ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

Transition from forced to natural circulation assessment in CIRCE-THETIS experimental facility

Preliminary experimental results

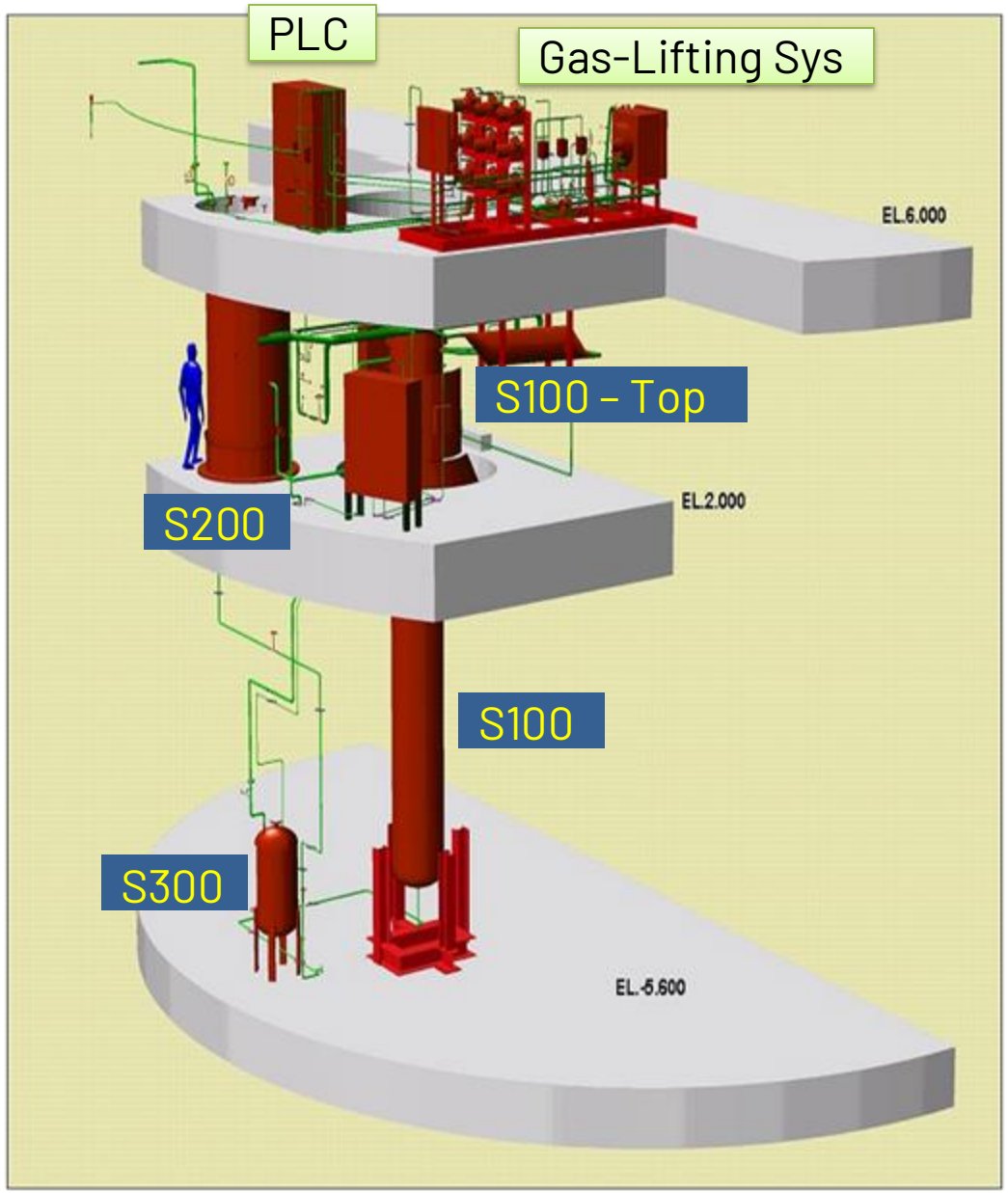
IAEA Technical Meeting on Advances and Innovations in Fast Reactor Design and Technology
Vienna, 29.09-03.10.2025

Alessandro Bellomo (ENEA/UNIPI), Ivan Di Piazza, Daniele Martelli, Mariano Tarantino
Speaker: Simone Gianfelici

CIRCE Infrastructure

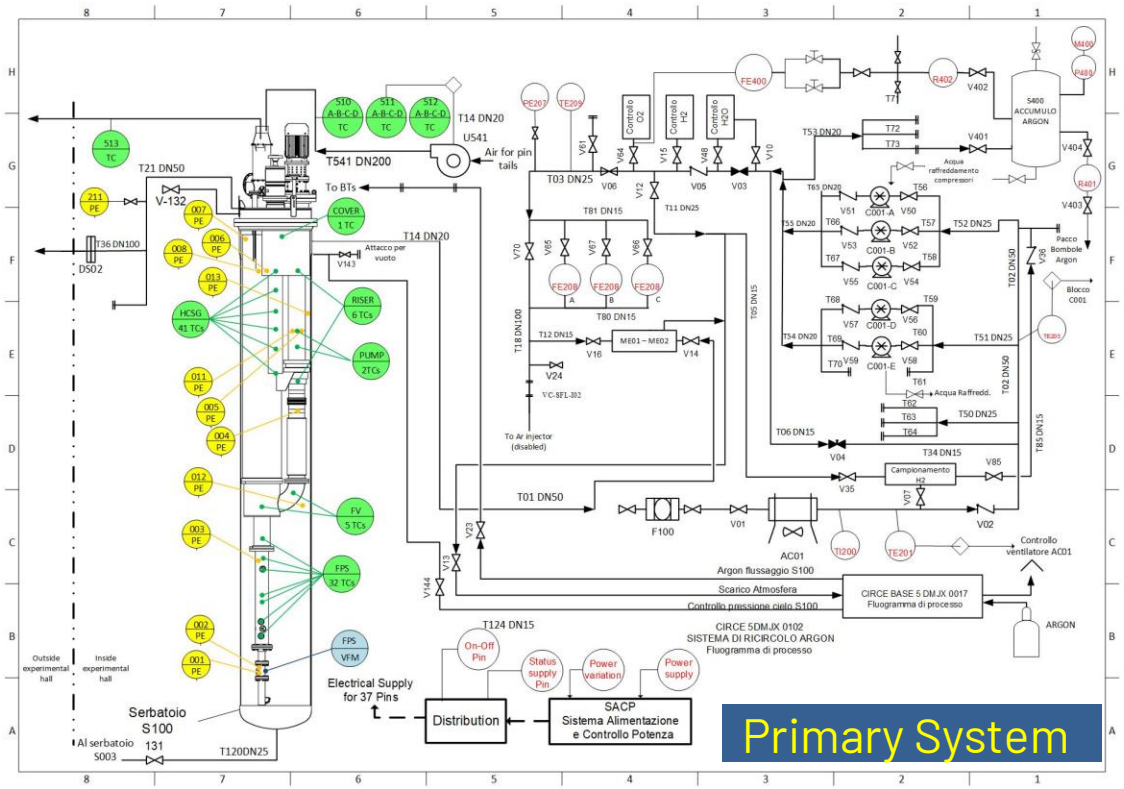
Fill&Drain/Storage system

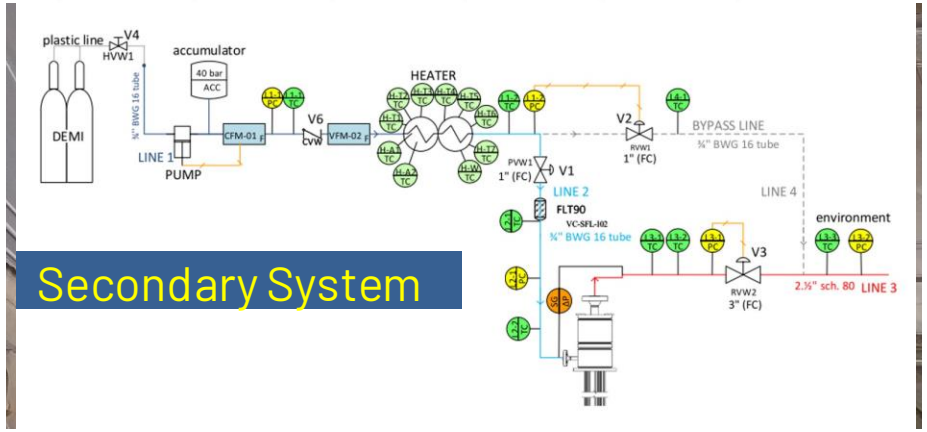
- S200 – Storage tank for **90 tons** of Lead Bismuth Eutectic (LBE) alloy
- S300 – Transfer tank to perform several load cycles, transferring the LBE from S200 to S100 and vice versa
- S100 – Main Vessel (CIRCE) design to host different test sections for each experimental campaign, **8.1 m** LBE pool level, **450°C** LBE pool temp., 0.1 barg cover gas



