IAEA TM on

"Benefits and Challenges of Fast Reactors of the SMR Type"

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ALFRED PROTECTED LOSS OF FLOW ACCIDENT EXPERIMENT IN CIRCE FACILITY

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FRAMEWORK OF THE ACTIVITIES

FALCON (Fostering ALFRED CONStruction), an international consortium under the leadership of Ansaldo Nucleare with ENEA (IT) and ICN (RO), is pursuing the re-design of the LFR-DEMO in addition to the definition of an R&D and licensing roadmap.

ALFRED is considered also the prototype of a viable competitive LFR commercial unit in the SMR segment, by 2035-2040.

Among these organizations, CIRTEN (IT) and Servizi di Ricerche e Sviluppo (SRS, IT) takes part as Supporting Organization to FALCON to enhance the R&D activities devoted to ALFRED.

In this frame an R&D activity has been carried out at the CR ENEA Brasimone, aiming at investigating the thermal-hydraulic behavior

INTRODUCTION

- R&D activities carried out at the ENEA Brasimone Research Centre for characterising SGBT performance in steady-state and transient conditions and the pool thermal hydraulics phenomena

- A mock-up of 7 BTs 1:1 in length for ALFRED SG designed, assembled and implemented in HERO test section for the CIRCE facility at ENEA CR Brasimone

- An Experimental Test consisting of Protected Loss of Flow Accident (PLOFA) transitions will be carried out in the framework of the European Project HORIZON2020 SESAME (Simulations and Experiments for the Safety Assessment of MEtal cooled reactors).

Objectives of the activity

- to compare best-estimate TH-SYS code calculations to experimental data, thus, to validate RELAP5-3D© system code in simulating liquid metal pool type FR designs

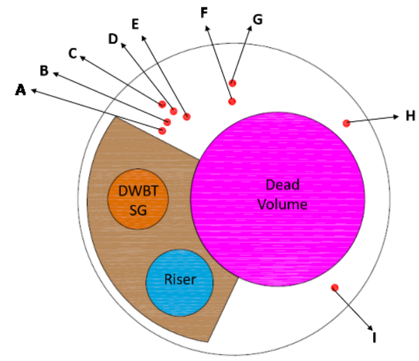
- to assess the reliability of SYS-TH multiD components in modeling transient in LM pool FR

- to identify and, as far as possible, to quantify the code limitations and the source of uncertainties in simulating postulated accidents occurring in heavy liquid metal FR designs

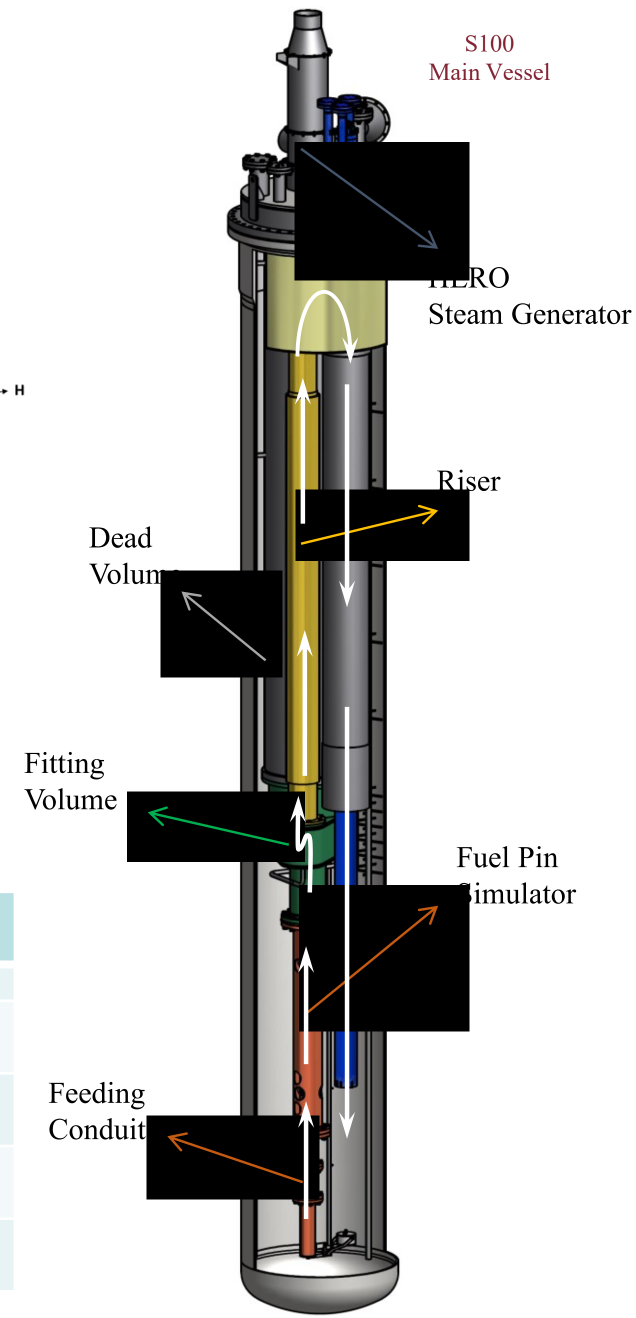
- to improve the understanding of the TH processes and phenomena observed in LOFA test

CIRCE-HERO OVERVIEW

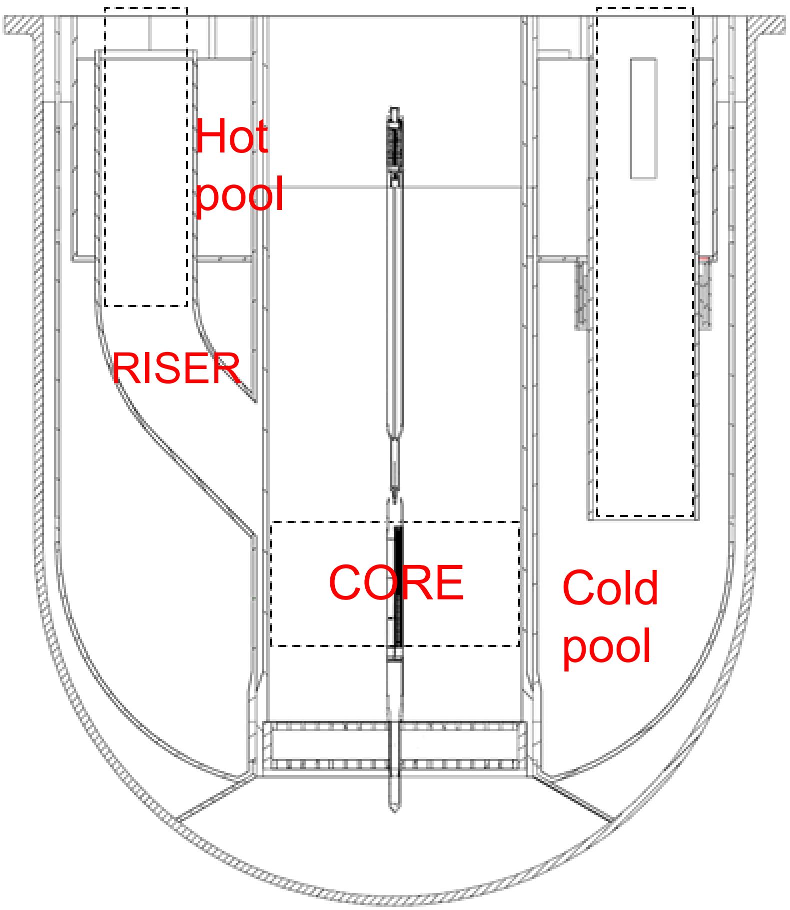
- **Primary circuit**
  - **Feeding conduit**
  - **Fuel Pin Simulator**: 37 electrically heated pins; 800 kW nominal thermal power
  - **Fitting volume:** large not insulated volume
  - **Riser**: double wall with air gap insulated pipe. A nozzle installed at the inlet section allows the argon injection for the LBE circulation enhancement
  - **Separator**: expansion volume where the separation of the two phases occurs
  - **SG**: 7 double wall bayonet tubes (6 m of active length) equipped with leakage monitoring system
- **Instrumentation**
  - 39 thermocouples (TCs) monitoring different FPS sub-channels
  - 42 TCs installed in the SG
  - 119 monitoring the LBE temperature along the whole height of the pool

