IAEA ICSP on MASLWR

IAEA ICSP on Integral PWR Design Natural Circulation Flow Stability and Thermo-hydraulic Coupling of Containment and Primary System during Accidents

Blind Calculation Results for SP-3 and SP-2

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Outline of the Presentation

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- ❑ Proposed Tests: SP3 and SP2
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- ❑ Conclusions SP3 test
- ❑ Simulation and results of SP3 test
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- ❑ Summary and queries

Introduction and objectives of ICSP

The ICSP has been started with the following main objective:

- **Natural circulation flow instability:** Conduct stepwise reduction in primary system coolant volumetric inventory at decay power in order to determine the effect of coolant volumetric inventory reduction on natural circulation flow rates in small integral PWRs.

- **Coupled Containment Pressurization:** Conduct a loss of feedwater transient with subsequent ADS blowdown and long term cooling to determine the progression of a loss of feedwater transient in small integral natural circulation PWRs. These tests would examine the ***blowdown phase*** as well as the ***coupling of the primary to containment systems*** and the ***long term cooling using sump natural circulation***. This data could be used for the analysis of system codes to determine if they model specific phenomena in an accurate manner.

Introduction and objectives of ICSP

The three workshops have been conducted with following agenda:

- First Workshop, 16-19 March 2010
  - Review of draft plan for ICSP.
  - Review of MASLWR test facility description report.
- 2nd Workshop: 21-23 March 2011, Vienna
  - Double blind calculation results presented and compared.
- 3rd Workshop: 26-30 March 2012, Daejeon
  - Blind calculation for SP3 and SP2 has been performed and results are submitted.
  - Results of blind calculation are being presented.

Specified Problems

IAEA ICSP has been proposed to conduct the following tests.

1. SP-1 : Stepwise reduction in primary system inventory at decay power.

These tests will determine the effect of coolant volumetric inventory reduction on natural circulation flow rates in small integral PWRs.

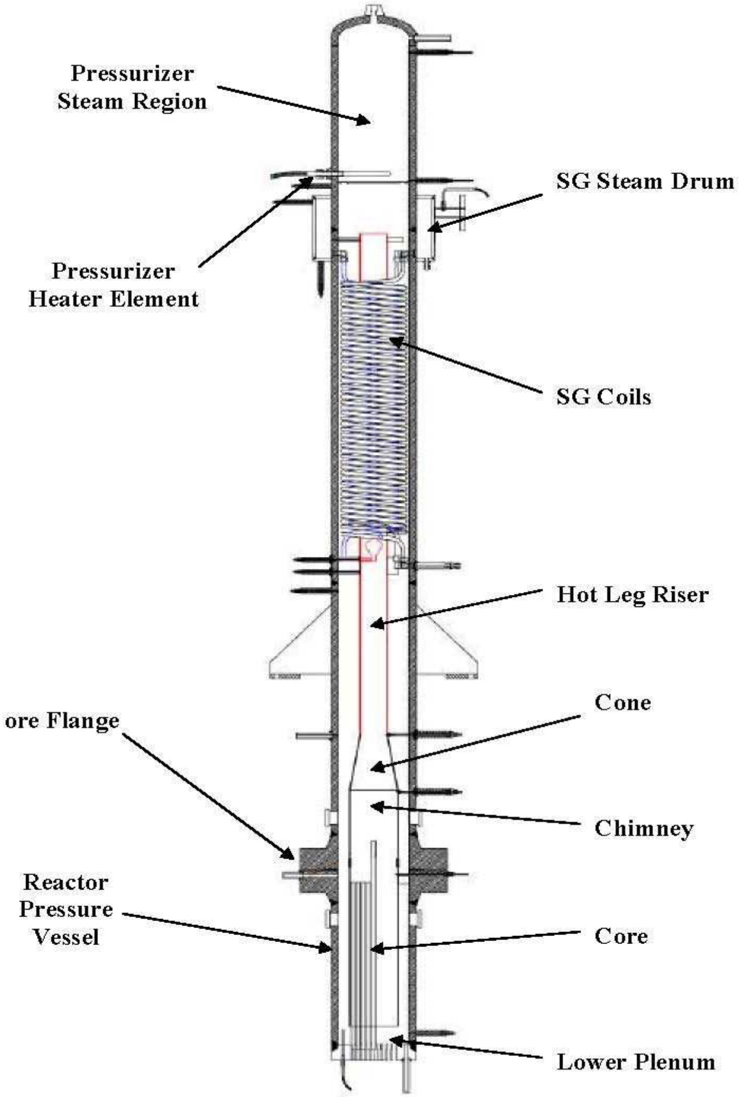
3. SP-3: Normal operating conditions at different power levels.

The test has been proposed as a substitute of SP1 test.

2. SP-2: Loss of feedwater transient with subsequent ADS blowdown and long term cooling.

These tests will determine the progression of a loss of feedwater transient in small integral natural circulation PWRs.

MASLWR Test Facility



OSU MASLWR Test Facility

- Oregon State University (OSU) has constructed a system-level test facility to examine natural circulation phenomena of importance to MASLWR. It is scaled at 1:3 length scale, 1:254 volume scale and 1:1 time scale.
- Experiments on the steady state performance and accidental scenarios to be performed in this test facility.
- The data generated by the testing program is proposed to be used to assess computer code calculations and to provide a better understanding of the thermal-hydraulic phenomenon related to integral type of reactors.

Analysis Methodology

Two system codes are used for the simulation of the thermal hydraulics phenomena in the integral facility :

- RELAP5 M3.2
- CATHARE 2 V2.5_1 used for SP-3 transient only, SP-2 transient could not be simulated.

REALP5 M3.2

- RELAP5/MOD3.2 is one of the best estimate codes to simulate the thermal-hydraulics of nuclear reactors.
- The computer code adopts finite differencing cells to describe the hydrodynamics of the system.
- Two-fluid model is utilized to describe the transfer phenomenon of mass, momentum and energy.
- Six differential equations for mass, momentum and energy conservation for the two phases, i.e. water and vapor are solved for each fluid cell.
- The governing equations are solved by utilizing partial implicit scheme.

CATHARE 2 V2.5_1

- CATHARE code solves the two fluid model equations using a completely implicit numerical method.
- Constitutive models for simulating the mass, energy and momentum exchanges between the liquid and vapor, and between the two phases and the walls, are incorporated in the code.
- CATHARE code is well suited for PWR transient and safety analysis.
- The code is used in a large range of applications: Western PWR and WWER, BWR, RBMK, Fusion reactor, Gas Cooled Reactors and Full Scope Plant Simulator.

RELAP5/M3.2 model for OSU MASLWR Test Facility

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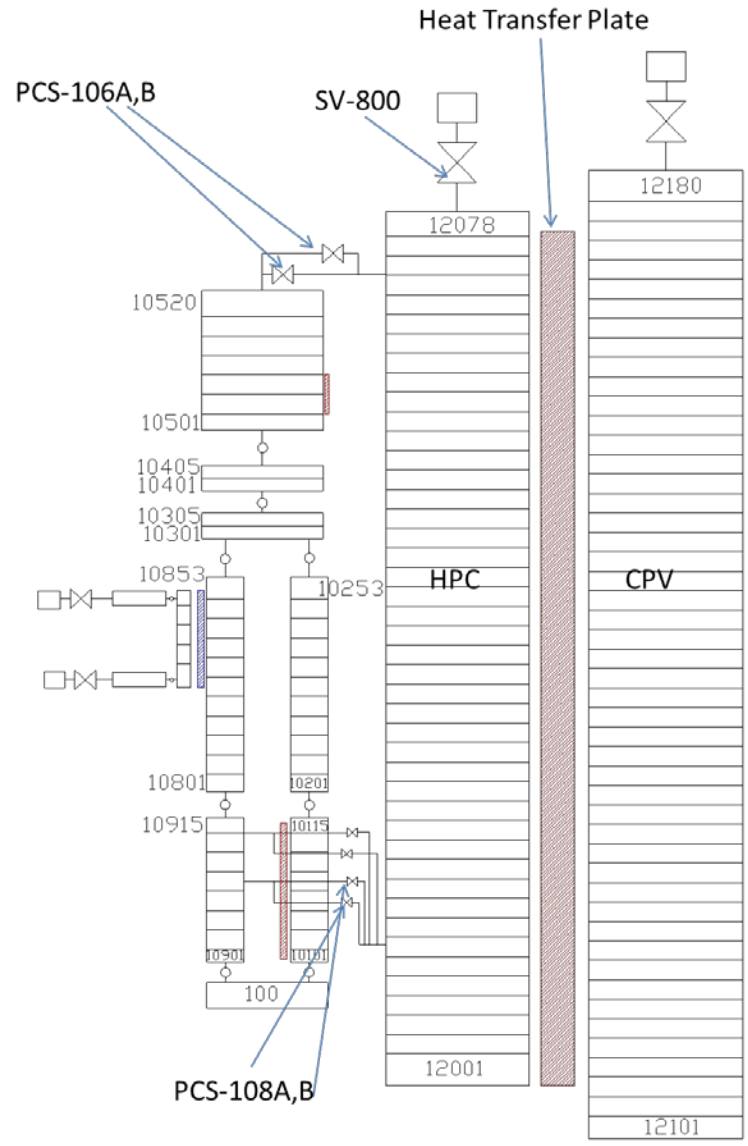
SALIENT Features of the Nodalisation

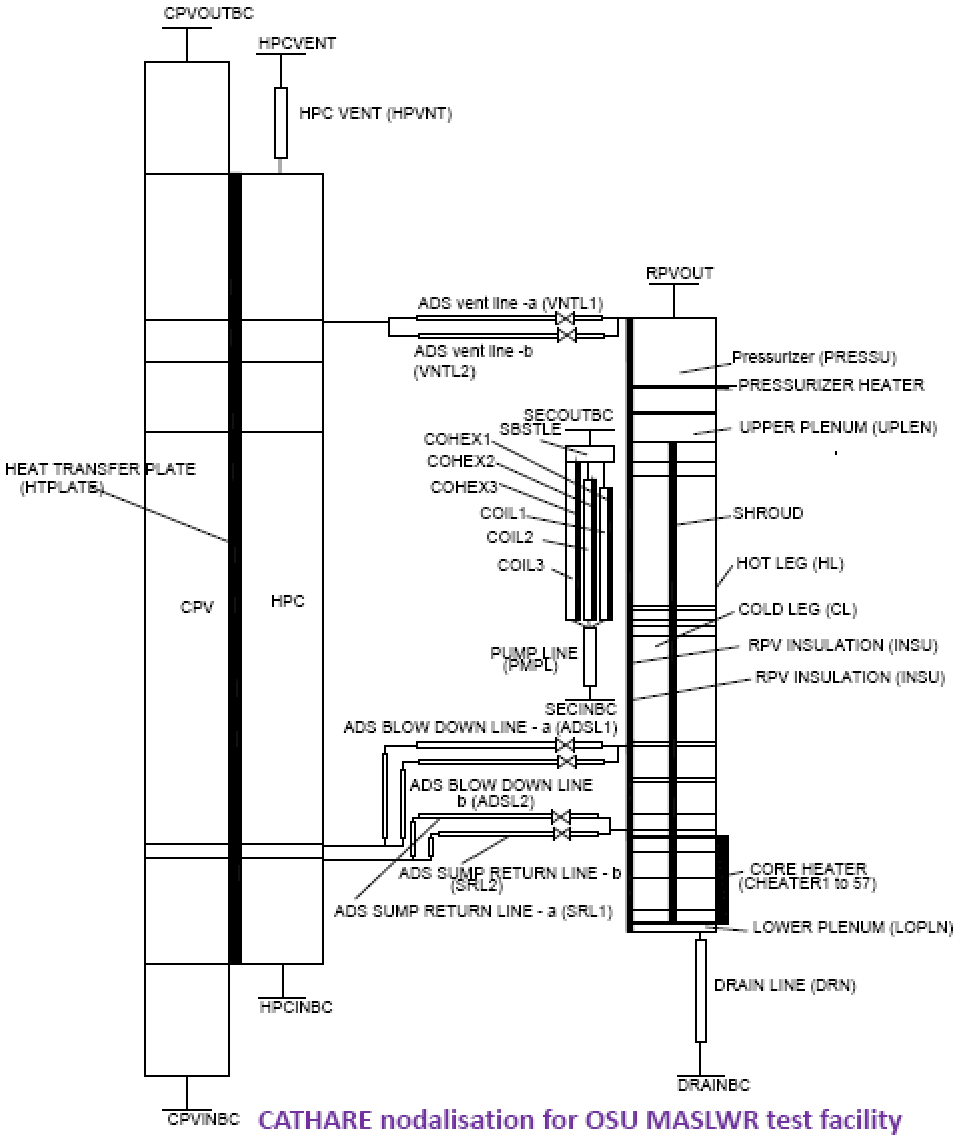
- The valves are modeled as trip valve with instant opening and closing.
- Abrupt area change model has been employed for loss coefficients.

