IAEA Safety Assessment Education and Training (SAET) Programme

Joint ICTP-IAEA Essential Knowledge Workshop on Deterministic Safety Assessment and Engineering Aspects Important to Safety

Verification and validation of computer codes

Exercise

IAEA
International Atomic Energy Agency

Exercises on verification and validation of computer codes (V&V)

Computer codes like RELAP5, ATHLET, CATHARE etc. aim to simulate the system behavior of nuclear power plants as realistic as possible (’best estimate’). These computer codes are used to investigate − incidents and accidents of different scenarios and their consequences, − the effectiveness of emergency procedures.

The process carried out by comparing code predictions with experimental measurements or measurements in a reactor plant (if available) is called validation. A code or code model is considered validated when sufficient testing has been performed to ensure an acceptable level of predictive accuracy over the range of conditions for which the code may be applied. Accuracy is a measure of the difference between measured and calculated quantities taking into account uncertainties and biases in both. Bias is a measure, usually expressed statistically, of the systematic difference between a true mean value and a predicted or measured mean. Uncertainty is a measure of the scatter in experimental or predicted data. The acceptable level of accuracy is judgmental and will vary depending on the specific problem or question to be addressed by the code. The procedure for specifying, qualitatively or quantitatively, the accuracy of code predictions is also called code assessment.

The validation of codes is mainly based on pre-test and post-test calculations of separate effects tests, integral system tests, and transients in commercial plants. An enormous amount of test data, usable for code validation, has been accumulated in the last decades. In the year 1987 the Committee on the Safety of Nuclear Installations (CSNI) of the Nuclear Energy Agency (NEA) in the Organisation for Economic Co-Operation and Development (OECD) issued a report compiled by the Task Group on the Status and Assessment of Codes for Transients and ECC. It contains proposed validation matrices for LOCA and transients, consisting of the dominating phenomena and the available test facilities, and the selected experiments. The Task Group on Thermal Hydraulic System Behavior updated the integral test matrices and extended their work to separate effects tests.

Tasks to be performed

1. Review the provided description of computer code simulation of selected PIEs (SB LOCA and LB LOCA).
2. From the description identify the phenomena, which occur during the PIEs.
3. Using the information provided in OECD/NEA computer code validation matrix relevant for the simulated PIE, identify the integral test facilities and experiments suitable for the computer code validation.
4. Review the provided plots with results of the computer code simulation and its comparison against relevant experiment. Provide the judgment on qualitative and quantitative code accuracy using the following scale:

   E: excellent, if code predicts qualitatively and quantitatively the phenomena/parameter

   R: reasonable, if code predicts qualitatively but not quantitatively the phenomena/parameter

   M: minimal, if code does not predicts the phenomena/parameter, but the reason is understood and predictable)

   U: unqualified, if code does not predicts the phenomena/parameter and the reason is not understood

Example 1 - SB LOCA

After the break occurred at time zero, the primary system depressurizes quickly. At a pressurizer pressure of 12.97 MPa, the reactor scrams. This signal closed the turbine throttle valve. The turbine bypass system was inactive due to the assumption of loss of- offsite power occurring concurrently with scram. The loss of offsite power terminated the main feed water, and also tripped the reactor coolant pumps to initiate coastdown. The reactor coolant pumps completely stopped at about 265 s after break.

At a pressurizer pressure of 12.27 MPa, the safety injection signal is sent that trips ECCS to be actuated at respective pressure set points. However, the high pressure charging system and the high pressure injection system are assumed to fail. The accumulator system and the low pressure injection system (LPIS) are specified to initiate coolant injection into the primary system at pressures of 4.51 and 1.29 MPa, respectively. The accumulator-cold system injects into the cold leg A and the accumulator-hot system into the cold leg B.

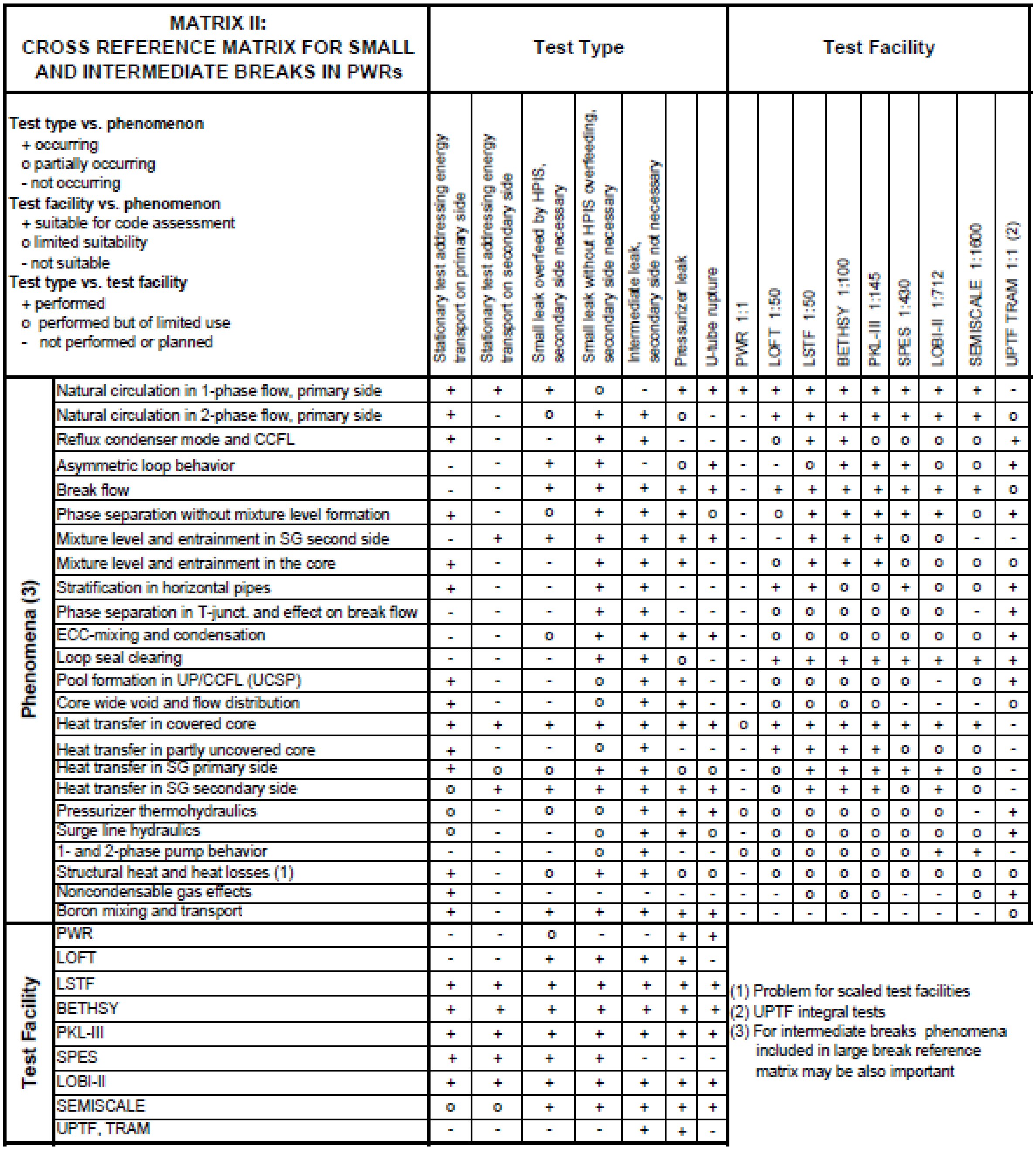
The secondary pressure increased after the closure of the turbine throttle valve, but was maintained at approximately 8 MPa due to the SG relief valve operation.

