



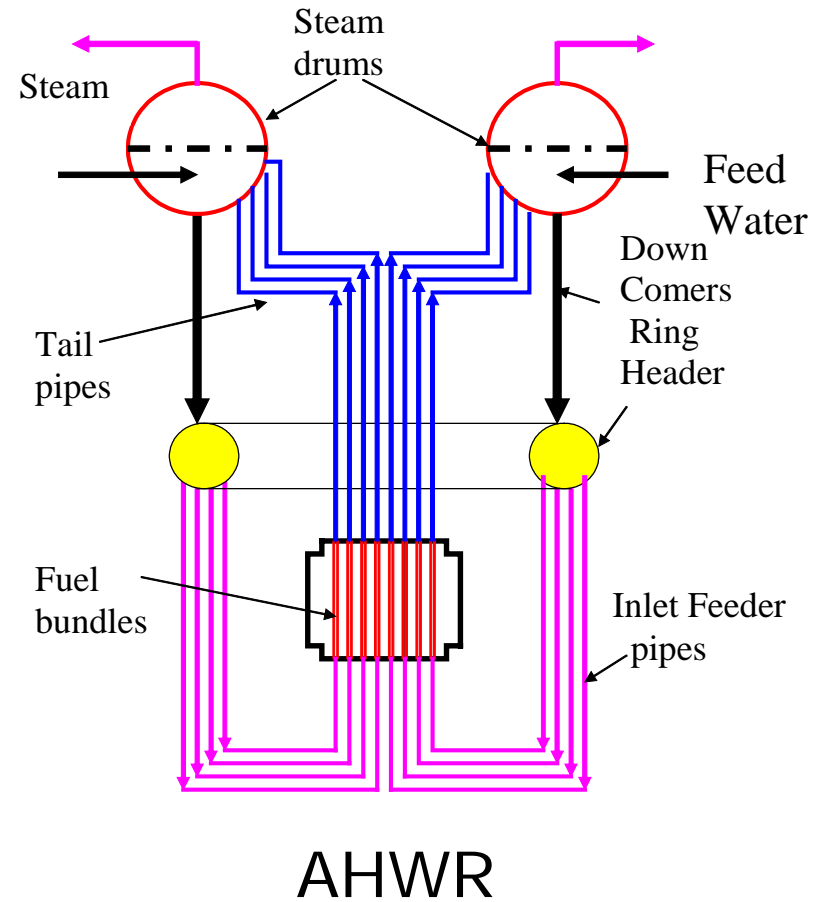
Integral System Tests in ITL simulating AHWR

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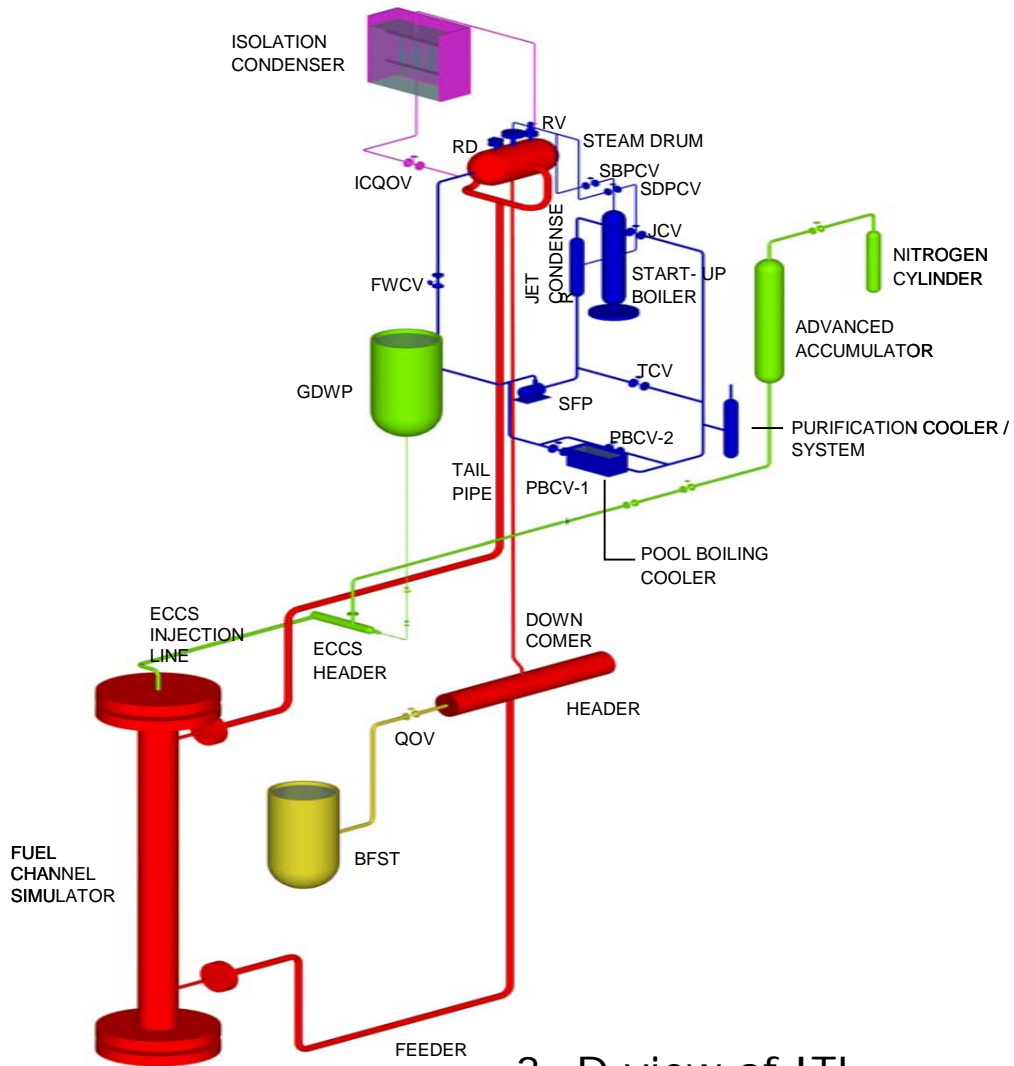


Integral Test Loop (ITL) Bldg. & AHWR





Integral Test Loop



3- D view of ITL



Major Objectives

ITL Simulates the Main Heat Transport System (MHT) and safety systems of AHWR. Major objectives are:

- ❖ Validation of start-up method
- ❖ System behaviour under normal operating conditions
- ❖ Operational transients study
- ❖ Studies on stability of natural circulation flow
- ❖ System behaviour under accidental conditions
- ❖ Performance evaluation of components like passive valve.



Scaling Philosophy

A three level approach is followed

(a) GLOBAL SCALING

Power – to – Volume scaling philosophy adopted

Pressure, temperature and elevation : 1:1

Volume scaling ratio : 452

(b) BOUNDARY FLOW SCALING

Feed water and steam flow simulation

Pressure, temperature and enthalpy : 1:1

(c) LOCAL PHENOMENA_SCALED ARE

CHF, Geysering, flashing, Carry-over and carry-under in steam drum, etc.



