The PUMP components located in each loop simulate the reactor coolant pumps, for which their nominal conditions and the characteristic curves are defined.

The High-Pressure and Low-Pressure Injection Systems (HPIS and LPIS, respectively) in the facilities consist of safety injection pumps. These devices are included in the models by means of FILL components and impose the injected mass flow rate. FILL components are also used to simulate the main and auxiliary feedwater supply to the steam generators.

The core power is supplied by POWER components, which transfer the power to the electric heater rods modeled with cylindrical HEAT STRUCTURE (HTSTR) components. Each HEAT STRUCTURE represents the set of heaters located in a certain ring and sector of the vessel. The axial and radial power profiles of the heaters are implemented in the POWER component.

During an IBLOCA, the countercurrent flow limitation (CCFL) phenomenon is expected to occur in sections where high energetic steam flows, and concretely during this scenario, CCFL may appear at the fuel alignment plate, the upper core plate, along the hot legs and at the U-tubes inlet. In ATLAS facility, it also occurs at the perforated upper plenum plate. CCFL TRACE5 option has been set up at some of these locations by making use of the Wallis (Wa) and Kutateladze (Ku) correlations and the coefficients suggested in [11][12]].

Table 4-1 Application of CCFL Wallis Models

Location	ATLAS		LSTF	
Fuel alignment plate	**m**	**c**	**m**	**c**
Upper core plate	1 (Wa)	1 (Wa)	1 (Wa)	0.86 (Wa)
U-tubes inlet	0.63 (Ku)	1 (Ku)	---	---
	1 (Wa)	1 (Wa)	1 (Wa)	0.72 (Wa)

Moreover, special attention is paid to the modeling of the break to reproduce the discharged inventory and the primary system depressurization during the transient. The break units are simplified into a short PIPE, which is jointed upwardly to the cold leg throw a cross-flow junction, a VALVE and a BREAK component, as shown in Figure 4-1. Besides, the simulation of the break boundary conditions requires TRACE special models set in the nodes representing the break nozzle, i.e., offtake model and the choked-flow models (Burnell model for liquid critical flow and Ransom and Trapp model for two-phase critical flow), which are applied through Choked Flow Multipliers (CFM). Default coefficients (CFM=1) in the LSTF model provide simulation results consistent with the experiment. Nevertheless, ATLAS model requires reduced coefficients (CFM=0.9 for subcooled liquid and CFM=0.8 for two-phase flow) to obtain simulations comparable to the test.

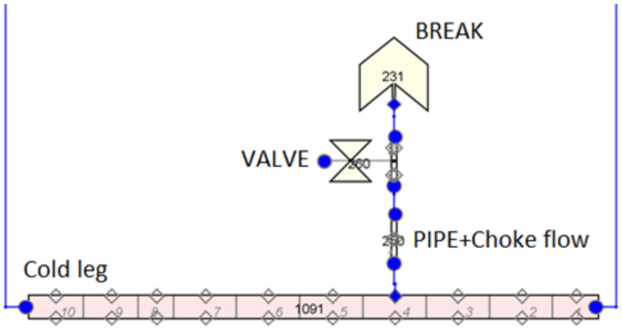


Figure 4-1 Break Unit Nodalization

Figure 4-2 shows the nodalization of the ATLAS and LSTF TRACE5 models using the Symbolic Nuclear Analysis Package (SNAP) software, version 2.6.8.