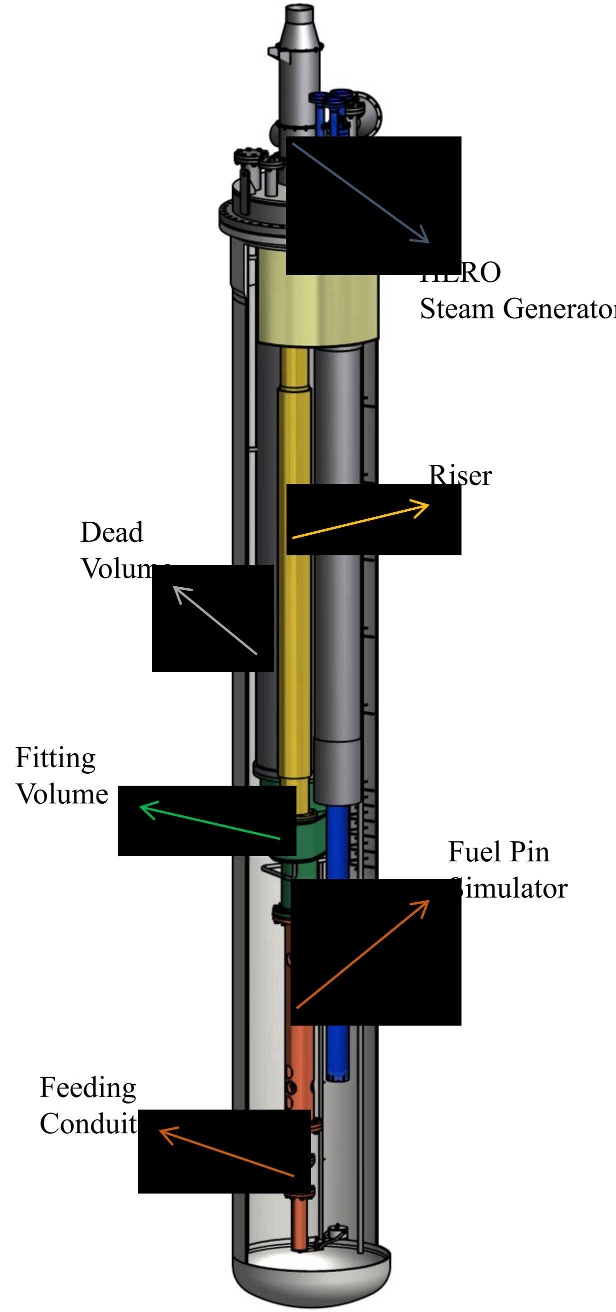


CIRCE Parameters	Value
S100 OD [mm]	1200
S100 height [mm]	8500
Max LBE Inventory [kg]	90000
Temperature Range [° C]	200-500
Operating Pressure [kPa]	15(g)