Major Design parameters

Pressure	: 100 bar
Temperature	: 315 deg. C
Elevation	: 32.5 m (bottom of steam drum)
Number of channels	: 1
Number of feeders	: 1
Number of tail pipes	: 1
Channel power	: 1.67 MW
Number of rods in a bundle	: 54
Diameter of heated rod	: 11.2 mm
Inlet Feeder diameter	: 115 mm
Tail pipe diameter	: 140 mm
Header diameter	: 173 mm
Header length	: 1.3 m
Steam drum diameter	: 1 m
Steam drum length	: 1.385 m



ECCS

ECC System :

(a) Advanced Accumulator with FFCD inside

Initial N₂ pressure : 55 bar

(b) Gravity Driven Water Pool (GDWP)

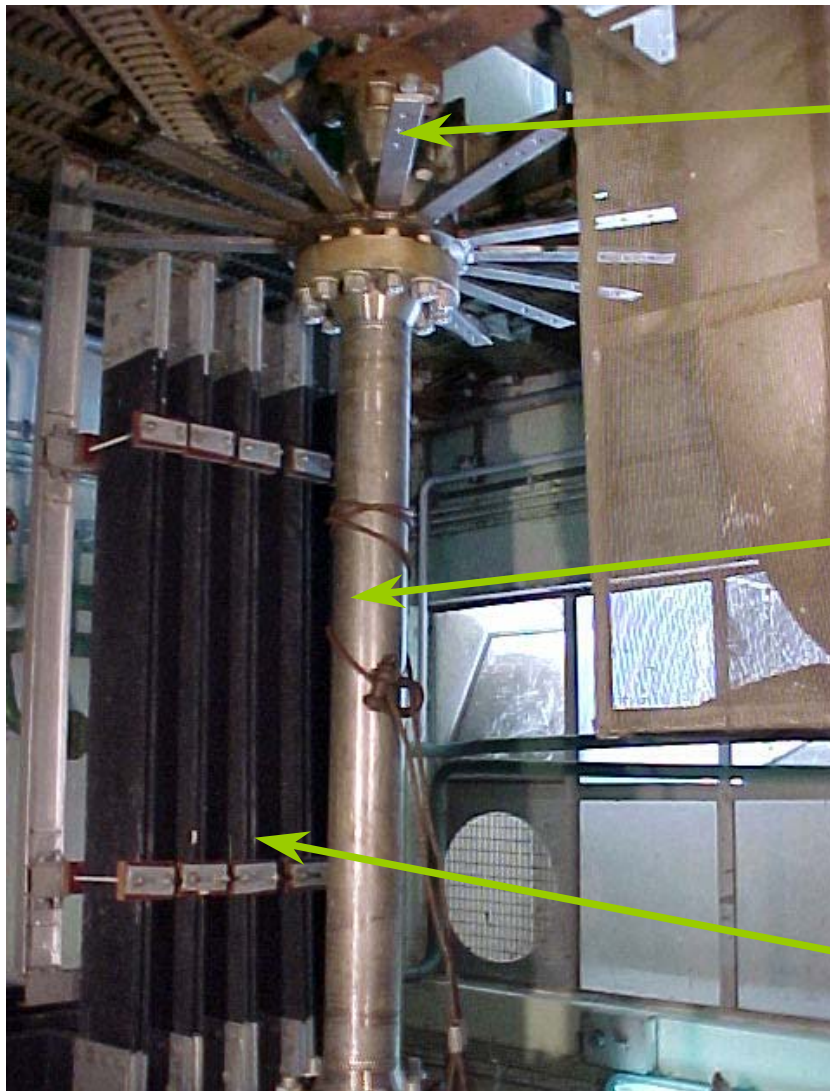
Elevation difference between core bottom to GDWP has been simulated by N₂ pressure



Description of Major Equipments / Systems



A View of the Fuel cluster Simulator



Connection to electrical busbars, (1.67 MW maximum)

- Directly heated rod bundle
- 54 rod cluster,
- 6 spacers,
- In-bundle ECCS injection tube inside,
- 3.5 m heated length,

Aluminum electrical busbars



LOCA Simulation

- The Loss of Coolant Accident phenomena of the AHWR can be simulated by various break sizes in the ITL header.
- The break sizes are simulated by having pre-determined size of orifices.
- A quick opening valve (QOV) has been installed in the downstream of the orifice to simulate the break initiation. The opening time is approximately 70 ms.



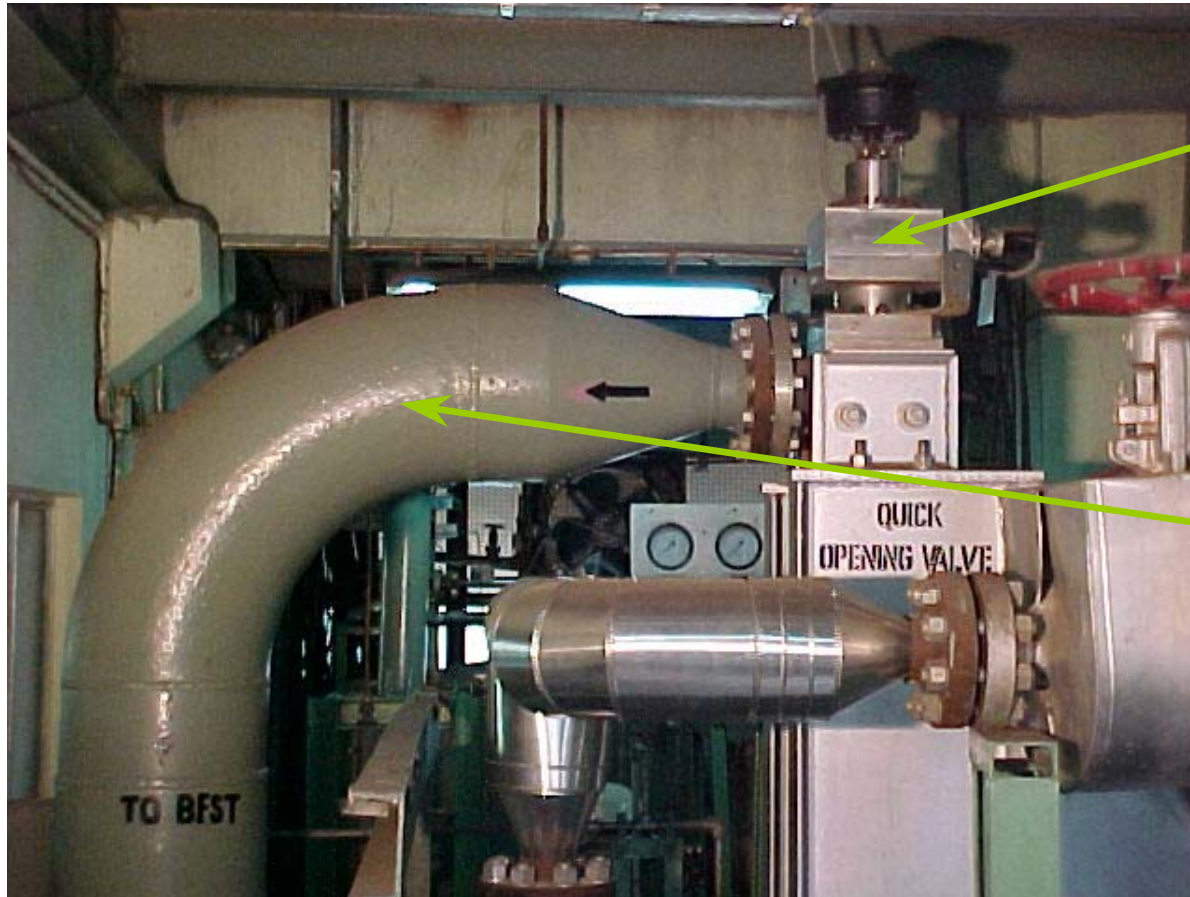
LOCA simulation

Thermalhydraulics Simulation during Loss of Coolant Accident

- Simulates the Advanced accumulator using a fluidic device to inject emergency coolant during the initial stages of LOCA
- Simulates Gravity driven cooling system (GDACS) for prolonged uninterrupted core cooling after the accumulators are exhausted



