DEPARTMENT OF CIVIL AND INDUSTRIAL ENGINEERING
UNIVERSITY OF PISA -ITALY

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LARGE SCALE EXPERIMENTAL FACILITY FOR ASSESSMENT THE PERFORMANCES OF THE VACUUM VESSEL PRESSURE SUPPRESSION SYSTEM OF ITER

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- Small Scale Experimental Facility (SSEF - scale1/22)
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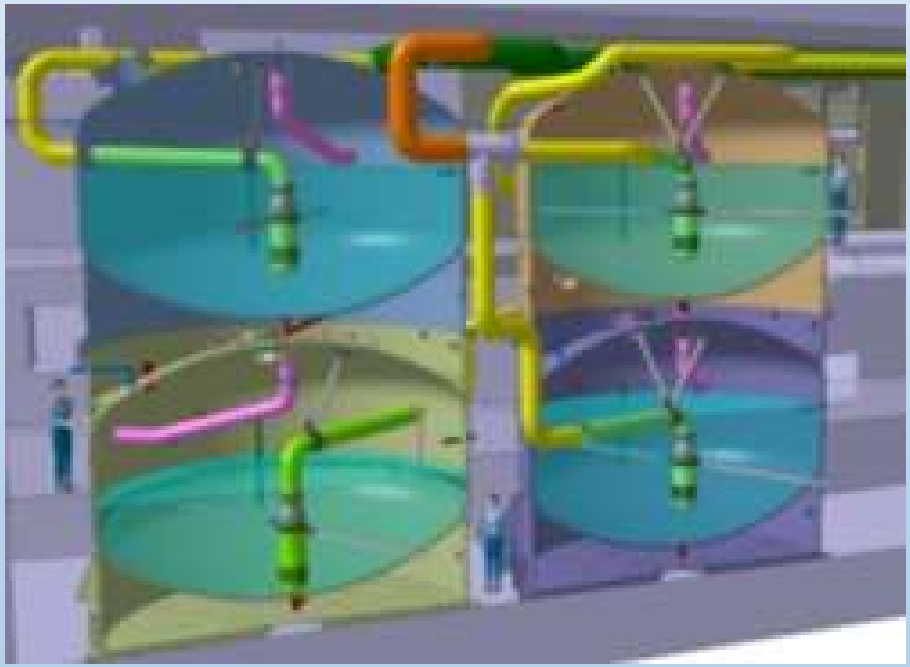
Objectives of the research activity

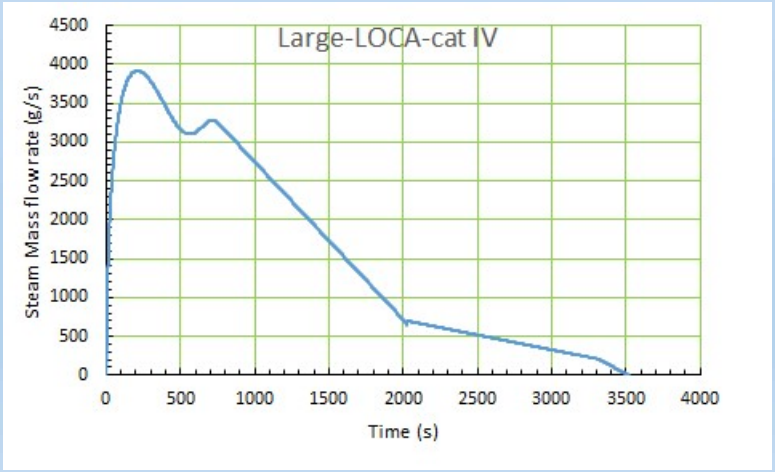
- To assess the Pressure Suppression System (PSS) of the International Thermonuclear Experimental Reactor (ITER)
- To acquire knowledge, by means experimental tests in reduced scale facilities, about the direct condensation of the steam at sub-atmospheric pressure which are the peculiar ITER thermal-hydraulic conditions, applied for the first time.
- To elaborate similitude analysis and to derive scale laws for extrapolating the results to the full scale system

