WP5 “Heat removal and temperature control ”

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Final meeting

28/11/2023

WP5 on Heat removal and temperature control

Objective: Development and validation of heat transfer models for MSR safety studies.
Application of models/codes to support WP6 activities. Design and salt properties from other WPs.

- **Task 5.1** Extension and validation of the SIMMER multiphase fluid-dynamics model; KIT, EDF
- **Task 5.2** Multiphase phenomena and heat transfer in MSFR; EDF, KIT
- **Task 5.3** Effects on heat transfer by free surface, radiation heat, solidification/melting; CNRS, TUD
- **Task 5.4** Natural convection and heat transfer in MSR; POLIMI, CNRS

Milestones M14, M26 and Deliverables D5.1-D.5.6

2020 (M14): SWATH-S ready for experiments (CNRS); Verification: Technical note (TN): Done

2021 (M26): e-Dynasty ready for experiments (POLIMI); Verification: TN: Done

D5.1 (M48) Extension and validation of the SIMMER code for treating gas-liquid interface, KIT: In progress

D5.2 (M48) Assessment of calculation models for study DHR capability in MSR, KIT: In progress

D5.3 (M30) Report on the SWATH experiments, CNRS: Done

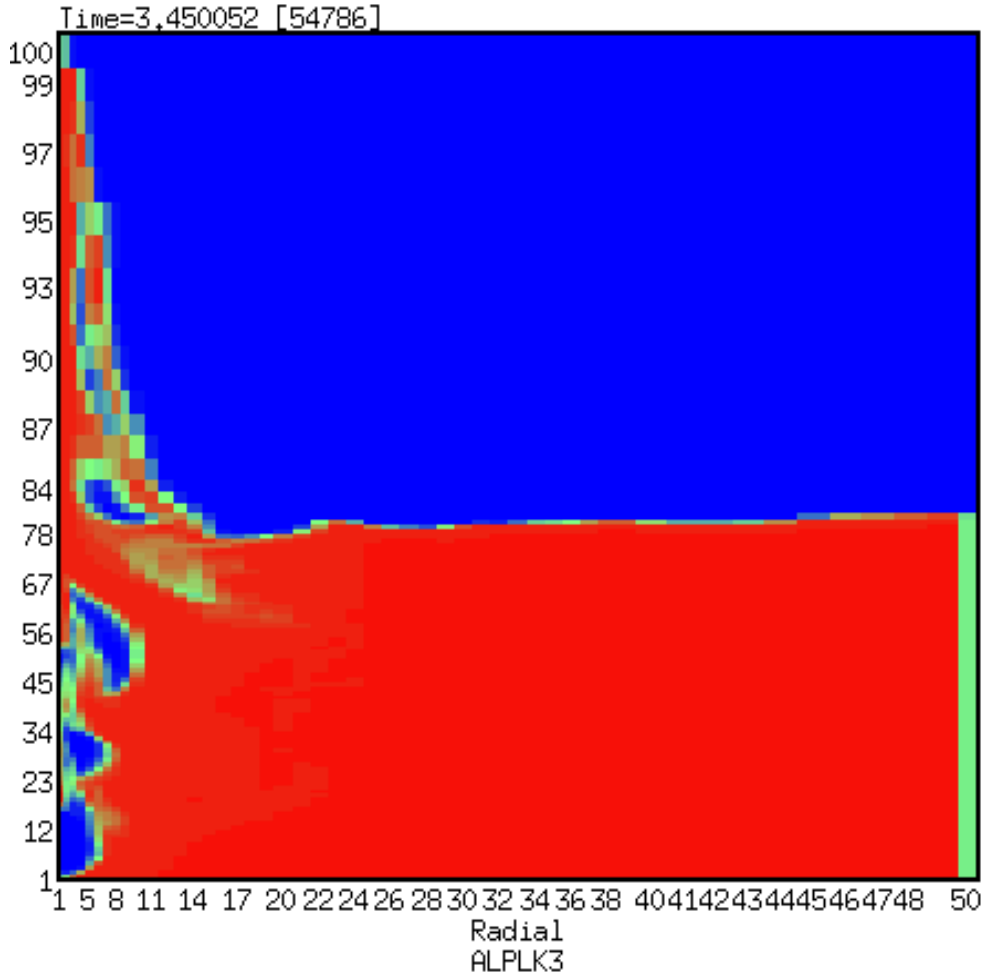
D5.4 (M48) Radiation heat transfer: model development and validation (R,CO), TU Delft: In progress