The core was temporarily uncovered between about 120 s and 155 s after break, and the fuel rods in most of the core experienced superheating of up to about 190 K. This temporary core uncovery occurred during water accumulation in the loop seals. The core liquid level was depressed concurrently with the level drop in the cross-over leg downflow sides. The core level drop was amplified by the manometric effect caused by an asymmetric coolant holdup in the SG upflow and downflow sides. At about 140 s after the break, loop seal clearing occurred in both loops and the core liquid level recovered rapidly. After the loop seals cleared, the break flow changed from low quality to high quality two-phase flow, and the depressurization of the primary loop was accelerated. By about 180 s after the break, the primary loop pressure decreased below the SG secondary side pressure. Thereafter, the steam generators no longer served as heat sinks and the energy removal from the primary system was through the discharge of coolant from the break. It is noted that the loop seal clearing occurred before the reversal in primary and secondary pressures.

The core was uncovered again after about 420 s due to vessel inventory boil-off, and the fuel rods in the upper part of the core showed superheating of up to about 80 K. Due to depressurization of the primary system, the accumulators were automatically actuated at 455 s to fill the system with the ECC water. The core was covered with two-phase mixture again after about 540 s by the ECC water injection.

The maximum peak cladding temperature was approximately 740 K, observed during the temporary core uncovery just before the loop seal clearing.

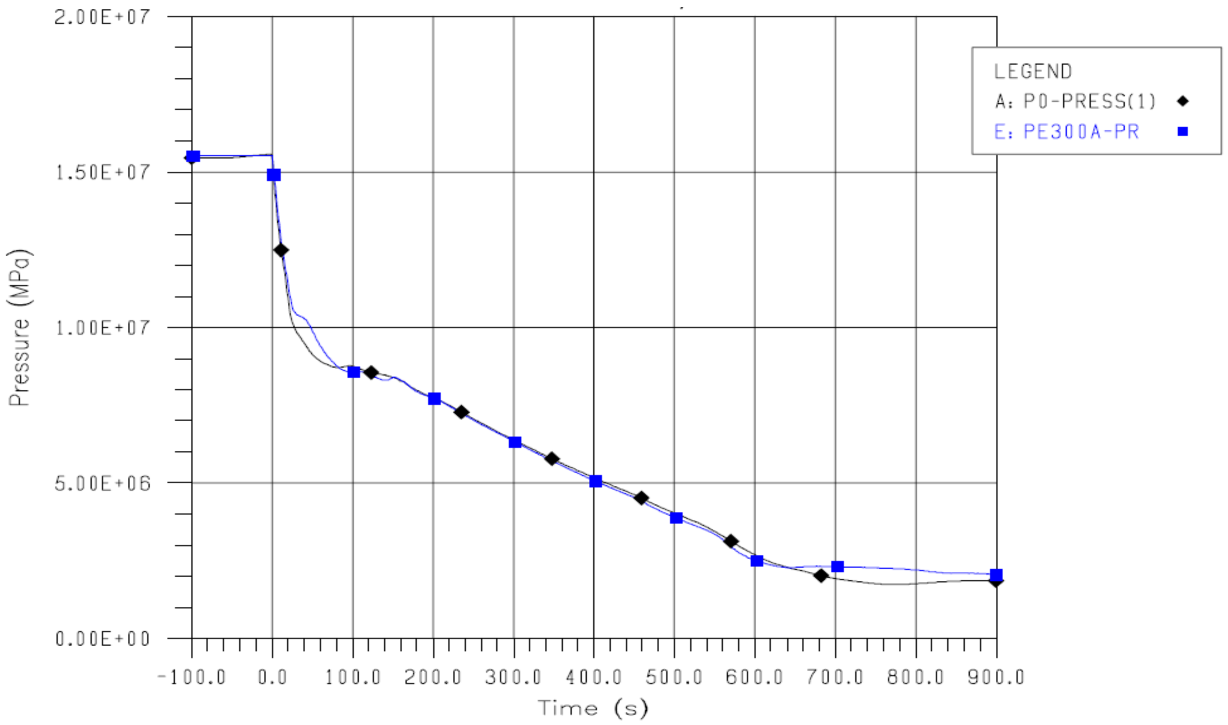
OECD/NEA Computer code validation matrix for SB LOCA