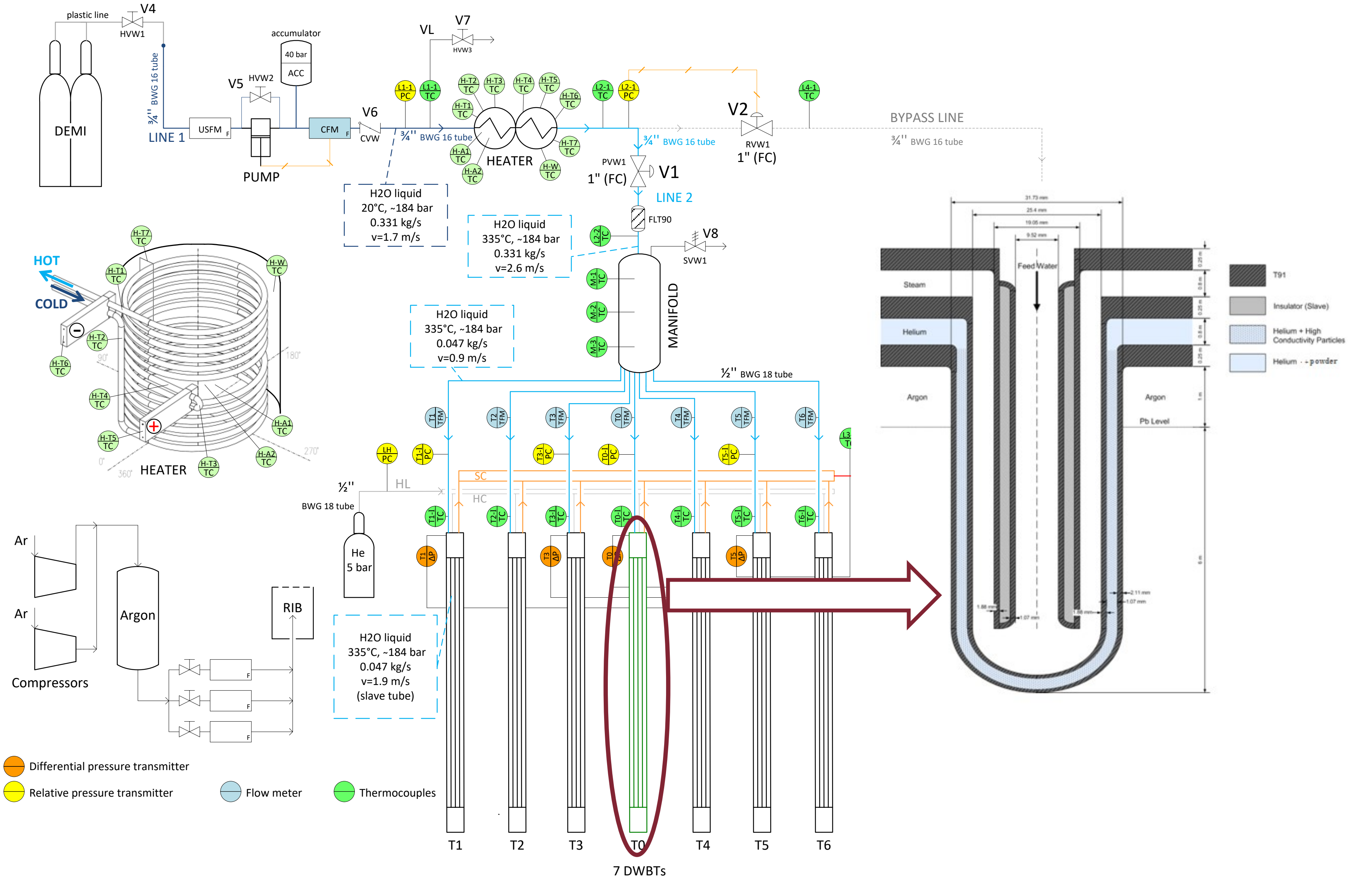


ALFRED RELEVANCE





CIRCE-HERO Secondary circuit Layout



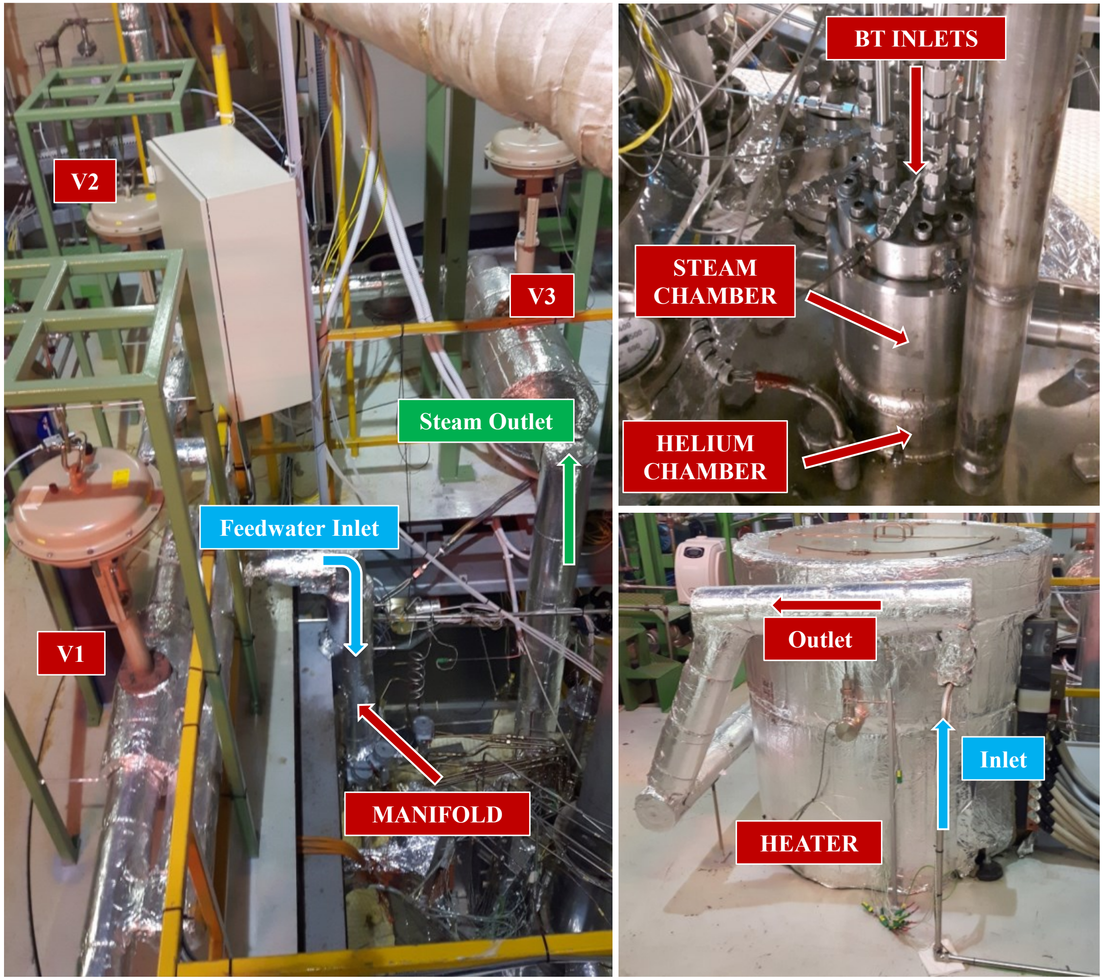
CIRCE-HERO Layout

CIRCE-HERO Secondary Side

Secondary Side Steady State Conditions: water @ 335ºC at SGBT inlet and @172 bar at SGBT outlet, water mass flow rate 0.33 kg/s.

Secondary system composed of:

- a demineraliser;
- an alternative pump with an accumulator and a check valve;
- a helical heating system (HEATER)
- a MANIFOLD with seven outlet ½" tubes connected to the BTs of SGBT;
- a 3" discharge line equipped with a regulation valve V3, operated for maintaining upstream about 172 bar;
- a 3/4" bypass line equipped with the regulation valve V2;
- a helium line, for pressurizing the outer gap of bayonet tubes at about 10 bar.

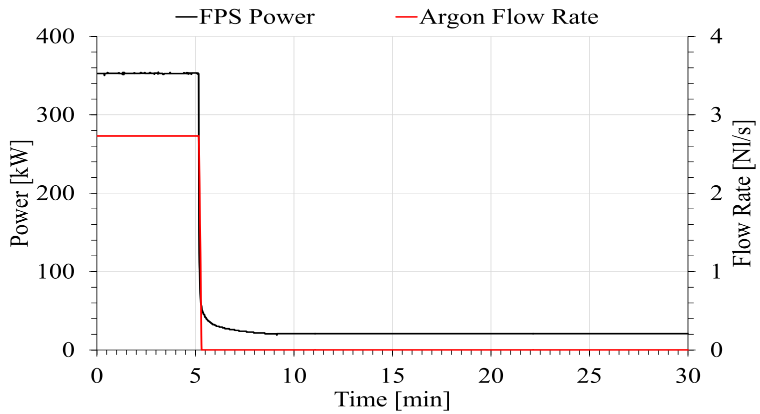


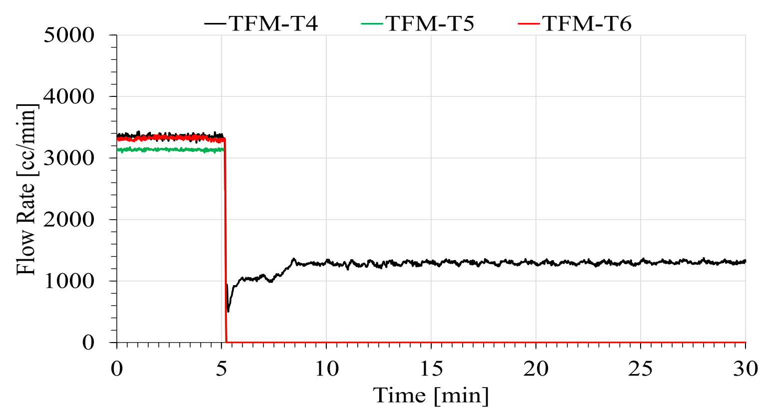
TEST #1 description

PLOFA scenario is reproduced

- FPS power according to a characteristic heat decay curve,
- Loss of the primary pumping system simulated by reducing the argon flow rate from 2.75 Nl/s to 0 in 10 s
- Loss of the primary heat sink simulated reducing the SG feedwater to 30% of the nominal value in 2 s

Parameter	Unit	Before Transient	After Transient
FPS Power	[kW]	352	20
Argon Flow Rate	[Nl/s]	2.75	0
H2O mass flow rate	[kg/s]	0.274	0.095
H2O T inlet SG	[° C]	~336	~336