D5.5 (M36) CNRS natural circulation stability experiment (R,CO), CNRS: In progress

D5.6 (M42) Experimental and simulation results of the e-DYNASTY natural circulation experiment, POLIMI: Done

Task 5.1 Extension & Validation of SIMMER multiphase fluid-dynamics model

- SIMMER is a coupled, multiple velocity, multi-component code, developed mainly for SFR studies
- KIT extended it for MSR, LFR, etc.; SIMMER with some KIT extensions is used by some EU partners
- Castillejos experiment on gas injection in water: used for initial SIMMER validation
- More recent model in SIMMER for momentum transfer between liqiud-gas: developed for an experiment on gas injection in HLM
- We now show that the model improves the results also for gas in water
- Average gas fraction: now more accurate in 2D
- Spatial distribution of the fraction: less accurate, expected to be more accurate in 3D
- Benchmark on gas injection in molten salt proposed



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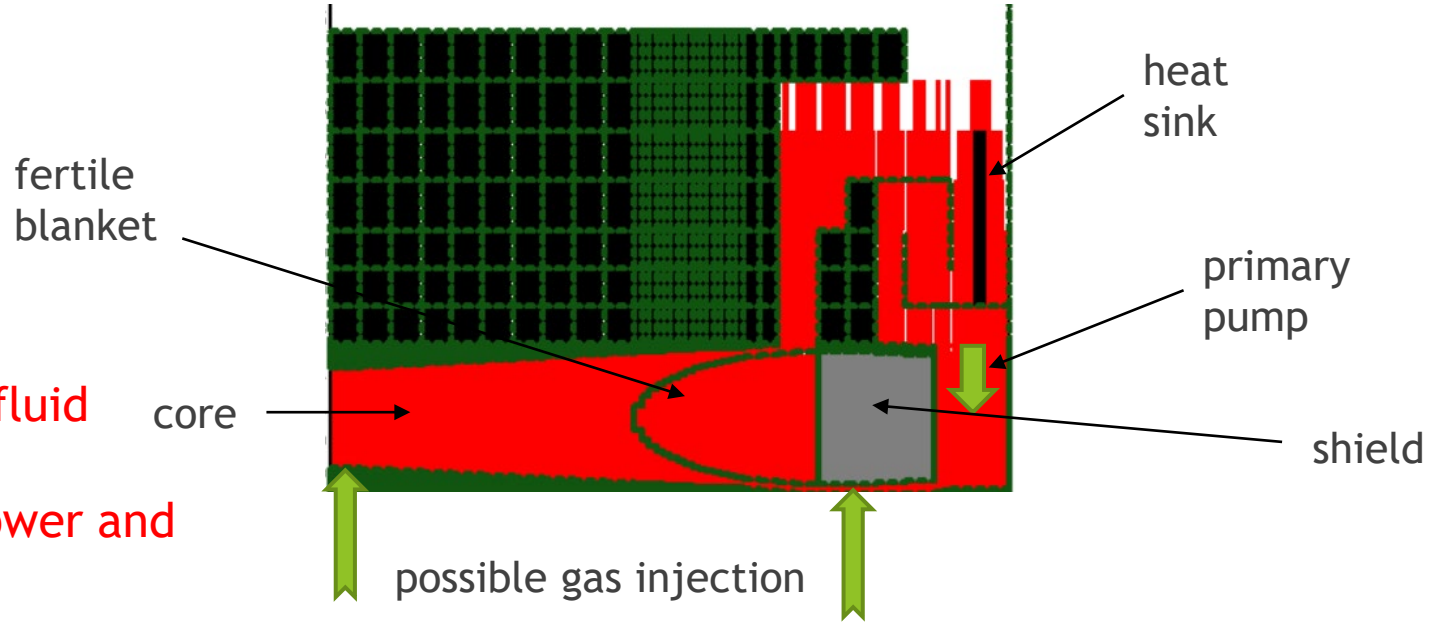
Task 5.2 MSFR modelling in SIMMER

- SIMMER features
  - Turbulence-diffusion effect on the viscuous drag term
  - Modification of bubble drag coefficient, interpolated between ellipsoidal bubbles and cap bubble‘s (Suzuki 2003)

conclusions from Castillejos

- Improved primary circuit model
  - Simplified IHX (heat sink)
  - Adjusted cover gas section
  - Modified downcomer
  - Start-up procedure



Observations:
Very strong coupling: neutronics and fluid dynamics.
Gas injection brings instabilities in power and flow pattern