A view of quick opening valve of ITL

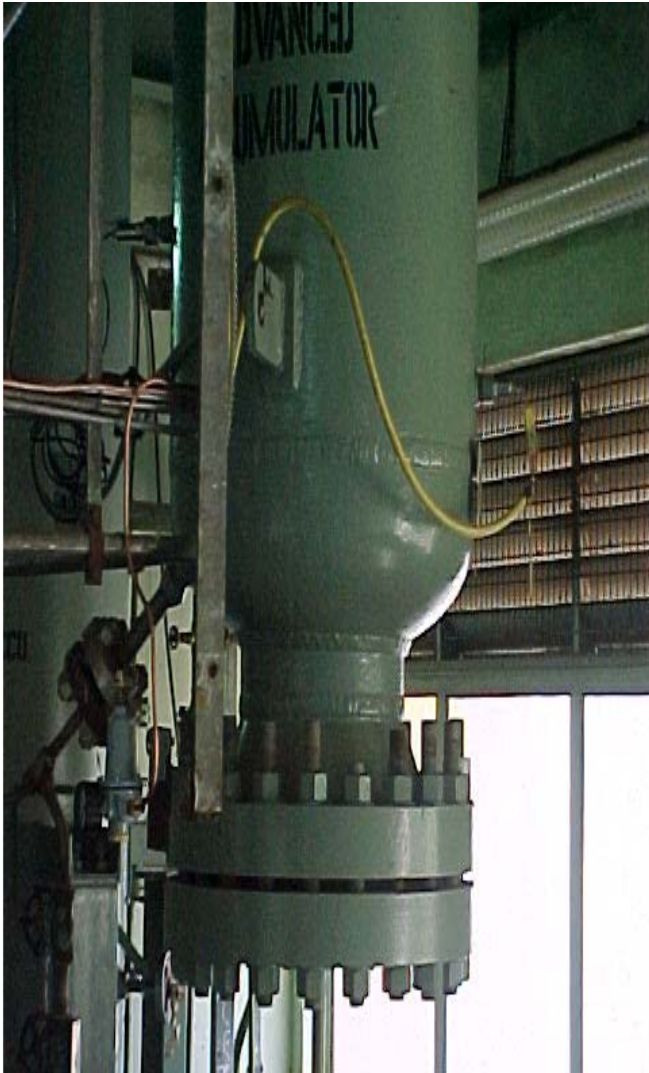


Quick opening valve

Pipe downstream of the break, sufficiently large size since critical flow occurs. The steam is taken to a Break Flow Storage Tank for condensation and estimation of break flow rate.



Advanced accumulator of ITL



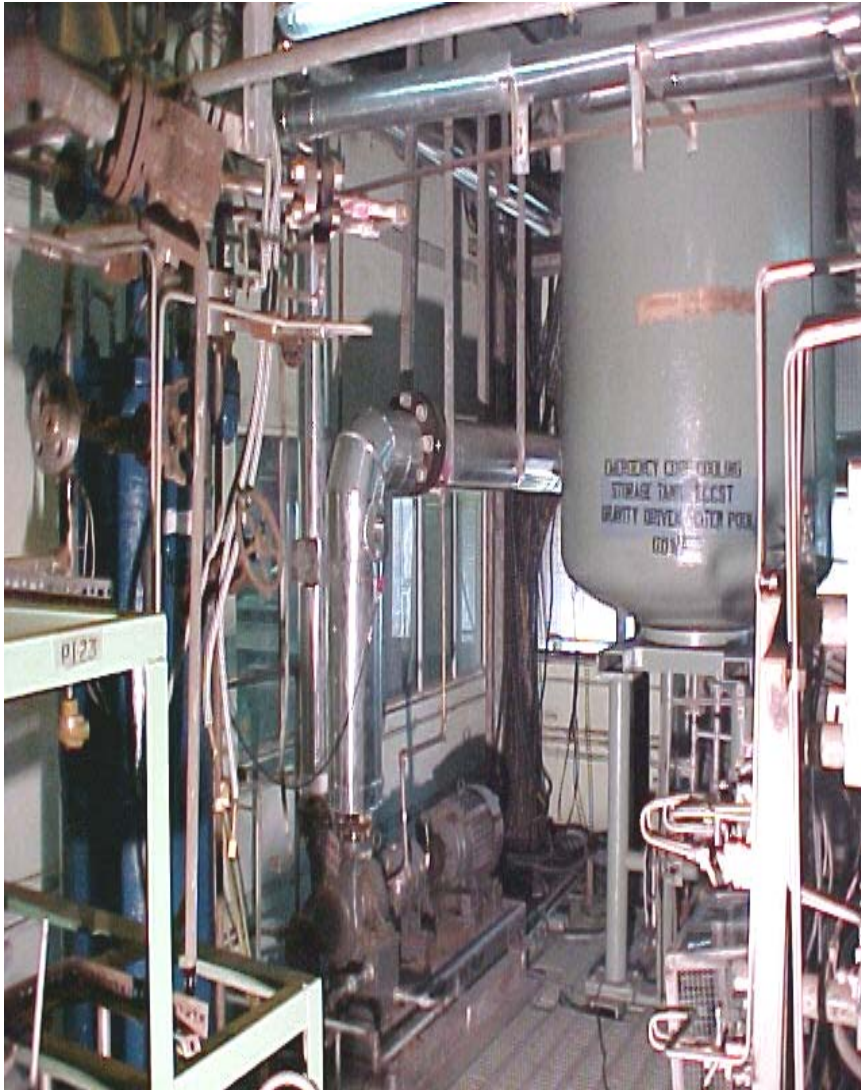
Advanced accumulator is designed to inject large flow during initial period of LOCA and then a lower flow rate over a long period as the transient proceeds with the help of a fluidic device.

Scaling considerations:

- volume scaling is adopted.
- Accumulator pressure is simulated.
- Fluidic flow control device is geometrically simulated, proportions of water volume below and above stand pipe are simulated.
- Pressure drop from the accumulator to MHT is simulated



The Gravity Driven Water Pool



The gravity driven core cooling system (GDCCS) simulates the AHWR long term core cooling system so as to provide water injection for 72 hours after a reactor trip following LOCA.

The water inventory in the tank is volumetrically simulated.