ASSUMPTIONS

- Heat loss from HPC and CPV to the atmosphere is neglected.
- The helical coil of SG is modeled as single pipe volume with same flow area and 50% more heat transfer area.
- Secondary mass flow rate is calculated by heat balance to obtain the required superheat with net primary power i.e. core power – heat loss.
- Heat loss from the RPV is modelled and heat transfer coefficient is taken as 1 W/m^{2}K upto 293K and 2.5 W/m^{2}K above this.



CATHARE Model for OSU MASLWR Test Facility



CATHARE nodalisation for OSU MASLWR test facility

SALIENT features of the nodalisation

- The RPV, HPC, CPV, ADS vent lines, ADS blow down and sump return lines are modelled as circuit of hydrodynamic volumes.
- The Heat loss from RPV is modelled using heat structure with thermal properties of insulation.
- The core heaters are simulated using heat structure with internal heat generation.
- The heat exchange between the RPV and SG coils (3 numbers), RPV hot leg and cold leg, HPC and CPV is modelled using heat exchanger model.
- The helical coil of SG is modeled as single pipe volume with same flow area and double heat transfer area.
- The form loss coefficients are applied at the appropriate junctions in the model. The loss coefficients were calculated from standard correlations for abrupt area change.

Modeling details

- What nodalization strategies have been used, if any, in model development?

  One D model has been formulated.

- Have any 2/3D component been used to model any of the following components? if so, describe:
  - RPV
  - HPC
  - CPV

  No

- How have the following components been modeled—separately or lumped in N pipes?
  - core channels
  - helical coil tubes

  lumped

- Have the following components been modeled? if so, describe:
  - PRZ heaters **yes**
  - HPC heaters No
  - steam line **No**
  - feed water lines **No**

Modeling details

- Have the following components been modeled separately?
  - blowdown lines — yes
  - two vent lines — yes
  - two sump recirculation lines — yes
- Has the insulation on any of the following components been modeled? If so, describe:
  - RPV — yes
  - HPC — adiabatic
  - CPV — adiabatic
  - ADS lines — adiabatic
- Has the heat loss from the following components been simulated? If so, please describe:
  - RPV — yes
  - HPC — adiabatic
  - CPV — adiabatic
  - ADS lines — adiabatic
- Describe specific models used for the following phenomena:
  - heat transfer in the helical coils — RELAP default madel
  - condensation in the HPC — Default model of RELAP

Modeling details

Has you model been checked against available characterization data such as height versus volume and the heat structure mass?

No

Are there any differences between the SP-2 and SP-3 models? If so, describe.

No

Are there any changes in model or methodology between blind and double blind calculation results? If so, describe.

In blind calculations the actual initial and boundary conditions have been applied and procedure of the tests are not followed which was followed in double blind calculations.

Description of SP-3 Transient

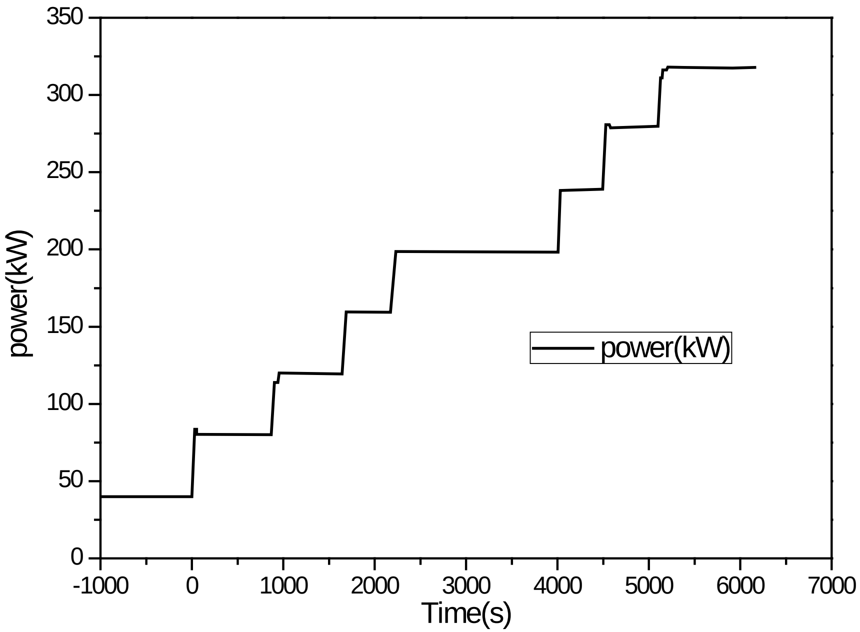
Objective: *Run the OSU-MASLWR test facility at normal operating conditions as a substitute for SP-1 , step wise reduction in primary system volume at decay power.*

The sequence of events considered is:

- At time t < 0 s, OSU MASLWR test facility is operating at steady state with constant core power of 40 kW, RPV pressure 1250 psig (8.618 MPa gage). Secondary system operating with steam pressure of 200 psig (1.379 MPa gage) and inlet flow rate maintained to remove net primary heat (core power-heat loss from RPV). Pressurizer heater is operating in automatic mode to maintain the RPV pressure. The level in pressurizer at steady state is 14” (0.3556 m).
- After achieving the steady state the power has been varied in a step of 10%FP.
- The feed water temperature and flow rate has been varied to achieve the steady state at higher power and to keep the saturated conditions at secondary side outlet and maintaining at least 8.33^{0}C subcooling at core outlet.

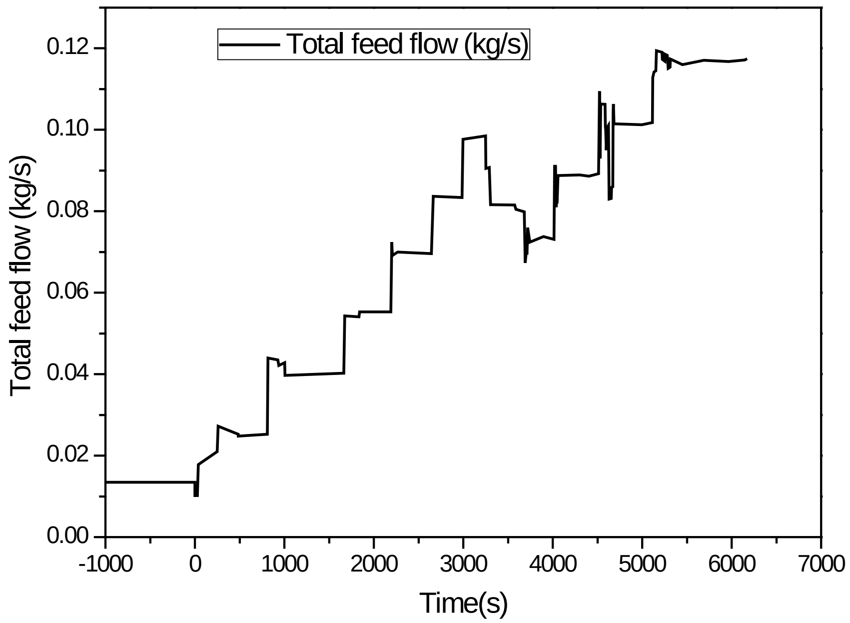
Boundary conditions for SP-3 Transient

- Power, feed water flow and feed water temperature has been varied as per the experiment carried out.