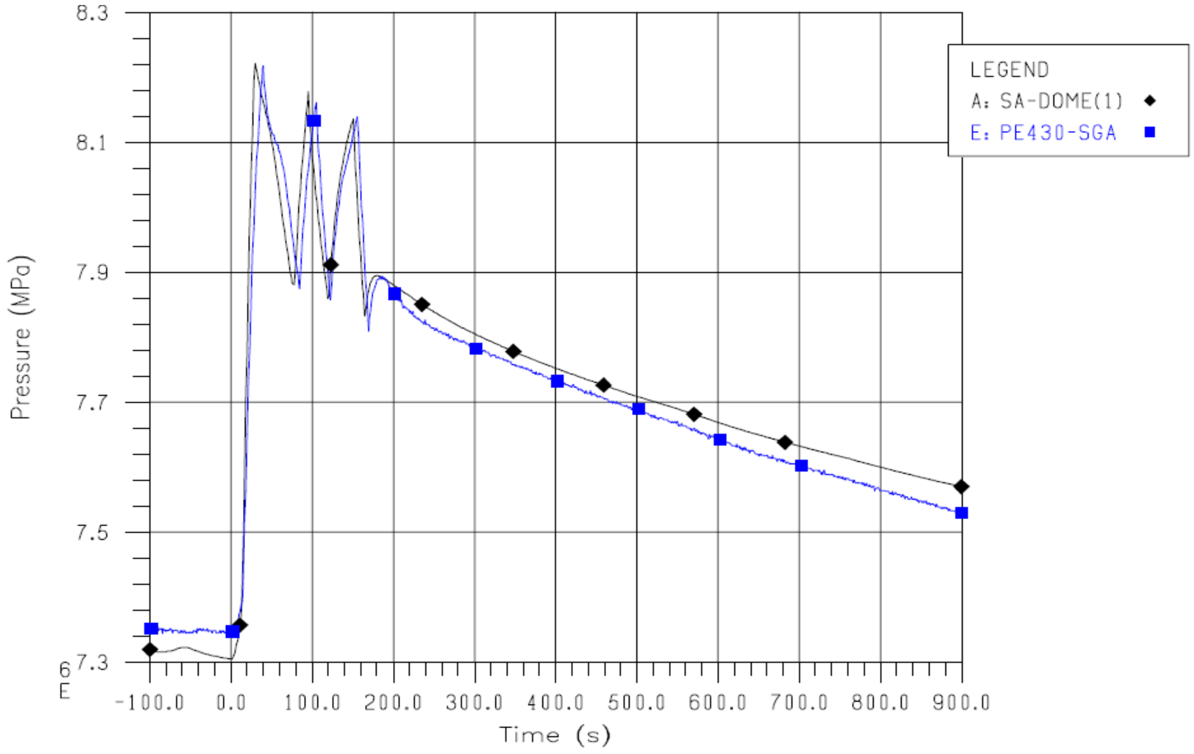
MATRIX II: CROSS REFERENCE MATRIX FOR SMALL AND INTERMEDIATE BREAKS IN PWRs		Test Type							Test Facility								
Test type vs. phenomenon + occurring o partially occurring - not occurring **Test facility vs. phenomenon** + suitable for code assessment o limited suitability - not suitable **Test type vs. test facility** + performed o performed but of limited use - not performed or planned		Stationary test addressing energy transport on primary side	Stationary test addressing energy transport on secondary side	Small leak overfeed by HPIS, secondary side necessary	Small leak without HPIS overfeeding, secondary side necessary	Intermediate leak, secondary side not necessary	Pressurizer leak	U-tube rupture	PWR 1:1	LOFT 1:50	LSTF 1:50	BETHSY 1:100	PKL-III 1:145	SPES 1:430	LOBI-II 1:712	SEMISCALE 1:1600	UPTF TRAM 1:1 (2)
Phenomena (3)	Natural circulation in 1-phase flow, primary side	+	+	+	o	-	+	+	+	+	+	+	+	+	+	+	-
	Natural circulation in 2-phase flow, primary side	+	-	o	+	+	o	-	-	+	+	+	+	+	+	+	o
	Reflux condenser mode and CCFL	+	-	-	+	+	-	-	-	o	+	+	o	o	o	o	+
	Asymmetric loop behavior	-	-	+	+	-	o	+	-	-	o	+	+	+	o	o	+
	Break flow	-	-	+	+	+	+	+	-	+	+	+	+	+	+	+	o
	Phase separation without mixture level formation	+	-	o	+	+	+	o	-	o	+	+	+	+	+	o	+
	Mixture level and entrainment in SG second side	-	+	+	+	+	+	+	-	-	+	+	+	o	o	-	-
	Mixture level and entrainment in the core	+	-	-	+	+	+	-	-	o	+	+	+	o	o	o	o
	Stratification in horizontal pipes	+	-	-	+	+	-	-	-	+	+	o	o	+	o	o	+
	Phase separation in T-junct. and effect on break flow	-	-	-	+	+	-	-	-	o	o	o	o	o	o	-	+
	ECC-mixing and condensation	-	-	o	+	+	+	+	-	o	o	o	o	o	o	o	+
	Loop seal clearing	-	-	-	+	+	o	-	-	+	+	+	+	+	+	+	+
	Pool formation in UP/CCFL (UCSP)	+	-	-	o	+	+	-	-	o	o	o	o	o	-	o	+
	Core wide void and flow distribution	+	-	-	o	+	+	-	-	o	o	o	o	-	-	-	o
	Heat transfer in covered core	+	+	+	+	+	+	+	o	+	+	+	+	+	+	+	-
	Heat transfer in partly uncovered core	+	-	-	o	+	-	-	-	+	+	+	+	o	o	o	-
	Heat transfer in SG primary side	+	o	o	+	+	o	o	-	o	+	+	+	+	+	o	-
	Heat transfer in SG secondary side	o	+	+	+	+	+	+	-	o	+	+	+	o	+	o	-
	Pressurizer thermohydraulics	o	-	o	o	+	+	+	o	o	o	o	o	o	o	-	+
	Surge line hydraulics	o	-	-	o	+	+	o	-	o	o	o	o	o	o	o	+
	1- and 2-phase pump behavior	-	-	-	o	+	-	-	o	o	o	o	o	o	+	+	-
	Structural heat and heat losses (1)	+	-	o	+	+	o	o	-	o	o	o	o	o	o	o	o
	Noncondensable gas effects	+	-	-	-	-	-	-	-	-	o	o	o	-	-	o	+
	Boron mixing and transport	+	-	+	+	+	+	+	-	-	-	-	-	-	-	-	o
Test Facility	PWR	-	-	o	-	-	+	+									
	LOFT	-	-	+	+	+	+	-									
	LSTF	+	+	+	+	+	+	+									
	BETHSY	+	+	+	+	+	+	+									
	PKL-III	+	+	+	+	+	+	+									
	SPES	+	+	+	+	-	-	-									
	LOBI-II	+	+	+	+	+	+	+									
	SEMISCALE	o	o	+	+	+	+	+									
	UPTF, TRAM	-	-	-	-	+	+	-									

