Activities of plant thermal-hydraulics unit

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Valeria **Parrinello** – Senior Thermal-Hydraulic Analyst

1. Activities of *new*cleo plant thermal-hydraulics unit

The unit supports the **design and licensing** of *new*cleo LFRs and is responsible for the **thermal hydraulic analyses** aimed at providing deterministic demonstration of the safety of the plant.

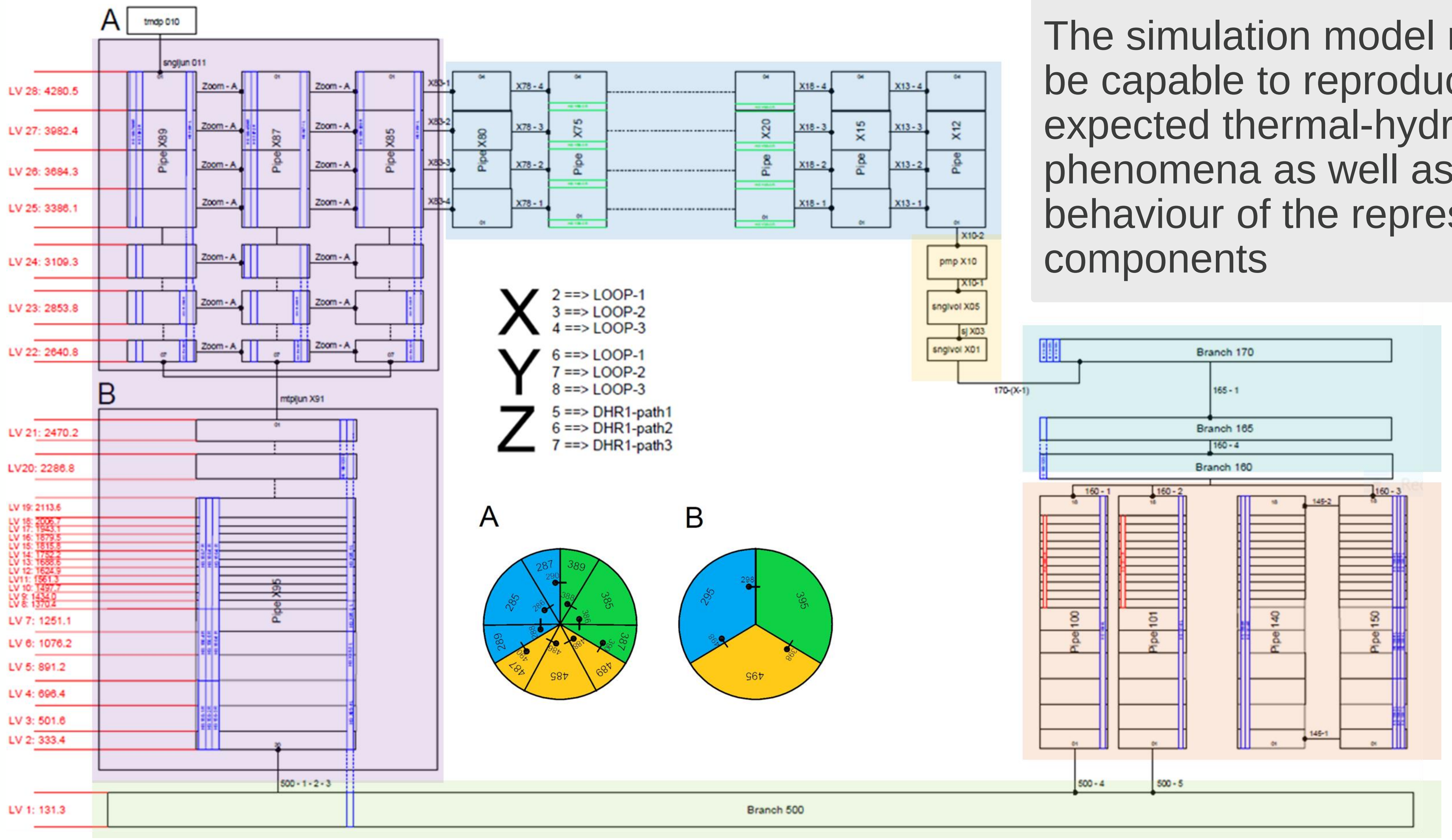
The unit will provide **input data** for Mechanical Design, I&C, auxiliary system, etc.