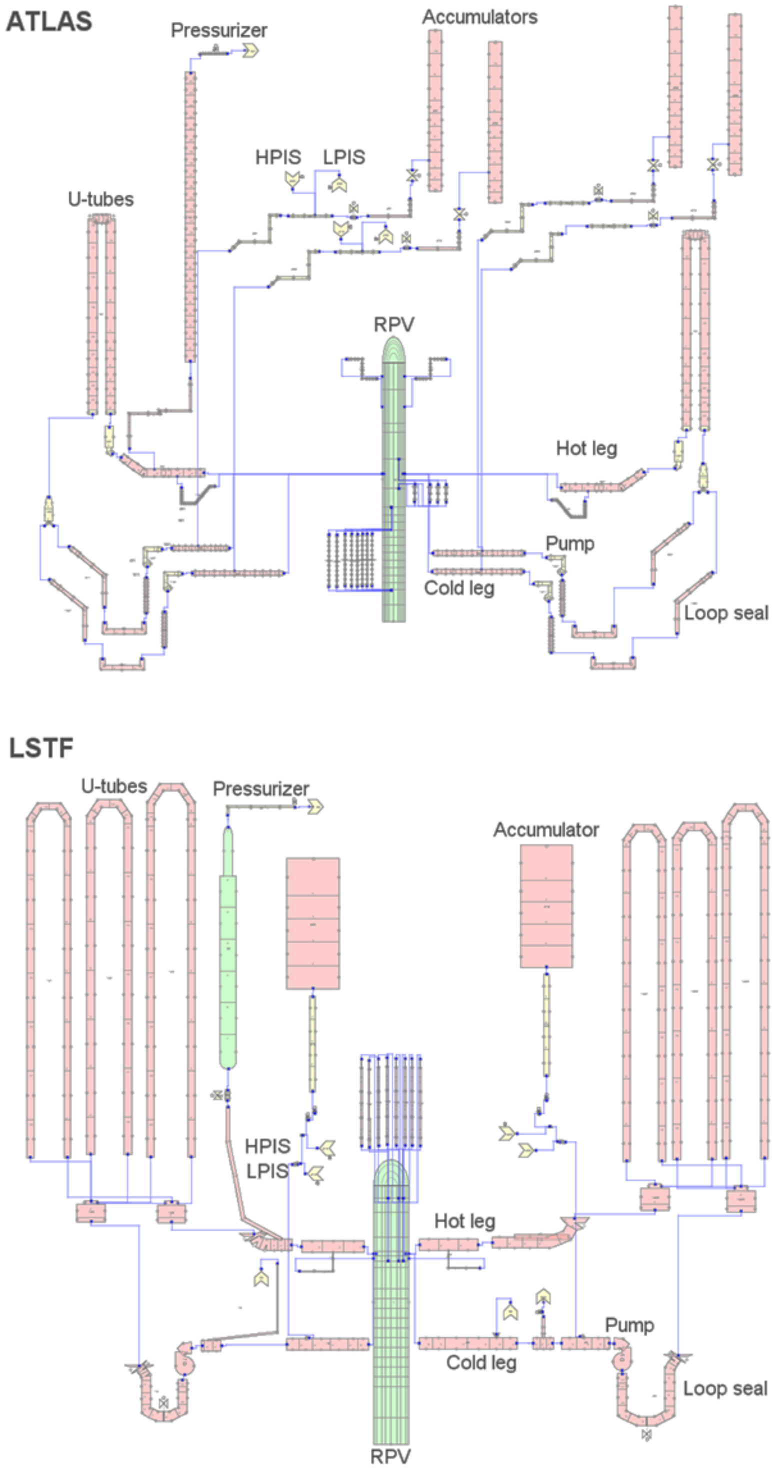


Figure 4-2 TRACE5 Models

5 SCALING CONSIDERATION

The counterpart scenario A5.2 of ATLAS was designed taking as a reference the test IB-CL-05 in LSTF. The strategy to determine the initial and boundary conditions of the experiment in ATLAS is based on the application of Ishii's similarity criteria for one-phase and two-phase flow [13]. To that end, the geometric parameters (lengths, areas and volumes) that characterize both the components and the facilities are compared and, among them, two independent ones are used to calculate the scaling ratios. Specifically, the effective heating length of the core and primary inventory are selected as major parameters. The length ratio (l_R) is equal to 1.905 m/3.66 m = 0.52 and the volume ratio ($l_R d_R^2$) is 1.64 m^3/8.14 m^3=0.2. The rest of the ratios for diameters, power, time or flow are dependent on the previous two. To preserve pressures and temperatures and reproduce the same fluid conditions in both systems, scale ratios equal to 1 are imposed on these variables. Table 5-1 lists the scale ratios between ATLAS and LSTF, used to establish the initial and boundary conditions of the test and to compare the evolution of thermal-hydraulic parameters and phenomena.

The initial core power in the LSTF IB-CL-05 test is 10.02 MW distributed into three groups at a rate of 1.435, 1.00 and 0.71 in the high, medium and low heat zones, and the chopped-cosine shape for the axial profile. According to the power scaling ratio, $l_R^{1/2} d_R^2$, the initial power in ATLAS should be 2.8 MW. The power assigned to the high heat group would preserve the heat flux scaling ratio, $l_R^{-1/2}$, and the rest of the power would be distributed evenly between the heaters of medium and low groups. However, due to the limitation of maximum power that can be supplied, the core power is set to 1.6 MW and distributed following the same fraction distribution. Once the SCRAM occurs, the power in ATLAS results from directly scaling the curve programmed in LSTF by a factor of 0.28.