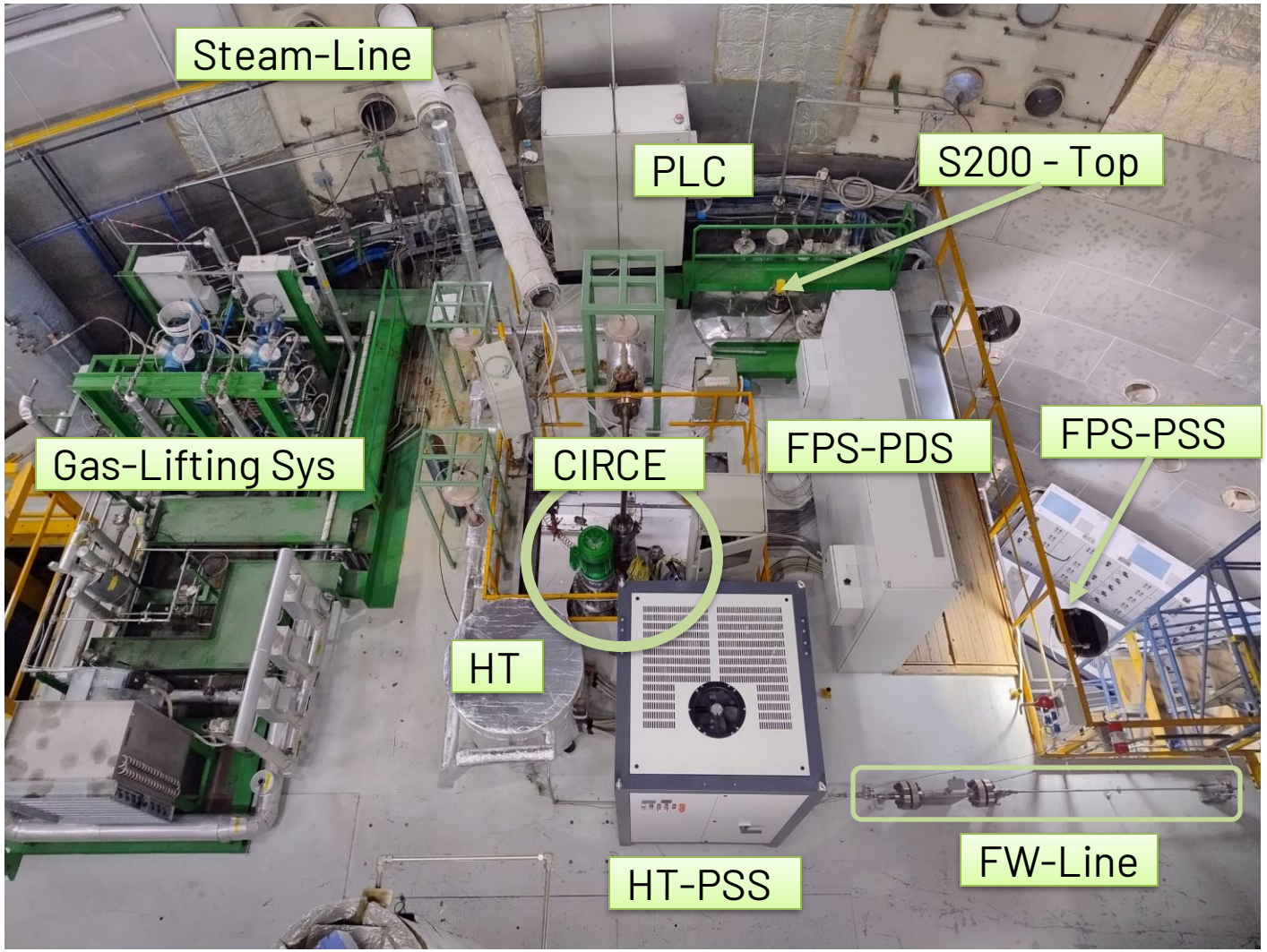
CIRCE-THETIS

- It is the only facility in Europe that replicates the primary and a significant portion of the secondary side of a pool-type lead-cooled fast nuclear reactor (LFR).
- CIRCE is used to study a wide range of accident scenarios and cool-down procedures in LFRs, aiming to demonstrate core cooling capabilities. Furthermore, it is used to test full-scale prototype components (e.g., pumps, HX)
- The data obtained from CIRCE experiments are used to validate thermal-hydraulic codes, which are crucial for reactor safety analysis and design.





CIRCE – Experimental hall



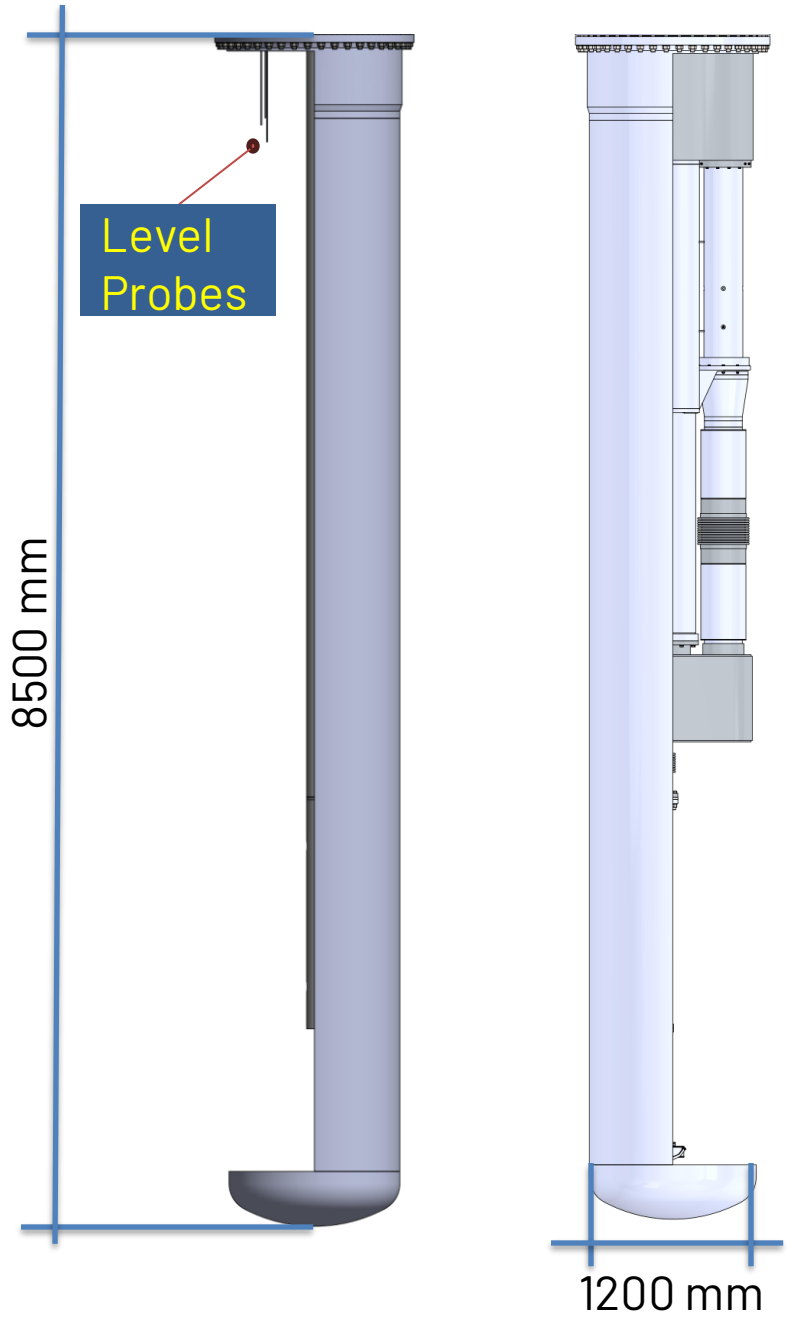
CIRCE S100 – Main vessel

Main Vessel – S100

Geometric parameters

Main Vessel - S100	
Inner Diameter	1170 mm
Height	8500 mm
Wall Thickness	15 mm
Material	AISI 316L
Design Pressure	16 bar
Design Temperature	450°C
LBE Inventory	83 500 kg
Working fluid	LBE