THE VACUUM VESSEL SUPPRESSION SYSTEM (VVPSS)

Configuration of VVPSS (3 LLT and 1 SLT)



4 tanks, 100 m3 of volume partially filled by water, to manage Large LOCA events (3 tanks) and Small LOCA event (1 tank)



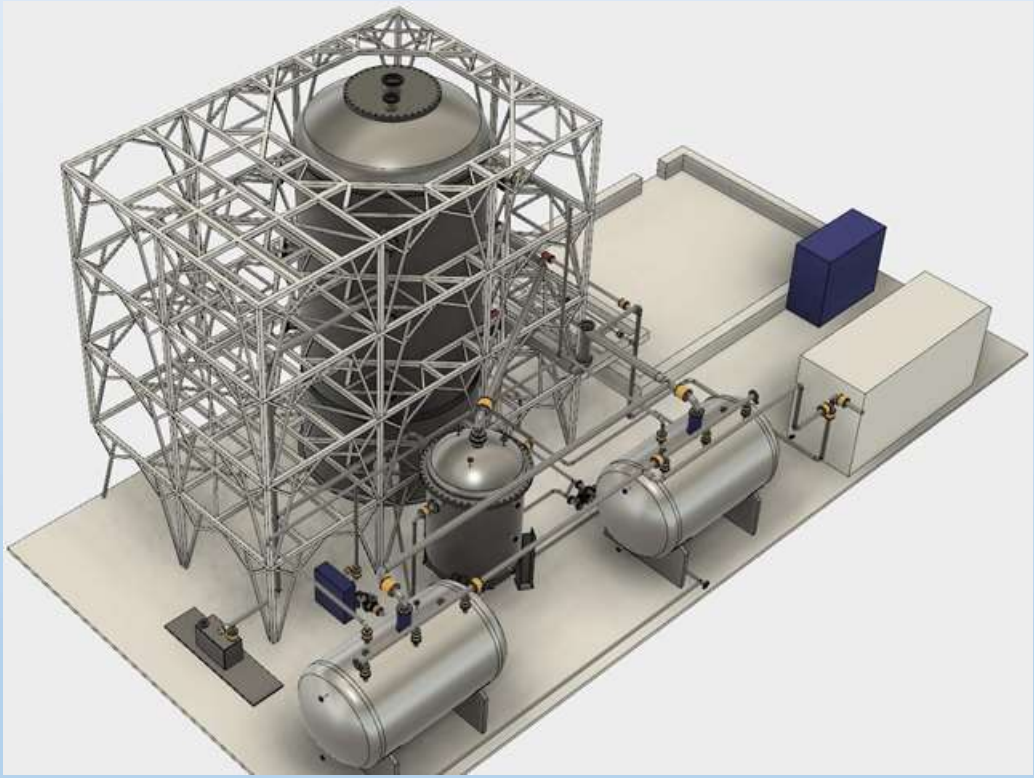
Small Scale Experimental Facility (SSEF - scale1/22)

400 tests at different water temperature (10-96°C), pressure (18-117Pa) and steam mass flow rate per hole(1-10g/s)

MAIN COMPONENT

- A reduced Condensation Tank (RCT), instrumented with 28 temperature sensors and 8 pressure transducers.
- An internal vertical sparger with several holes (1-16)
- electric steam generator (150Kw, steam q=50g/s, p=150 kPa)
- steam mass flow rate sensors: Vortex and Coriolis