The inventory available in the facility is decisive in the reproduction of LOCA scenarios, specifically, because the amount of water remaining in the core preserves its integrity. In this counterpart test, the analysis of the PCT is a major concern. To preserve the behavior between facilities, the total inventory is determined by setting the pressurizer level at 2.07 m in ATLAS, that is, scaling the inventory placed at a level above the core.

The ECCS injection is at the intact loop, located downstream of the reactor coolant pumps. The HPIS and LPIS mass flow rates are determined from the scaling analysis with the ratio 0.28, and then equally divided into the two cold legs of each loop in ATLAS. The two accumulators in ATLAS discharge the quantity of water of 0.2 that of LSTF.

Table 5-1 Scale Ratios Between ATLAS and LSTF Parameters

Parameter	Similarity ratios	ATLAS/LSTF ratio
Length	l_R	**0.52**
Diameter	d_R	0.62
Area	d_R^2	0.38
Volume	$l_R d_R^2$	**0.2**
Core ΔT	T_R	1
Pressure	P_R	1
Heat flux	$l_R^{-1/2}$	1.38
Core power	$l_R^{1/2} d_R^2$	0.28
Flow rate	$l_R^{1/2} d_R^2$	0.28
Velocity	$l_R^{1/2}$	0.72
Time	$l_R^{1/2}$	0.72

6 RESULTS AND DISCUSSION

6.1 Global System Analysis

The IBLOCA accidents show different evolution depending on the break size and location, and the accident management measures implemented. The following assumptions are imposed to reproduce this IBLOCA scenario:

1) Break size is 13% of the cold leg flow area.
2) An upward long break nozzle is located on top of the cold leg in the broken loop without a pressurizer.
3) Loss of off-site power concurrent with the scram.
4) HPIS, Accumulators and LPIS activate in the intact loop.
5) Non-condensable gas inflow from accumulator tank may take place.
6) Total failure of AFW.

Under these test conditions, the scenario may be split into four chronological phases as shown in Figure 6-1:

- Blowdown: Rapid depressurization due to loss of a large amount of coolant at high temperature and pressure conditions.

- Natural circulation: Circulation of coolant within the loops owing to natural convection. Pressure keeps in quasi-equilibrium conditions.

- High-quality discharge: Depressurization due to a very high-quality mixture or steam discharge.

- Refill: Recovery of liquid levels with actuation of ECCS.

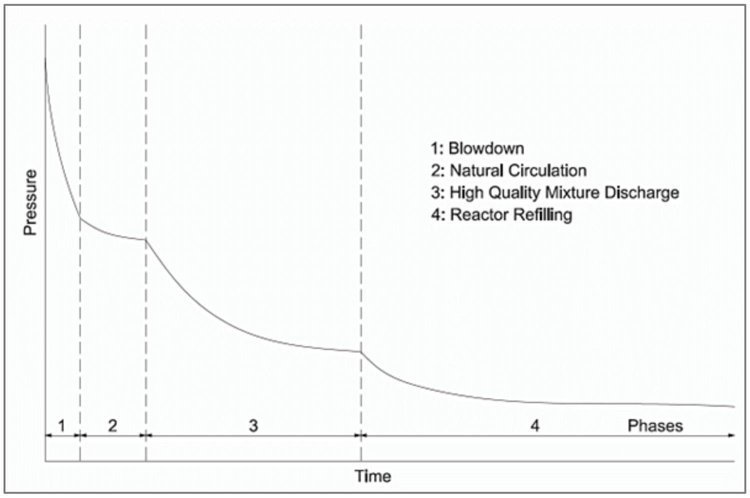


Figure 6-1 IBLOCA Phenomenological Phases

6.2 Initial conditions

Table 6-1 shows the steady-state conditions in both counterpart tests and the respective simulations using TRACE5.