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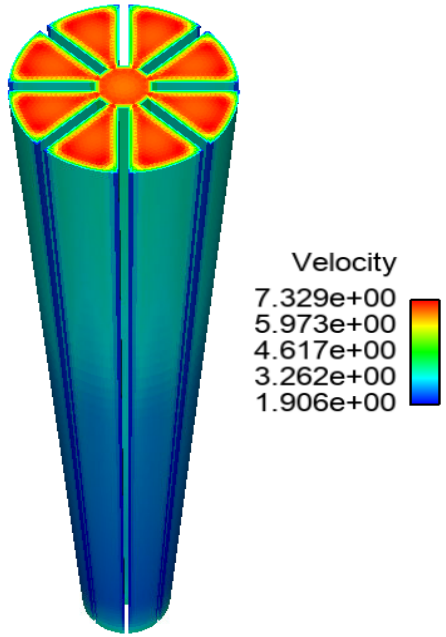
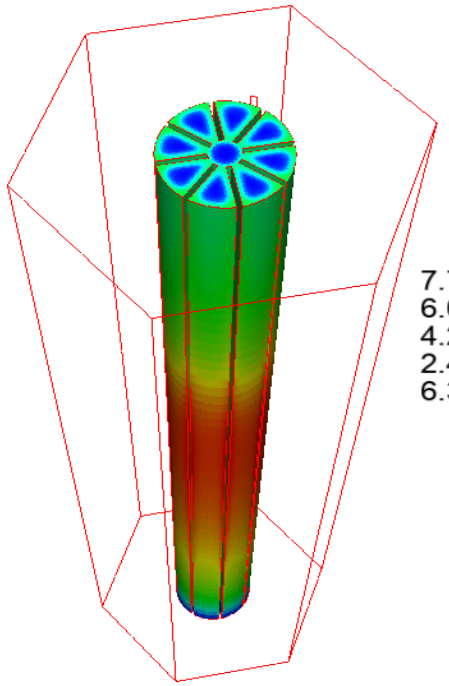
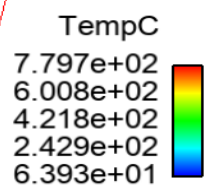
Task 5.2 Multiphase phenomena and heat transfer in MSFR, decay heat removal (DHR) in EDT (Emergency Draining Tank): a channel in 3D







- EdF applied industrial codes (SYRTHES, Code_Saturn), for DHR simulation from the core and EDT, see the considered EDT element design above

- The simulations show the viability, importance and limits of different simulation options and physical phenomena

- Natural air convection seems to be insufficient for this design,
- radiation heat transfer and convection effects should be considered

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Task 5.2 Multiphase phenomena and heat transfer in MSFR: simulation of decay heat removal from the core

- 3 passive circuits simulations at EdF: with industrial codes

In the past: focus on DHR from EDT.