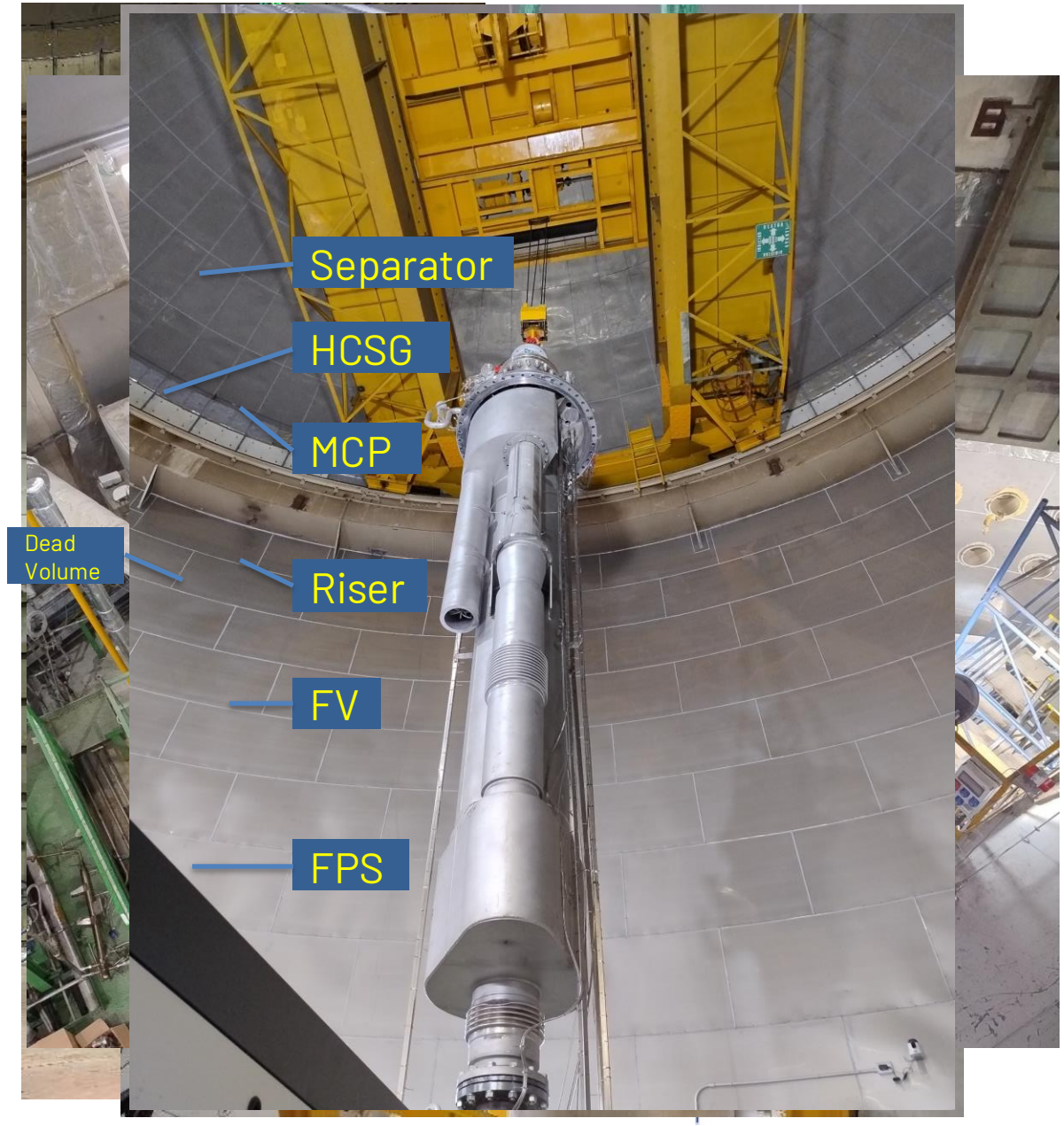
Lead-Bismuth Eutectic (LBE)



THETIS Test Section

Primary System flow-path

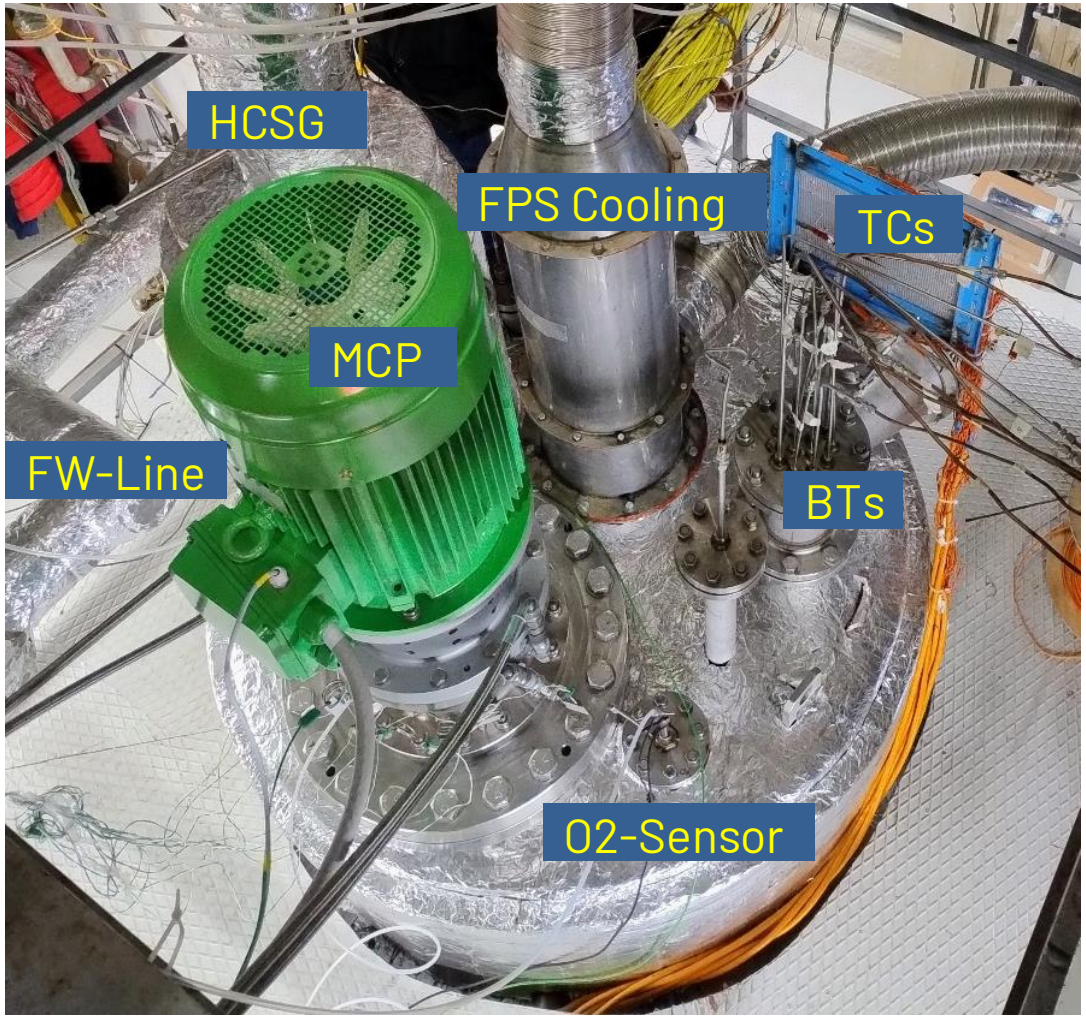
- FPS – Fuel Pin electric Simulator (core). Hexagonal bundle, 37 pins, 25 kW/m, 8,2 mm O.D, P/D=1,8.
- FV – Fitting volume, to collect the LBE coolant exiting the core
- Riser + MCP – Main Coolant vertical axial flow Pump, 120 kg/s, 1.5 barg head
- Separator - the hot pool of the LFR simulator
- HCSG – shell & Helical Coil tube Steam Generator, 450 kW, 0.3 kg/s, 90 barg



THETIS – Cover Flange

The cover flange of THETIS has in total n. 7 penetrations, to host and assembly the components of the primary system, the auxiliary systems and the instrumentations.

The cover flange and the HCSG collector are thermally insulated



Main Coolant Pump

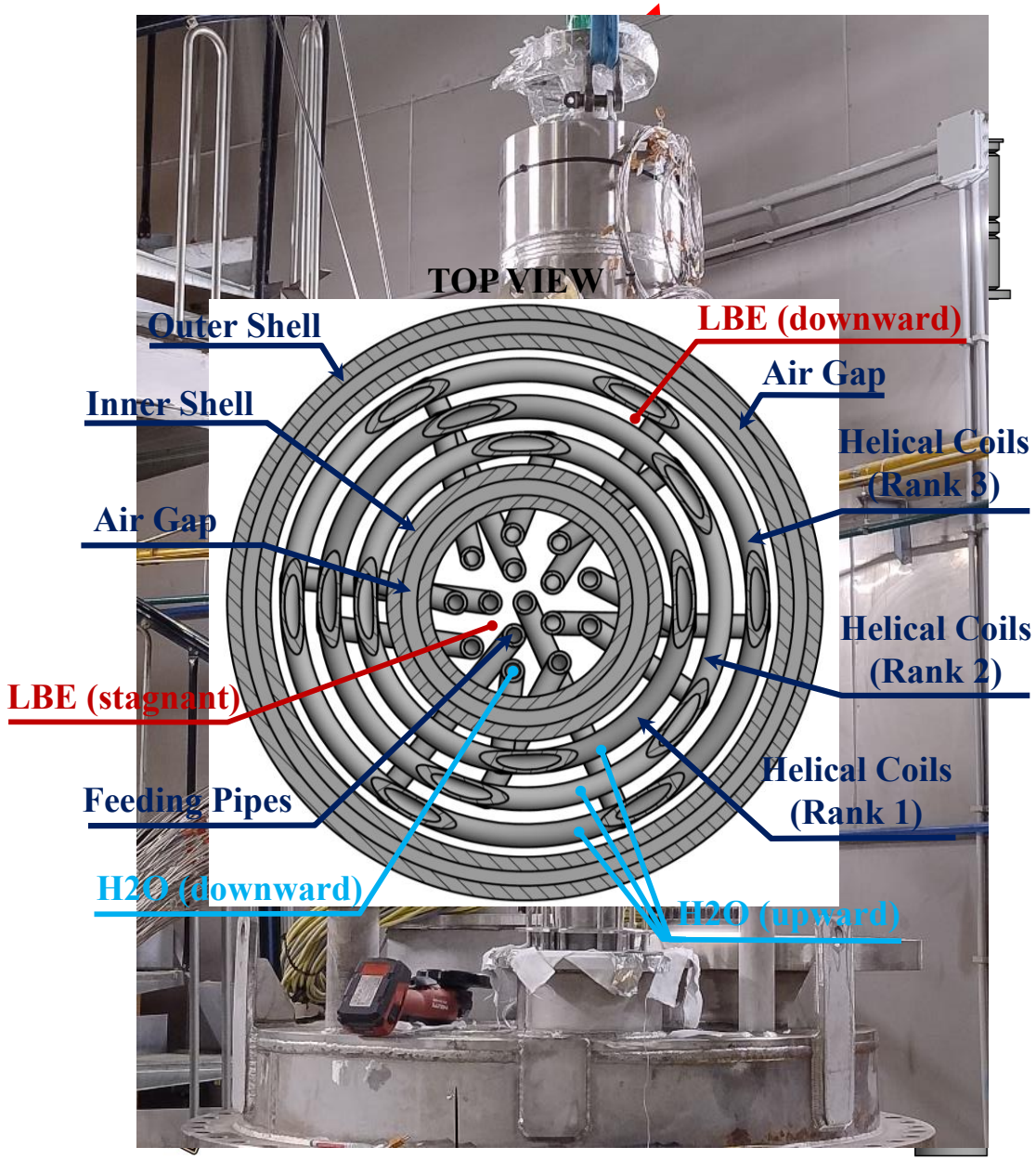
Design parameters
Instrumentation

MCP – Geometry & T-H	
Inner Diameter	300 mm
Height (O. A.)	4000 mm
Motor Power	30 kW
Material	AISI 316L
Head	> 1.5 barg
Design Temperature	450°C
LBE Mass flow rate	> 100 kg/s