Table 6-1 Steady-State Conditions in the TRACE5 Simulations

Parameter	A5.2 ATLAS	TRACE5 ATLAS	IB-CL-05 LSTF (scaled)	TRACE5 LSTF (scaled)
Core Power (MW_t)	1.67	1.67	10.10 (2.83)	10.10 (2.83)
Hot leg Fluid Temperature (K)	598	598	598 (598)	598 (598)
Cold leg Fluid Temperature (K)	563	565	563 (563)	564 (564)
Mass Flow Rate (kg/s)	3.88	3.85	24.55 (6.87)	24.42 (6.84)
Pressurizer Pressure (MPa)	15.50	15.54	15.50 (15.50)	15.53 (15.53)
Pressurizer Liquid Level (m)	2.10	2.15	7.30 (7.80)	7.28 (3.79)
Accumulator System Pressure (MPa)	4.51	4.51	4.52 (4.52)	4.52 (4.52)
SG Secondary-side Pressure (MPa)	7.86	7.86	7.34 (7.34)	7.34 (7.34)
SG Secondary-side Liquid Level (m)	5.29	5.34	10.20 (5.30)	10.40 (5.41)
Steam Flow Rate (kg/s)	0.44	0.43	2.67 (0.75)	2.52 (0.71)
Main Feedwater Flow Rate (kg/s)	0.44	0.43	2.63 (0.74)	2.52 (0.71)
Main Feedwater Temperature (K)	505	505	496 (496)	496 (496)

6.3 Transient

Table 6-2 lists the chronology of major events during the transients. The timing is presented for both the experiments and their simulations. Furthermore, the values corresponding to the LSTF facility are scaled by a timing ratio equal to 0.72 to be equivalent to those in ATLAS.

The figures below present the evolution of the main thermal-hydraulic parameters. To compare both scenarios, the LSTF experimental and simulated results are shown scaled according to the similarity ratios between the two facilities.

Table 6-2 Chronological Sequence of Events – Time After Break (s) and Scaled Timing

Event	A5.2 ATLAS	TRACE5 ATLAS	IB-CL-05 LSTF (scaled)	TRACE5 LSTF (scaled)
Break valve open.	0	0	0	0
Scram signal.	5	4	9 (6)	8 (5)
Initiation of HPI system.	25	16	27 (20)	26 (18)
PCT excursion	48	51	---	---
Loop seal clearing	63	70	60 (43)	72 (52)
Maxinun PCT	143	109	67 (48)	84 (61)
Initiation of ACC discharge	128	129	150 (108)	157 (113)
End of ACC discharge	268	240	350 (252)	670 (482)
LPI injection	544	492	800 (576)	701 (505)
End of the test.	800	800	1100 (792)	1100 (792)

The blowdown phase takes place similarly in ATLAS and LSTF due to the release of an equivalent amount of coolant. Therefore, in the first seconds of the test, the HPI systems are activated simultaneously. Soon after, during a brief natural circulation phase, the main difference in the behavior of the facilities occurs. At 50 s in ATLAS, there is a pronounced excursion of the PCT and lasts for 100 s. However, this phenomenon does not occur in LSTF. Once the high-quality discharge begins, depressurization continues, allowing the discharge of the accumulators and the subsequent activation of the LPI system. As a result of the resemblance of the thermal-hydraulic phenomena, the three ECCS maintain the chronology of operation.

6.3.1 System Pressures

The test is initiated with the break valve opening. The high pressure and temperature conditions cause a large loss of liquid for a short period and a sharp depressurization. When the primary pressure decreases below 12.97 MPa, a SCRAM signal initiates the core power decay and, a few seconds later, the HPIS activates at 12.27 MPa.

Simultaneously with the scram signal, the secondary system is isolated and pressure in the steam generators keeps almost constant through the safety valve cyclic openings, while the primary pressure stagnates. Soon, the primary pressure continues decreasing and becomes lower than the secondary one. From this moment on, the steam generators no longer act as heat sinks.

As the coolant through the break changes to gas phase, the depressurization smooths and, when the primary pressure is lower than 4.51 MPa and 1.24 MPa, the accumulators and LPIS restore the inventory to reach safe and stable conditions.

Figure 6-2 shows the primary pressure in ATLAS and LSTF. As can be seen, pressure evolution is very similar in both systems and the simulations provide pressure data close to the experimental values. Secondary pressures in the experiments keep almost constant but, in the simulations, decrease roughly 1 MPa in 800 s due to heat loss overestimation (Figure 6-3).