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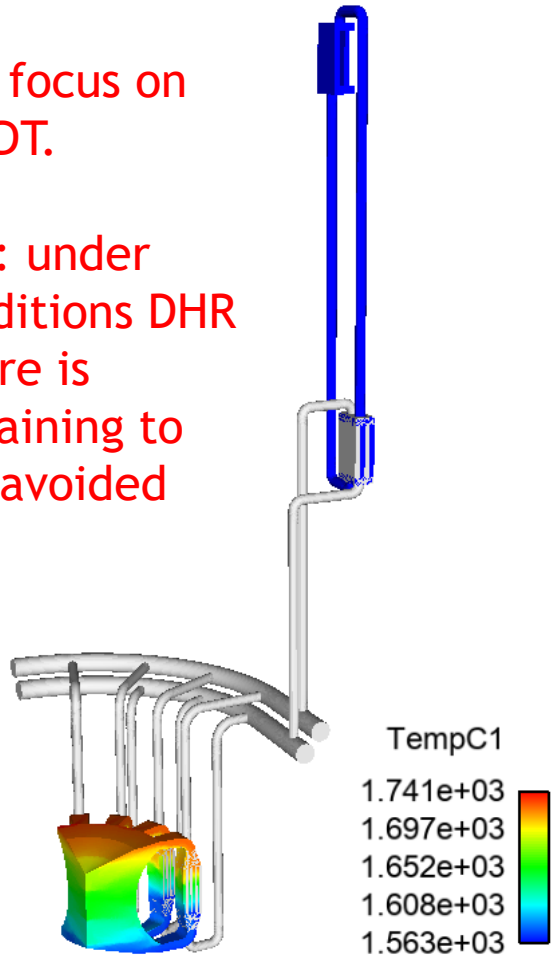
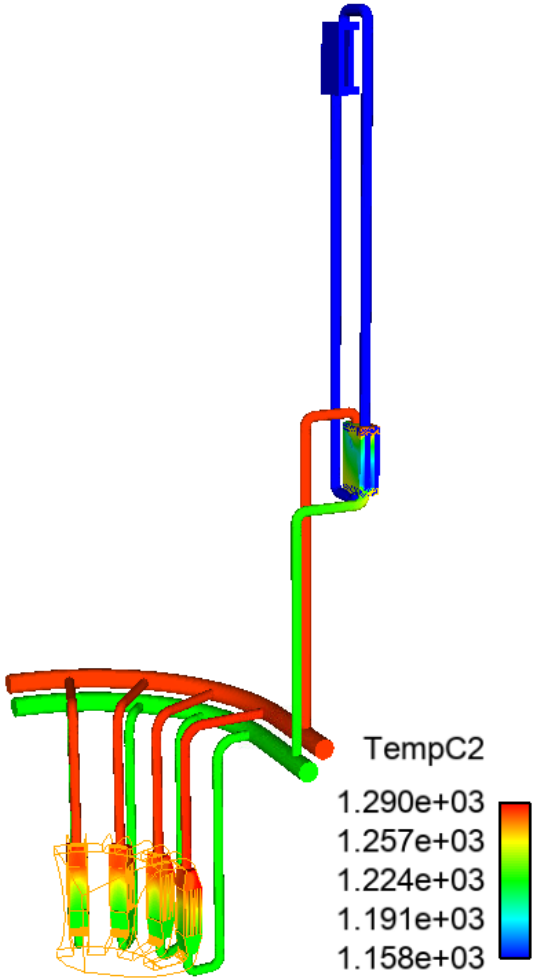
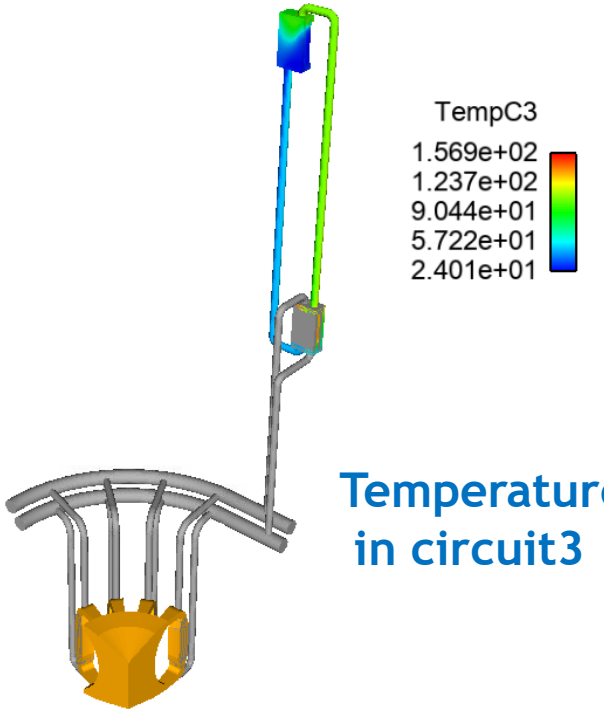


Temperature in circuit1



Temperature in circuit2



Temperature in circuit3

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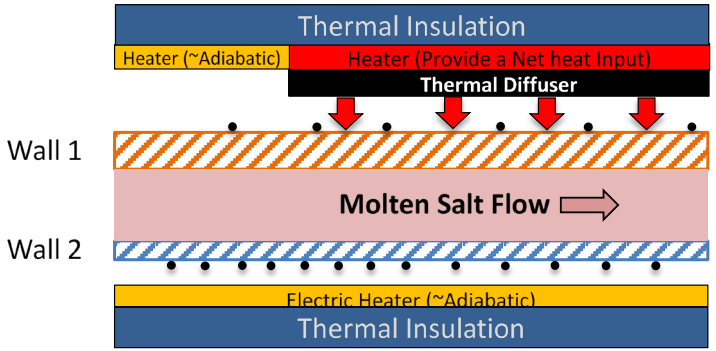
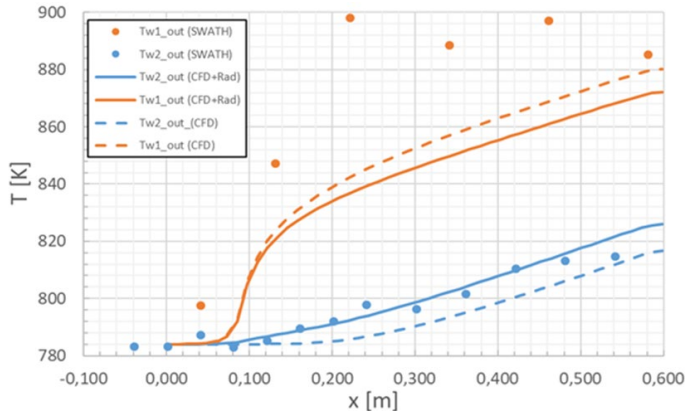
Task 5.3 - Effects on decay heat transfer due to free surface, heat radiation and solidification/melting phenomena (CNRS)