The tank is pressurized with nitrogen gas so as to simulate the water static head difference between the GDWP and the ECCS Header of the AHWR



A view of the direct in-bundle injection from the ECCS



ECCS ring header, designed by volume scaling. 60 mm diameter, 1.4 m length

Injection tube connecting the ECCS header with channel

Channel

Working philosophy:

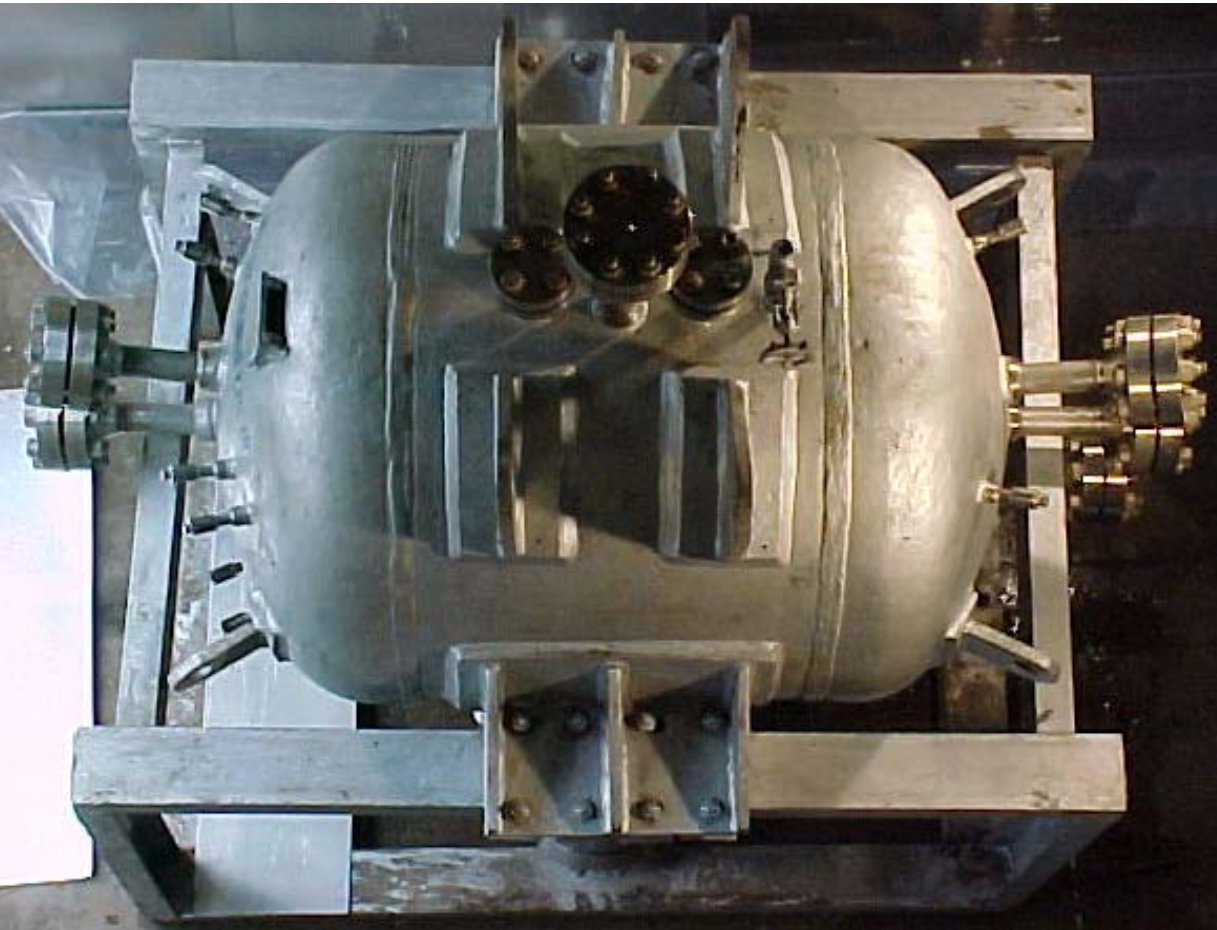
Advanced accumulator and GDWP are isolated from the MHT under normal operation.

When the MHT pressure falls below 55 bar, water from the advanced accumulator is injected directly into the heated bundle.

If the pressure falls below 10 bar, water from the GDWP is injected directly into the bundle.



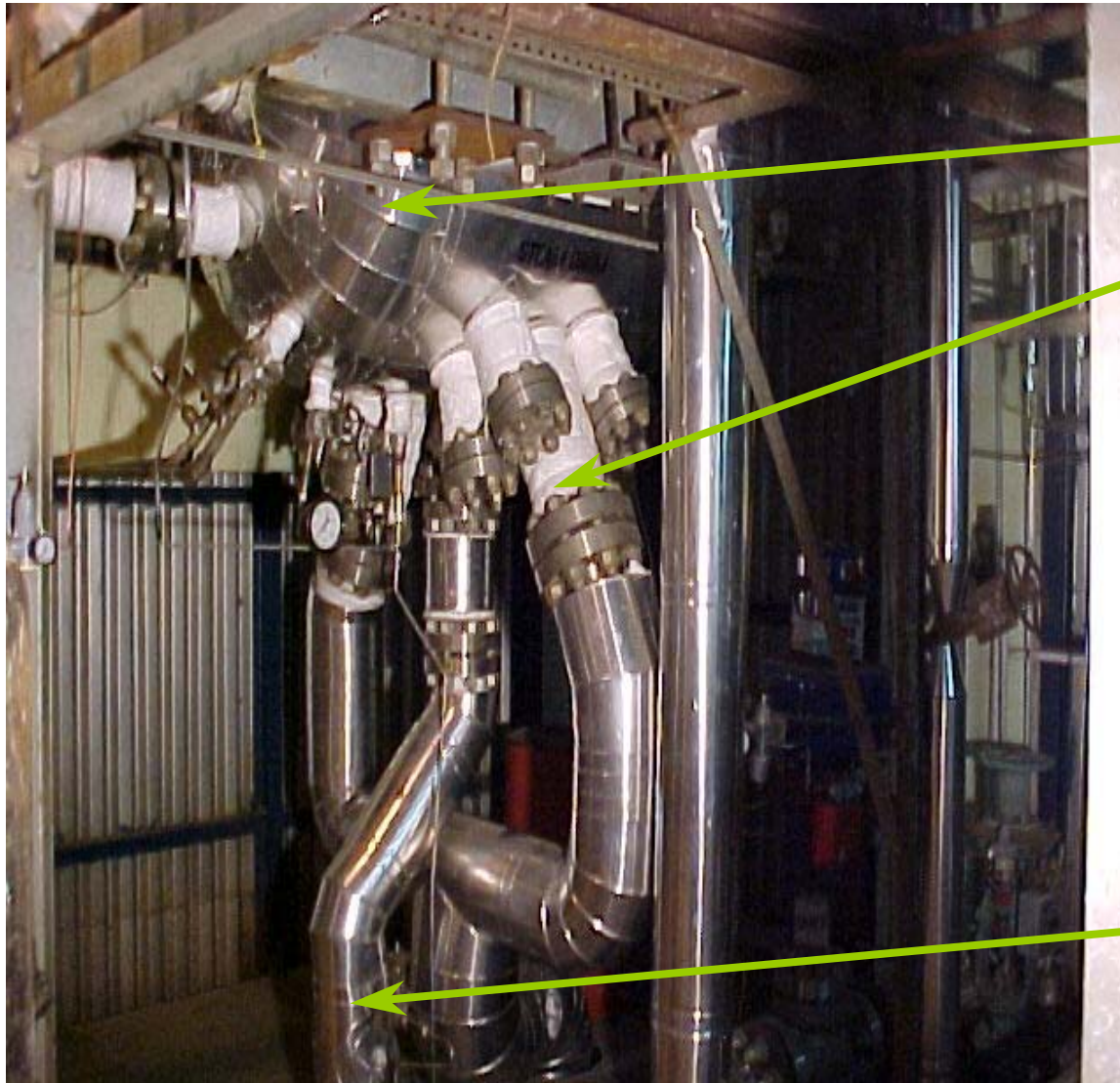
View of ITL Steam drum before installation



- Steam drum, one of the most important components, simulates the gravity separation phenomena of the AHWR
- Froude number simulation in addition to power volume scaling is adopted for its design
- Pressure, temperature and level are measured during all transient operations.