Large Scale experimental facility



MAIN COMPONENTS

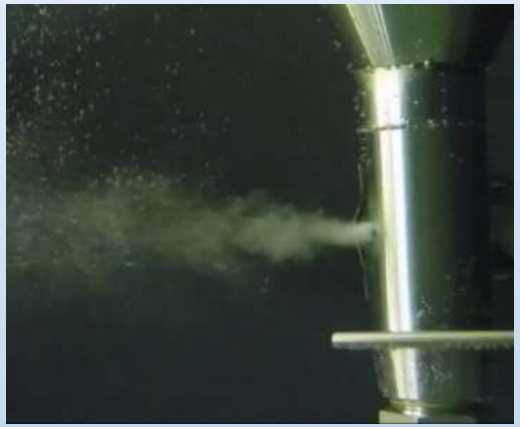
- -condensation tank : volume: 92 m3 instrumented with 70 temperature sensors and 12 pressure transducers.
- internal vertical sparger (100 or 1000 holes)
- electric steam generator: 1500 kW, 0.5 Kg/s mass flow rate of steam, p=22bar,
- 3 control lines for the steam, 2 control lines for non condensable gas .

geometric scale:1/1.09
Power scale (steam mass flow rate) :1/10

TEST RESULTS OBTAINED BY THE SMALL SCALE EXPERIMENTAL FACILITY

1g/s

2.5 g/s

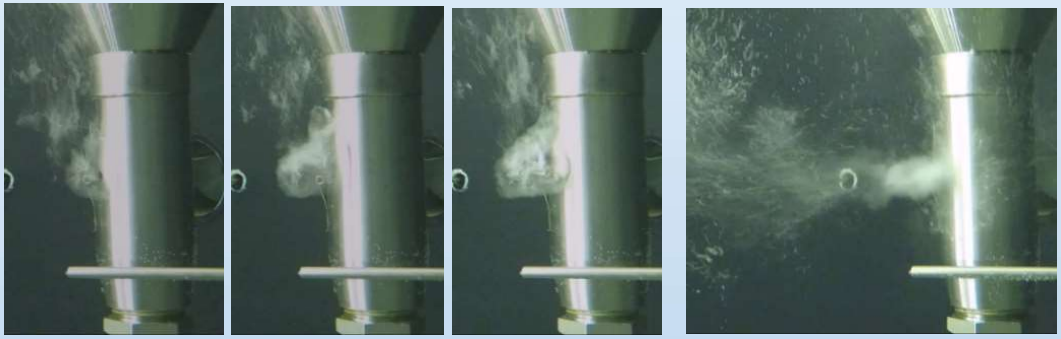


5 g/s

- *Steam condensation in a water pool at 10°C – 15 kPa :*

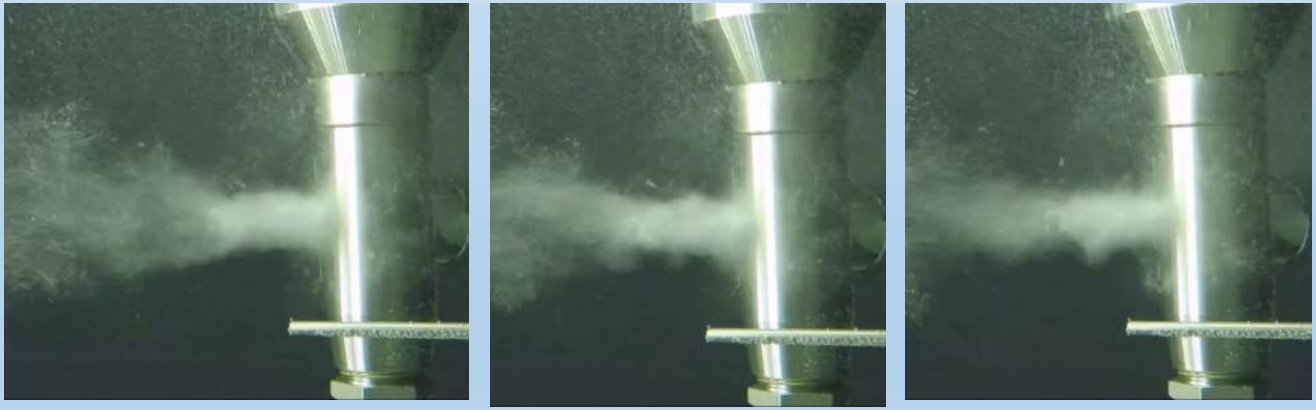
TEST RESULTS OBTAINED BY THE SMALL SCALE EXPERIMENTAL FACILITY

1g/s



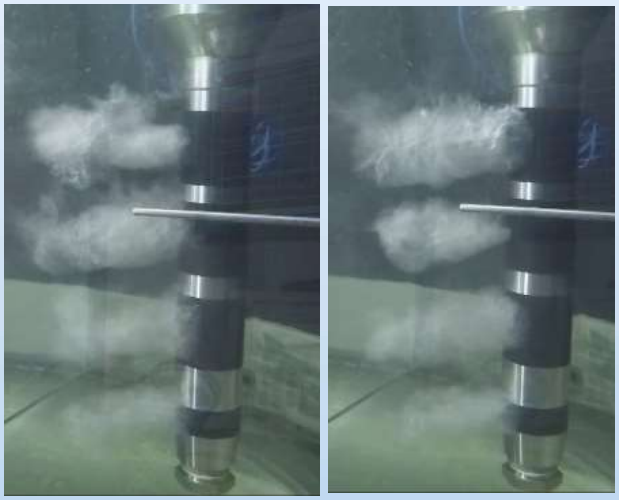
2.5 g/s

5 g/s