Two test sections were designed, built and operated in the SWATH (LPSC) facilities for these studies:

1) **Flat Channel test section (2021):**
   - Employed to investigate the effect of radiative heat transfer on a molten salt flow inside a close channel formed by two large plates with different temperatures
   - Experiments performed using: (i) Water (SWATH-W) to measured the flow field with PIV and (ii) FLiNaK molten salt (SWATH-S)
   - Numerical simulations using conjugated heat transfer with thermal radiation allowed in the fluid and between the walls (FLUENT and OpenFOAM)
   - Measured temperature profile on the adiabatic wall is compatible with the presence of a thermal radiation transfer between the two plates





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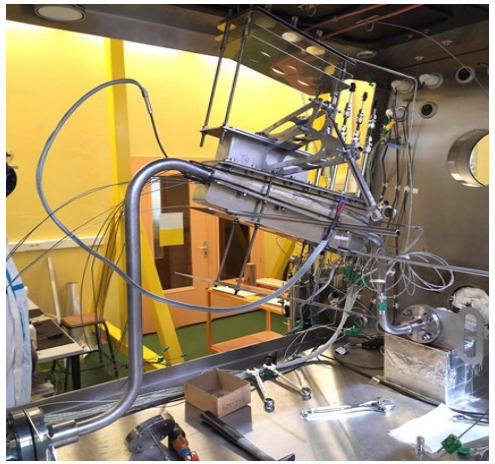
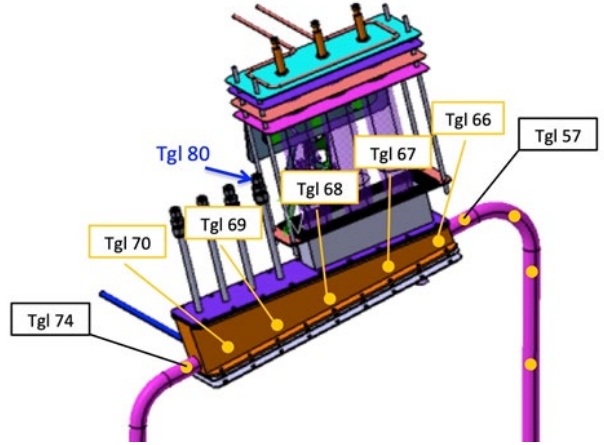
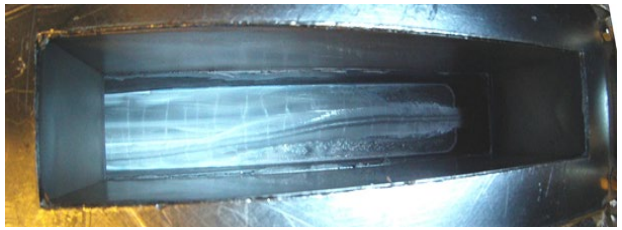
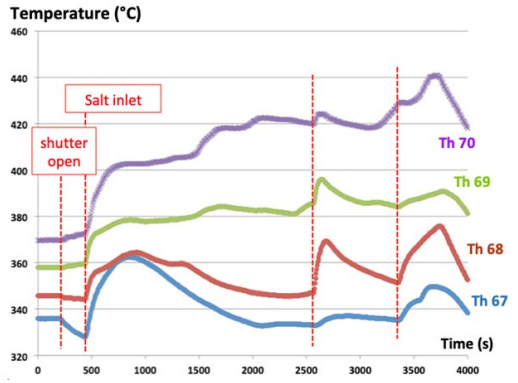
Task 5.3 - Effects on decay heat transfer due to free surface, heat radiation and solidification/melting phenomena (CNRS)