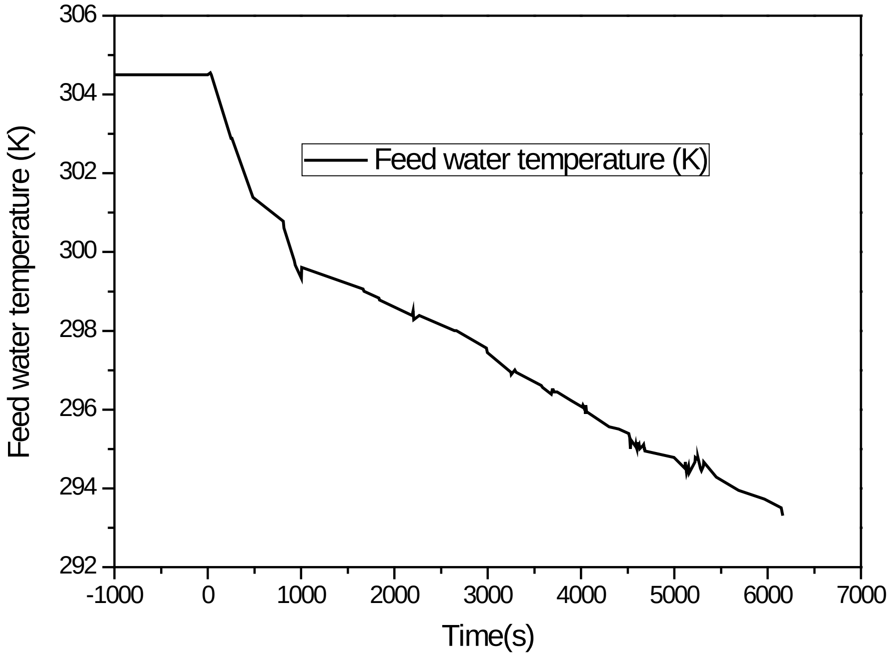


Input Power variation

Boundary conditions for SP-3 Transient



Feed water flow rate

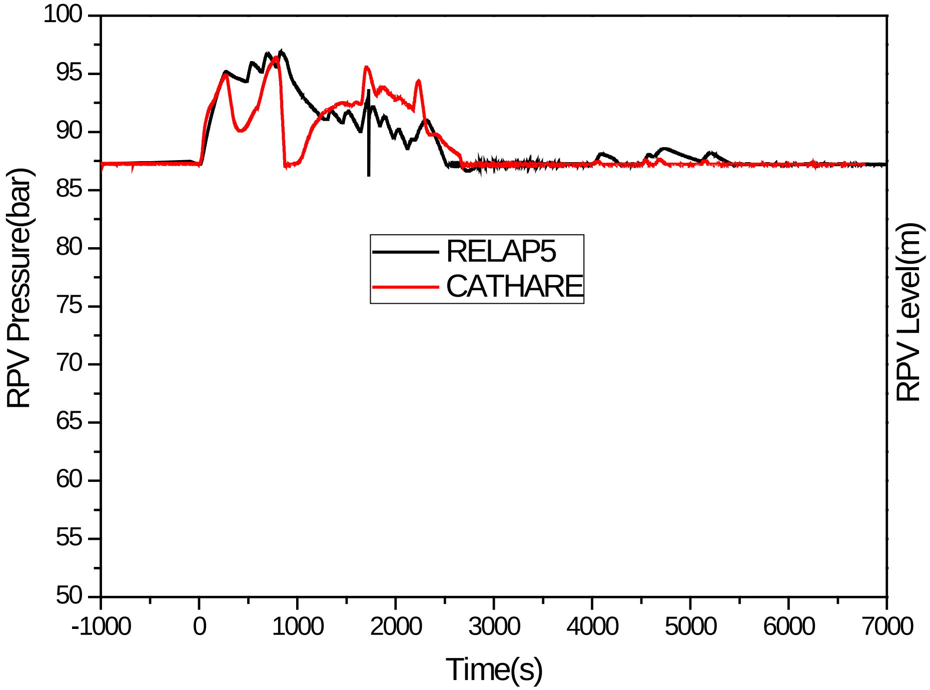


Feed water Temperature variation

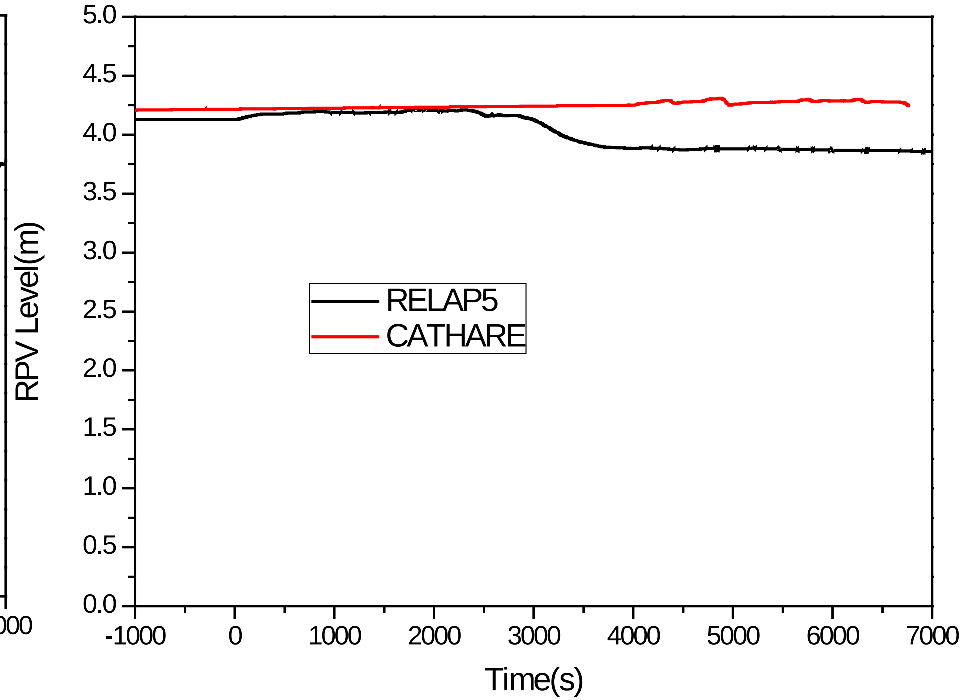
Steady state values SP-3

Parameter	MASLWR	Unit	Experimental Value	Steady-State Value from RELAP5	Steady-State Value from CATHARE
Pressurizer pressure	PT-301	MPa(a)	8.719	8.719	8.723
Pressurizer level	LDP-301	m	0.3574	0.330	0.4833
Power to core heater rods	KW-101/102	kW	40	40	40.0
Feedwater temperature	TF-501	ºC	30.5	30.5	31.49
Steam temperature (average)		ºC	255.0	261.9	255.0 to 257.0 fluctuating
Steam pressure	FVM-602-P	MPa(a)	1.446	1.446	1.464
Ambient air temperature		ºC		27	30
Primary flow at core outlet	FDP-131	kg/s		0.63458	0.6024
Primary coolant temperature at core inlet	TF-121/122/123/124	ºC	250.0	258.9	256.6
Primary coolant temperature at core outlet	TF-106	ºC	262.76	270.8	269.5
Feedwater flow	FMM-501	kg/s		0.01365	0.0134
Steam flow	FVM-602-M	kg/s		0.01365	0.0134
Primary coolant subcooling at core outlet		ºC		30.27	31.57
Total heat loss through primary system		kW		1.6	0.989
Heat transfer through SG		kW		38.0	37.73
Maximum surface temperature of core heater rods		ºC		320.0	286.86
Location from the SG secondary inlet to reach - saturation - superheat		m		0.4 m for saturation, 2.45 m for superheat	0.38 m for saturation, 2.4478 m for superheat

Results for SP-3 Transient



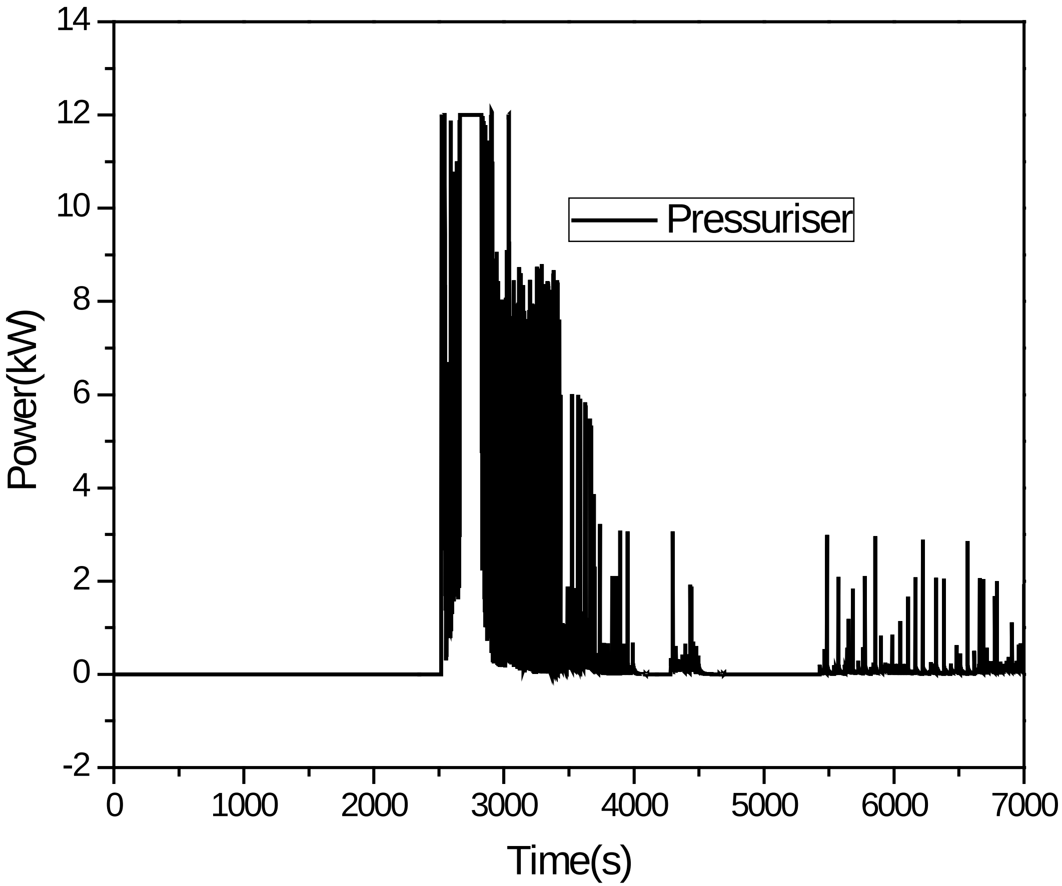
RPV Pressure



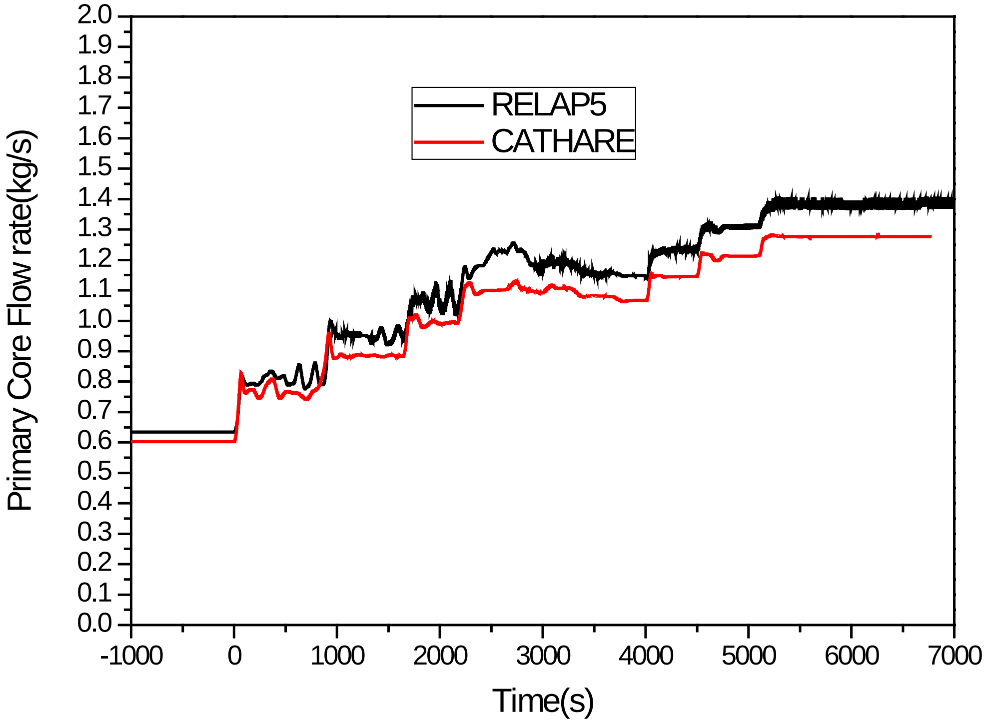
RPV Level

RPV pressure variation is same there are differences in the predicted RPV level by the two codes.