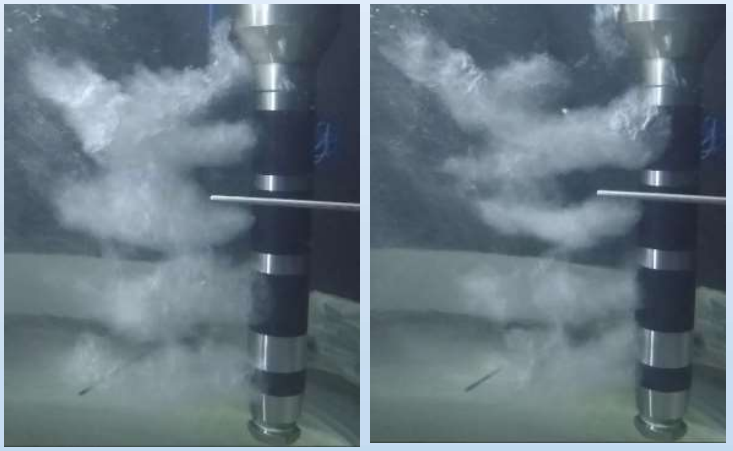


- *Steam condensation in a water pool at 50°C – 30 kPa :*

TEST RESULTS OBTAINED BY THE SMALL SCALE EXPERIMENTAL FACILITY



69.2 °C
24.87g/s
43 kPa



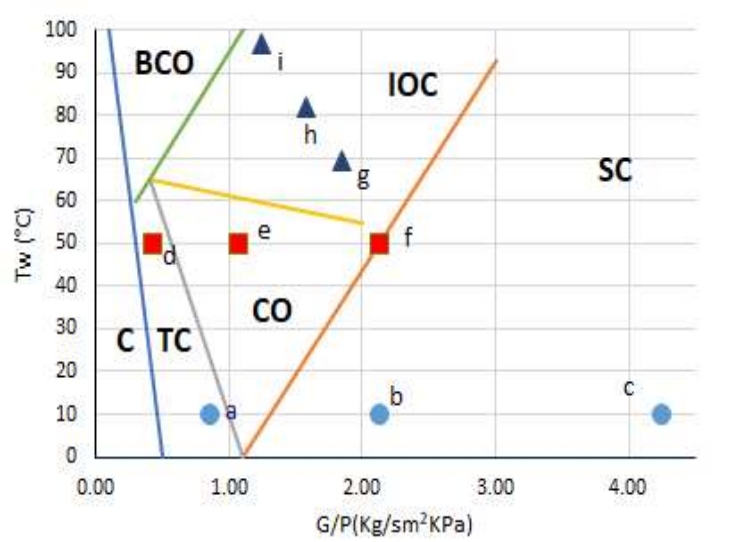
81.7°C
31.79g/s
64kPa

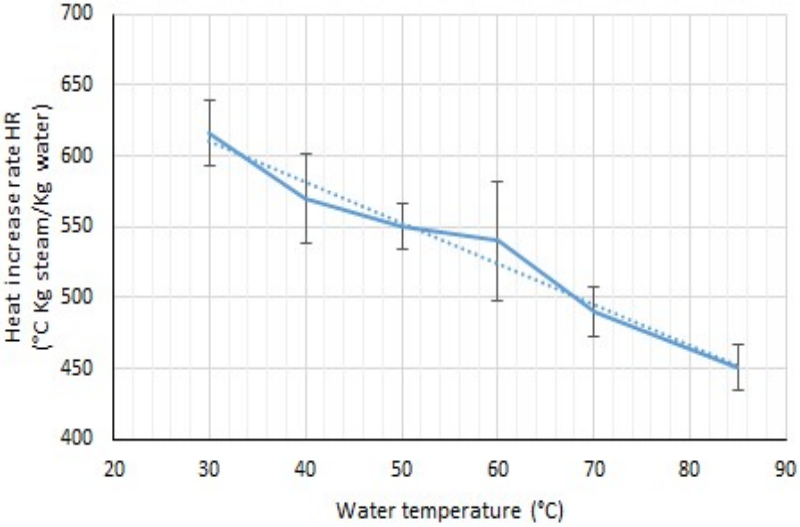
96.7°C -40 g/s -103 kPa

- *Steam condensation regimes*
- Chugging (C)
- Transitional Chugging (TC)
- Bubbling Condensation Oscillation (BCO)
- Condensation Oscillation (CO)
- Stable Condensation (SC)
- Interfacial Oscillation Condensation (IOC)

TEST RESULTS OBTAINED BY THE SMALL SCALE EXPERIMENTAL FACILITY

a)





b)

- *Condensation regime Map (a) and heat increase rate per unit of injected steam mass and unit mass of the water pool (b)*

- $HR(T_W) = 697.8 - 2.92\,T_W$ heat increase rate (diagram b)
- $\Delta T_W(t) = HR\,\frac{M_S(t)}{M_W}$ water temperature increase (Ms, steam mass,Mw, water mass)

SIMILITUDE ANALYSIS OF THE STEAM CONDENSATION AT SUB-ATMOSPHERIC PRESSURE

-water temperature increase, ΔT_W, depends on the water mass in the tank, M_W, and on the steam condensed mass, M_S.
-downstream pressure, P_S, depends on the saturation pressure correspondent to the water temperature, T_W, and on the water head, H_w.

SCALE LAWS

- the steam mass is scaled, as: $M_s(N_s/N_e)$ (being N_s: hole number of the scale sparger, N_e: hole number of actual sparger)
- the steam mass flow rate per hole, q_s, is maintained equal
- the transient duration (in order to have equal injection of energy in the water) is amplified of the factor: $K=(N_e/N_s)/S$ (being N_e: hole number of actual sparger; N_s: hole number of the scale sparger)
- the water head, H_w is maintained equal.