A view of flow path from steam drum of ITL



Steam drum view from bottom

Tail pipe connection to Steam drum,

Tail pipe diverges into two small pipes before joining the steam drum for better flow distribution in both sides of baffle plates

Downcomer outlet from steam drum



Start-up boiler



Objective:

To generate steam externally and pressurize the MHT of the ITL so as to simulate the AHWR cold start-up from atmospheric to 70 bar

Power : 36 kW

Steam generation rate : 0.6 kg/min

Heater material : SS



Steam and Feed System

- The ITL steam and feed system simulates the steam supply system up to the governor valve of the AHWR.
- The controls on the steam pressure including steam discharge, safety relief valve, dump valve and Combined Isolation and Stop Valve (CIES) are simulated.
- The steam produced in the MHT is condensed using a Jet condenser and pool boiling cooler.
- Feed water temperature and feed flow rate are simulated.



A View of the Pool Boiling Coolers



The Pool Boiling Cooler is the ultimate heat sink of the ITL, cooled by the service water supply. The service water boils and steam is sent to the atmosphere.

It provides cold water at the required temperature to the jet condenser.



Isolation Condenser Unit as installed



The Isolation Condenser of the ITL simulates the decay heat removal of the AHWR.

Designed based on volume scaling.

Located at the same elevation as the prototype so as to simulate the natural circulation.

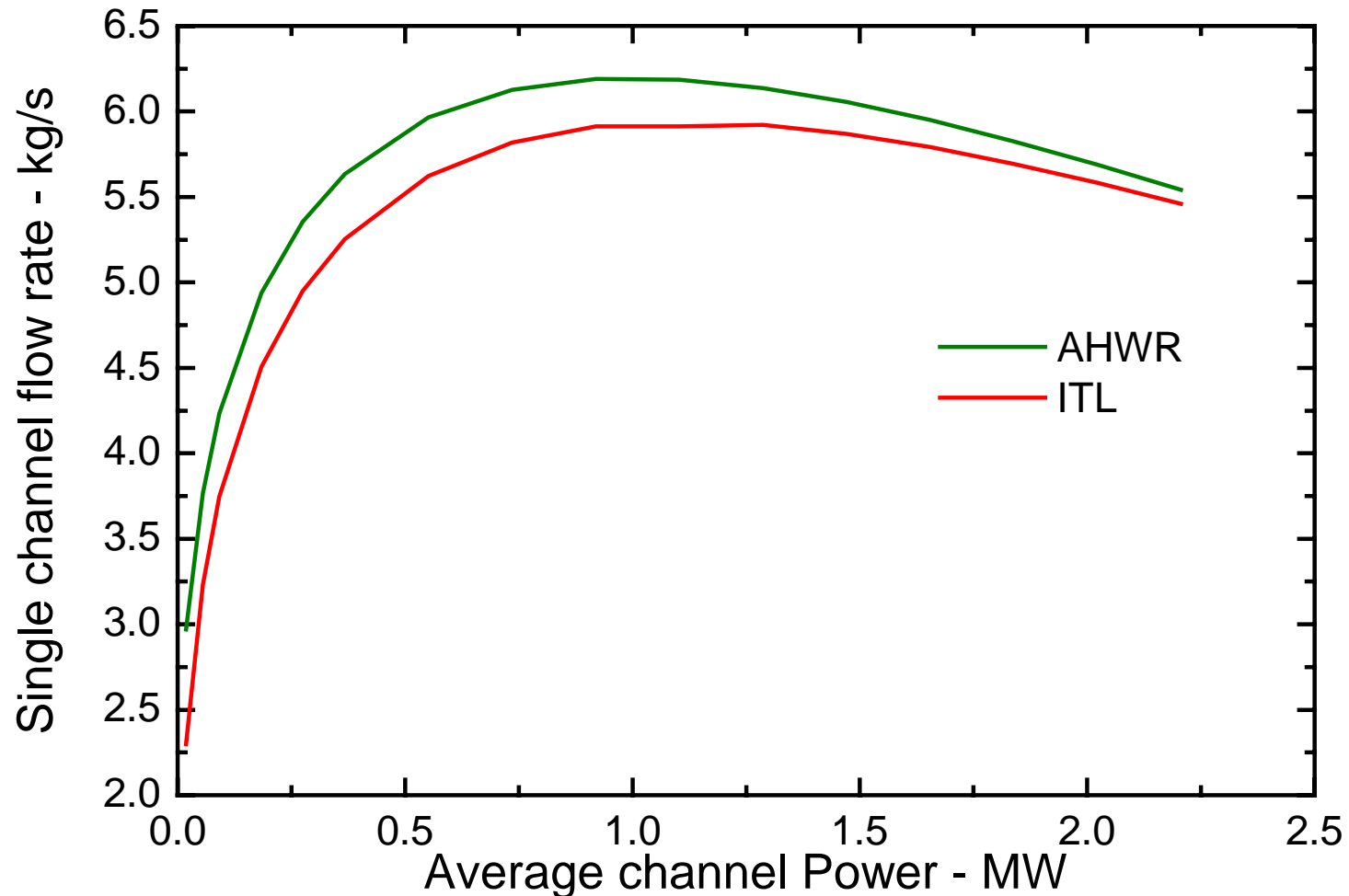


Experiments conducted in ITL

- Steady state behaviour investigations
- Stability behaviour investigations
- Validation of Start-up method



Extent of Simulation of AHWR by ITL



Comparison of predicted steady state flow rates



Analytical Methods used for analysis

Code for Stability Analysis: TINFLO-S

Stability code TINFLO-S is based on linear stability theory, wherein the basic governing differential equations are linearised, perturbed and solved analytically to obtain characteristic equations. Formulation is based on homogeneous equilibrium model for two-phase flow.

Generalized correlations for steady state flow prediction in two-phase natural circulation loops.

Steady state governing equations for homogeneous equilibrium model viz. continuity, momentum and energy equations have been solved to obtain the dimensionless flow rate as a function of a modified Grashof number and a geometric number.

$$\text{Re}_{ss} = 0.1768 \left(\frac{Gr_m}{N_G} \right)^{0.5} \quad \text{For Laminar Flow ;}$$

$$\text{Re}_{ss} = 1.9561 \left(\frac{Gr_m}{N_G} \right)^{0.36364} \quad \text{For Turbulent Flow}$$