Results for SP-3 Transient



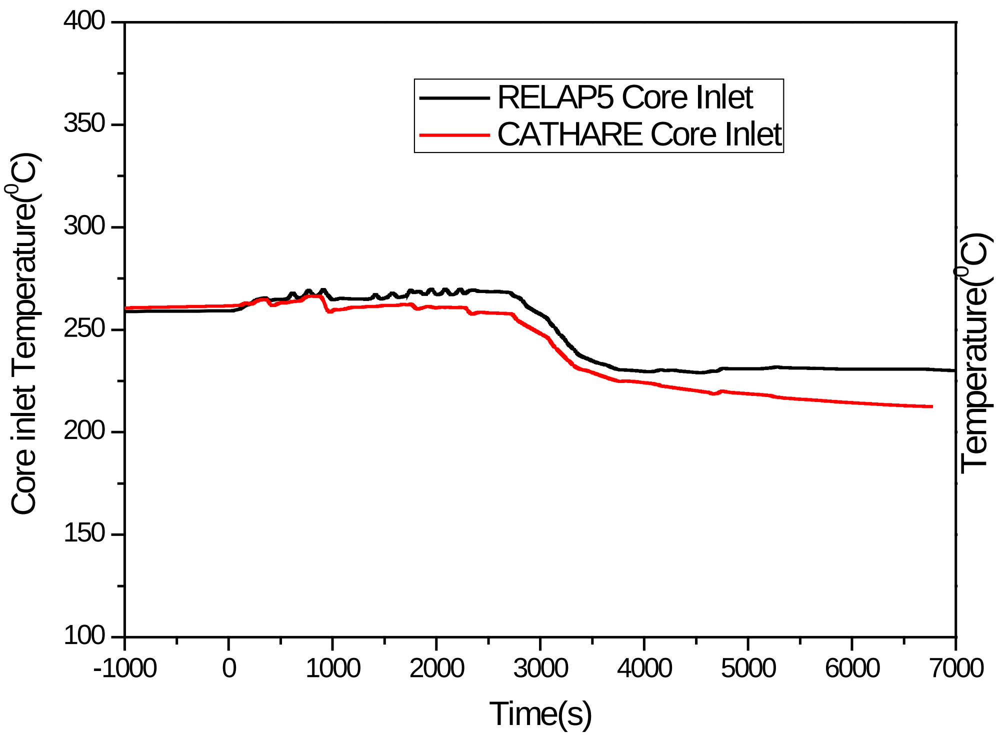
Results for SP-3 Transient



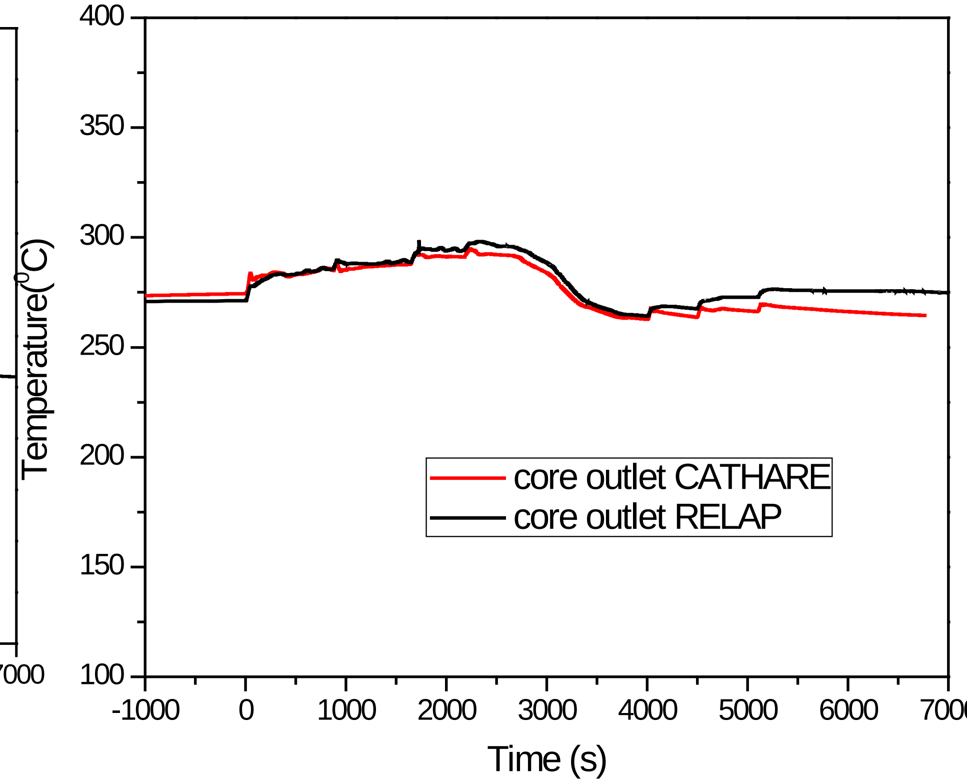
Primary flow rate

Qualitative as well as quantitative variation of primary flow rate is same as predicted by the two codes.

Results for SP-3 Transient



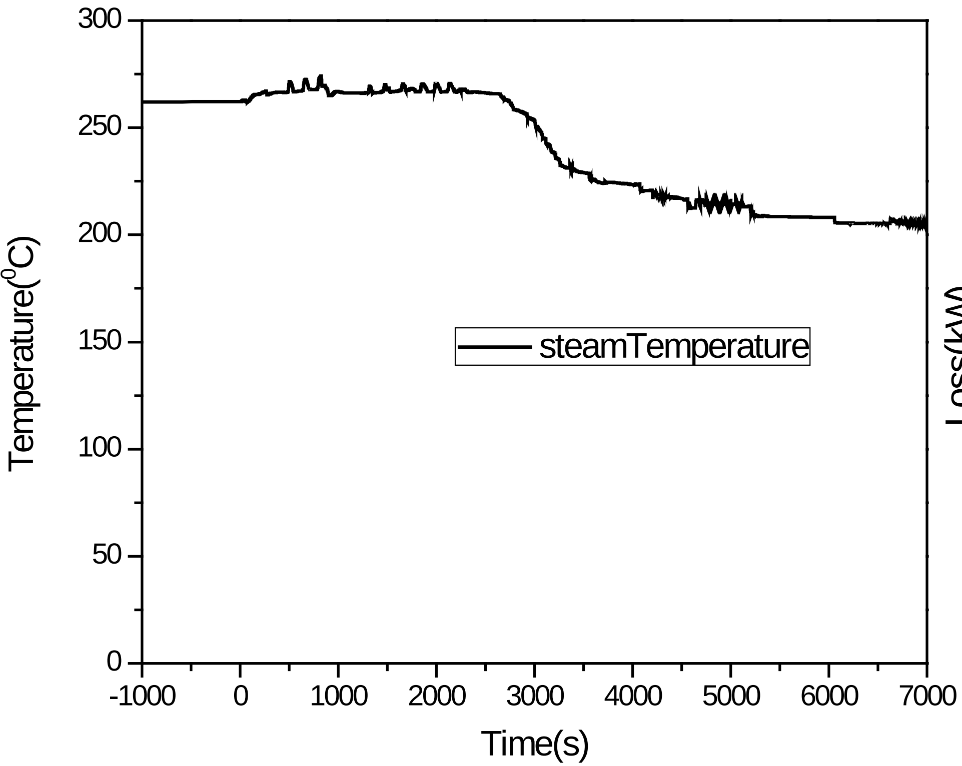
Core inlet Temperature



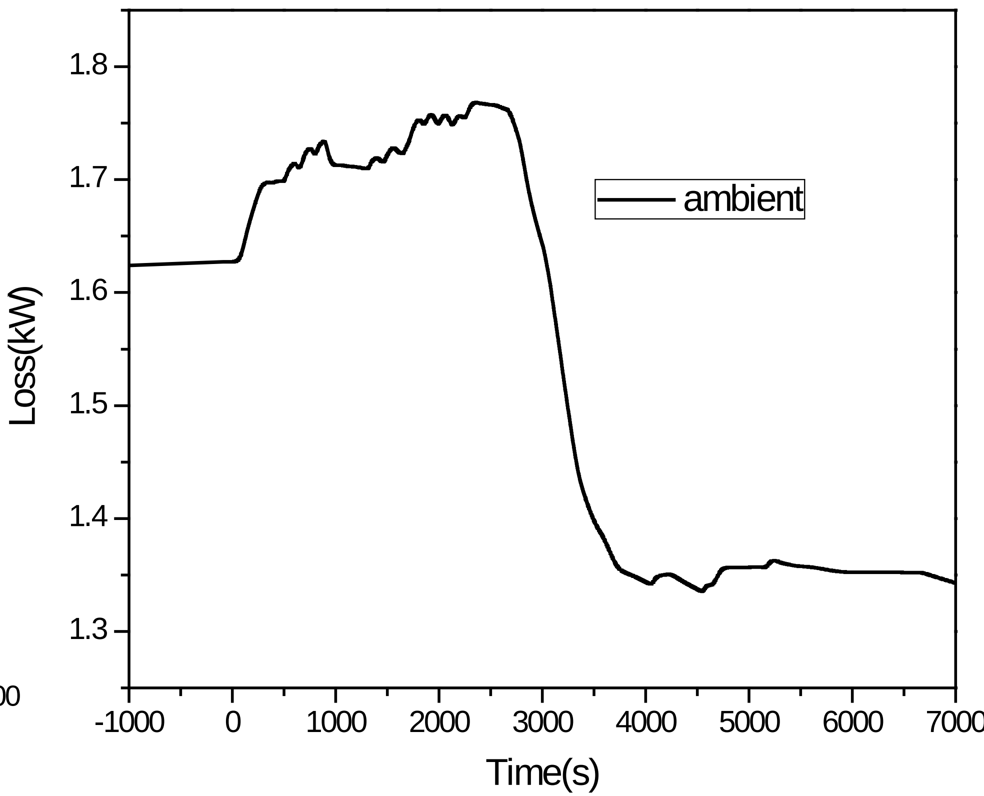
Core outlet Temperature

Variation of core inlet and outlet Temperature is same as predicted by the two codes.