(1) Problem for scaled test facilities
(2) UPTF integral tests
(3) For intermediate breaks phenomena included in large break reference matrix may be also important

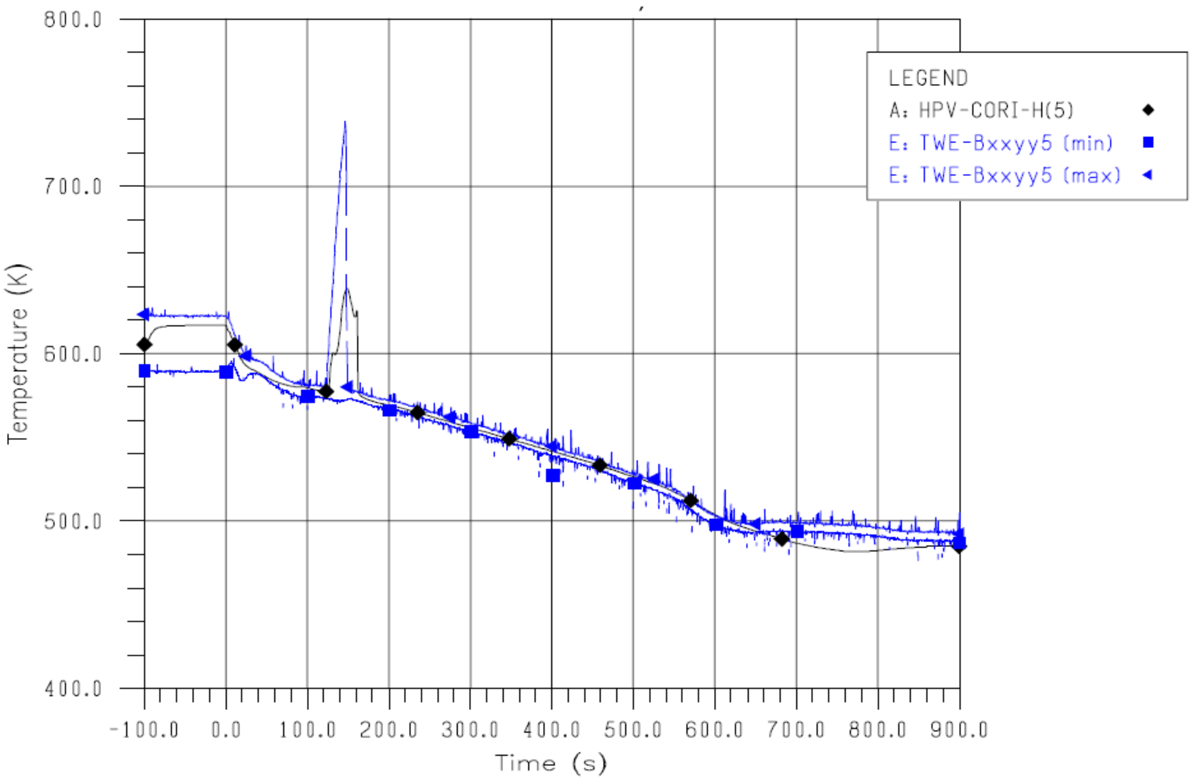
SB LOCA simulation – computer code (black curve) vs. experimental data (blue curve)