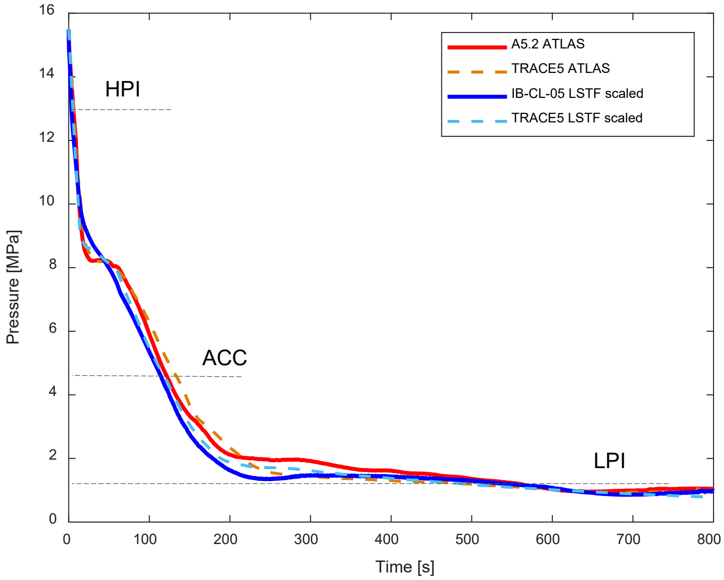


Figure 6-2 Primary Pressure

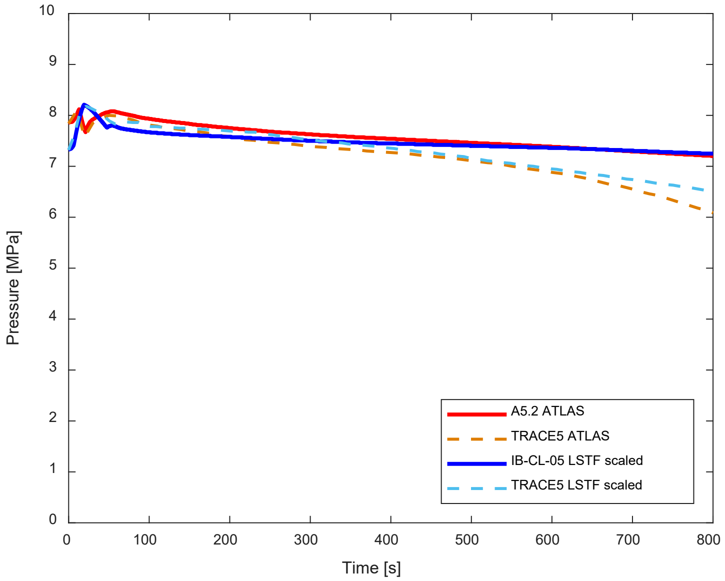


Figure 6-3 Secondary Pressure

6.3.2 Discharged inventory

Figure 6-4 shows the accumulated inventory released through the break. In the blowdown phase, the experimental values are in very good agreement with the simulated ones for reproducing the loss of coolant. When stratification appears in the broken cold legs and the flow condition at the break changes to two-phase flow and one-phase gas at around 60 s, TRACE5 results momentarily and slightly deviate from experiments. In the ATLAS facility, the code overestimates the discharged inventory, and this advances a second loop seal clearing (LSC) in the broken loop by 50 s. By contrast, LSTF simulation understates the mass flow rate released but from that moment on, the discharge is somewhat higher. Thus, the accumulated inventory curves in both simulations are consistently reproduced although the discharge at the end of the transient is 100 kg higher in the experiemnts.