2) **Open Channel test section (2022):**
   - Used to study molten salt flows having a free surface, where radiative heat transfer with the environment is possible, surface tension effects are non negligible and also solidification/melting phenomena exist
   - Experiments were performed using: (i) Water (SWATH-W) to develop the flow control system and (ii) FLiNaK molten salt (SWATH-S)
   - SWATH-S instrumentation included thermocouples, contactors and a camera for performing a visual inspections once the flow was terminated
   - Results showed that solidification takes place only if the salt temperature is already very close to the solidification temperature, otherwise an enormous cooling power surface would be required
   - Flow modeling in the case of an open channel is extremely challenging



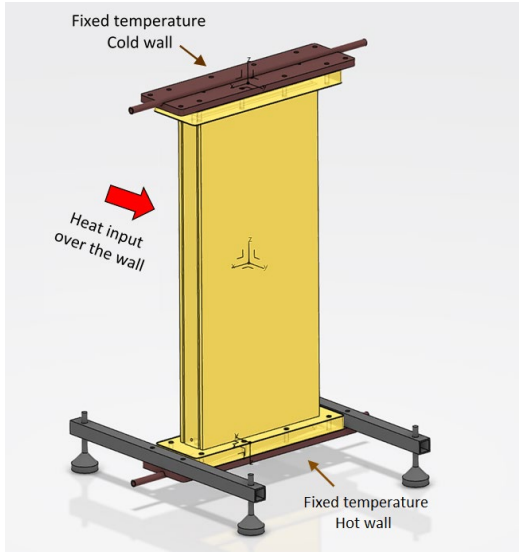


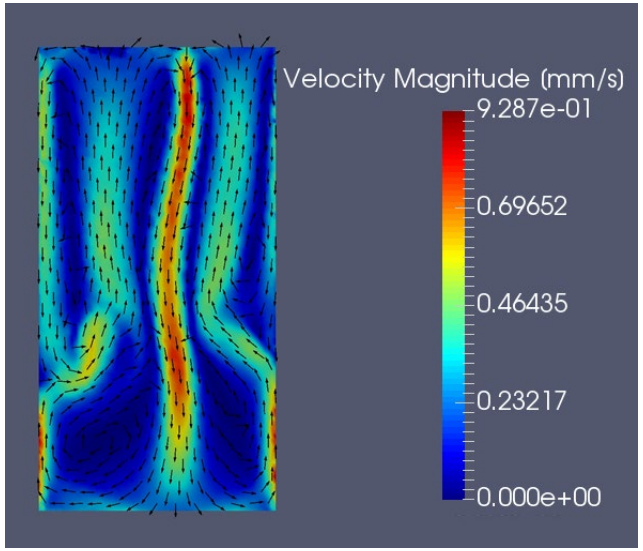




Task 5.4 - Natural convection and heat transfer in MSR (CNRS)

- LPSC-Grenoble (CNRS) and Polimi collaborated in this task through the conjoint PhD project of Jonas NARVAEZ
- A natural convection experiment was design, built and operated at the LPSC-Grenoble to study the stability analysis methodology originally developed by Polimi during the SAMOFAR project
- A flat cavity filled with a mixture of Glycerol and water was used in the experiments. Flow velocities were measured by a PIV technique
- Experiments were performed in 2023
- The comparison between the numerical predictions and the experimental results is challenging but the results significantly improved after considering all the identified phenomena in the experiments





Task 5.3 Radiation heat transfer code development

- A new development at TU Delft for simulation of radiation heat transfer
- Optical properties depend on salt composition, not well-known
- Preliminary studies and developments at the beginning of the project
- Then adaption of a neutral particle Sn transport code: with respect to sources, boundary conditions, sets of ordinates
- First results for a SWATH-like case are shown in this slide
- Stronger radiation effects compared to ones shown earlier
- Stronger effects are due to higher salt temperature (700K)