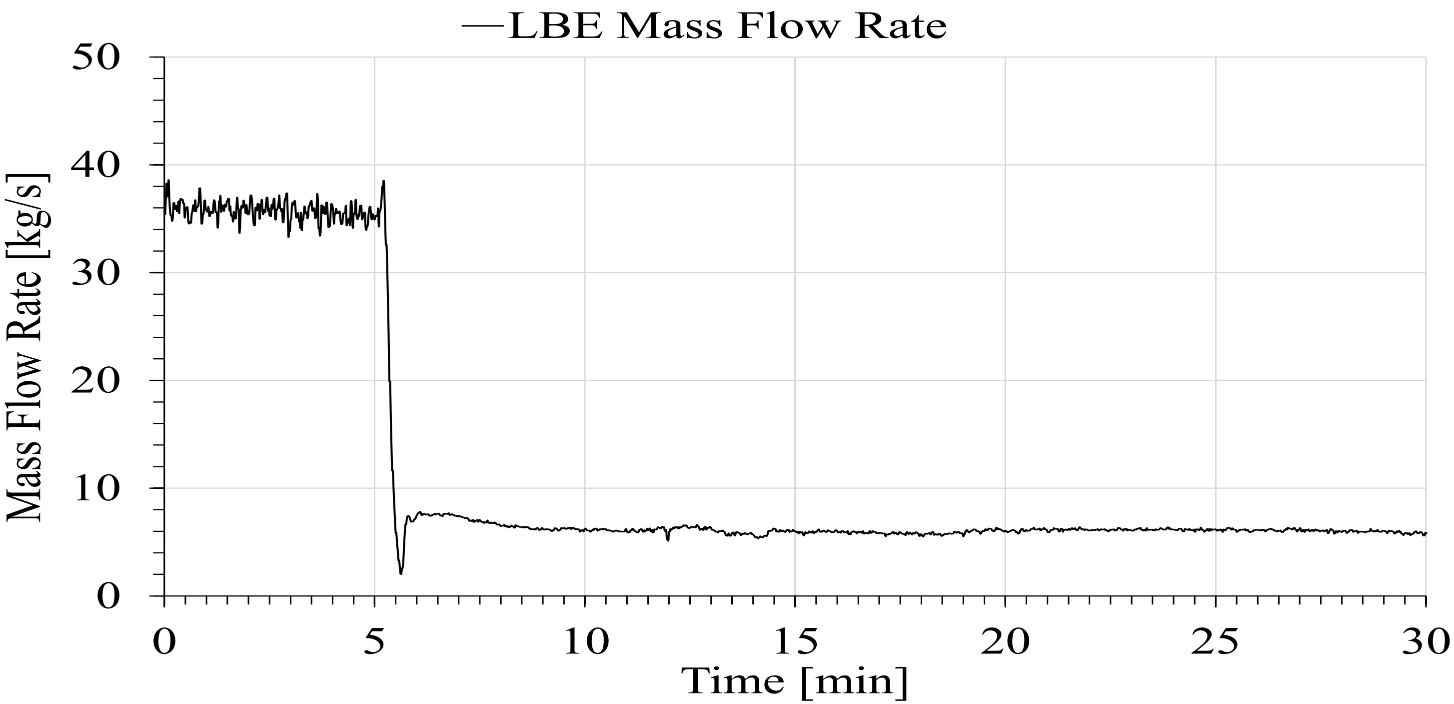




PLOFA EXPERIMENT

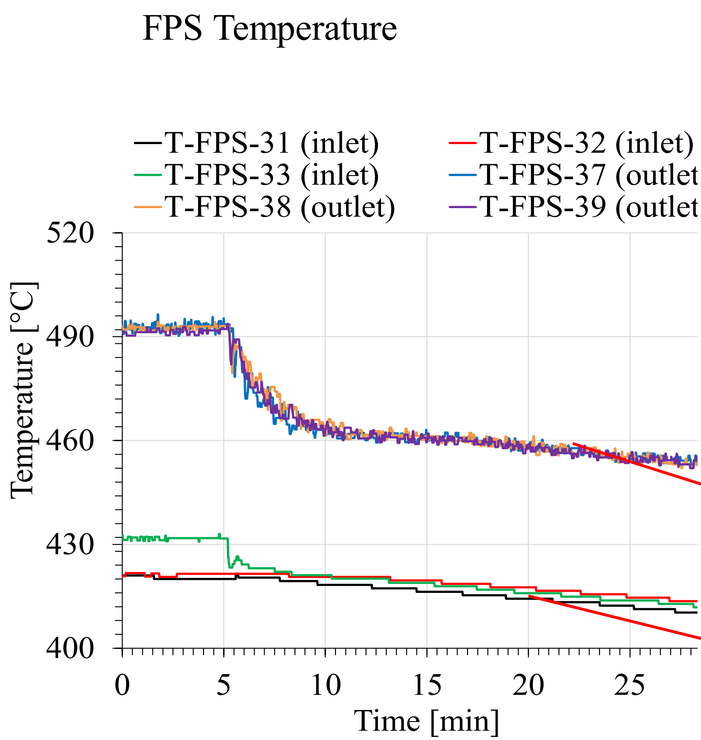
Experimental Results

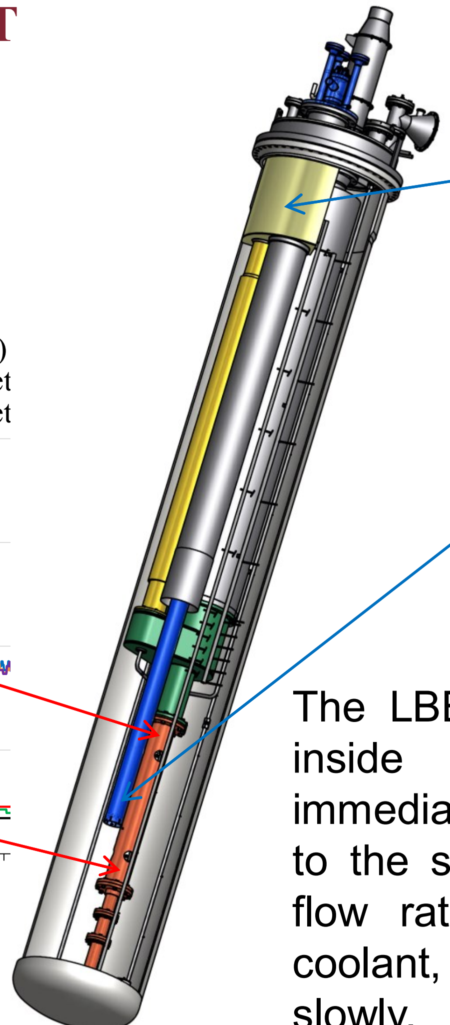
- LBE mass flow rate initial value ~34 kg/s subjected to a sudden decrease due to the argon flow rate reduction
- minimum of 2 kg/s immediately after the gas transition
- final value of about 6 kg/s when the Natural Circulation (NC) regime is established