HCSG

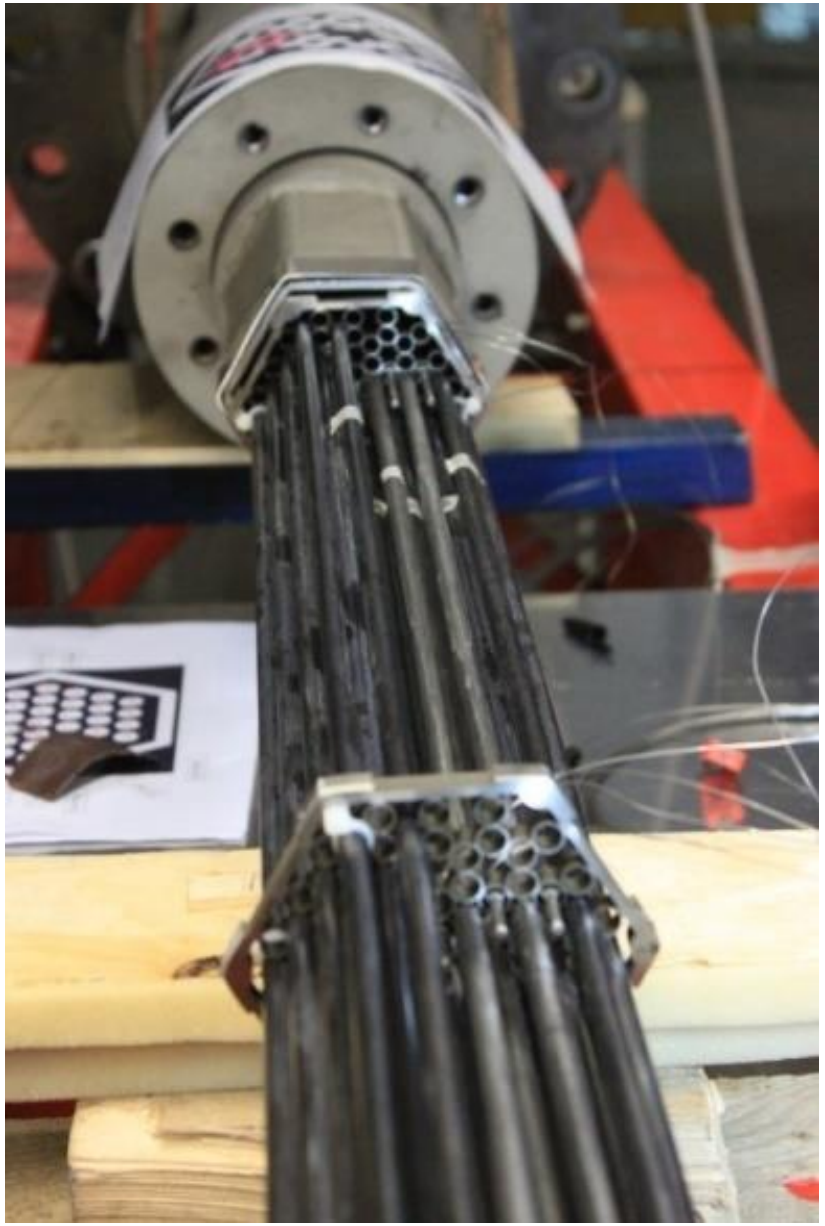
Geometric parameter

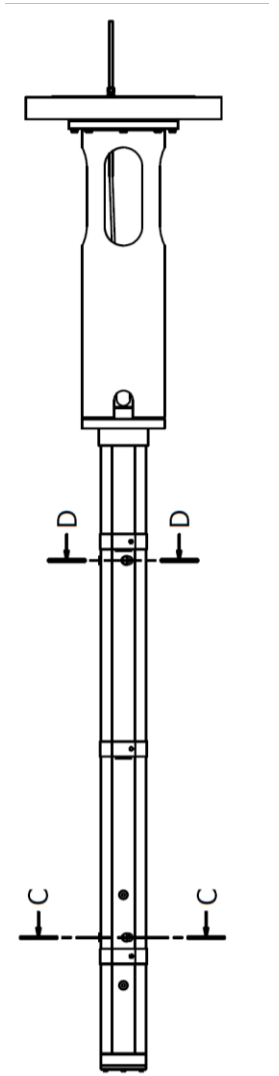
HCSG – Geometry & T-H	
Tube I. D.	6.22 mm
N.° Tubes	15
N.°Rank (tube/rank)	3 (4-5-6)
Rank D.	130–160–190 mm
Rank Pitch	15 mm
Active Length Tot.	27 – 33 – 39 m
Thermal Power	400 kW
Pressure	90 bar
T inlet	300°C
T outlet	400°C
FW Mass flow rate	0.23 kg/s



Fuel Pin Simulator

FPS	
N. Pin	37
Active length	1000 mm
Linear Power	25 kW/m
Current	DC
Material	AISI 316
Length (O.A.)	10500 mm