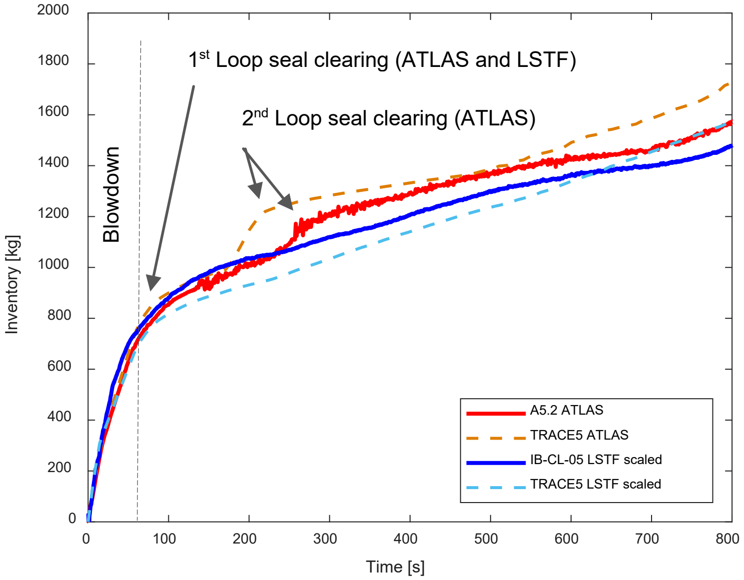


Figure 6-4 Accumulated Inventory Through the Break

6.3.3 Coolant Distribution

At the beginning of the transient, the liquid flow rate in the hot legs decreases sharply due to the loss of coolant and emptying of the upper plenum, the hot legs and the U-tube bundles in the steam generators. In a few seconds, only the loop seals, the core and the downcomer lower region are flooded. A small amount of water in the upper plenum remains because of countercurrent flow limitation in the upper core plate due to continuous upward steam. When LSC takes place (simultaneous in both facilities, Figure 6-5), the liquid level in the seals downflow-side drops to the bottom and rises in the vessel and the hot legs. This event is enough to fill the core and prevent PCT excursion in LSTF. When all the ECCS actuates the core in both facilities become refilled quickly with subcooled water.

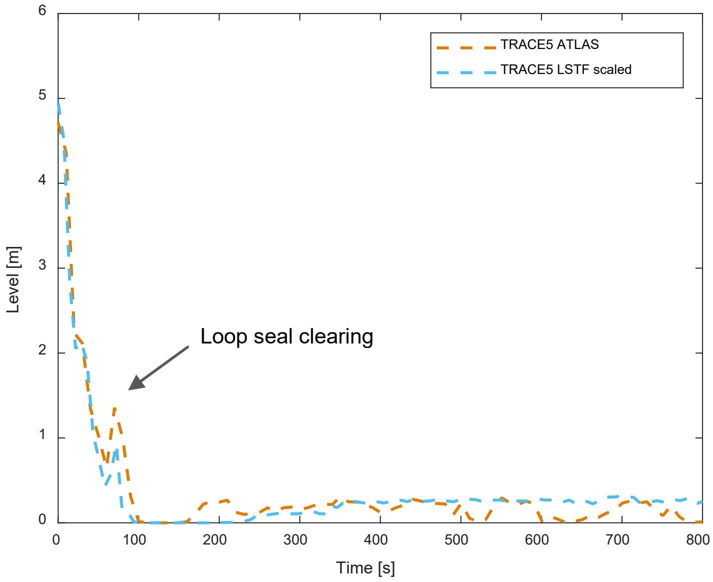


Figure 6-5 Collapsed Liquid Level in U-Tubes

6.3.4 Pressure Vessel Collapsed Liquid Level

Figure 6-6 shows the comparison between the ATLAS and the LSTF collapsed liquid level in the core and the corresponding simulations. The general trend is very similar in both facilities and the gap between the experimental data series is due to the characteristics of the vessels, specifically, the height of the lower plenum. TRACE5 reproduces the level behaviors although slight discrepancies occur in the sudden level drops.

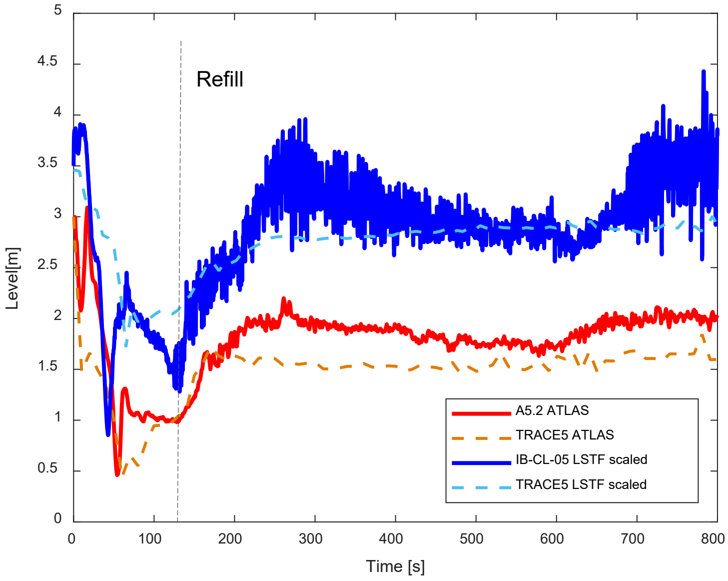


Figure 6-6 Collapsed Liquid Level in the Core

6.3.5 Peak Clad Temperature

Concurrently with the initial depressurization, the collapsed liquid level in the vessel falls rapidly and the HPIS actuates. From that moment, the PCT responses differ qualitatively between facilities, as Figure 6-7 shows.