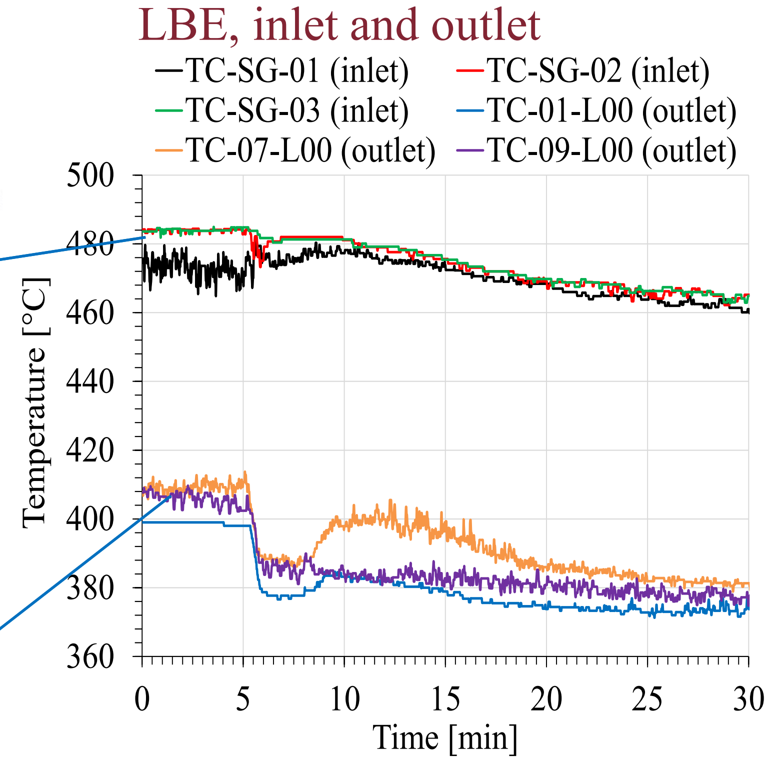


PLOFA EXPERIMENT

Experimental Results







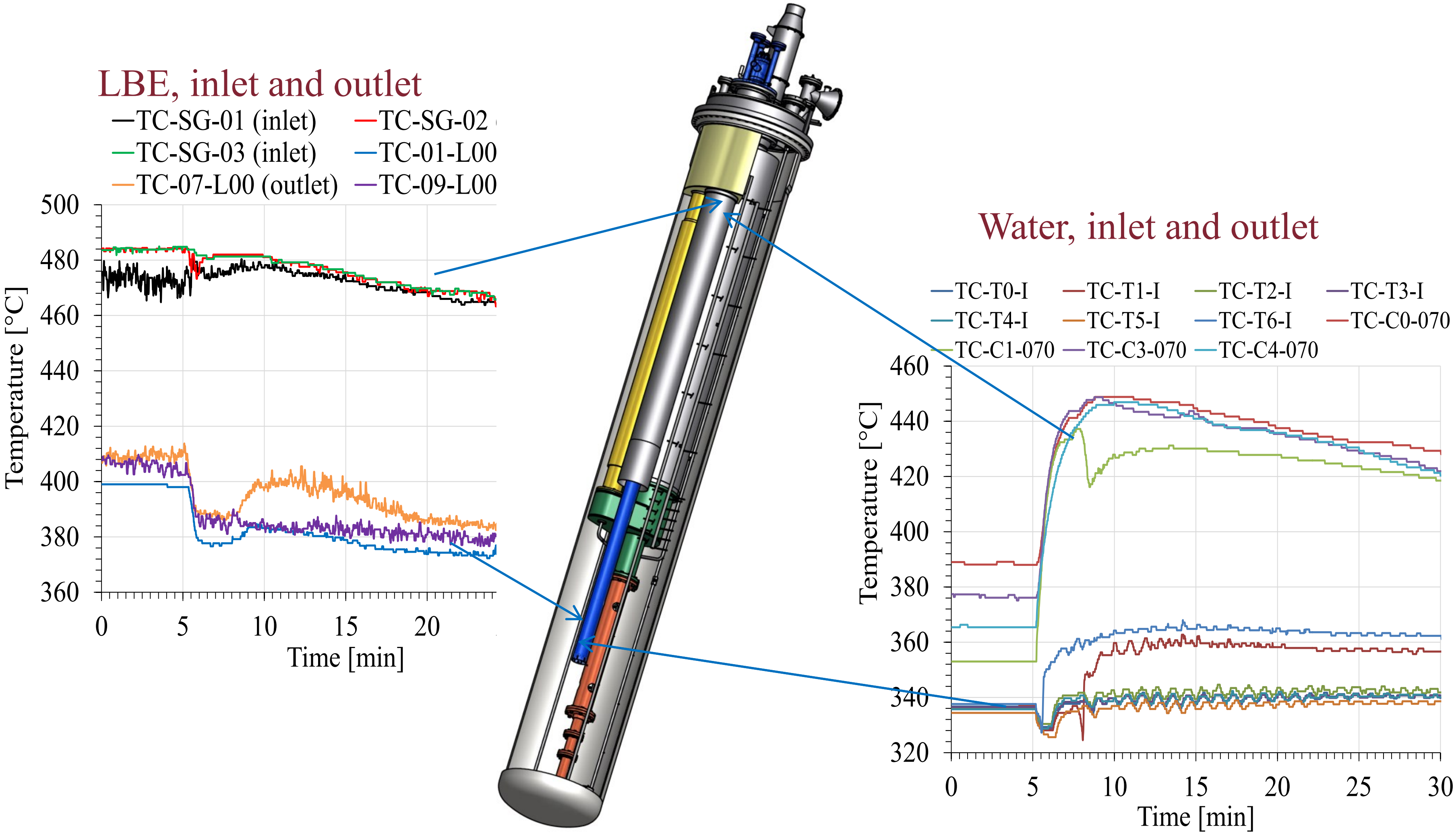
The LBE in the top part of the riser and inside the separator does not suffer immediately the effects of the transient, due to the sudden reduction of the LBE mass flow rate, which delays the rise of the coolant, and its temperature decreases slowly.

This results in an inversion of the temperatures in the rising leg, in which the LBE on the top remains hotter than the coolant flowing up from the FPS.

PLOFA EXPERIMENT

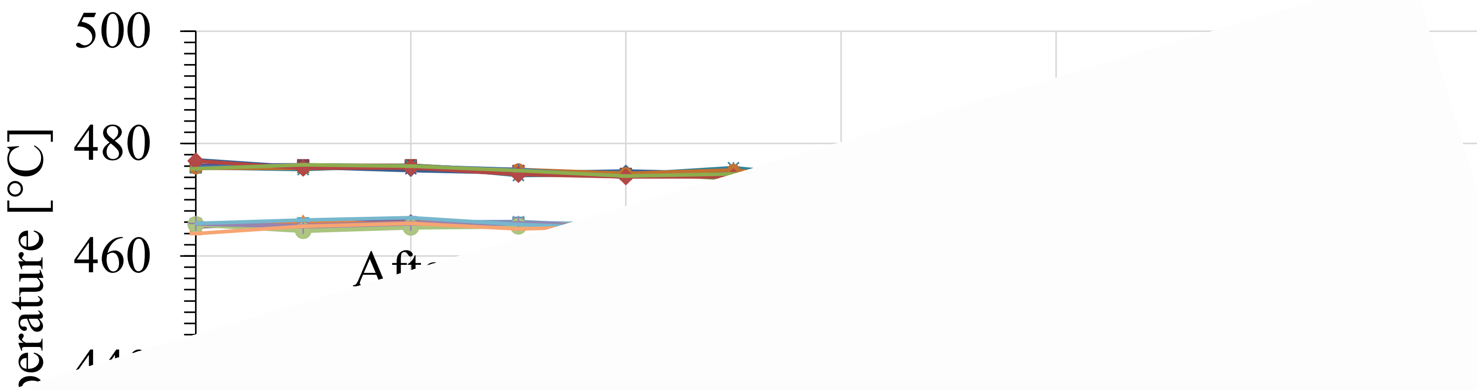
Experimental Results

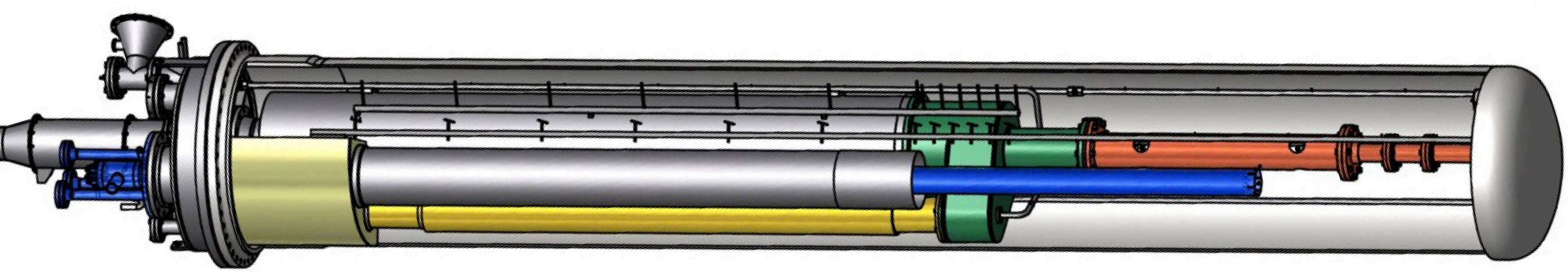
SGBTs temperatures



Thermal stratification

The relevant stratification phenomenon occurs at the SG outlet level. This is due to the heat losses between the hot leg and the main pool that warms the upper part of the pool. Downstream the SG outlet, the cold fluid exiting the heat exchanger cools the lower pool, causing the characteristic thermal stratification





RELAP5-3D MODELLING (1)

The nodalization scheme has been developed using **RELAP5-3D© ver. 4.3.4** (R5-3D)

Mono-dimensional model:

- Primary flow path
- Sub-channel analysis of the FPS
- SGBTs secondary side

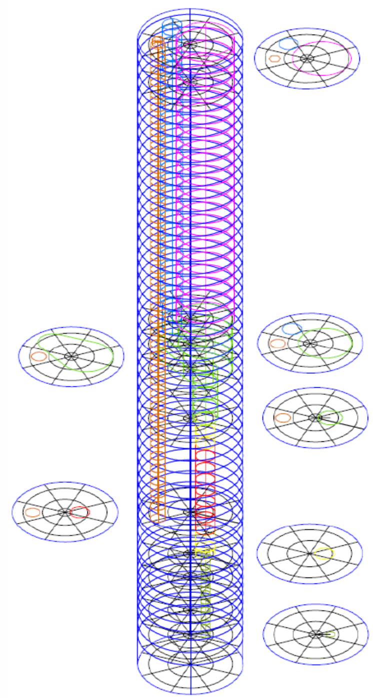
MULTI DIMENSIONAL COMPONENT:

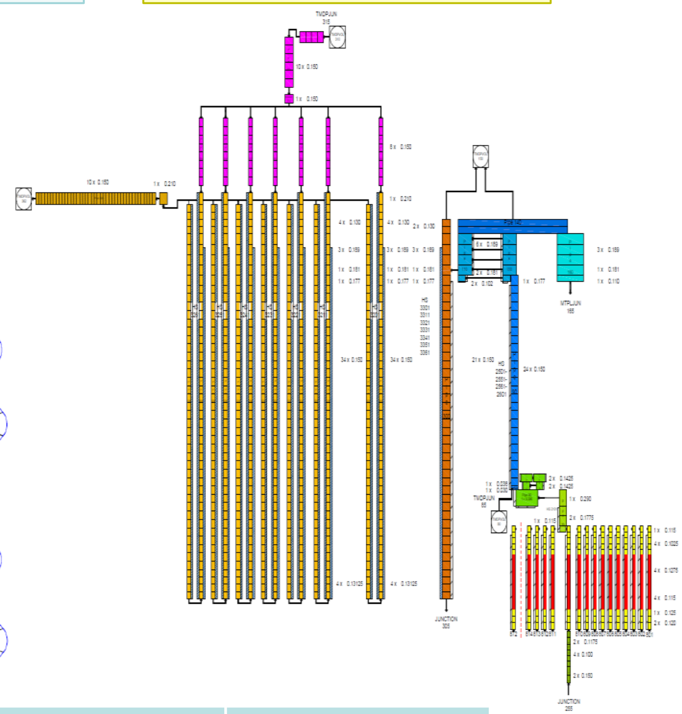
- CIRCE pool
- Calibrated porosity factors
- 3D momentum equations

Correlations:

- **Ushakov*** for HTC evaluation in bundle geometries
- **Seban-Shimazaki** for HTC evaluation in non-bundle geometries
- **Rehme** for local pressure drop coefficients Re-dependent

MULTI-D COMPONENT + **1D MODEL**



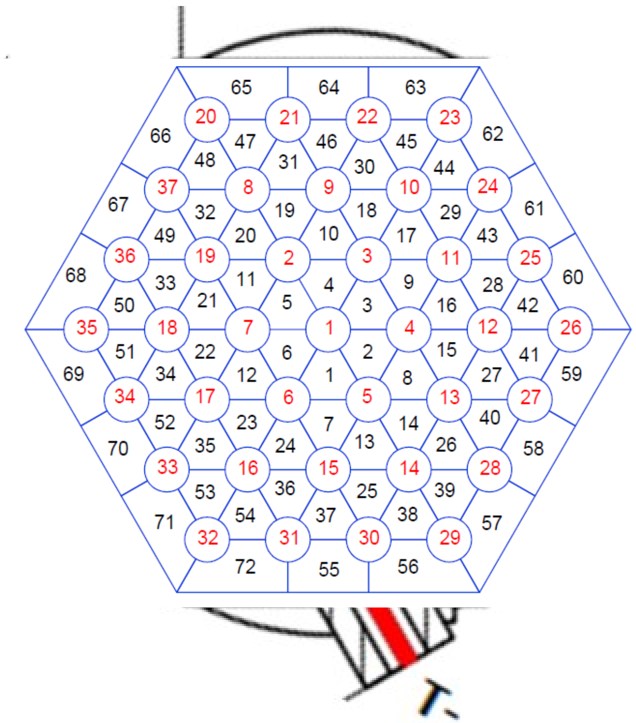


QUANTITY	Value
HYDR volumes	**3594**
HYDR junctions	**8322**
HEAT structures mesh points	**24263**

RELAP5-3D MODELLING (2)

- FPS is equipped with several TCs to measured the LBE temperature across the HS.
- The model is obtained to compare the temperature in the **exact position of the TCs**. The grids are simulated with pressure loss coefficients, dependent on the flow conditions and evaluated with **Rheme correlation**.

FPS SUB-CHANNEL ANALYSIS



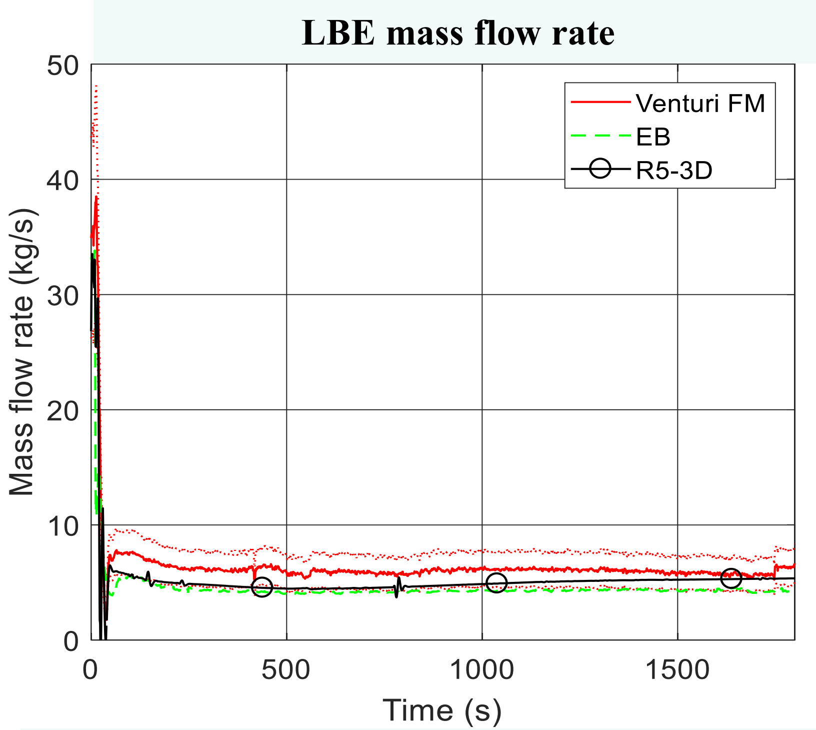
- **72 parallel pipes** divided into 15 control volumes
- **1536 cross junctions** to reproduce mass transfer between adjacent sub-channels
- **5760 heat structure active nodes** suppling the thermal power to the sub-channels
- **1728 heat structure passive nodes** simulating the heat losses through the hexagonal shell
- **3456 heat structure passive nodes**, assuming a “fake” material with negligible heat capacity and LBE thermal conductivity, to simulate the heat conduction through adjacent sub-channels
- **Calibrated fouling** factor is applied to the HTC of the active heat structure to correct Westinghouse correlation according with Ushakov correlation

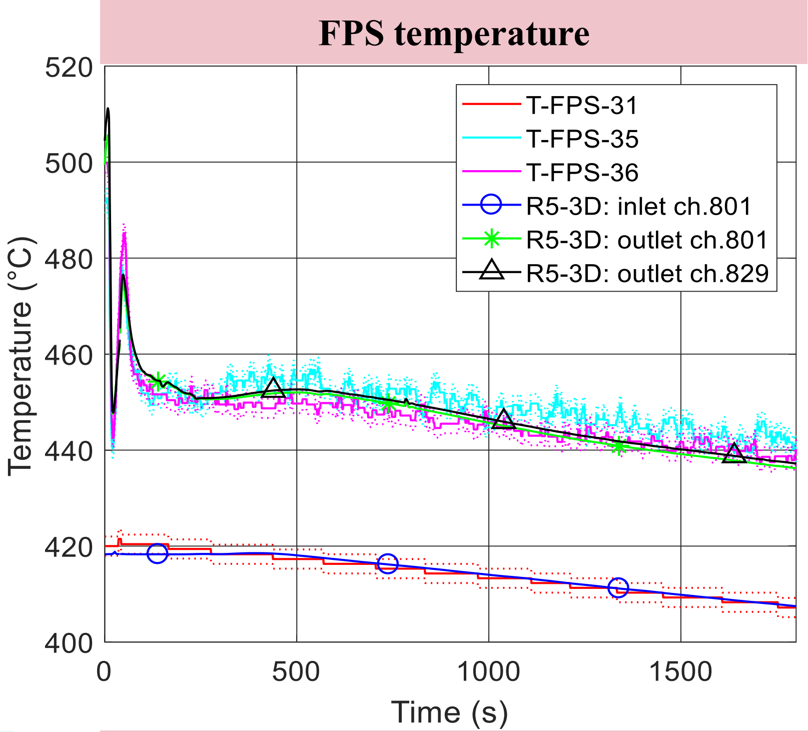
Full power calculation: main results

Parameter	Unit	Experiment	Uncertainty	R5-3D	Error
LBE MFR	kg/s	34.0	10 - 25%	31.7	-6.7%
Av. FPS inlet T	K	420.0	2.0	418.4	-1.6
Av. FPS outlet T	K	493.5	2.0	495.0	1.5
Av- SG inlet T	K	480.0	5.0	485.1	5.1
Av. SG outlet T	K	403.7	8.0	413.9	10.2
TFM-T4	kg/s	0.036	0.0044	0.039	0.003
TFM-T5	kg/s	0.033	0.0044	0.039	0.006
TFM-T6	kg/s	0.035	0.0044	0.034	-0.001
TC-C0-O70	K	387.9	2.0	387.9	0.0
TC-C1-O70	K	353.0	2.0	353.9	0.9
TC-C3-O70	K	376.1	2.0	366.1	-10.0
TC-C4-O70	K	365.4	2.0	366.1	0.7