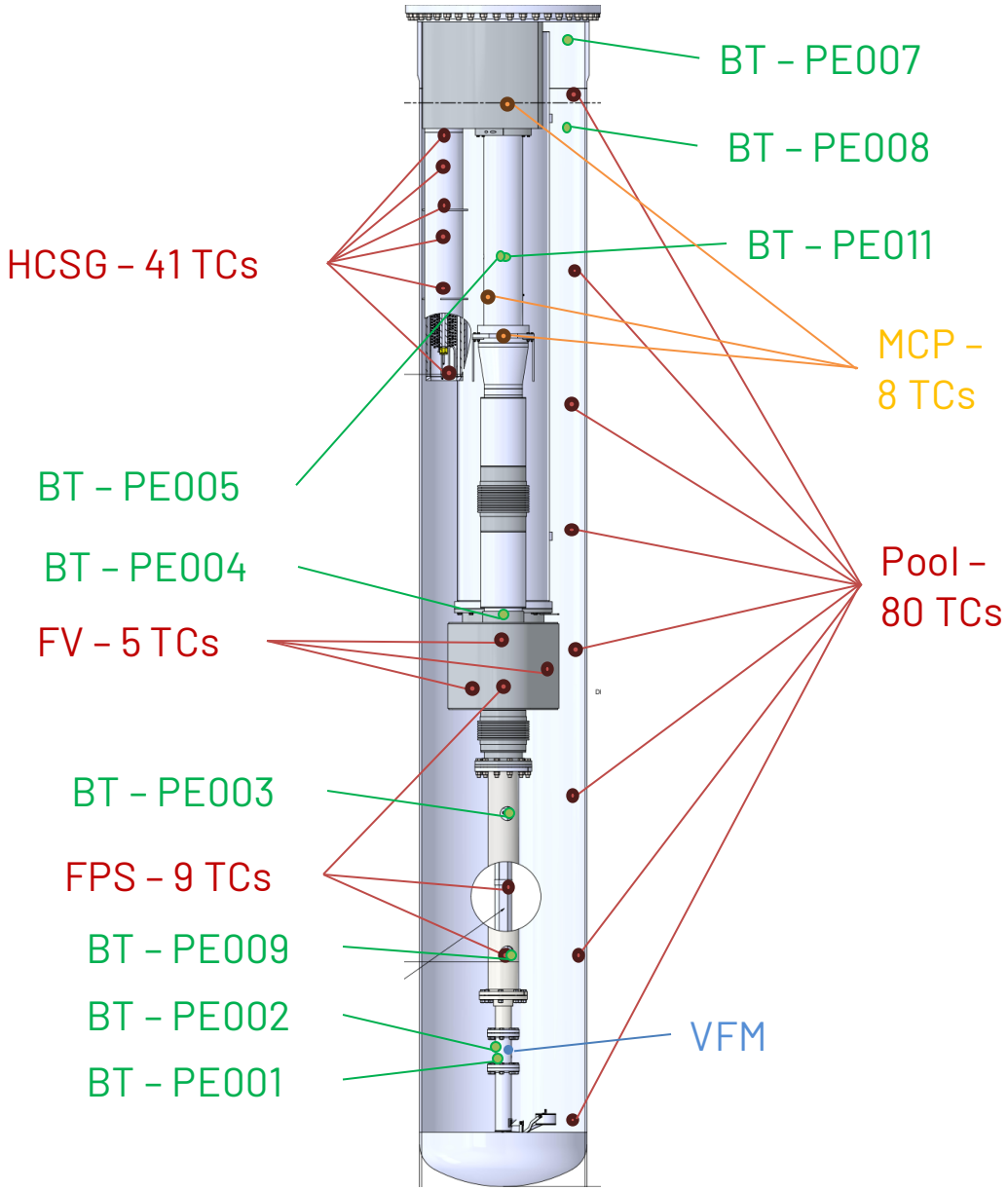


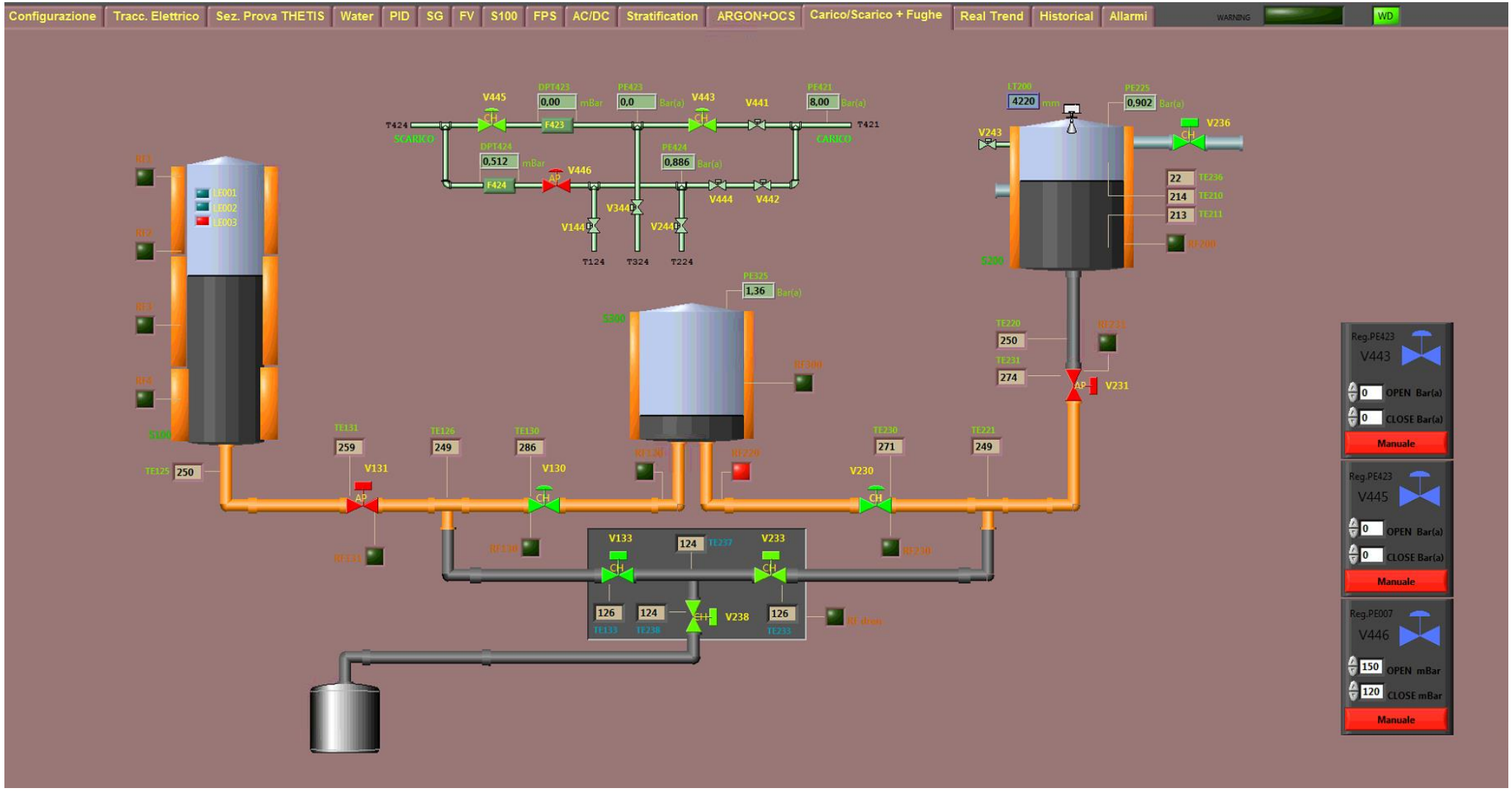


THETIS Instrument.

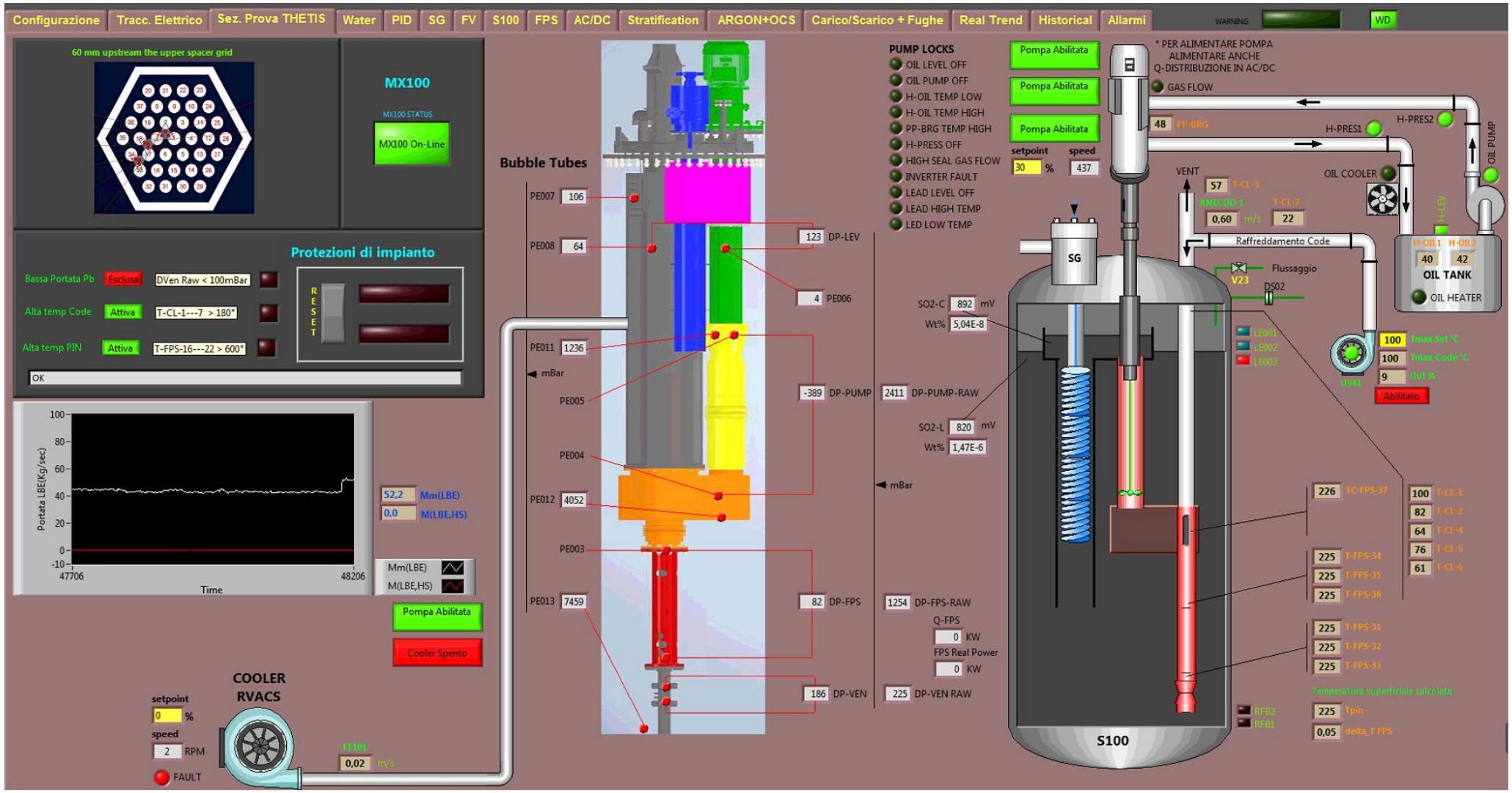
Primary System

- Thermocouples (TC) – The temperature measurement points cover the LBE pool and the flow path.
- Bubble Tubes (BT/PT) – These probes are used to measure static & total pressures, pressure drops across the components
- Oxygen Sensors (SO2) – To monitor the %wt oxygen content into the LBE pool
- Level sensors – to monitor the pool's free levels during operations
- Venturi Flow Meter – to measure the LBE mass flow