In ATLAS, the HPIS injection is not enough to recover the necessary inventory that avoids the core dry-out. Therefore, a sudden and large excursion in the PCT is produced. The temperature increases up to 862 K at 143 s and does not reduce until the discharge of the accumulators. In LSTF, the water injection in combination with the loop seal clearing prevents the core uncovering and the dry-out effects. However, due to the continuous boiling in the core and loss of coolant, another dry-out occurs shortly before the discharge of the accumulators. As a result, the PCT in LSTF presents two small peaks. It is noteworthy that during the first 200 s of the experiment, the coolant discharge (Figure 6-4) and the safety injections (Figure 6-8 and Figure 6-9), and therefore the net inventory, are similar in both facilities. However, this factor is not decisive to preserve the evolution of the PCT. The different behavior between ATLAS and LSTF may be partially justified by the characteristic geometry of each technology, and in particular, by the relative position of their core. However, it can also be identified as a potential cliff-edge effect on the PCT evolution in LSTF [14]. In any case, making use of the current verified models, the TRACE5 code reproduces both temperature trends.

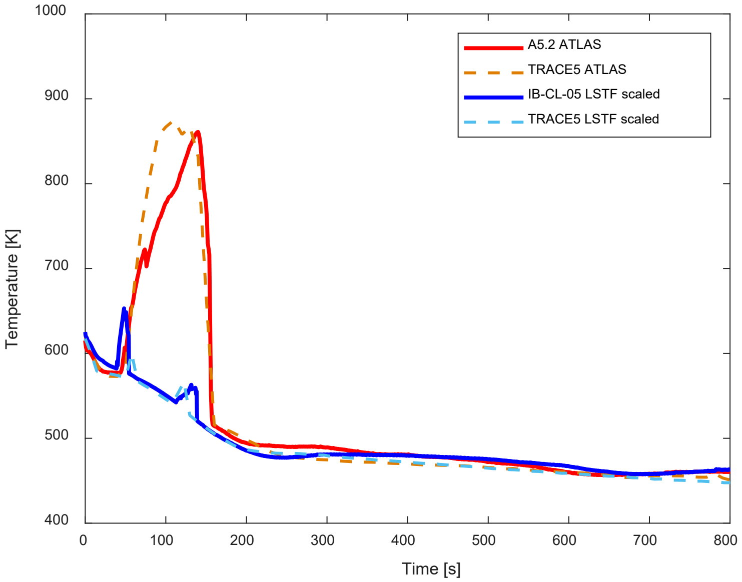


Figure 6-7 Peak Clad Temperature

6.3.6 Emergency Core Cooling System

As accident management measures, the experiments contemplate the operation of the HPIS, the LPIS and the discharge of the accumulators in the intact loop. Figure 6-8 and Figure 6-9 show the coolant mass flow rate injected from each ECCS.

HPIS and LPIS activate at 12.27 MPa and 1.24 MPa, respectively, and from then on, flow rates are controlled by the speed of the safety injection pumps. Thus, discrepancies between experimental and simulated data on the LPIS timing and the flow rate derive from minor pressure differences at the end of the transient.