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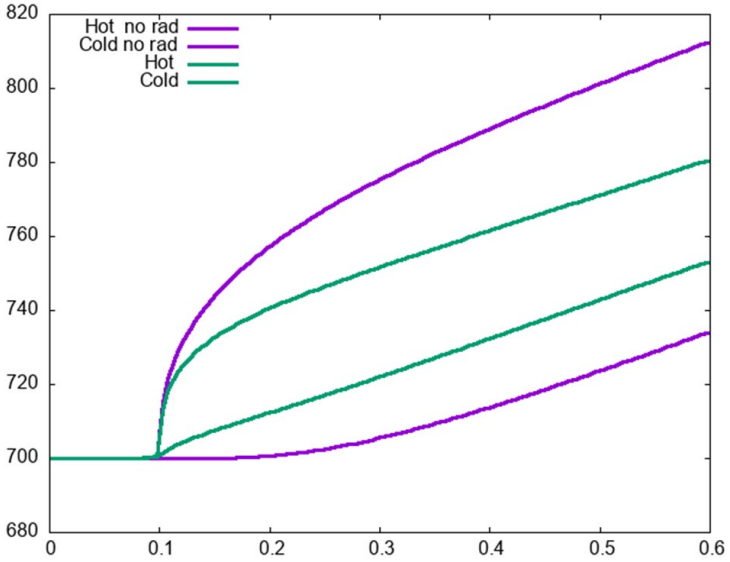

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Task 5.4 Natural circulation experiments

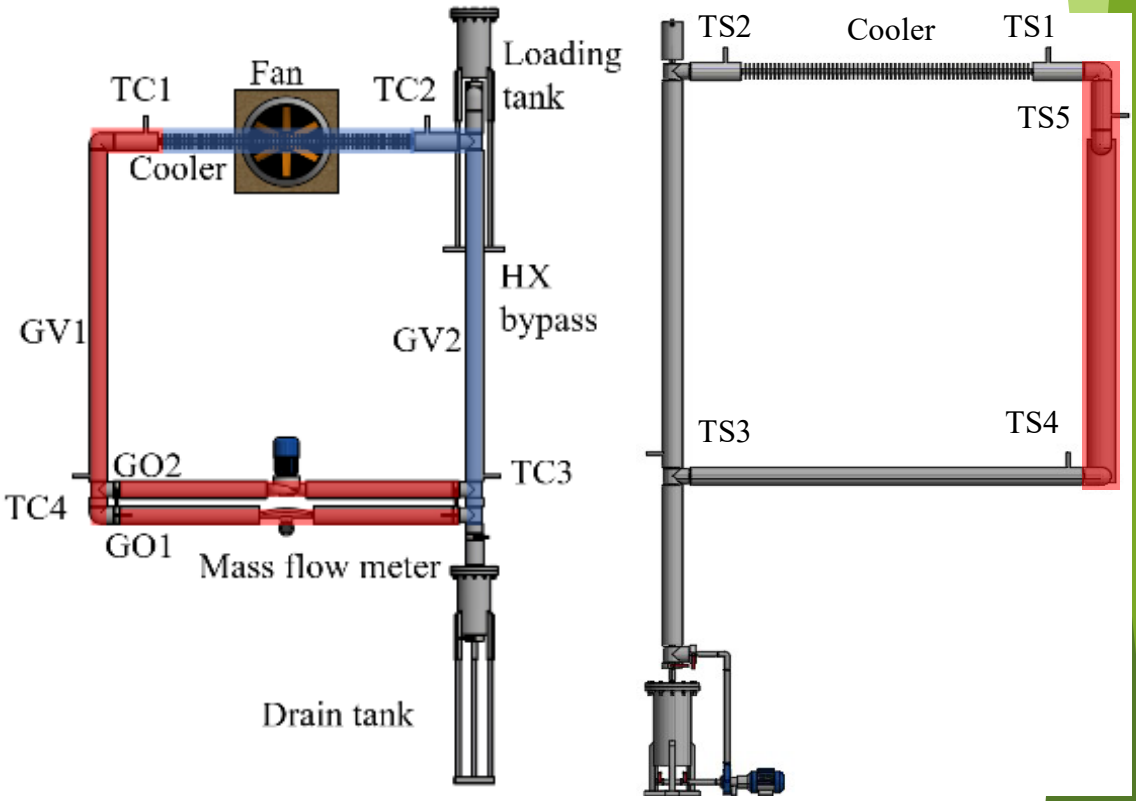
Need:

Need for having experimental datasets to analyze natural circulation phenomena in presence of distributed heating systems and to validate numerical tools

Dynamics of the natural circulation studied through the DYNASTY-eDYNASTY facilities at POLIMI, i.e., natural circulation loops. Three main cases:

1. Startup of natural circulation
2. Transition from forced to natural circulation
3. Passive heat removal during cool-down