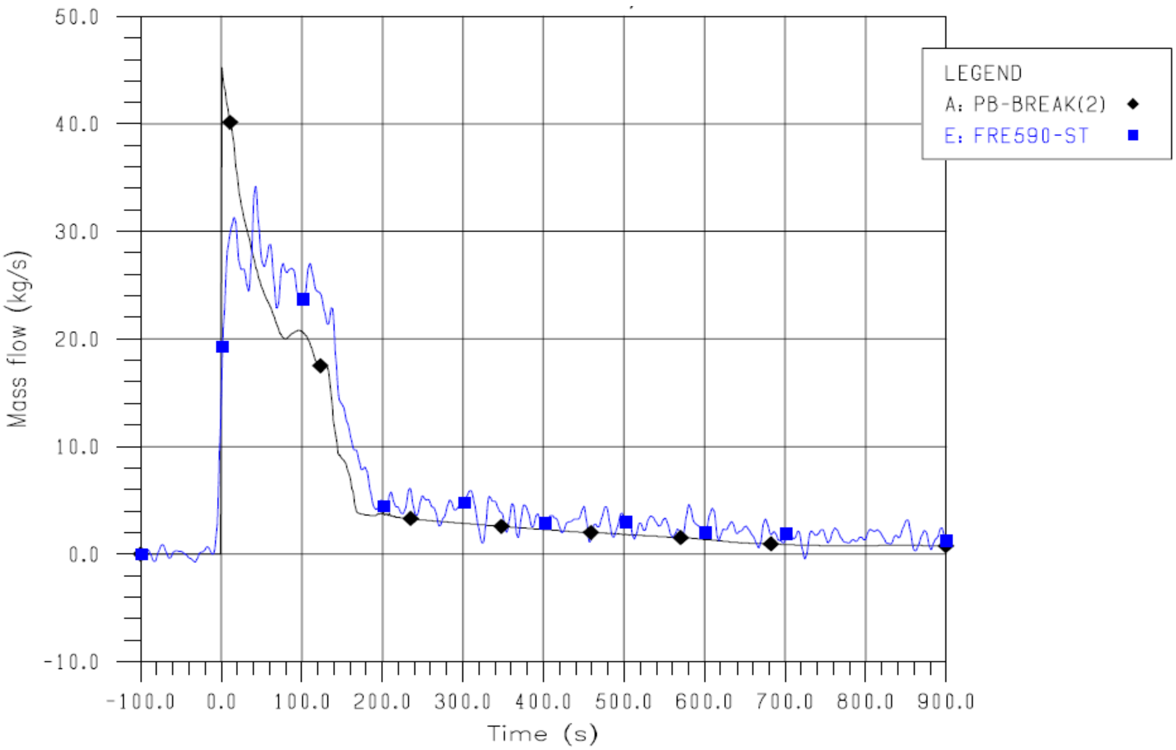
Primary pressure



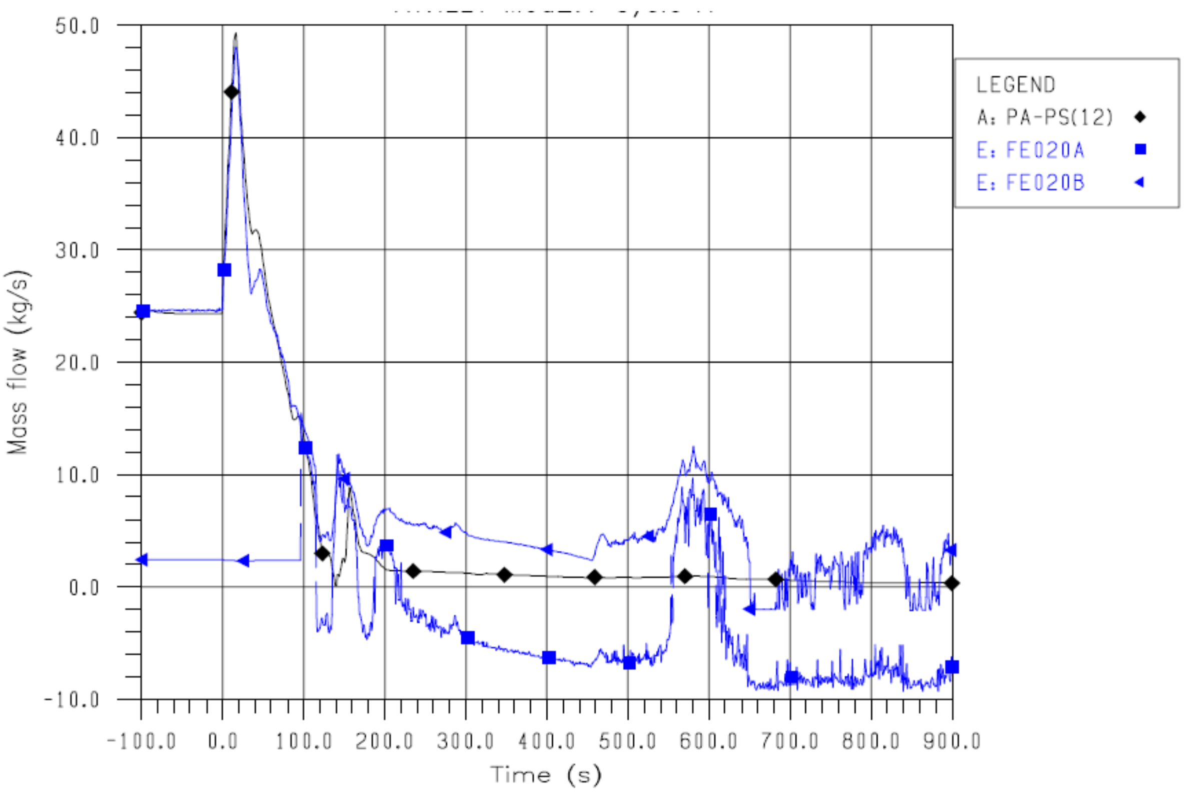
Secondary pressure



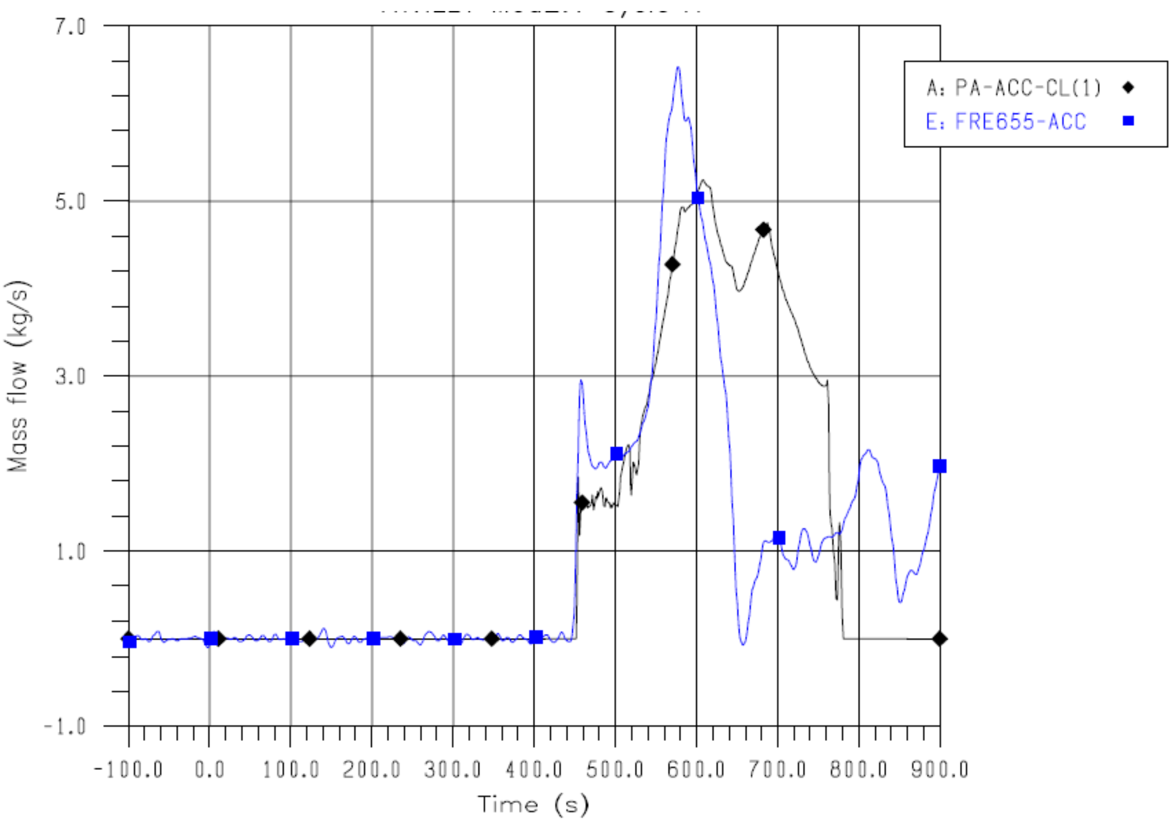
Cladding temperature



Break mass flow rate



Mass flow rate in intact loop

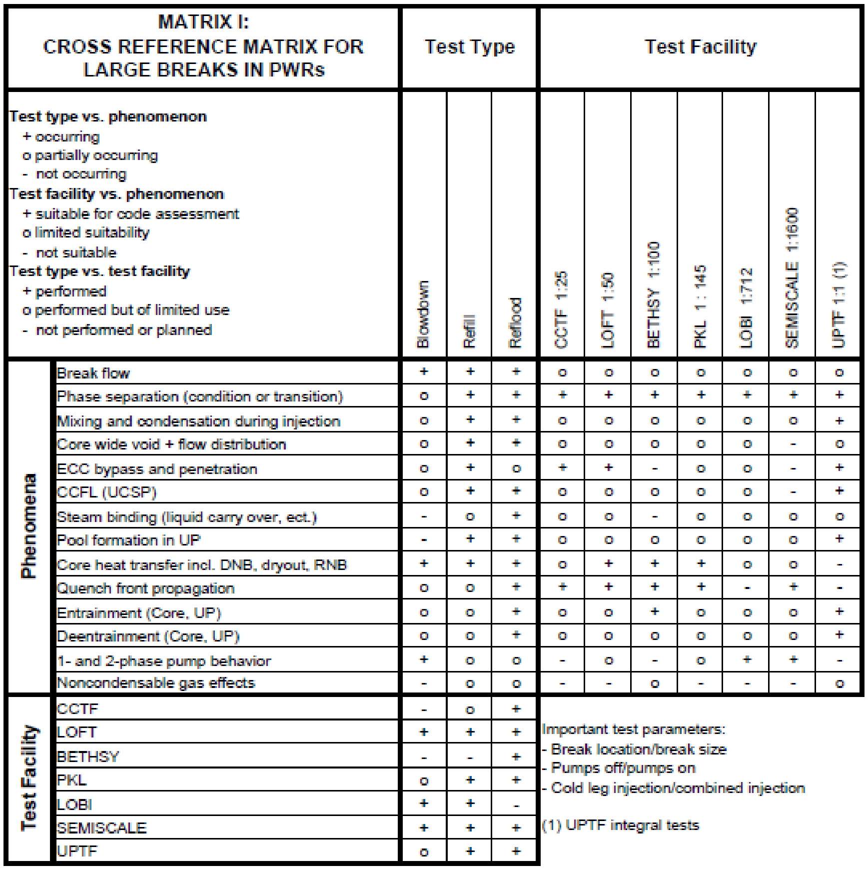


Accumulator injection

Example 2 – LB LOCA

After the accident initiation the system pressure rapidly drops to the saturation pressure of the hot core exit temperature of about 102 bar. Flashing initiates in the hot part of the primary system and the depressurization is slowed down. The reactor scrammed on indication of low pressure in the intact loop hot leg, the primary pumps were tripped and then decoupled from their flywheel, and the cladding temperatures deviate from saturation, all within 1 s. The primary system depressurized, and saturated fluid conditions were reached at 1 s in the broken loop hot leg and at 3.5 s in the broken loop cold leg. The maximum cladding temperature during blowdown, 1261 K, was reached at 13 s, and was followed by a slight decrease in temperature and then a gradual heatup which continued until 27 s, during the refill of the lower plenum. A top-down quench occurred in the upper third of the core starting at 13 s, which lasted until about 22 s, by which time the entire core had started to heat up. Around 30 s, a precursory cooling follows which gradually reduces the cladding temperatures. The core started to quench at 35 s, and was completely quenched at 72 s. The ECC injection initiated at 18 and 32 s from the accumulator and LPIS, respectively.