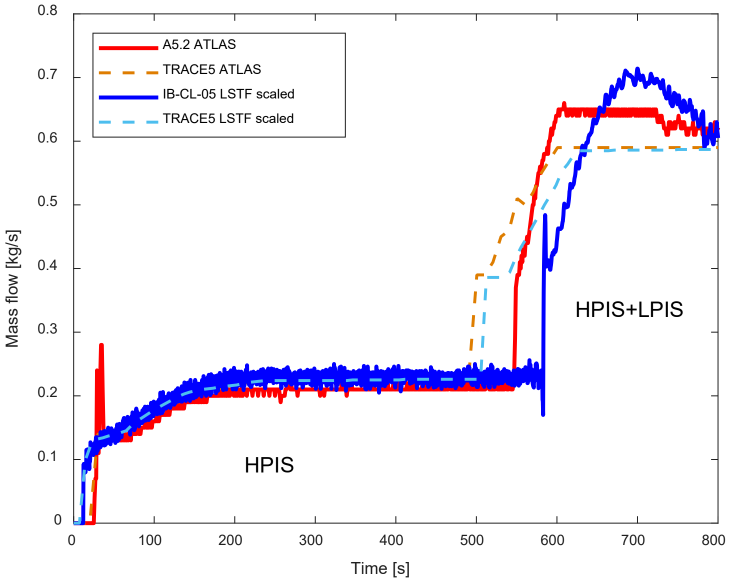


Figure 6-8 HPI+LPI Mass Flow Rate

The injection from the accumulators enables to bring the facilities to stable conditions due to the large amount of cold water that enters the systems. At 4.51 MPa, their isolation valves are opened and the coolant is discharged by gravity as the primary system is depressurized. As shown in Figure 6-9, the simulations capture the start of the discharge but do not reproduce the experimental trend for the mass flow. In ATLAS, the coolant is introduced abruptly but in LSTF two stages are distinguished and the injection is prolonged. Therefore, discrepancies in cooling lead to pressure deviations.

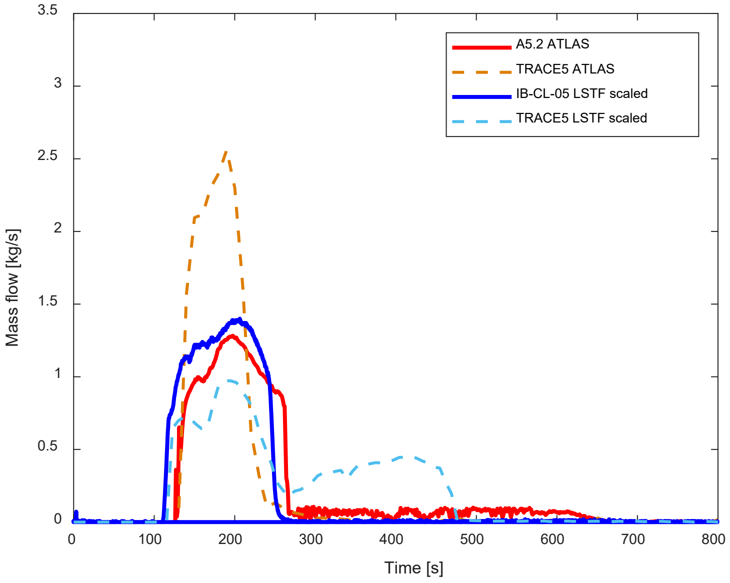


Figure 6-9 Mass Flow Rate From Accumulators

7 CONCLUSIONS

A counterpart experiment between the ATLAS and LSTF facilities was performed using the TRACE V5 Patch5 code. The scenario represents a 13 % IBLOCA caused by a double-ended guillotine break of one of the ECCS piping nozzle connected to a cold leg. Under these conditions, full injection of the ECCS in the intact loop was assumed as the only management accident measure.

The design of the counterpart scenario through scaling analysis results in a similar sequence of thermal-hydraulic phenomena and chronology of events in both facilities, including the action of the HPI, accumulators and LPI systems. However, despite the similarity of the scenarios, it is worth noting the different evolution of the PCT. A large temperature excursion is only noticed in ATLAS and the cause of this deviation is an open issue for discussion.

Focused on the major thermal-hydraulic parameters, the simulations were compared to the experimental data and to the counterpart results. In general, the TRACE5 calculations are in close agreement with both tests. The major phenomena, like the primary system depressurization or the break discharge, were correctly simulated. Moreover, the different behaviors between facilities related to de PCT are also captured in the simulations. Most significant discrepancies arise in the discharge of the accumulators, not being significant in the test evolution.

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10. SUPPLEMENTARY NOTES
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11. ABSTRACT (200 words or less)

The purpose of this work is to overview the results provided by the simulation of a counterpart experiment reproducing an Intermediate Break Loss-Of-Coolant Accident (IBLOCA) at the ATLAS and LSTF integral test facilities, using the thermal-hydraulic code TRACE5 patch 5 and the Symbolic Nuclear Analysis Packages software (SNAP) version 2.6.8.

The IBLOCA scenario simulates a 13% cold leg IBLOCA under the assumption of full High-Pressure Injection and Low-Pressure Injection, and total failure of the Auxiliary Feedwater.

The simulation results are compared with the available data of the A5.2 and IB-CL-05 tests, in the OECD-ATLAS and OECD/NEA ROSA-2 projects, respectively, to evaluate the prediction capabilities of TRACE5 and clarify the causes of the major differences between the transients. Furthermore, these results represent a contribution to assess the predictability of computer codes such as TRACE5.

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