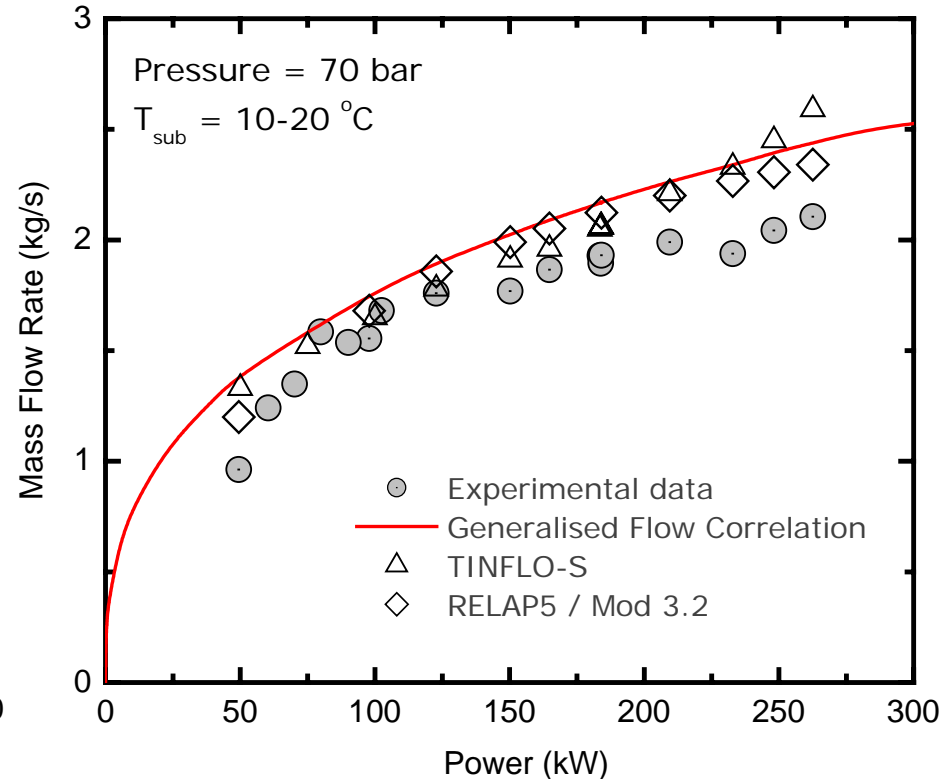
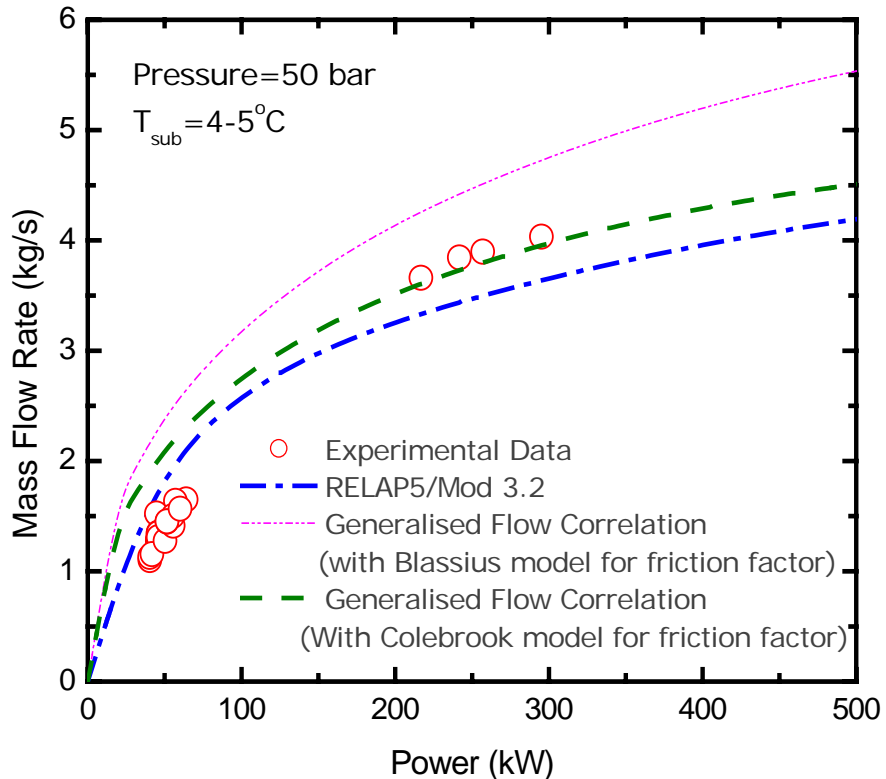
Where

Re_{ss} = Steady State Reynolds Number

Gr_m = Modified Grashof Number

N_G = Geometric Parameter

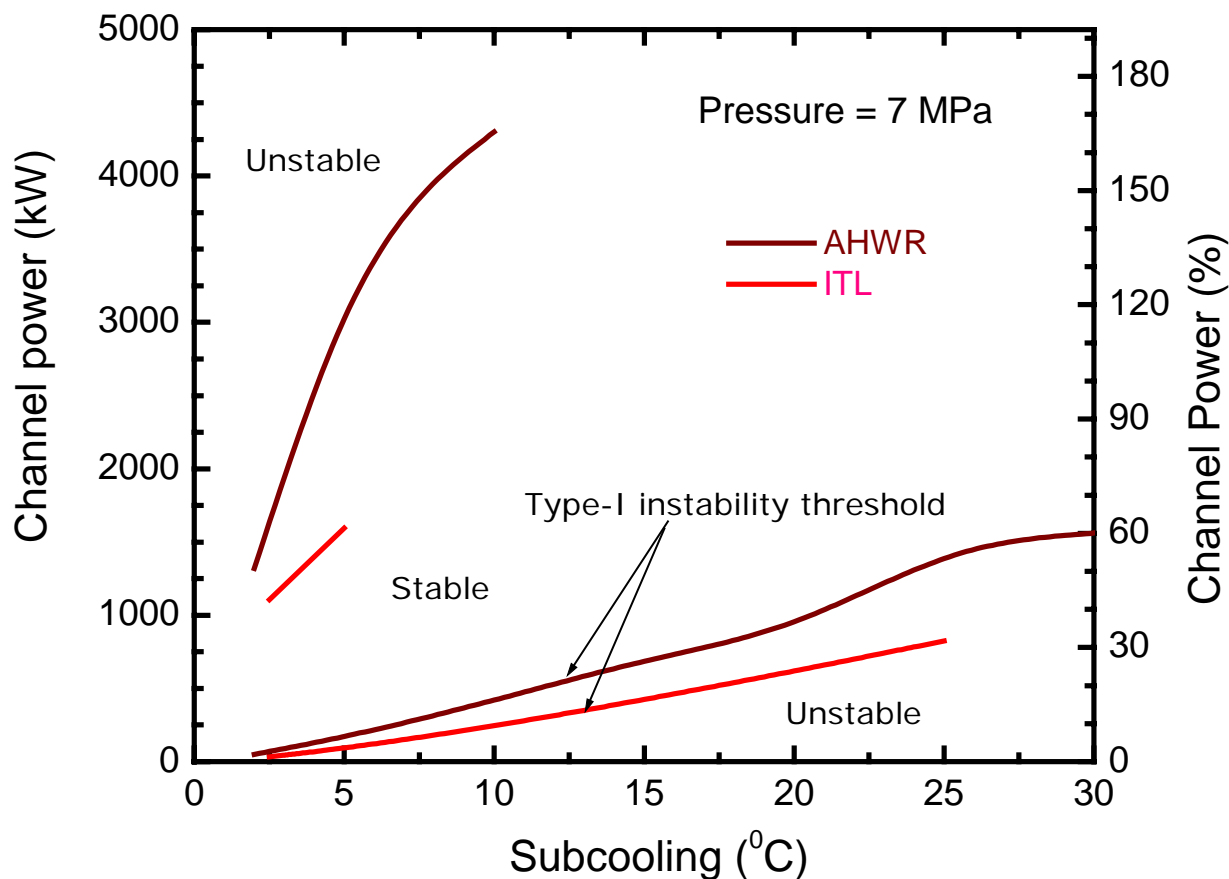
Comparison of steady state flow rate



- Both the RELAP5 and the analytical model do not consider the heat loss from the loop.
- Measured steady state flow rates are within 15% of RELAP5 predictions