Modelling part performed with Modelica system code



Dynasty and eDynasty facilities

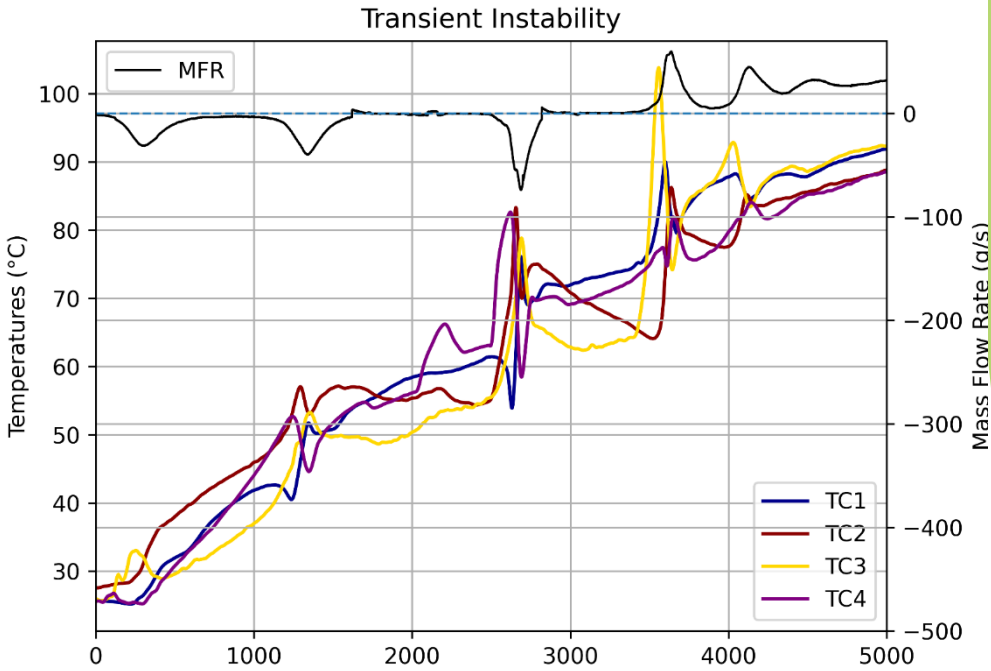
Task 5.4 Natural circulation experiments

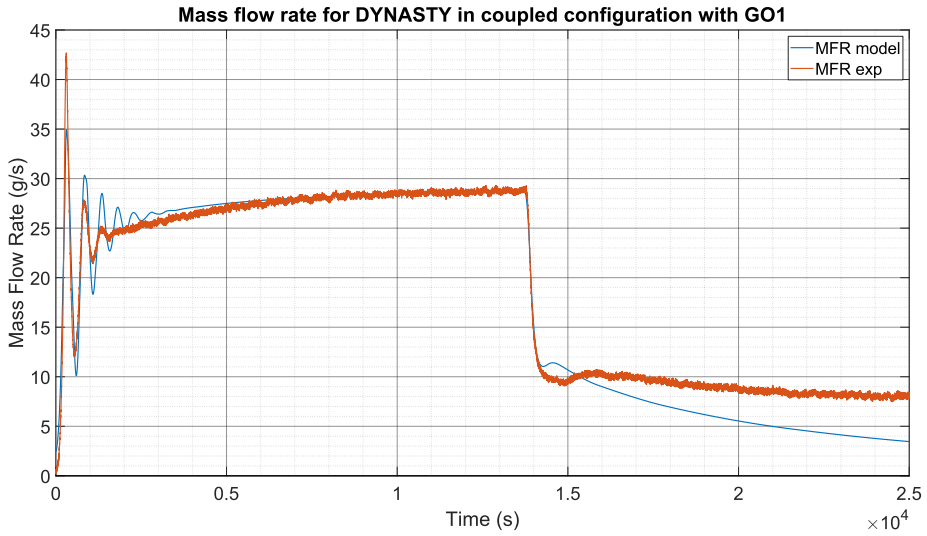
Main achievements

- Experimental datasets on natural circulation in different configurations (power, fan velocity) and with high Pr number (glycole)
- 1D Model of DYNASTY-eDYNASTY facilities

Outcomes:

- Startup of natural curculation depends on the creation of cold/hot fluid packets
- Glycole simulations show instable behaviour
- Estimation of heat losses is of paramount importance in the numerical modelling to represent the experimental behaviour





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Conclusions

- WP5 on “heat removal and temperature control”: mainly as planned
- COVID issues: minor delays
- Experimental activities, code/model developments, simulations: mainly finished
- Interesting results and appreciable progress in all tasks, by all WP5 partners
- Using data on design and salt properties from respective WPs
- Support of WP6 studies
- Documentation needs further effort, it should be possible to finish it soon.
- **Delays in documentation do not influence progress in other WPs**