RELAP5-3D Post-Test Analysis

Simulation Results



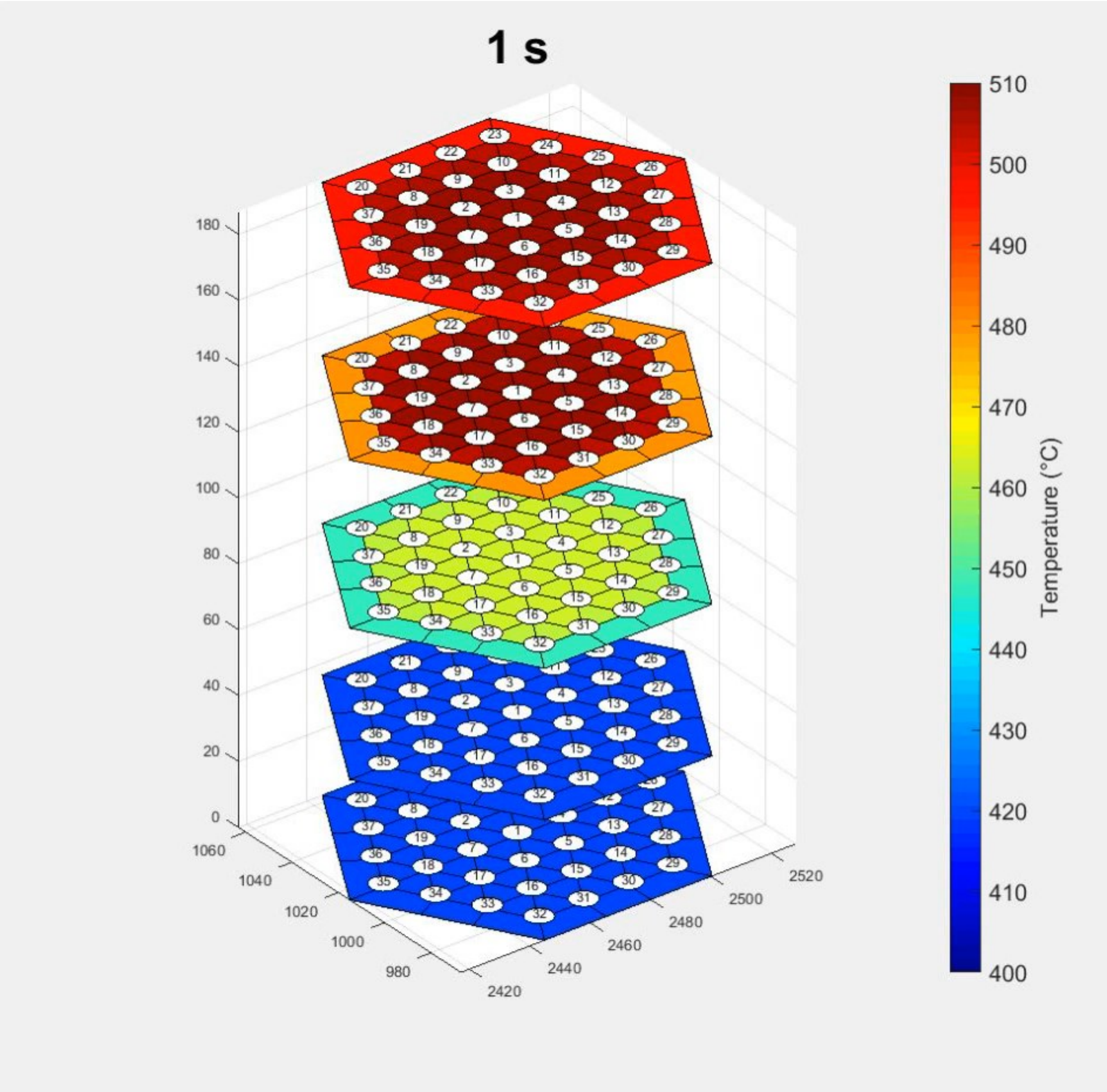


- **SHORT TERM:**
  - Good matching between experiment and calculation
  - Delay of the MFR decrease at SG inlet
- **LONG TERM:**
  - good prediction of the natural circulation with a little underprediction in the central part of the test

- **SHORT TERM:**
  - matching of the prompt temperature decrease (T_{min} = 439 ° C)
  - **100 ≤ t ≤ 110 s: small obsillations in** reverse flow → T_{peak} at FPS inlet (not clearly acquired by TCs) and quick T increase at the outlet (good prediction of the T_{max})
- **LONG TERM:** slight error prediction in T_{out}

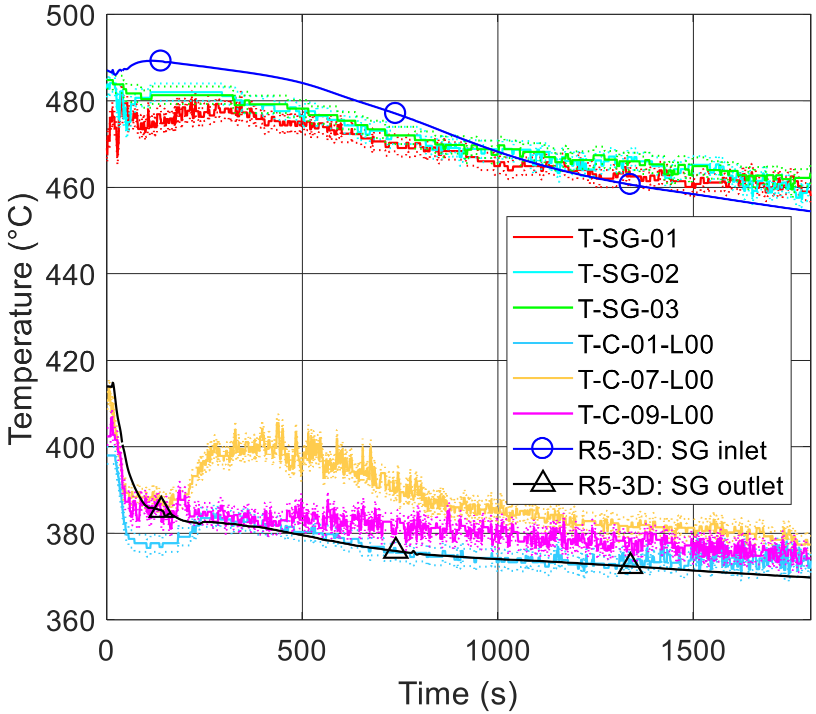
RELAP5-3D Post-Test Analysis

FPS temperatures

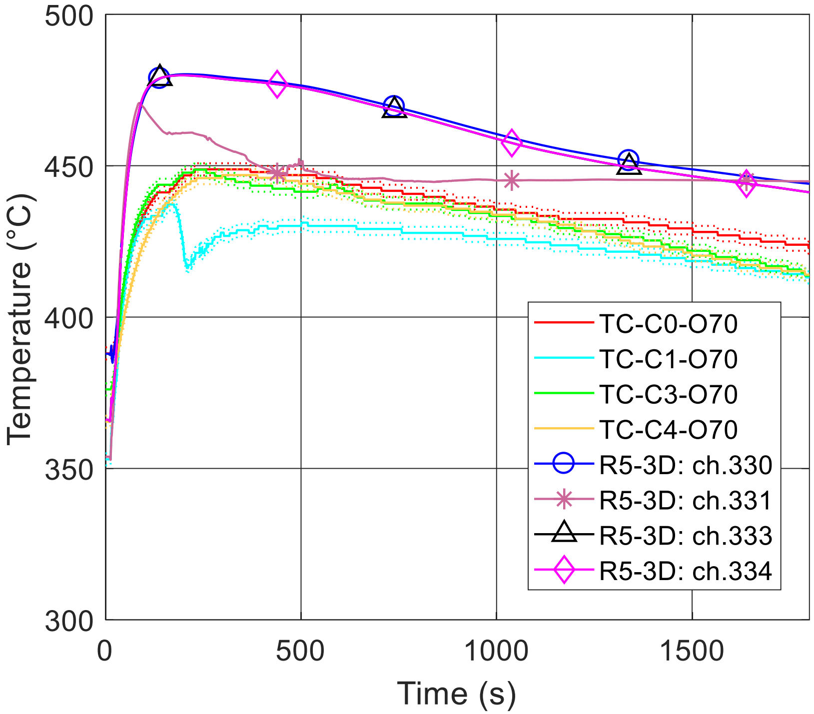


SGBTs temperatures

LBE temperature



Steam outlet temperature



- **0 ≤ t ≤ 100 s:** good prediction by R5-3D
- **100 s ≤ t ≤ END:**
  - ΔT overestimation by R5-3D
  - Uncertainties related to powder performances