Results for SP-3 Transient

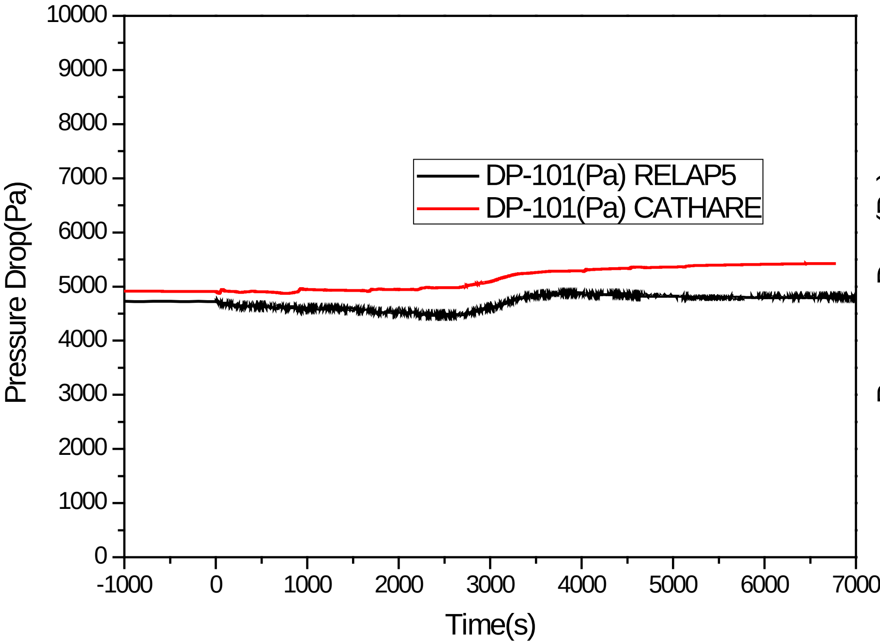


SG outlet Temperature

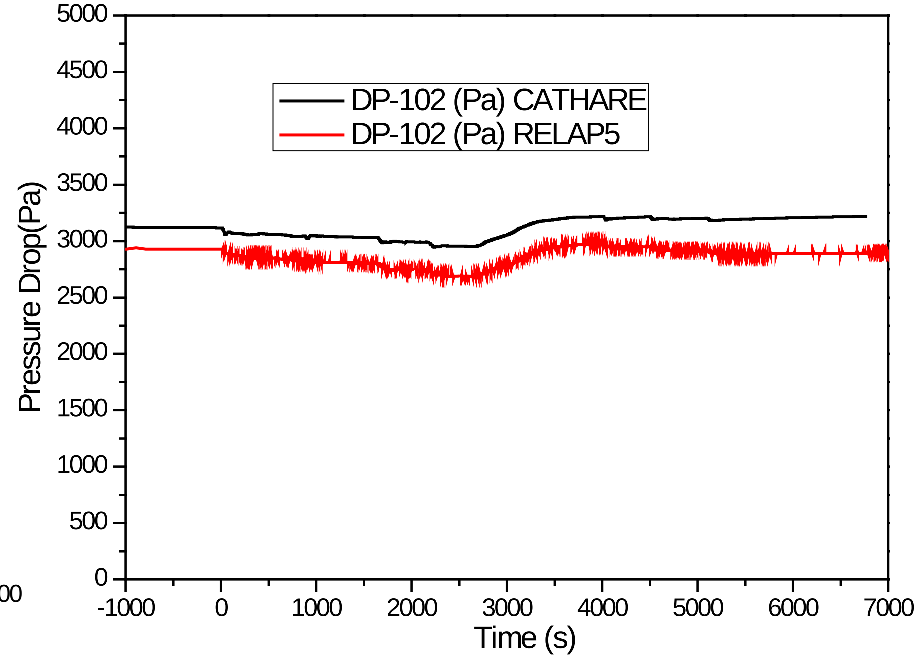


Loss from the RPV

Results for SP-3 Transient



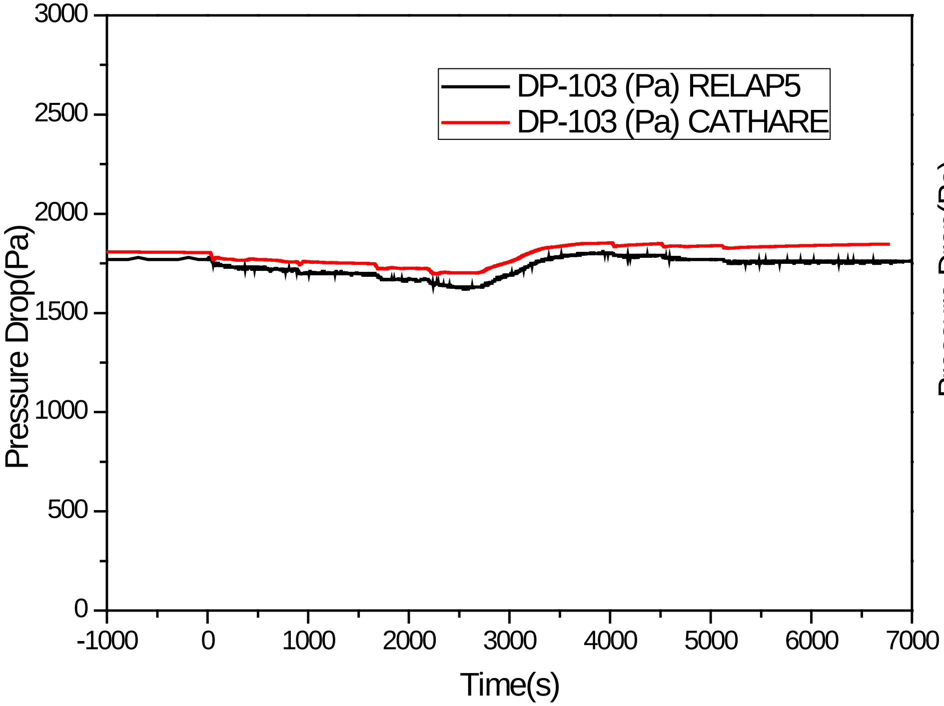
Pressure drop across the core



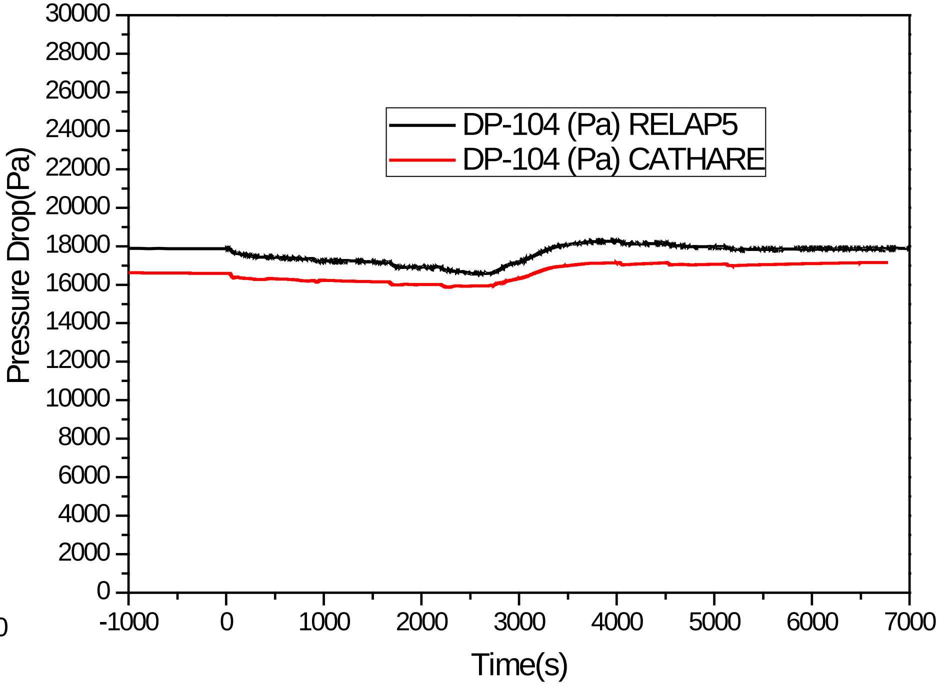
Pressure drop across the chimney

Similar trends are obtained for the pressure drop with the two codes. Approximately 4% variation is there in the predictions of the RELAP and CATHARE.

Results for SP-3 Transient

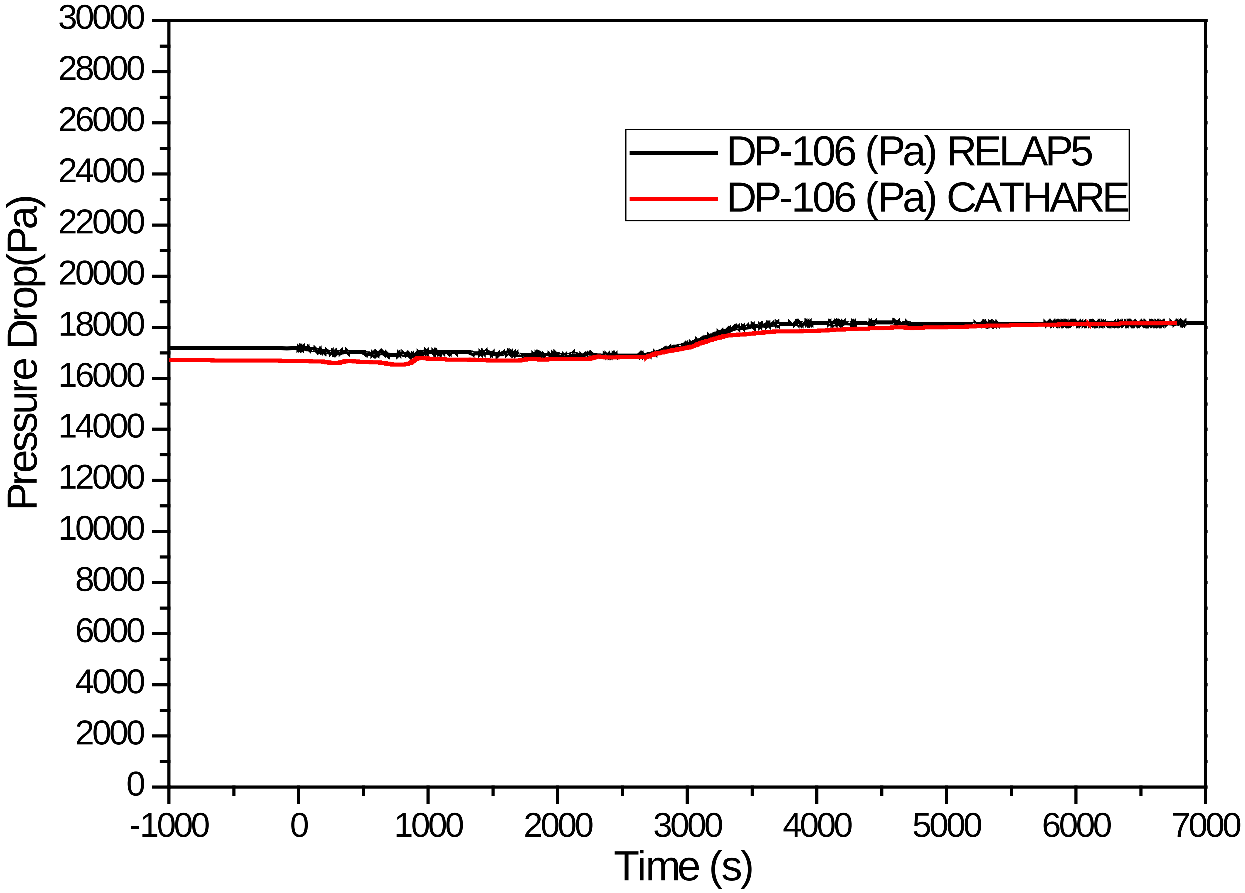


Pressure drop across the riser cone



Pressure drop riser cone top to RPV top

Results for SP-3 Transient



Pressure drop across the Downcomer

Conclusions SP-3

- Initial steady state flow and RPV temperatures predicted by both the codes are in close agreement when compared to that given in SP-3 Specification. However, the initial deviation during steady state itself has propagated in the whole transient.

- In general both the codes predict similar trends. The ratio of the quantitative results predicted by the two codes is maintained throughout the transient.

Description of SP-2 Transient

Objective: To analyze **loss of feedwater transient** with subsequent automatic depressurization system **(ADS) actuation** and **long term cooling** to determine the progression of a loss of feedwater transient in the MASLWR test facility.