Stability performance of ITL and AHWR

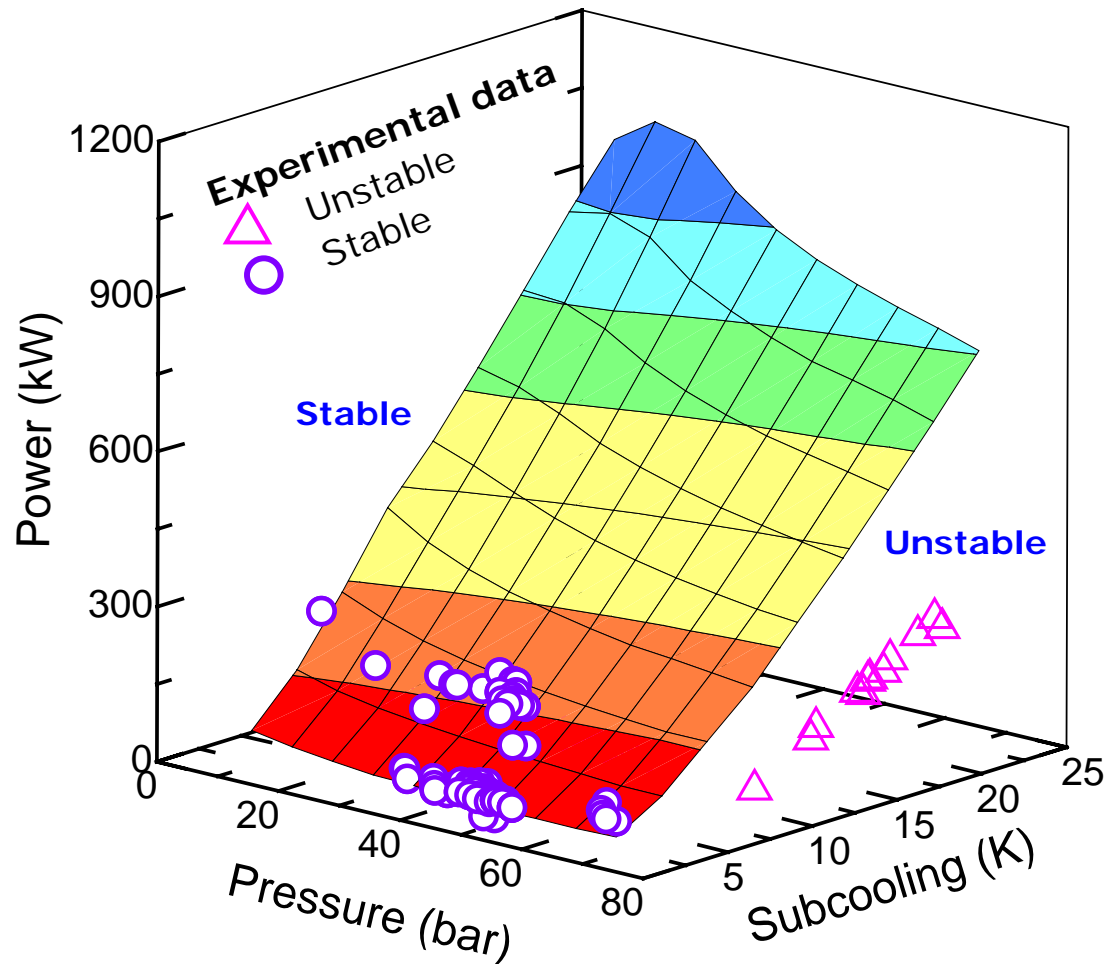


Stability map predicted by TINFLO-S for AHWR and ITL

- The lower threshold of ITL is somewhat lower compared to AHWR



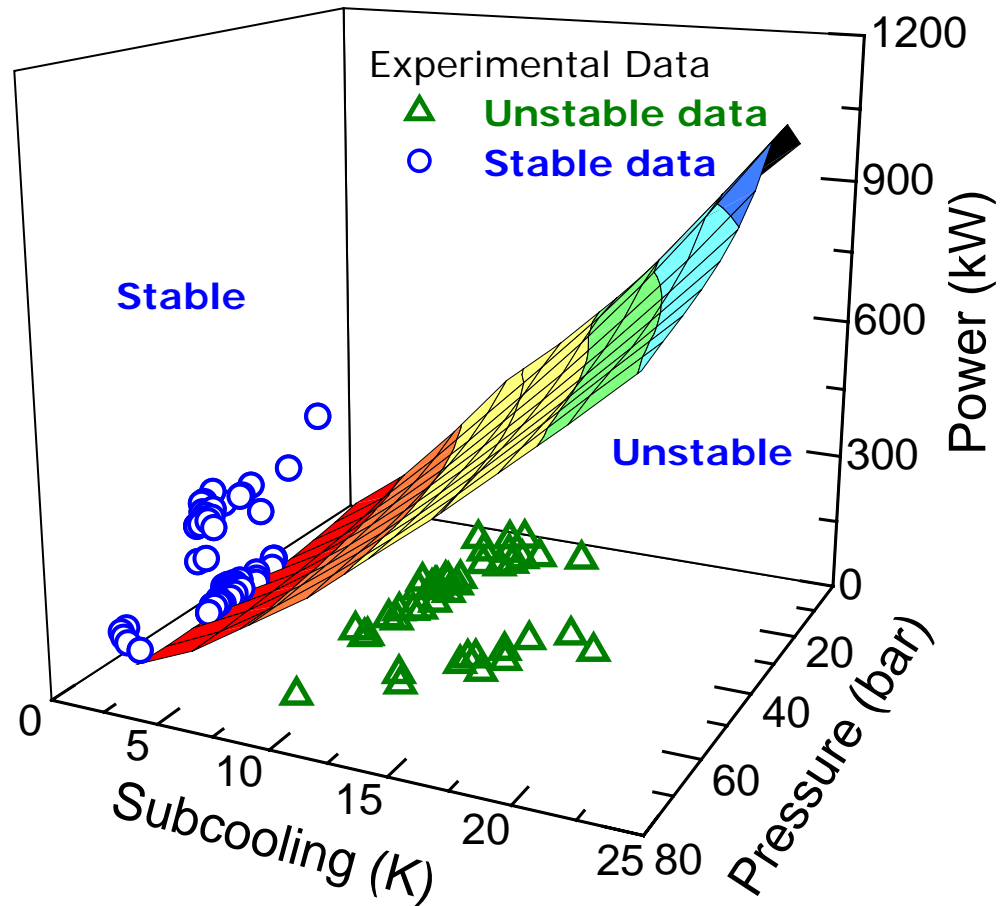
Stability performance of ITL



The surface shows the threshold of type-1 instability for ITL
➤ 100% success so far in characterizing stable and unstable points



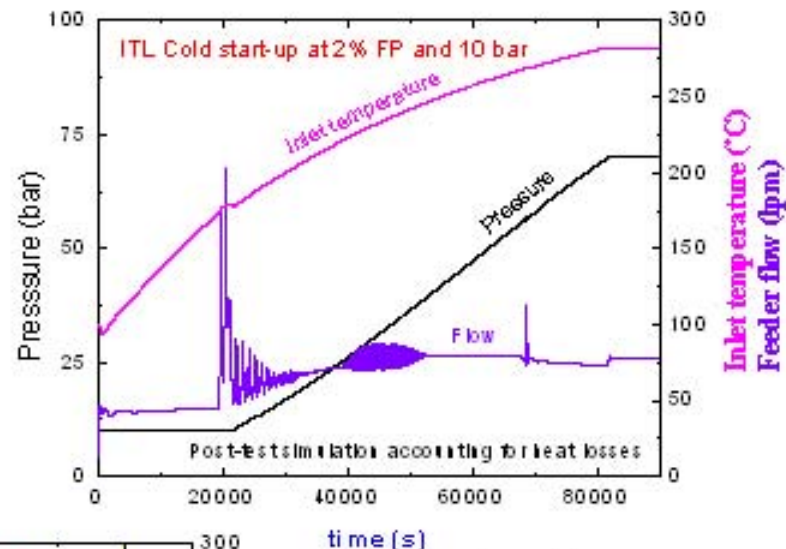
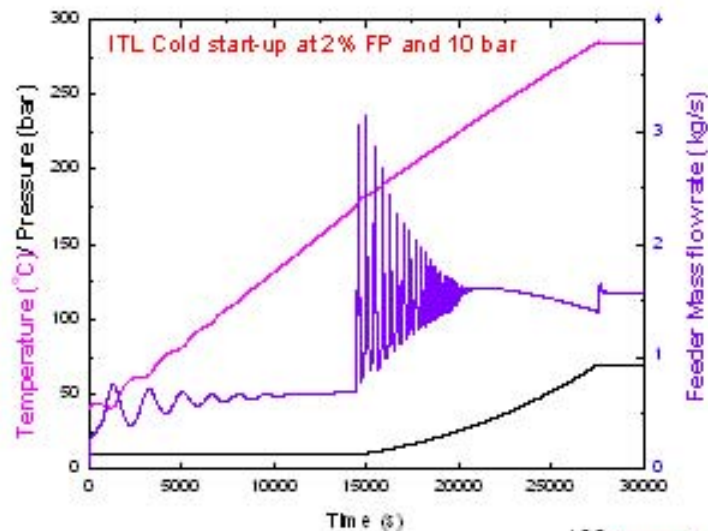
Stability performance of ITL