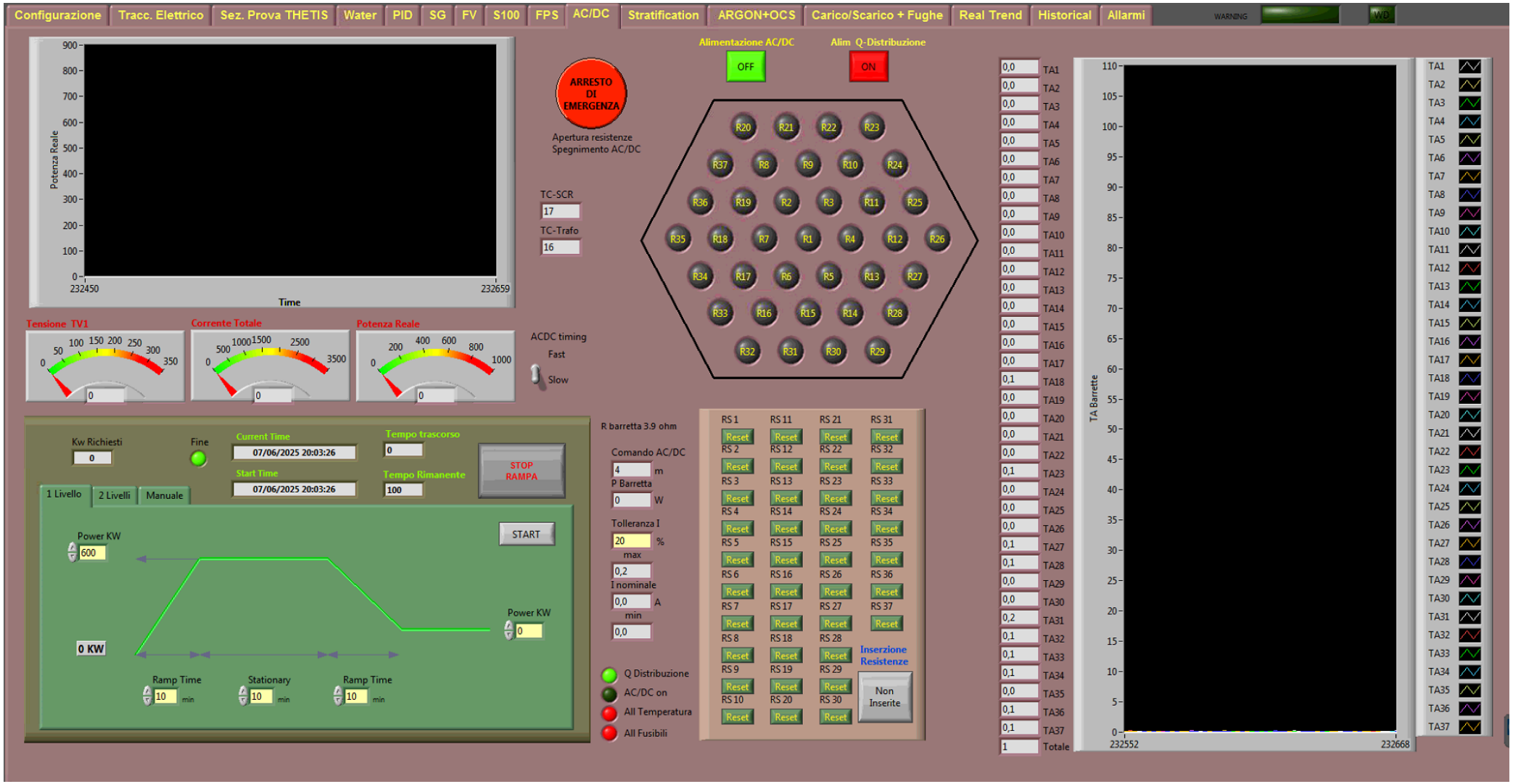




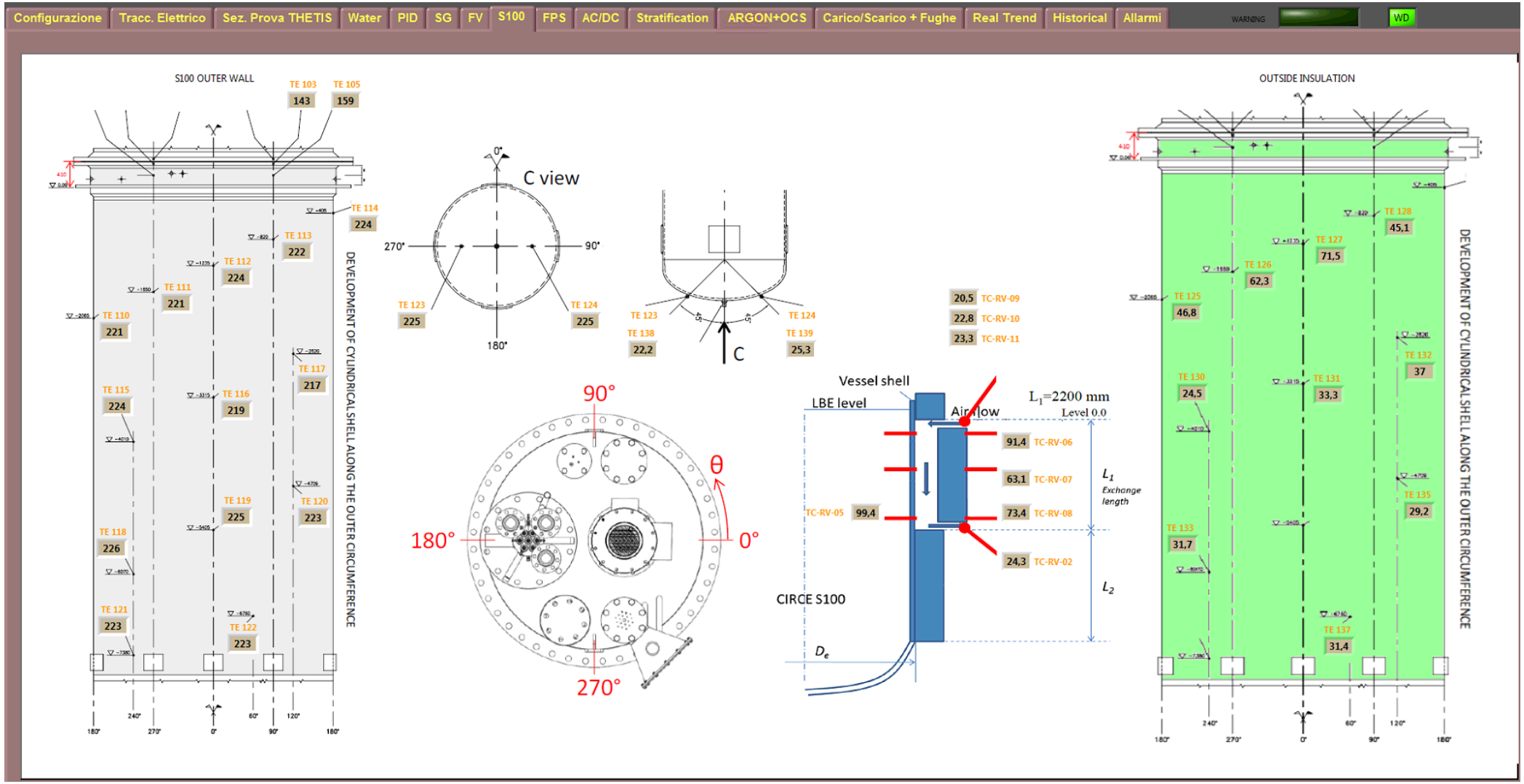
CIRCE-THETIS SCADA view – Fill&Drain control panel



CIRCE-THETIS SCADA view – Primary system control panel



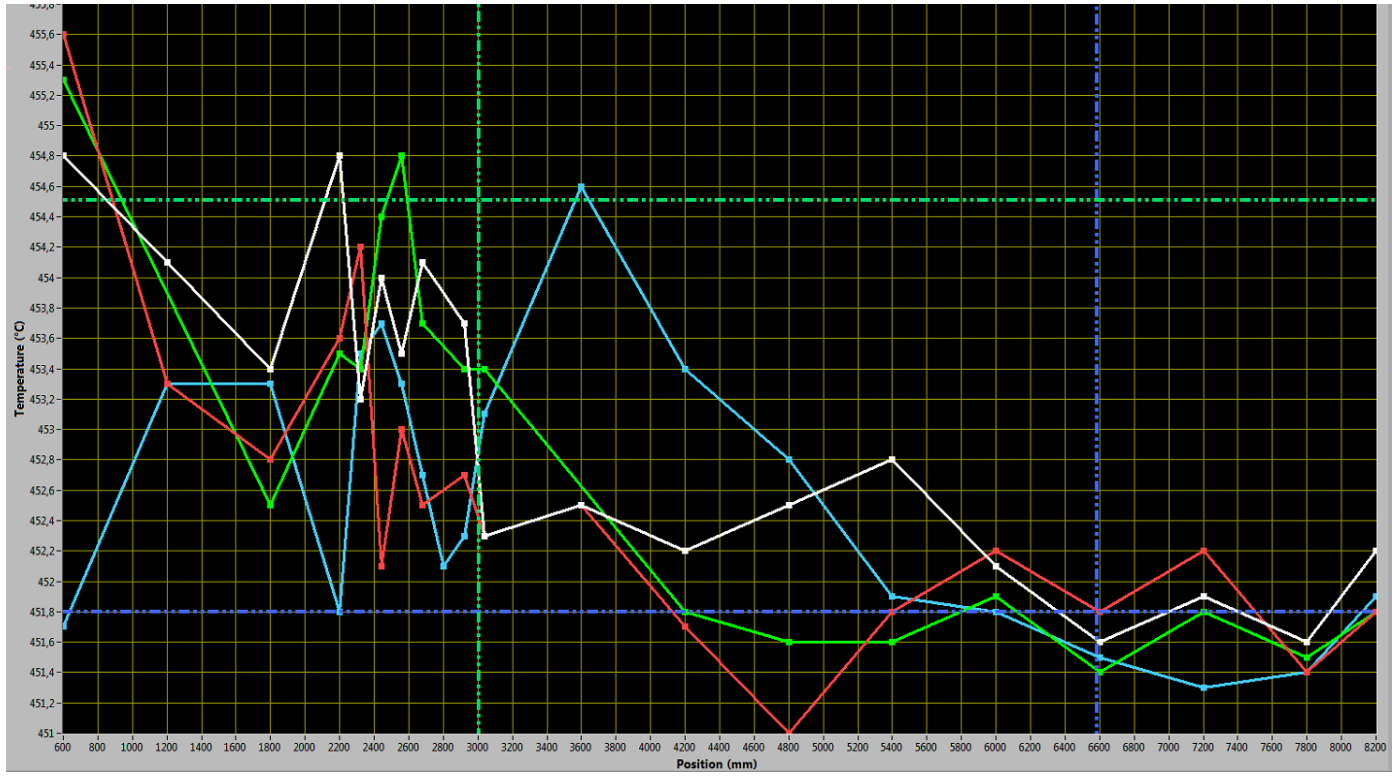
CIRCE-THETIS SCADA view – FPS control panel