- At time t<0 s, OSU MASLWR test facility is operating at steady state with constant core power of 298 kW, RPV pressure = 1250 psig (8.618 MPa gage). Secondary system operating with steam pressure of 200 psig (1.379 MPa gage) and inlet flow rate maintained to remove net primary heat (core power - heat loss from RPV). Pressurizer heater is operating in automatic mode to maintain the RPV pressure. The RPV level in pressurizer at steady state is 14” (0.3556 m).

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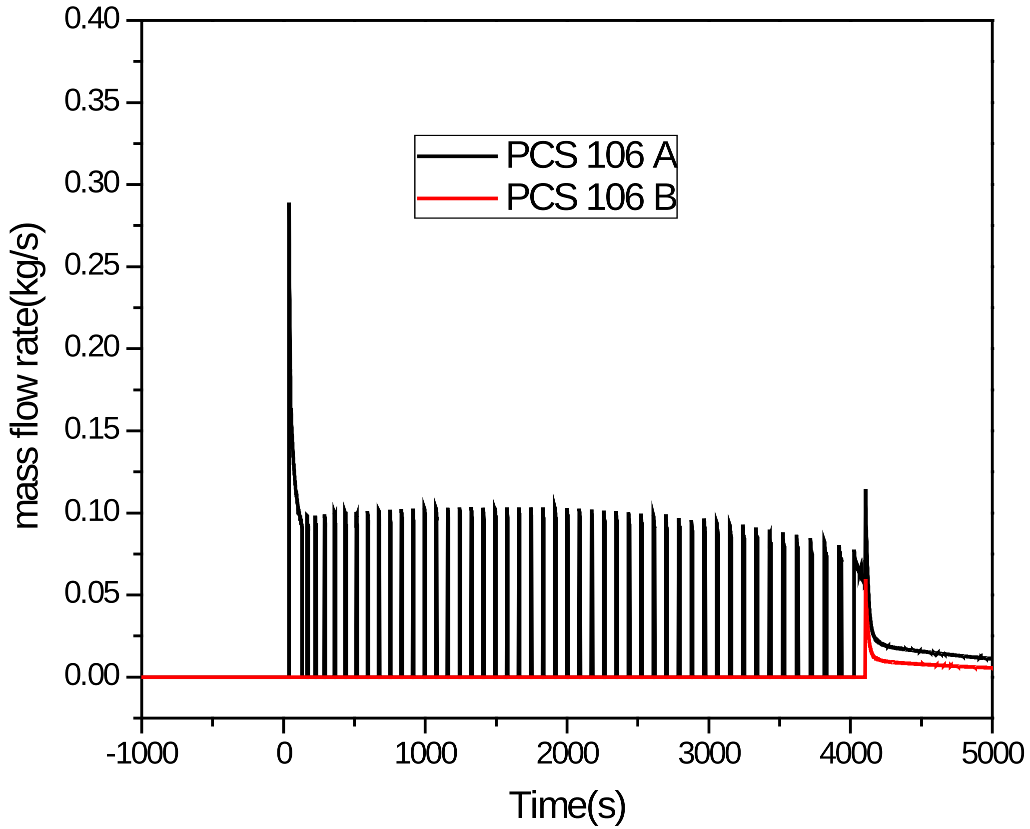
Description of SP-2 Transient

Event	Time (s)
Start of simulation – steady state (start of data collection)	-20000s
Stop MFP Close HPC vent valve SV-800	0.0s
PZR pressure (PT-301) reaches 9.064 MPa(a) (1300 psig) Enter decay power mode	22s
PZR pressure (PT-301) reaches 9.409 MPa(a) (1350 psig) De-energize PZR heaters Open ADS vent valve (PCS-106A)	55s
Record opening and closing times for PCS-106A	
Record opening and closing times for SV-800	Not opened
Start long-term cooling when pressure difference between primary system and HPC (PT-301 minus PT-801) becomes less than 5 psi (0.034 MPa) Open and remain open of PCS-106A and PCS-106B Open and remain open of PCS-108A and PCS-108B	 4024s,4114s 4116s,4117s
End of test when one of the following conditions is reached: - PZR pressure ≤ 0.135 MPa(a) (5 psig) - Primary coolant temperature (TF-132) ≤ 35 ºC (95 ºF) - 24 hours have elapsed	30000s

Steady state values SP-2

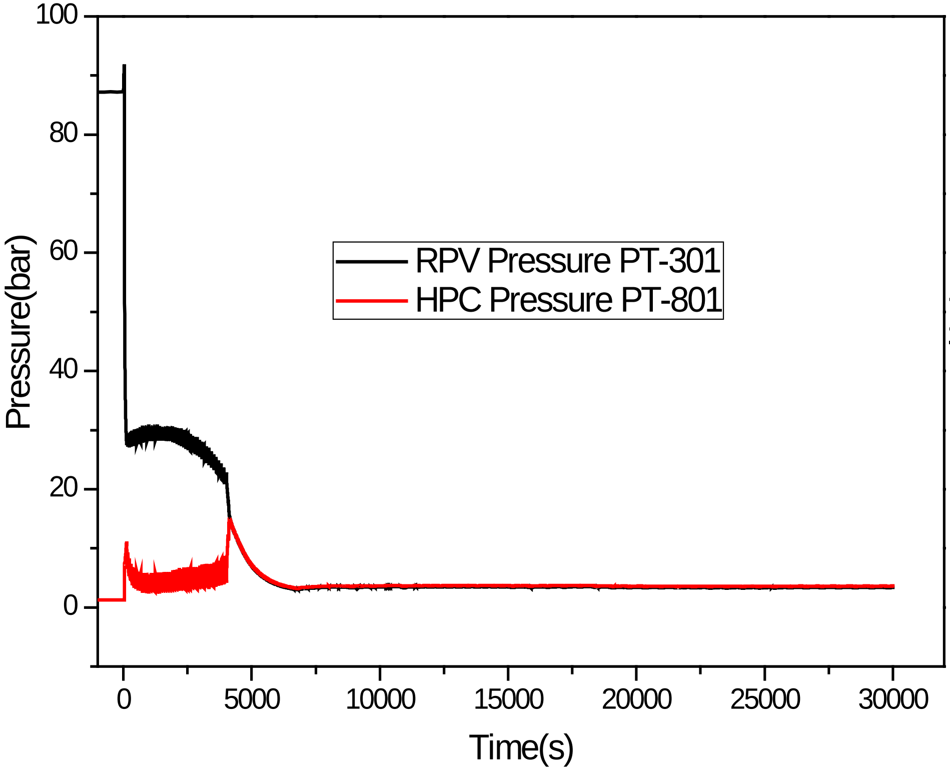
Parameter	MASLWR	Unit	Experimental Value	Steady-State Value from Code
Pressurizer pressure	PT-301	MPa(a)	8.719	8.719
Pressurizer level	LDP-301	m	0.36	0.28
Power to core heater rods	KW-101/102	kW		298.0
Feedwater temperature	TF-501	ºC	21.39	25.0
Steam temperature	FVM-602-T	ºC	205.0	205.0
Steam pressure	FVM-602-P	MPa(a)	1.427	1.421
Ambient air temperature	[redacted]	ºC	[redacted]	27.0
HPC pressure	PT-801	MPa(a)	0.1255	0.121328
HPC water temperature	TF-811	ºC	27.0	30.0
HPC water level	LDP-801	m	2.82	2.9
Primary flow at core outlet	FDP-131	kg/s		1.36
Primary coolant temperature at core inlet	TF-121/122/123/124	ºC	214.0	223.0
Primary coolant temperature at core outlet	TF-106	ºC	251.5	268.0
Feedwater flow	FMM-501	kg/s		0.111
Steam flow	FVM-602-M	kg/s		Fluctuating around 0.111
Primary coolant subcooling at core outlet	[redacted]	ºC	[redacted]	33.7
Total heat loss through primary system	[redacted]	kW	[redacted]	1.3
Heat transfer through SG	[redacted]	kW	[redacted]	296.7