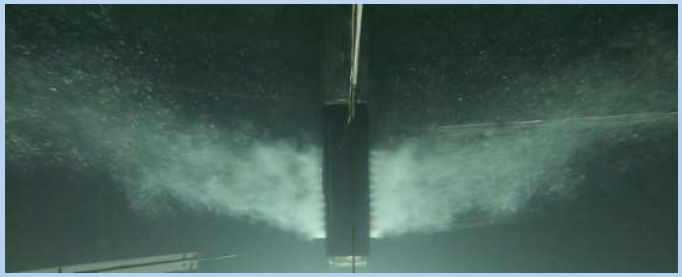
LARGE LOCA EVENT SIMULATED IN THE LARGE SCALE FACILITY

Extrapolation To The Full Scale Pressure Suppression Tank

test TTA17-t=141 s-q=107g/s-T_W=11.7°C

test TTA17-t=190s-q=140g/s-T_W=11.8°C

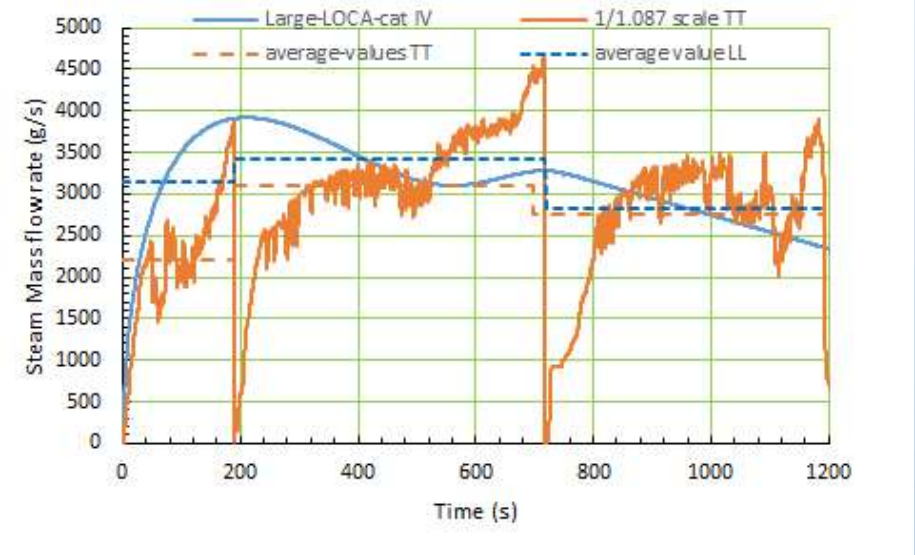
test TTA18-t=4869s-q=449 g/s- T_W=36.4 °C



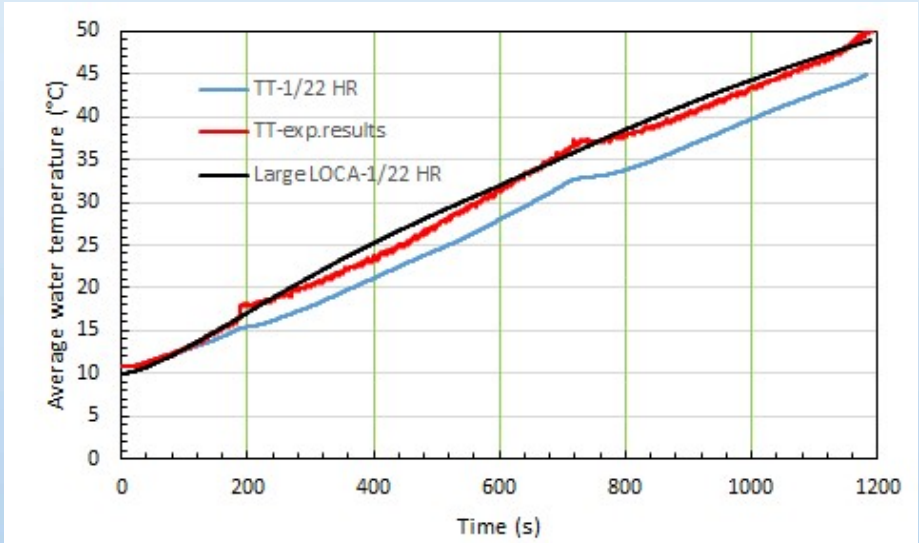
test TTA19-t=41771s-q=359 g/s – T_W=49.2°C