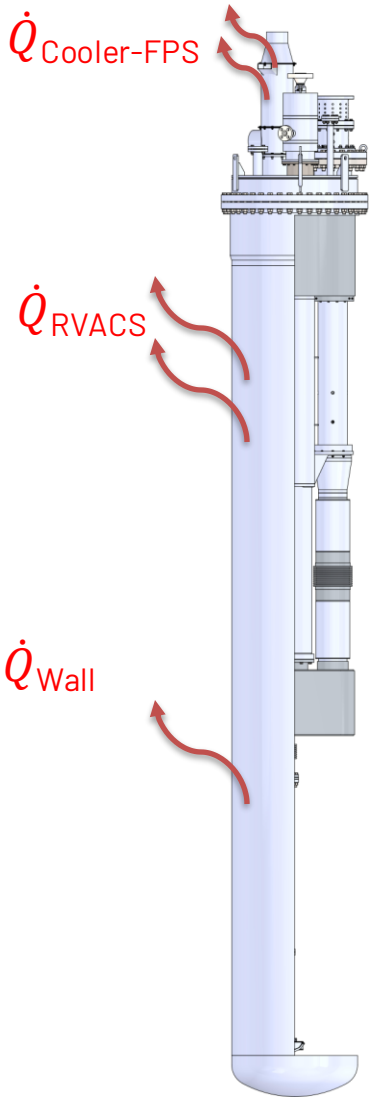


CIRCE-THETIS SCADA view – Inner wall / Outer wall / RVACS temperatures control panel

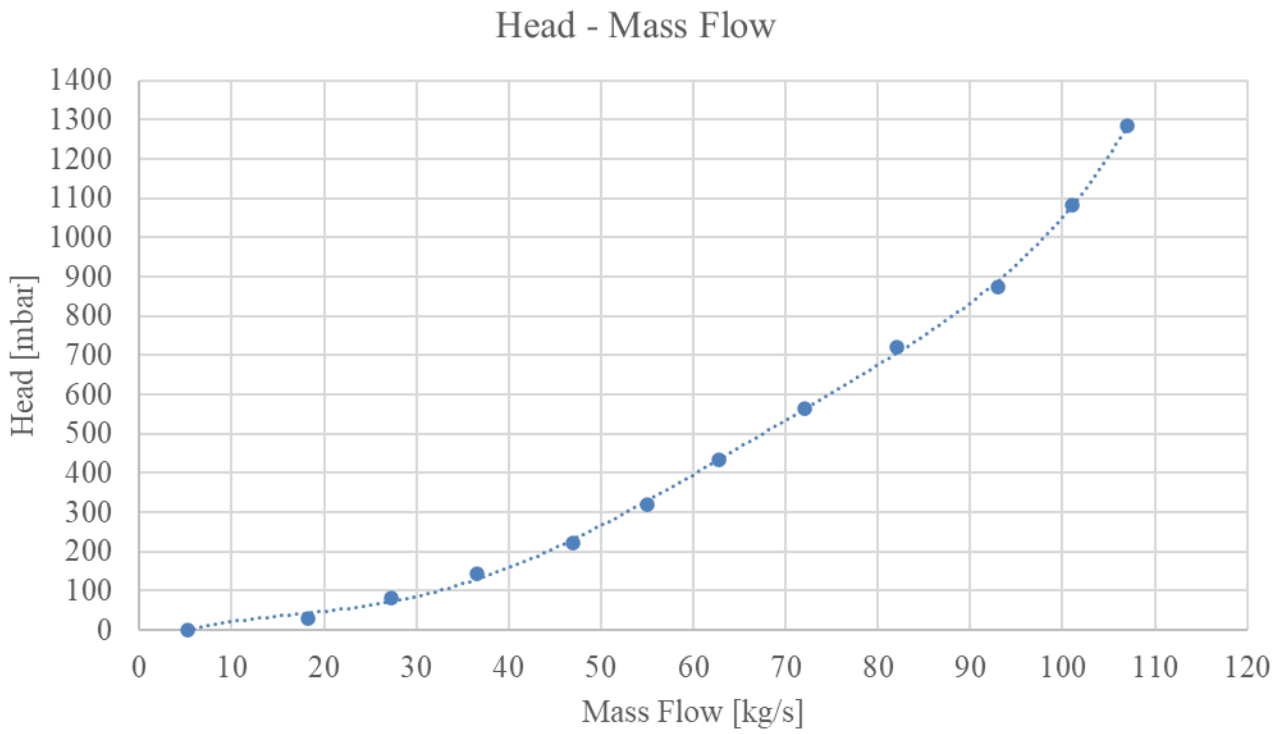
Heat losses preliminary results

Steady State	FPS [kW]	MCP [kg/s]	Pool Temp. [°C]	ΔT_{FPS} [°C]
#1	25	35.7	410	5
#2	50	35.7	450	9.5