OECD/NEA Computer code validation matrix for LB LOCA

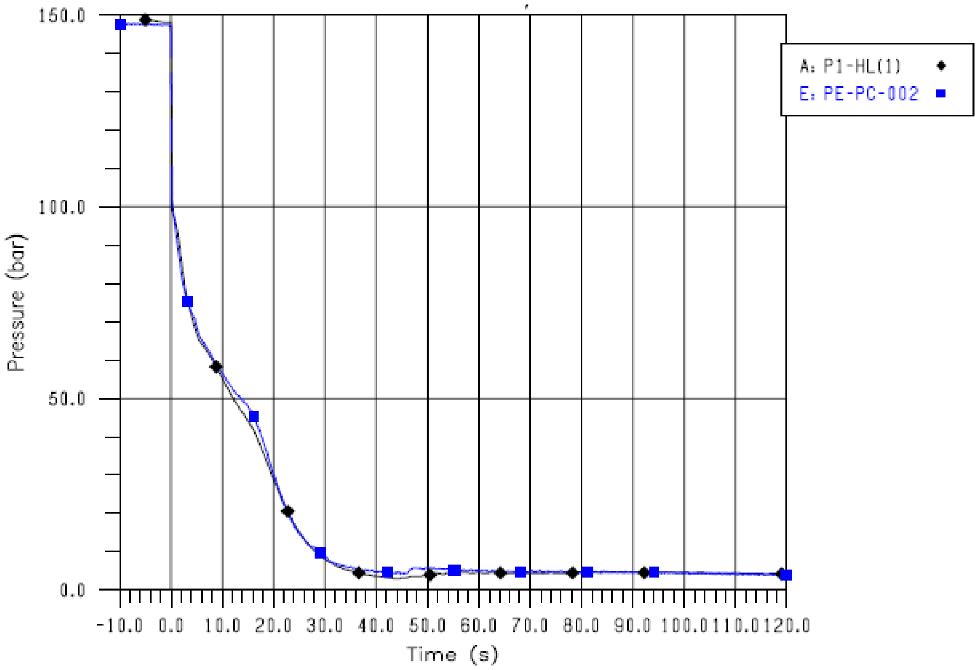


MATRIX I: CROSS REFERENCE MATRIX FOR LARGE BREAKS IN PWRs		Test Type			Test Facility						
Test type vs. phenomenon + occurring o partially occurring - not occurring **Test facility vs. phenomenon** + suitable for code assessment o limited suitability - not suitable **Test type vs. test facility** + performed o performed but of limited use - not performed or planned		Blowdown	Refill	Reflood	CCTF 1:25	LOFT 1:50	BETHSY 1:100	PKL 1 : 145	LOBI 1:712	SEMISCALE 1:1600	UPTF 1:1 (1)
Phenomena	Break flow	+	+	+	o	o	o	o	o	o	o
	Phase separation (condition or transition)	o	+	+	+	+	+	+	+	+	+
	Mixing and condensation during injection	o	+	+	o	o	o	o	o	o	+
	Core wide void + flow distribution	o	+	+	o	o	o	o	o	-	o
	ECC bypass and penetration	o	+	o	+	+	-	o	o	-	+
	CCFL (UCSP)	o	+	+	o	o	o	o	o	-	+
	Steam binding (liquid carry over, ect.)	-	o	+	o	o	-	o	o	o	o
	Pool formation in UP	-	+	+	o	o	o	o	o	o	+
	Core heat transfer incl. DNB, dryout, RNB	+	+	+	o	+	+	+	o	o	-
	Quench front propagation	o	o	+	+	+	+	+	-	+	-
	Entrainment (Core, UP)	o	o	+	o	o	+	o	o	o	+
	Deentrainment (Core, UP)	o	o	+	o	o	o	o	o	o	+
	1- and 2-phase pump behavior	+	o	o	-	o	-	o	+	+	-
	Noncondensable gas effects	-	o	o	-	-	o	-	-	-	o
Test Facility	CCTF	-	o	+							
	LOFT	+	+	+							
	BETHSY	-	-	+							
	PKL	o	+	+							
	LOBI	+	+	-							
	SEMISCALE	+	+	+							
	UPTF	o	+	+							

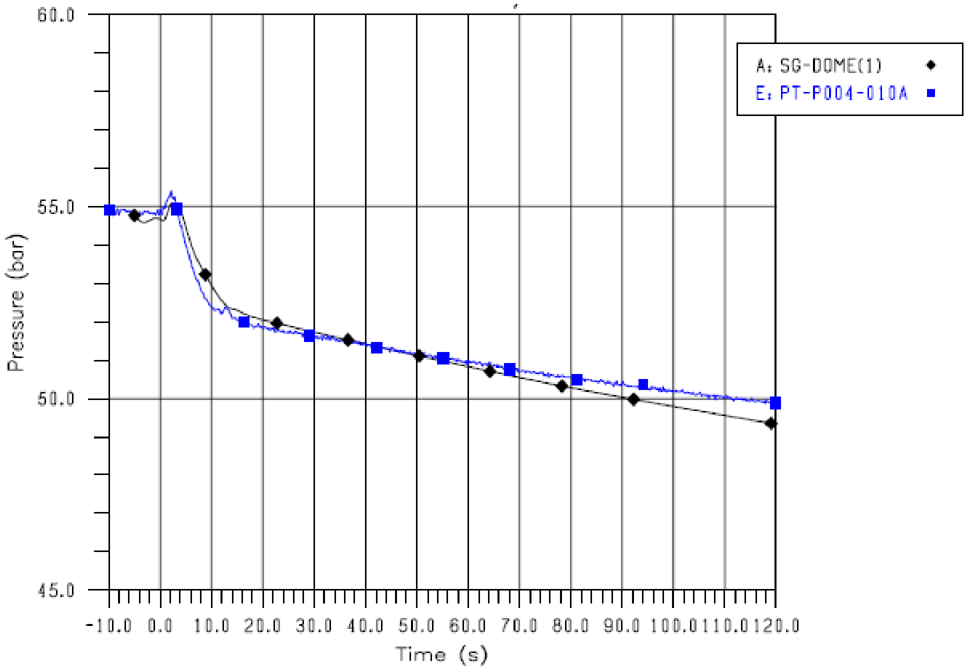
Important test parameters:
- Break location/break size
- Pumps off/pumps on
- Cold leg injection/combined injection

(1) UPTF integral tests

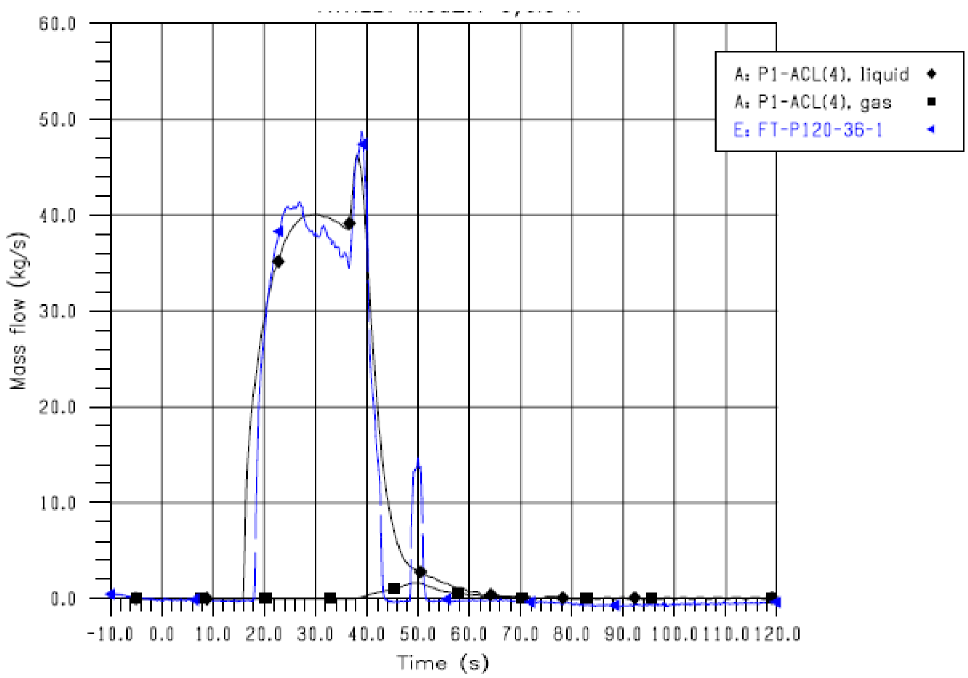
LB LOCA simulation – computer code (black curve) vs. experimental data (blue curve)