Results for SP-2 Transient

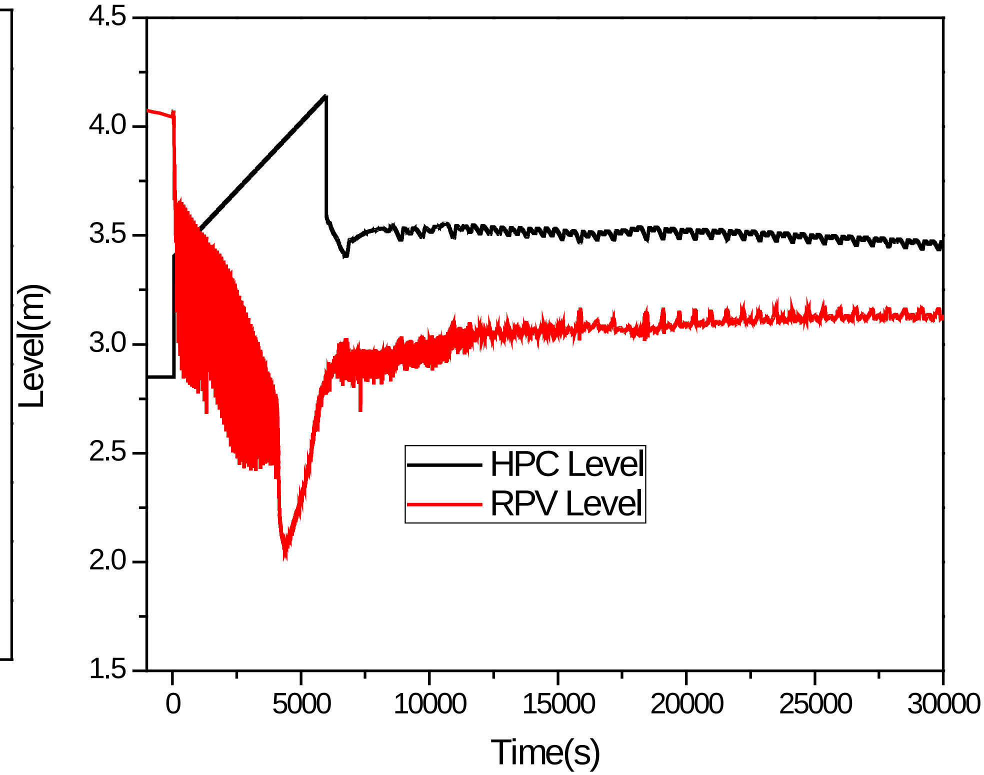


Mass flow rate of the vent valves

Results for SP-2 Transient



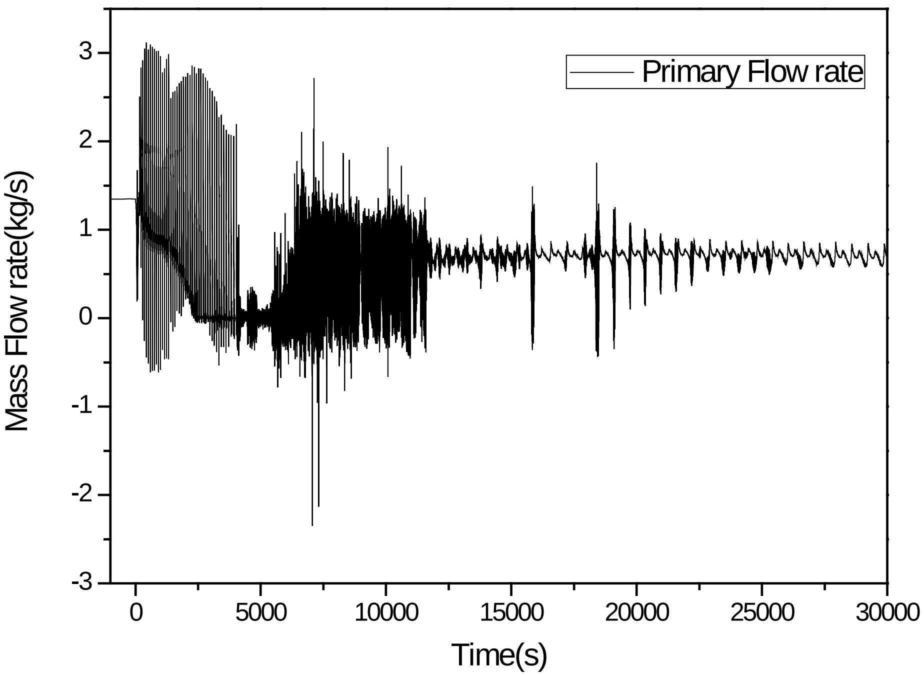
RPV and HPC Pressure



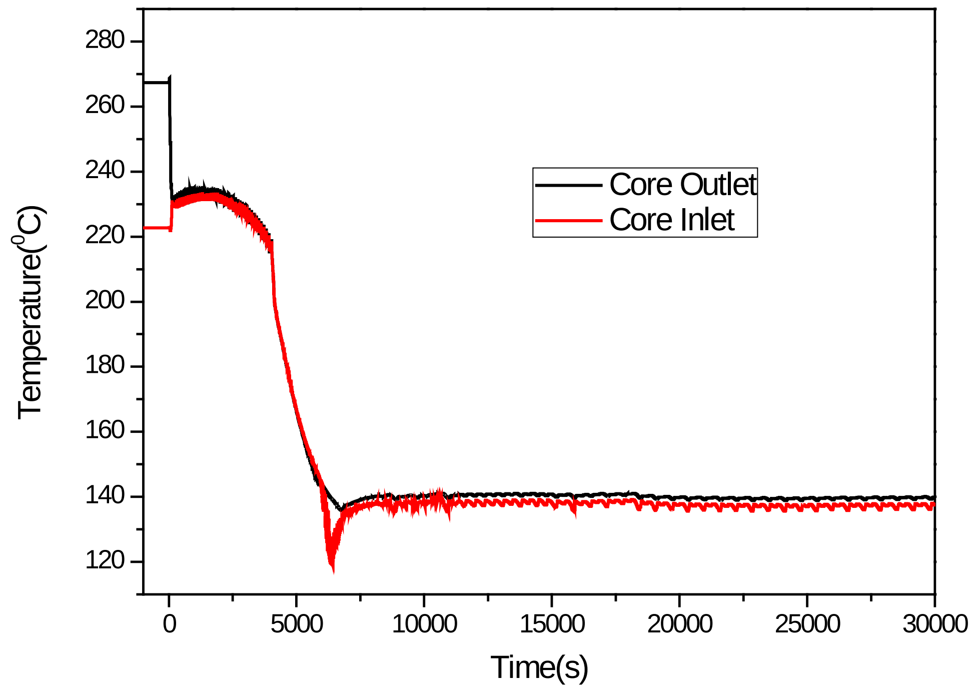
RPV and HPC Level

RPV and HPC Pressure get equalises with in 5000s

Results for SP-2 Transient

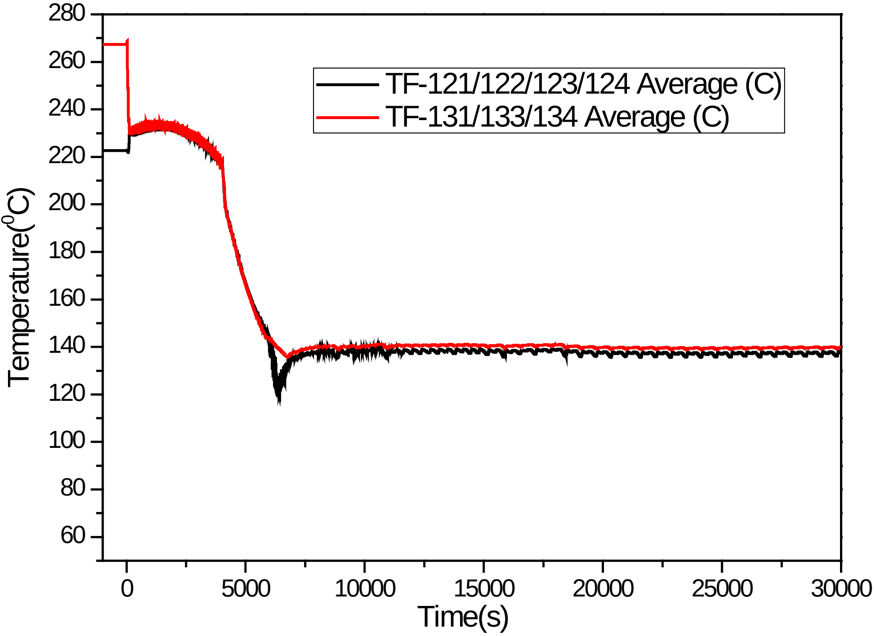


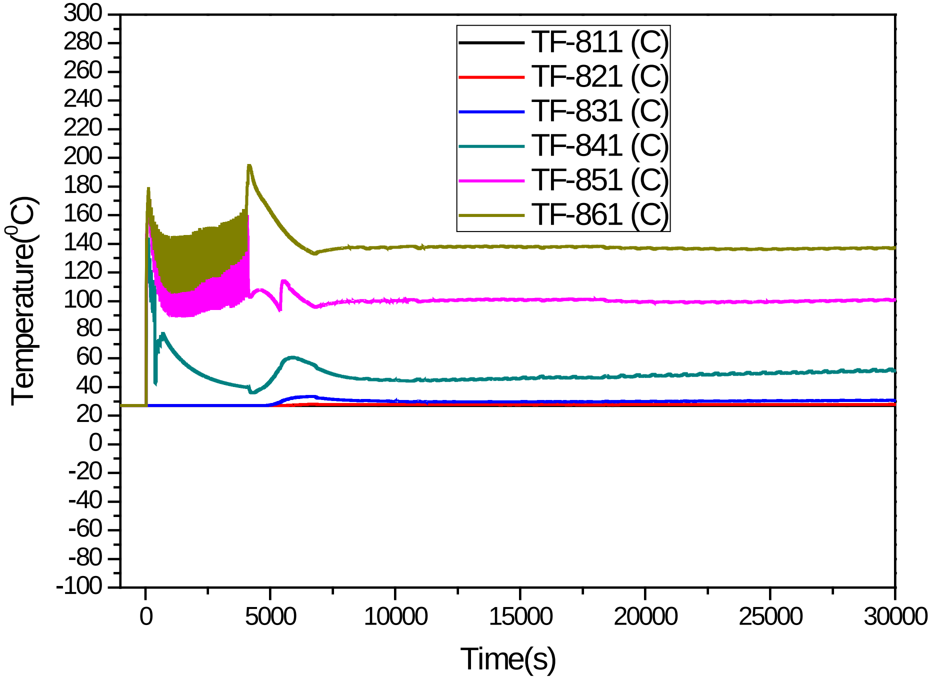
Core flow rate



Core inlet outlet temperatures

Results for SP-2 Transient

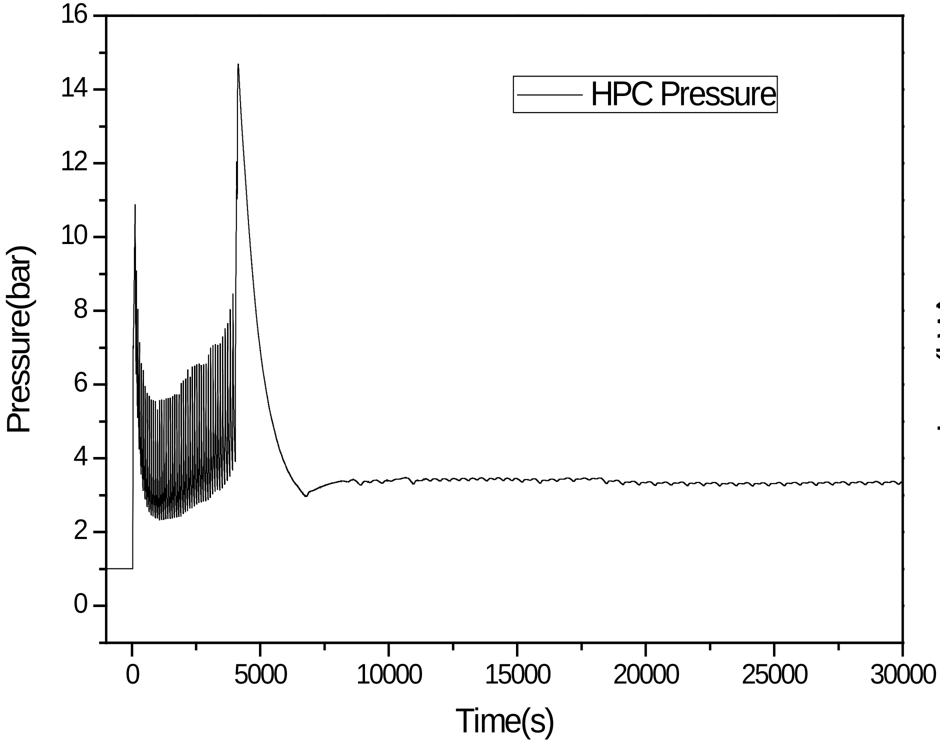




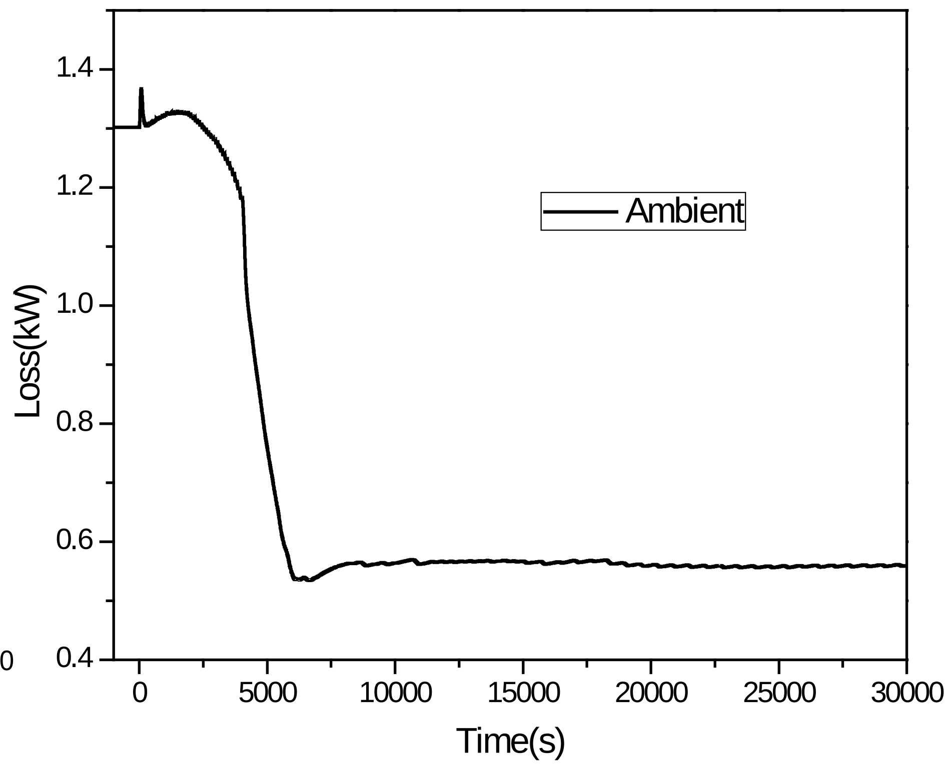
RPV Temperatures

HPC Temperatures

Results for SP-2 Transient



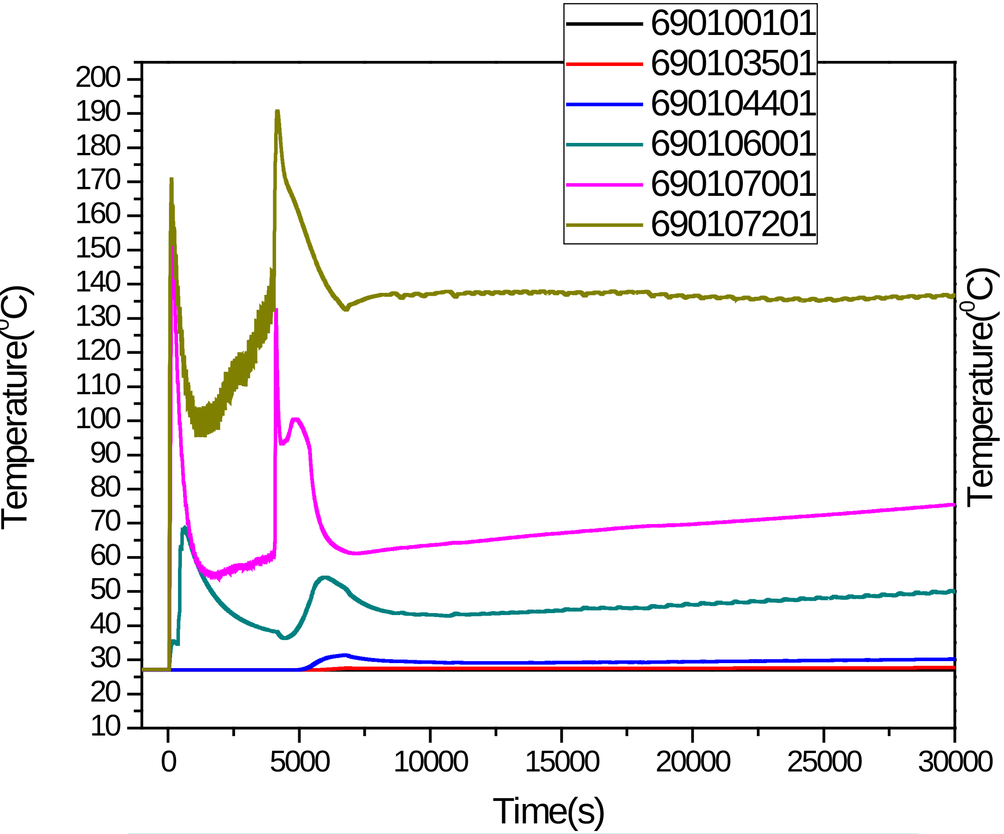
HPC Pressure



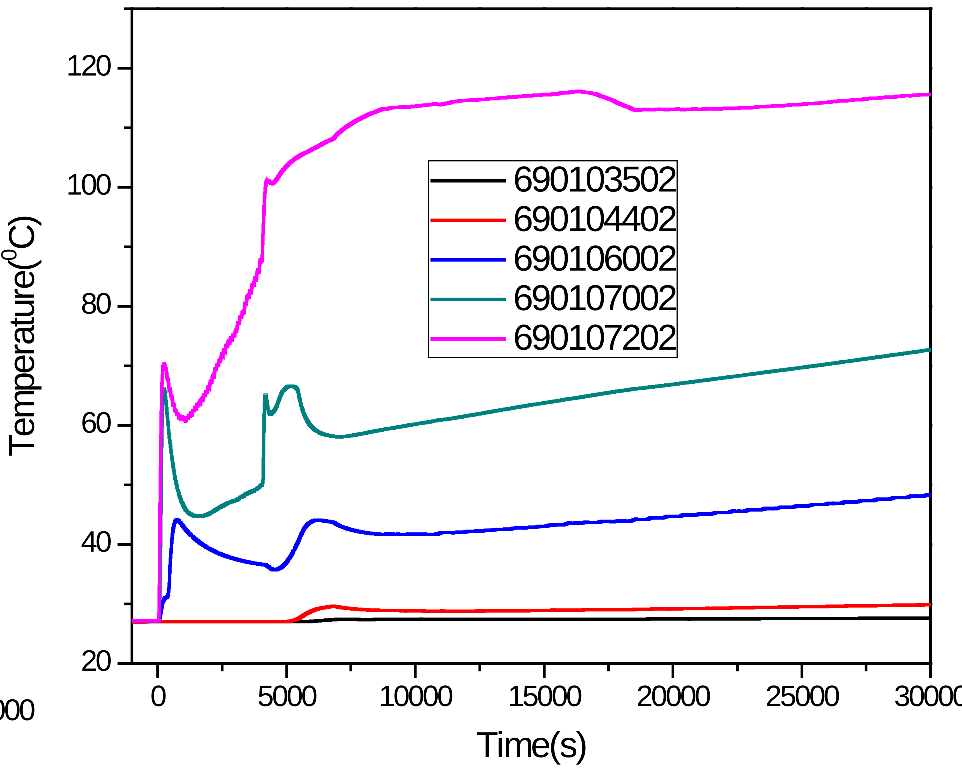
Heat Loss to ambient

HPC Pressure is nowhere reaching the safety limit

Results for SP-2 Transient

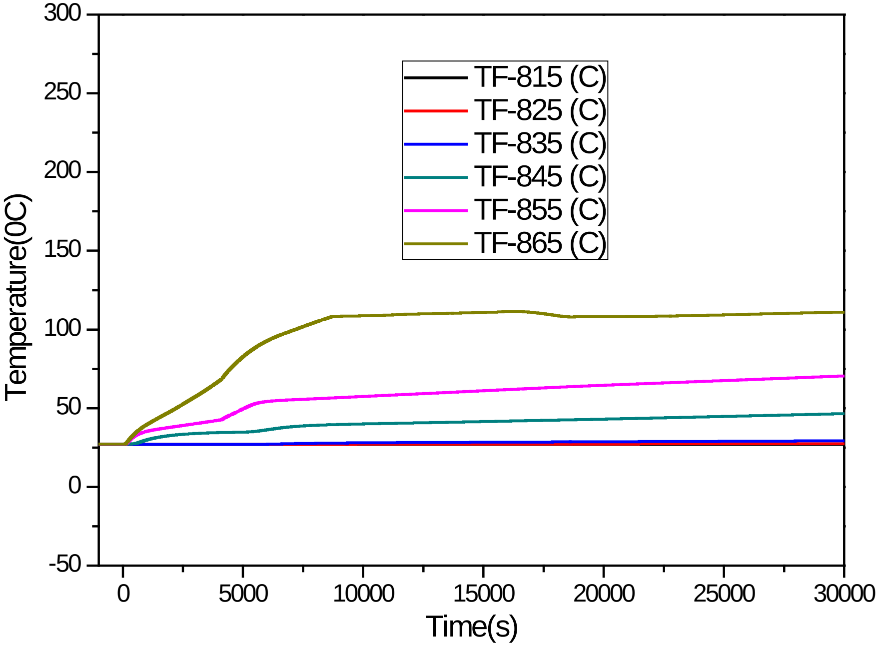


Heat Transfer Temperatures HPC side

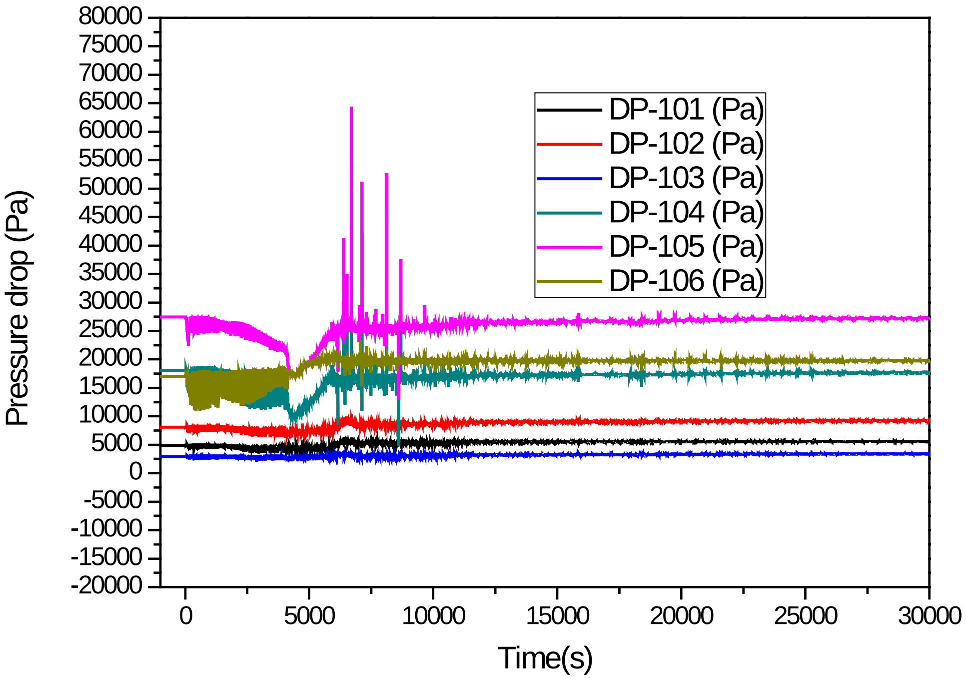


Heat Transfer Temperatures CPV side

Results for SP-2 Transient



CPV Temperatures



RPV Pressure drop

Conclusions

- Initial steady state flow and RPV temperatures predicted by RELAP code are in close agreement when compared to that given in SP-2 Specification.

- RELAP5 predicts the RPV depressurization up to 3.6 bar pressure within 7000 seconds of the transient and it remains constant for whole transient.

- Predicted core flow is oscillating with large amplitudes and flow is also reversing.

Summary

- SP2 and SP3 transients are analysed using RELAP5 M3.2 code and SP3 transient is also analysed using CATHARE code.
- With slight difference, the two codes predicts the phenomena appeared in SP3 transient in a close proximity with experimental data.
- In SP2 transient the RPV pressure along with the HPC pressure falls to approx 3.6 bar in nearly 7000s which seems to be early after seeing the experimental results. This may be because of the opening and closing of valves are taken as per the experimental data.

Thank you