- Analyses by means of thermal-hydraulics codes:
  - System thermal-hydraulics code (possibly coupled to neutron kinetics codes, CFD, etc.)
  - Subchannel codes
  - CFD codes
  - Containment thermal hydraulics codes
  - Severe accident codes, etc.
- V&V of the different adopted codes to be performed

SYS-TH studies

2.a System thermal-hydraulic analyses

- Evaluate relevant parameters to support the reactor design and
- Investigate reactor behaviour in normal, upset and accident situations



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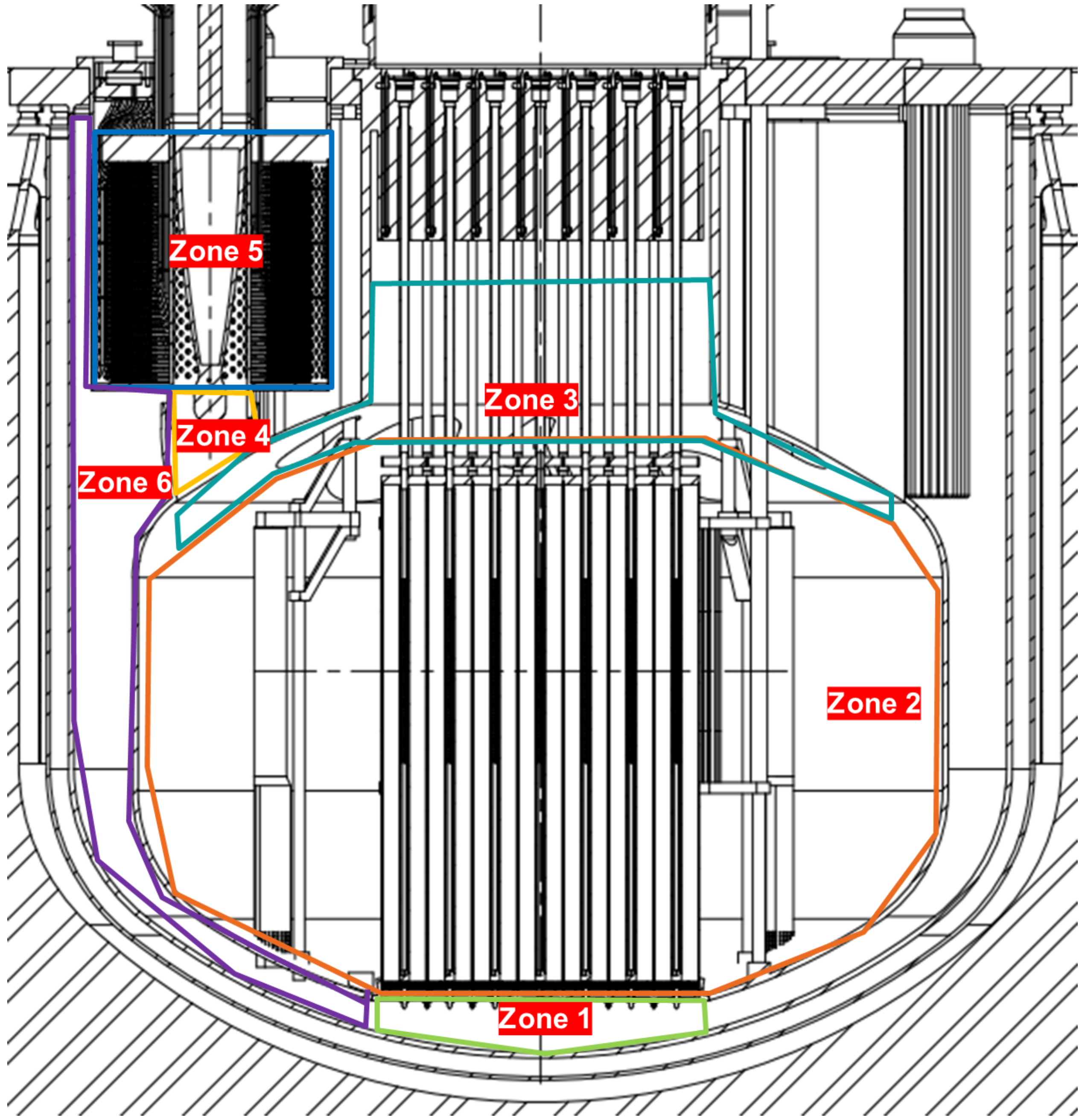
The simulation model must be capable to reproduce the expected thermal-hydraulic phenomena as well as the behaviour of the represented components