Another view of the stability surface
More data points are visible now

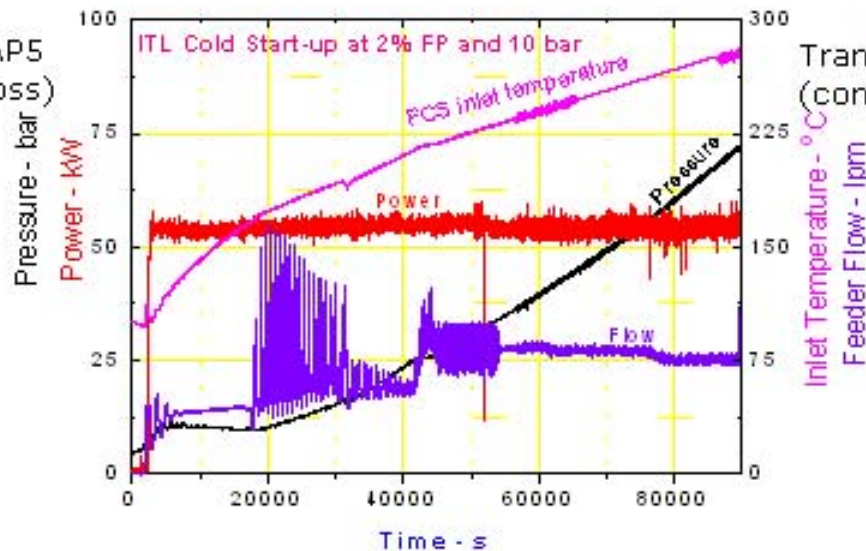


Cold Start-up at 2% FP



Transient predicted by RELAP5
(Without considering heat loss)

➤ General trends are similar. However, ITL takes about one day whereas RELAP5 simulation takes only half a day



Transient predicted by RELAP5
(considering heat loss)

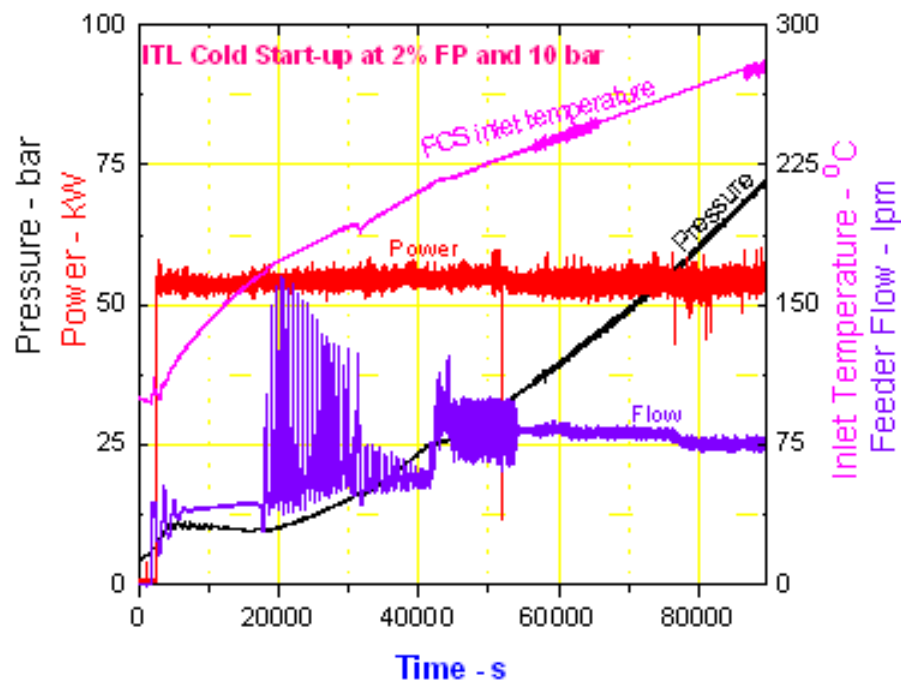
➤ The second unstable zone is observed now. However, the amplitudes are significantly different

Experiment in ITL

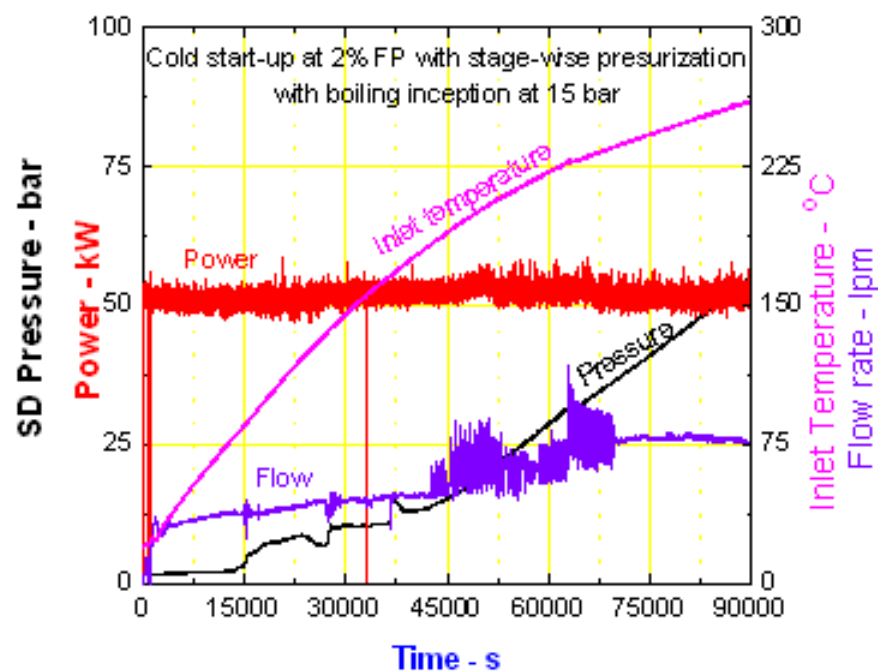




Effect of pressure on ITL Cold Start-up



Start-up with initial Pressurisation
of 1 MPa



Start-up with initial Pressurisation
of 1.5 MPa



CONCLUSIONS

Steady state and stability behaviour are found to be well within the expected range.

Pressurized start-up is found to eliminate the flashing instability as expected.