STEAM JET IN THE THREE CONDENSATION TESTS PERFORMED IN THE LARGE SCALE FACILITY

LARGE LOCA EVENT SIMULATED IN THE LARGE SCALE FACILITY

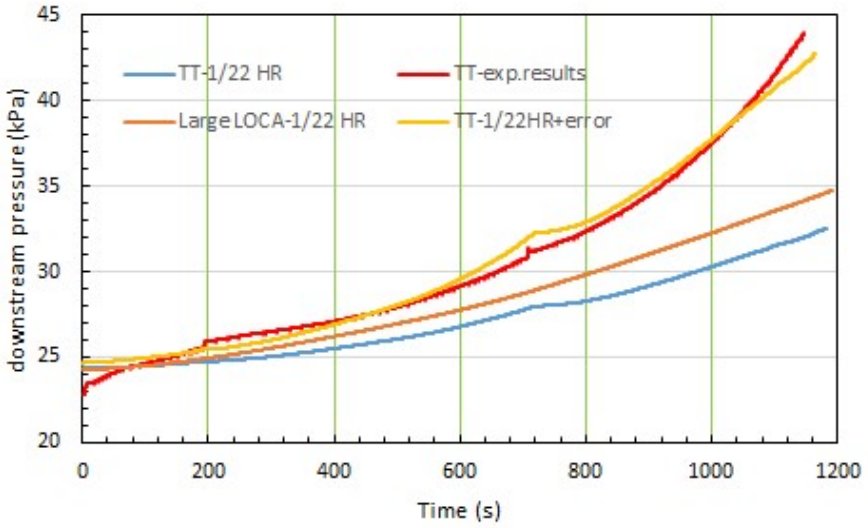


three tests performed in the Large Scale Facility extrapolated to the full scale system by means of the scale laws

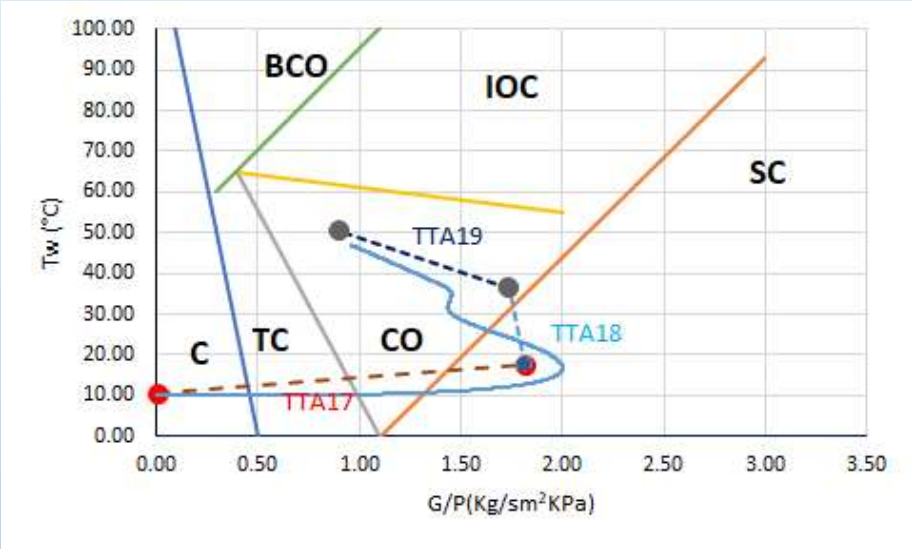


Average water temperature versus time as obtained by the experimental tests applying the scale laws