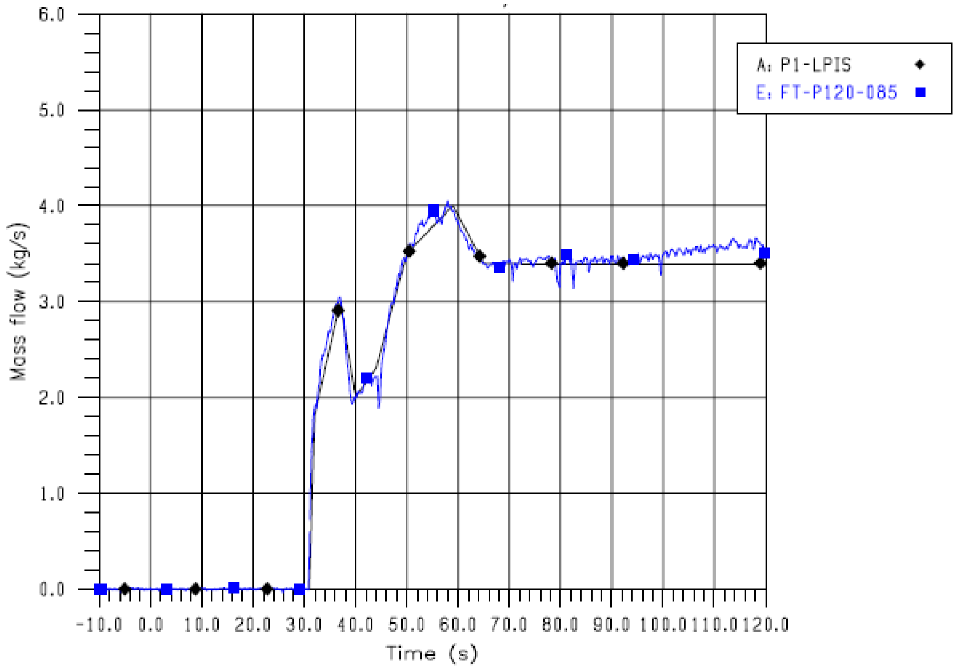
Primary pressure



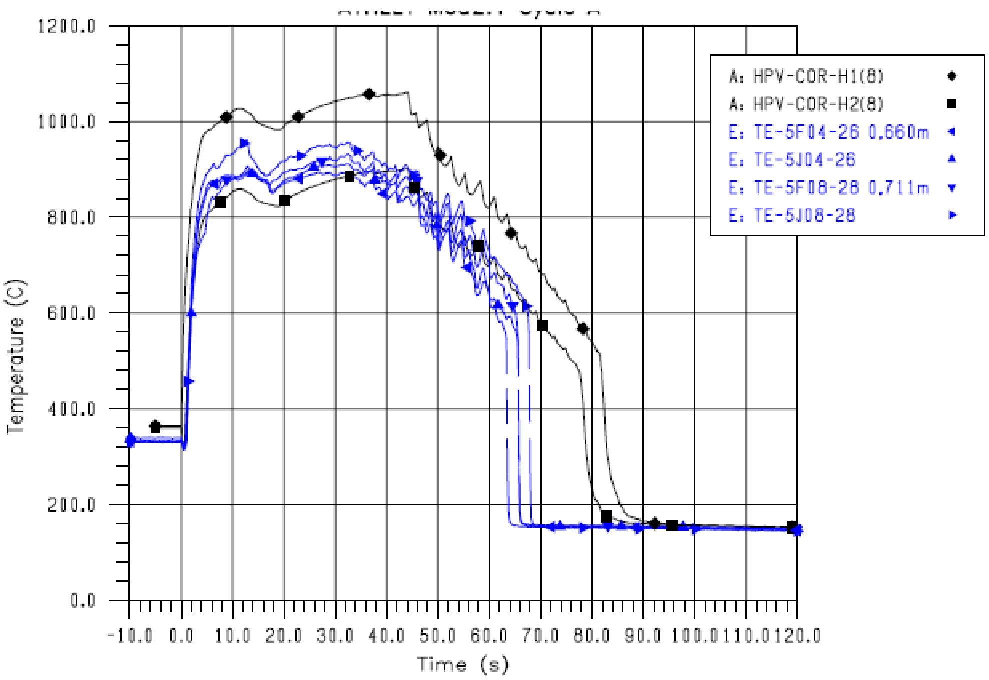
Secondary pressure



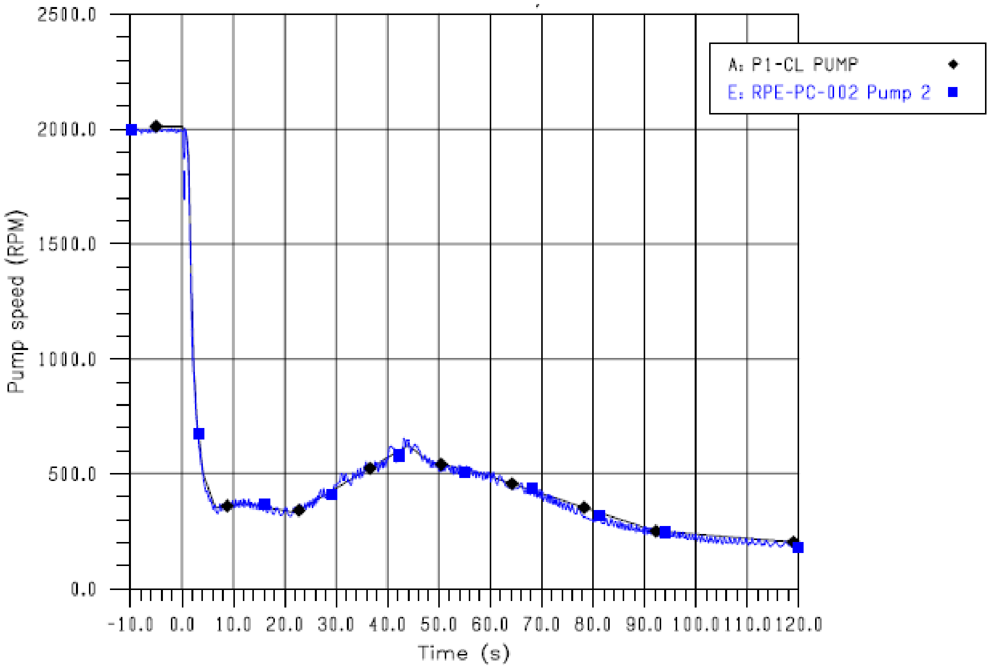
Accumulator injection



LPIS injection



Maximum cladding temperature



Speed of primary coolant pump