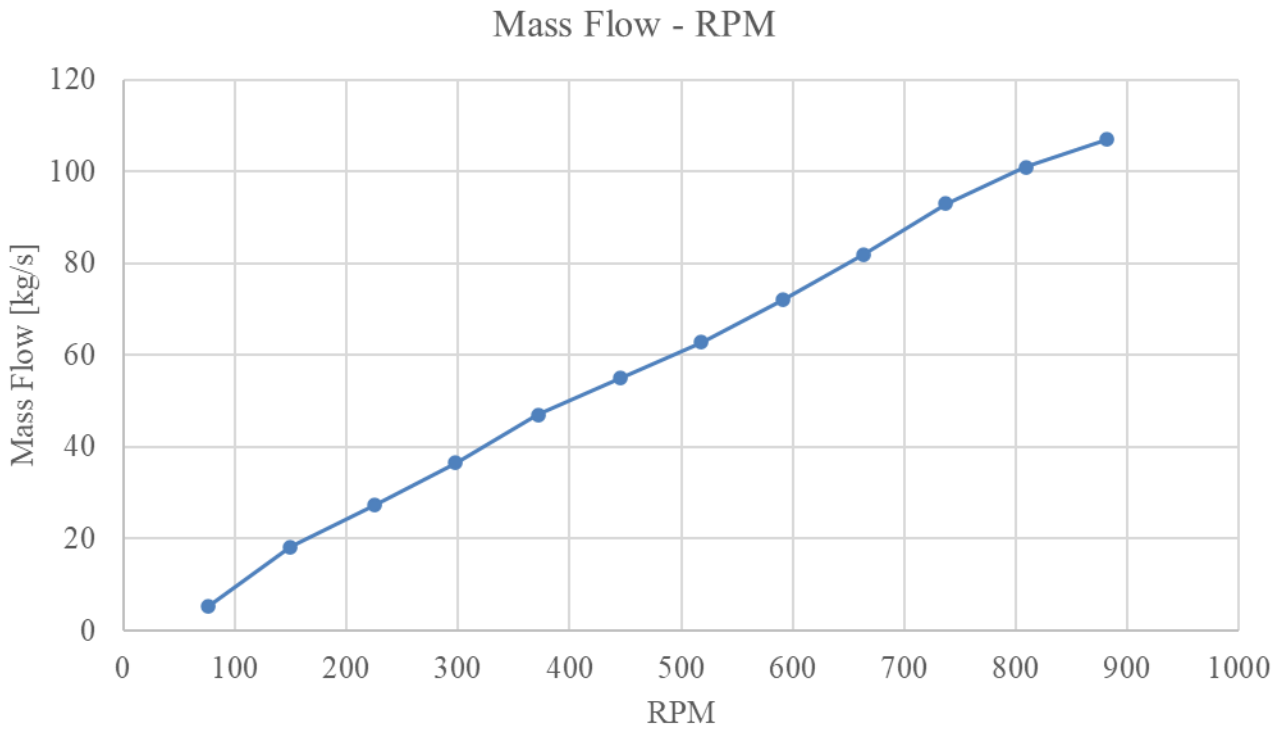


MCP performance preliminary results 1/2



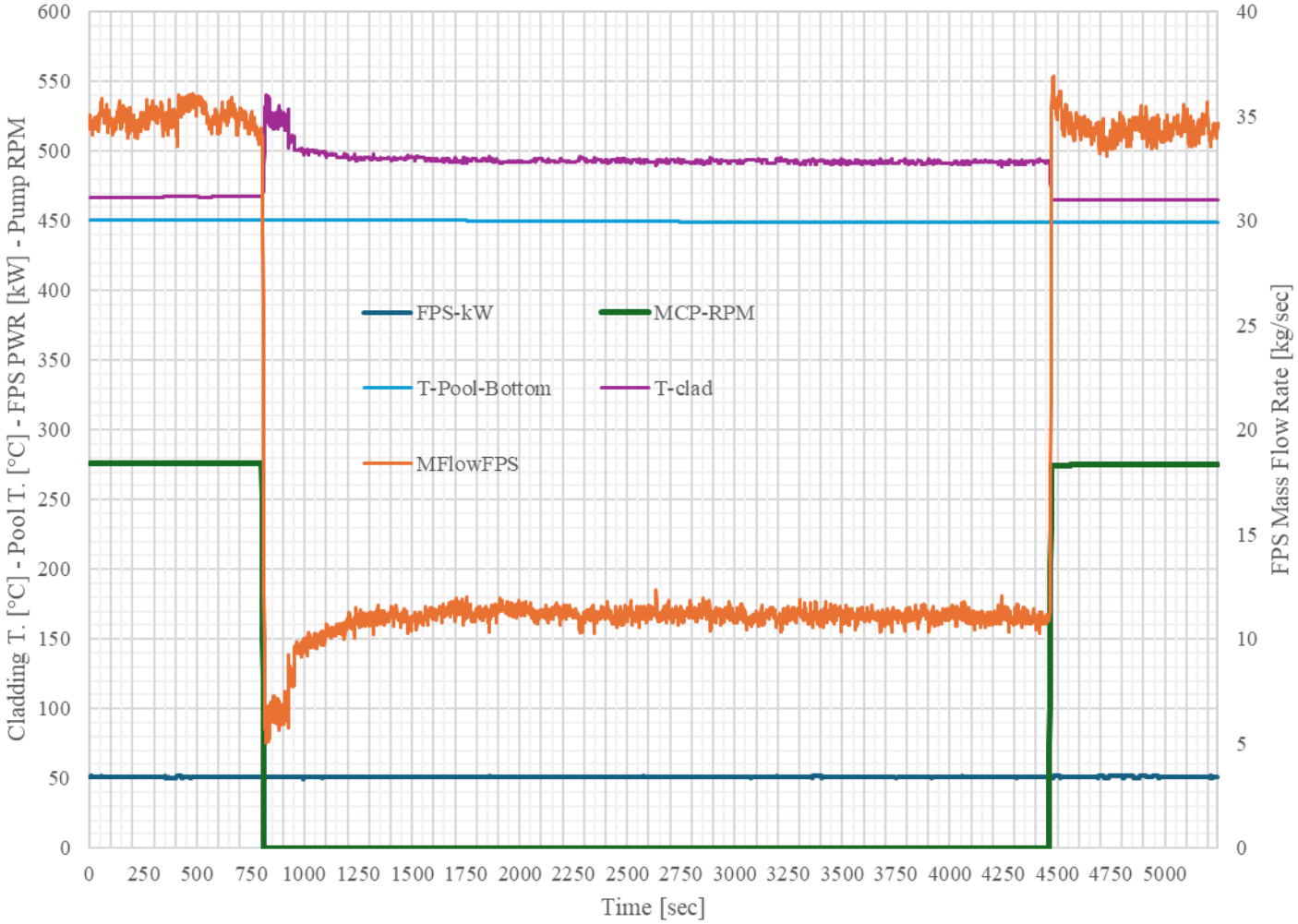
The test is conducted by imposing different rotation speeds, changing the RPM setpoint.
The measurement of the head is obtained by a differential pressure transducer coupled with two BTs across the impeller of the MCP. The nominal flow rate considered for the Test Matrix is 35.5 kg/s.

MCP performance preliminary results 2/2

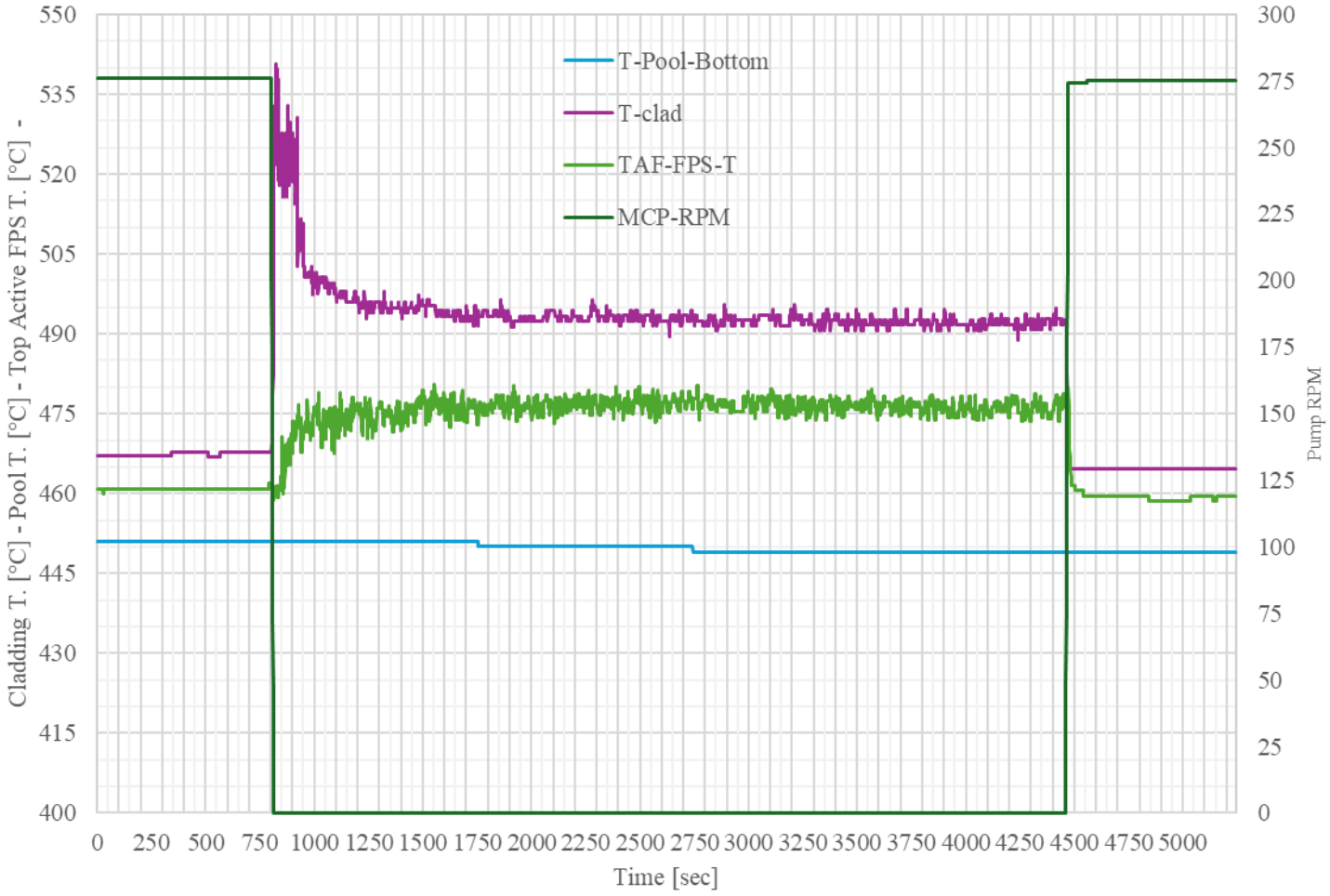


The test is conducted by bringing the pump up to 60% of the max RPM available, because the difference between the separator level and downcomer level at that regime is such that the protection in case of impeller uncovery causes the trip of the MCP. Furthermore, the Venturi flow meter is designed to measure up to 100 kg/s.

Transition from FC to NC – 50 kW FPS Power 1/2



Transition from FC to NC – PCT 2/2



CIRCE-THETIS test matrix (in post-processing)

Test	Description	FPS	MCP	FWP	RVACS
Steady-State	After completing the start-up of the HCSG, the plant is gradually transitioned to its full-power operating state	458 kW	36 kg/s	0.23 kg/s	0.05 kg/s
A	From full power – LOF – HCSG as DHR	458 kW to 88 kW	36 kg/s to NC (13.5 kg/s)	0.04 kg/s	0.05 kg/s
B	From full power – LOF & LOHS (HCSG) - RVACS as DHR	458kW to 88 kW	36 kg/s to NC (12-15 kg/s)	Off	0.5 kg/s
C	From DHR with HCSG – LOHS – RVACS as DHR	88 kW	NC (13 kg/s)	0.04 kg/s to off	0.5 kg/s
D	From full power – LOF – HCSG & RVACS as DHRs	458 kW to 88 kW	36 kg/s to NC (13.8 kg/s)	0.027 kg/s	0.33 kg/s

Conclusions

- The facility was commissioned and main performances assessed. It also accomplished the THETIS Test Matrix (post-processing ongoing)
- The performance assessment of the MCP at different regimes has been successful, showing the effectiveness and efficiency of operation of the prototypical pump.
- The CIRCE-THETIS configuration showed a considerable tendency for the establishment of natural circulation. In addition, it is to be noted that the heat losses of the system turns out to be sufficient for the establishment of natural circulation, up to electric core powers of more than 50kW

Thank you for your attention!

Main contact: Alessandro Bellomo
alessandro.bellomo@phd.unipi.it