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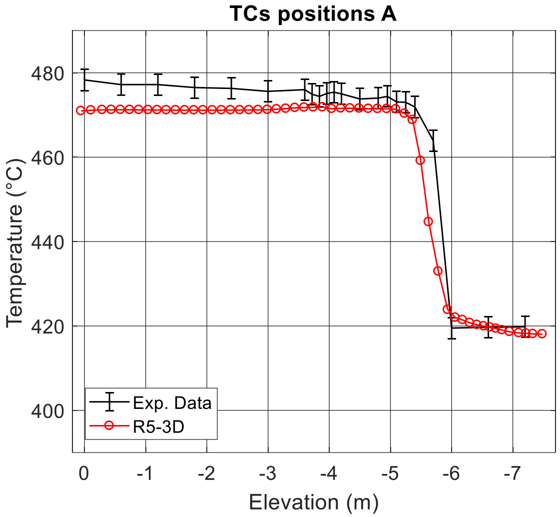
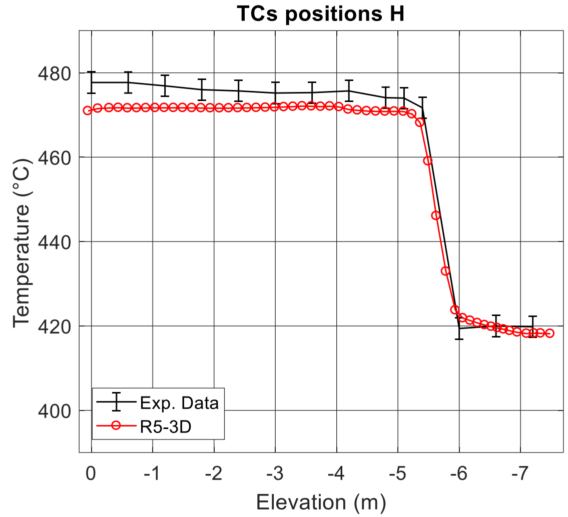
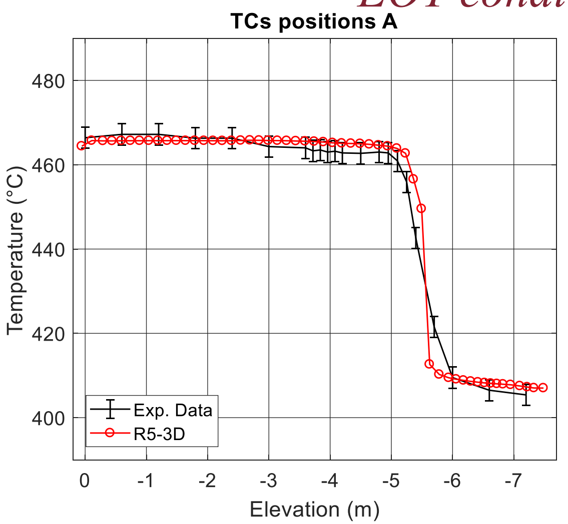
Pool thermal stratification

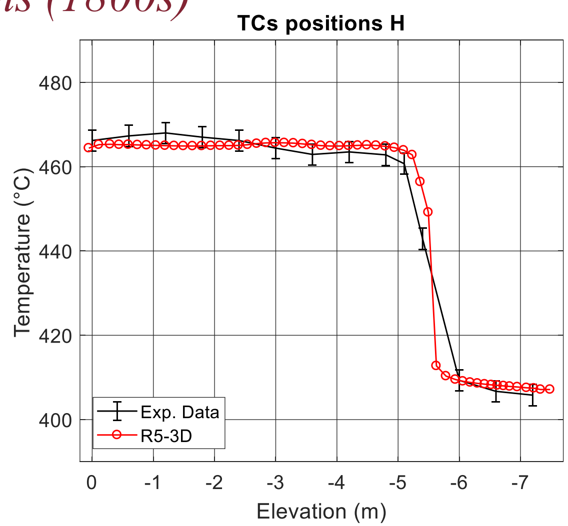
SOT conditions (0s)

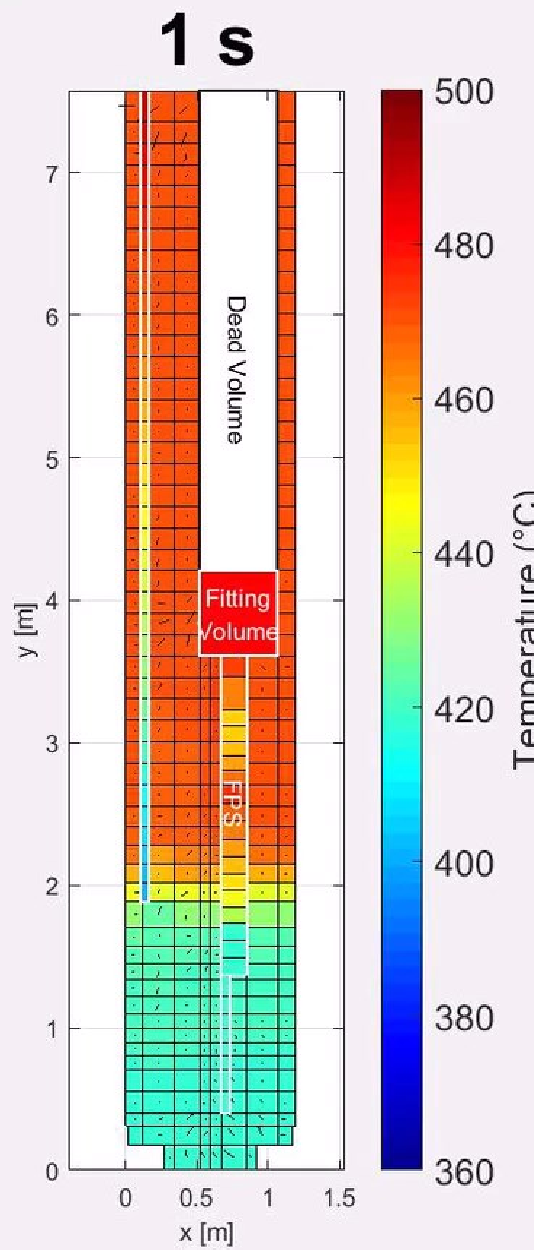




EOT conditions (1800s)







Conclusion

- The CIRCE-HERO PLOFA experiment #1 provided a useful data for the analysis in support to the HLM safety demonstration and for the validation of the TH transient analysis codes.

- The comparison of the experimental data and the numerical results (obtained with R5-3D) make know a good agreement.
- Multi-dimensional component offers a very fine prediction of the thermal stratification inside the pool with a large part of the values within the experimental error bars
- The prediction in natural circulation is good for the mass flow rate and the FPS inlet and outlet temperatures, but in this test is present an overestimation of the temperatures in the HERO TS both in the primary and secondary side in the central part of the transient, with a good long-term prediction. This needs additional analysis to investigate the HERO behavior at low mass flow rate for the secondary side

THANK YOU
FOR
YOUR ATTENTION