LARGE LOCA EVENT SIMULATED IN THE LARGE SCALE FACILITY

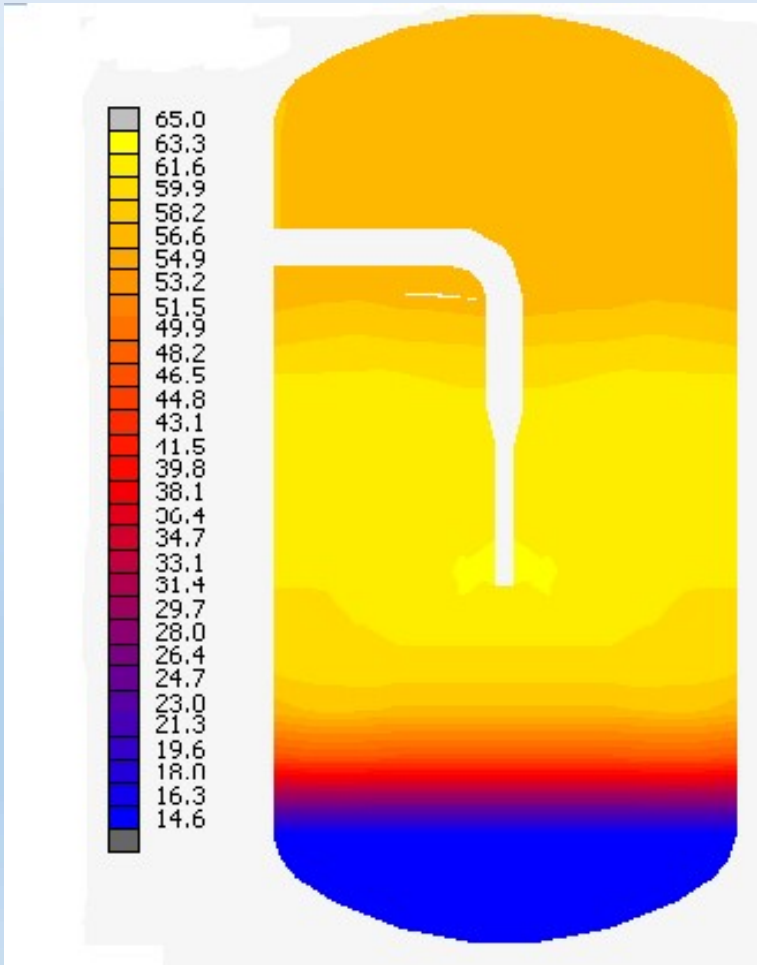


downstream pressure versus time as obtained by the experimental tests and applying the scale laws



Comparison of the condensation regimes: three tests performed in LSF and Large LOCA scenario

LARGE LOCA EVENT SIMULATED IN THE LARGE SCALE FACILITY



Distribution of temperature inside the condensation tank (t=1168s)

- the axial temperature stratification reaches the maximum value in correspondence of the water free surface (65°C while the average temperature is about 50°C) .
- the saturation pressure and the pressure in the void space depends on this temperature value (65°C)
- -the water mass near the bottom (about the 10-15%) partecipates very little to the steam condensation.

CONCLUSIONS

- scale laws (derived from tests with a Small Scale Facility) have been applied to analyse the performances of the Pressure Suppression System in order to manage a Large LOCA scenario foreseen in the Vacuum Vessel of ITER.
- Experimental tests, performed in a Large Scale Facility, simulating the first part of the Large LOCA, have assessed the scale laws
- some discrepancies have been determined in the extrapolation of the results obtained in the reduced scale to the actual system, which depend on.
  - ➢ the stratification of the temperature inside the water pool
  - ➢ the little participation at the steam condensation of a water volume (10-15%) located near the bottom tank.

CONCLUSIONS (2)

- The experimental results obtained by the Large Scale Facility have permitted to quantify the previously mentioned effects.
- A correction factor has been determined which permits to fit very well the extrapolated values of downstream pressure and the water temperature with the experimental ones.