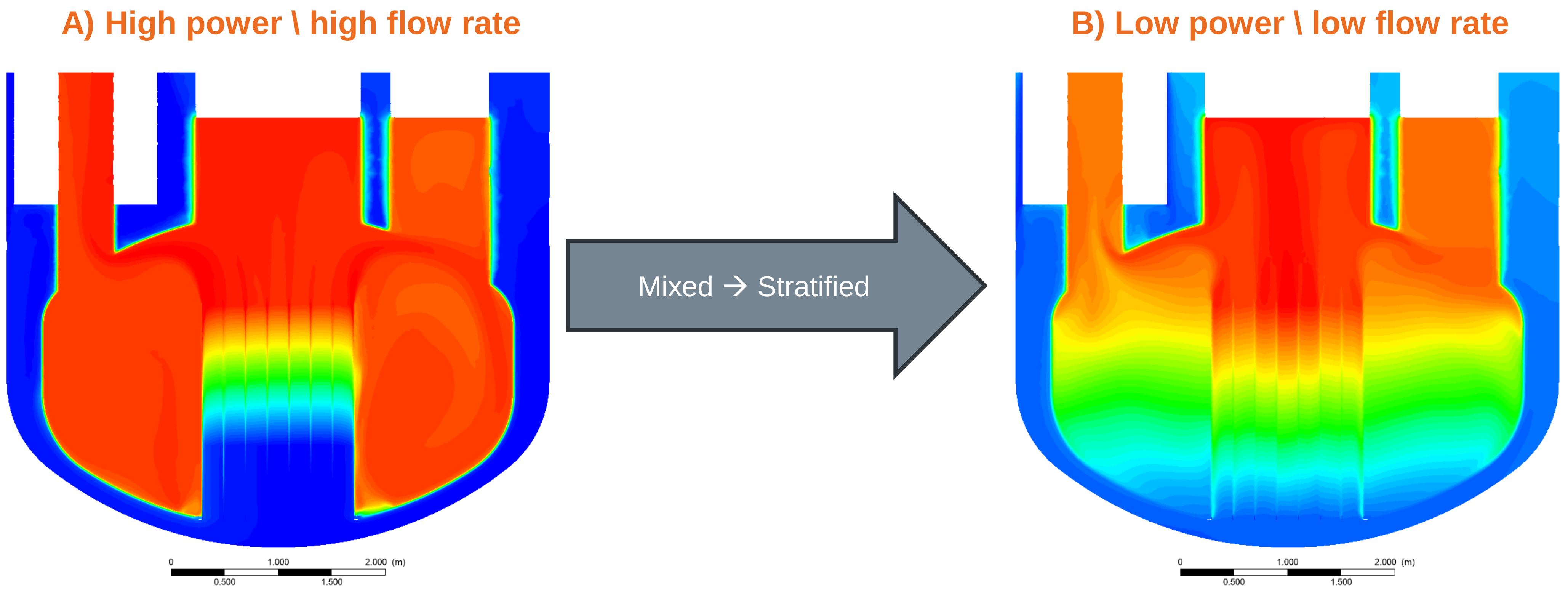
2.b System thermal-hydraulic analyses

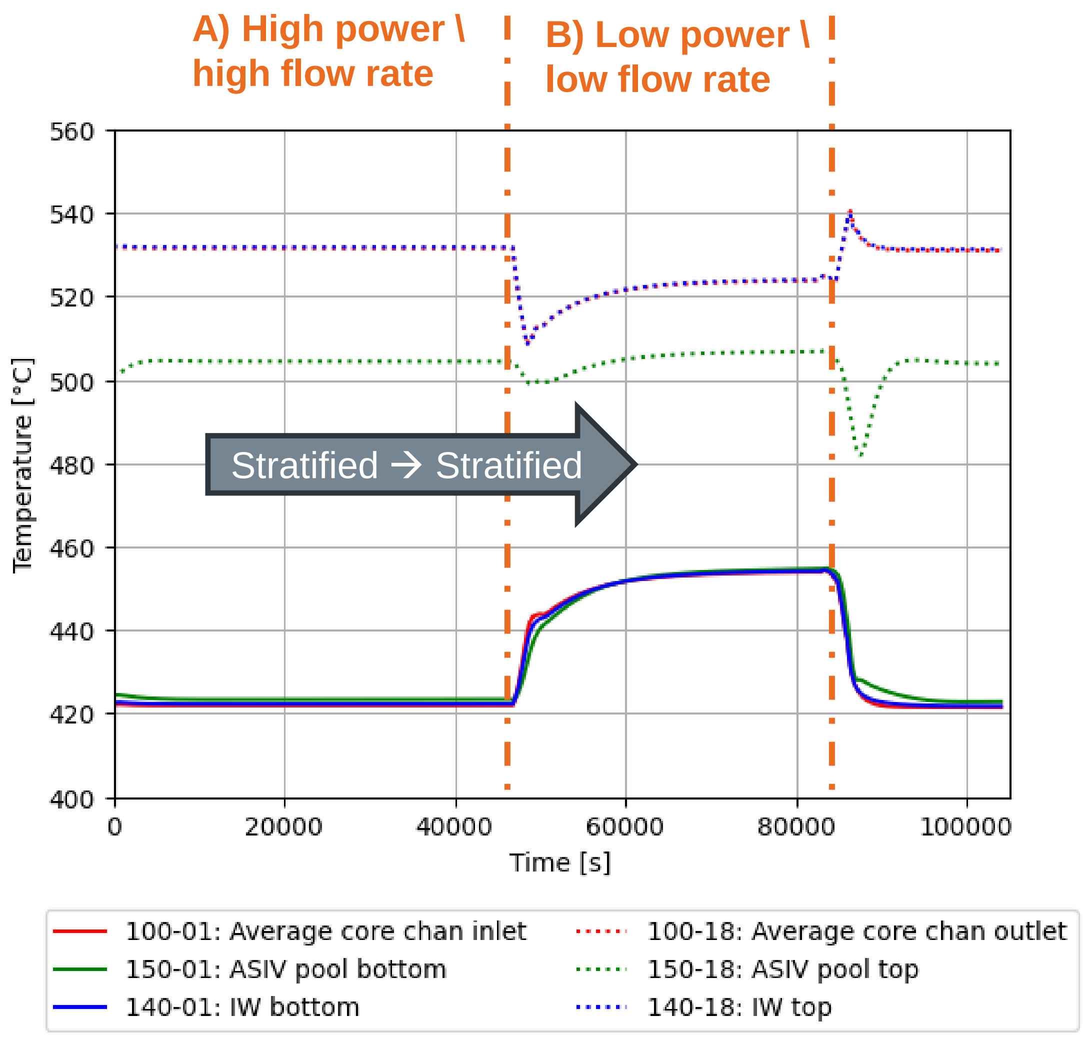
Example of modelling issue:

IN-ASIV pool → very complex velocity field to be addressed. Impact on temperature distribution and on the heat transfer with the surrounding downcomer, affecting the natural circulation.

Issues to be considered:

- Effect of pump suction in promoting thermal mixing at different flow rate/power conditions;
- Occurrence or transition to thermal stratification in some operating conditions;
- Convective heat transfer inside the pool.





2.c System thermal-hydraulic analyses

SYS-TH simulations have been utilized for various purposes:

1. **Thermal Loading Transients**: These simulations support the thermomechanical team in determining the dimensions and loads on reactor components. This is particularly crucial when significant gradients or multiple cycles are experienced.

2. **Other Design Requirements**: RSSIM simulations support component designers and control system engineers in sizing and designing components. An example is the definition of pump inertia.

3. **Safety Transients**: These simulations are employed to ensure that the reactor complies with safety and regulatory requirements. The objective is to demonstrate the favourable intrinsic safety behaviour of LFR-AS-30 in challenging accidental conditions.

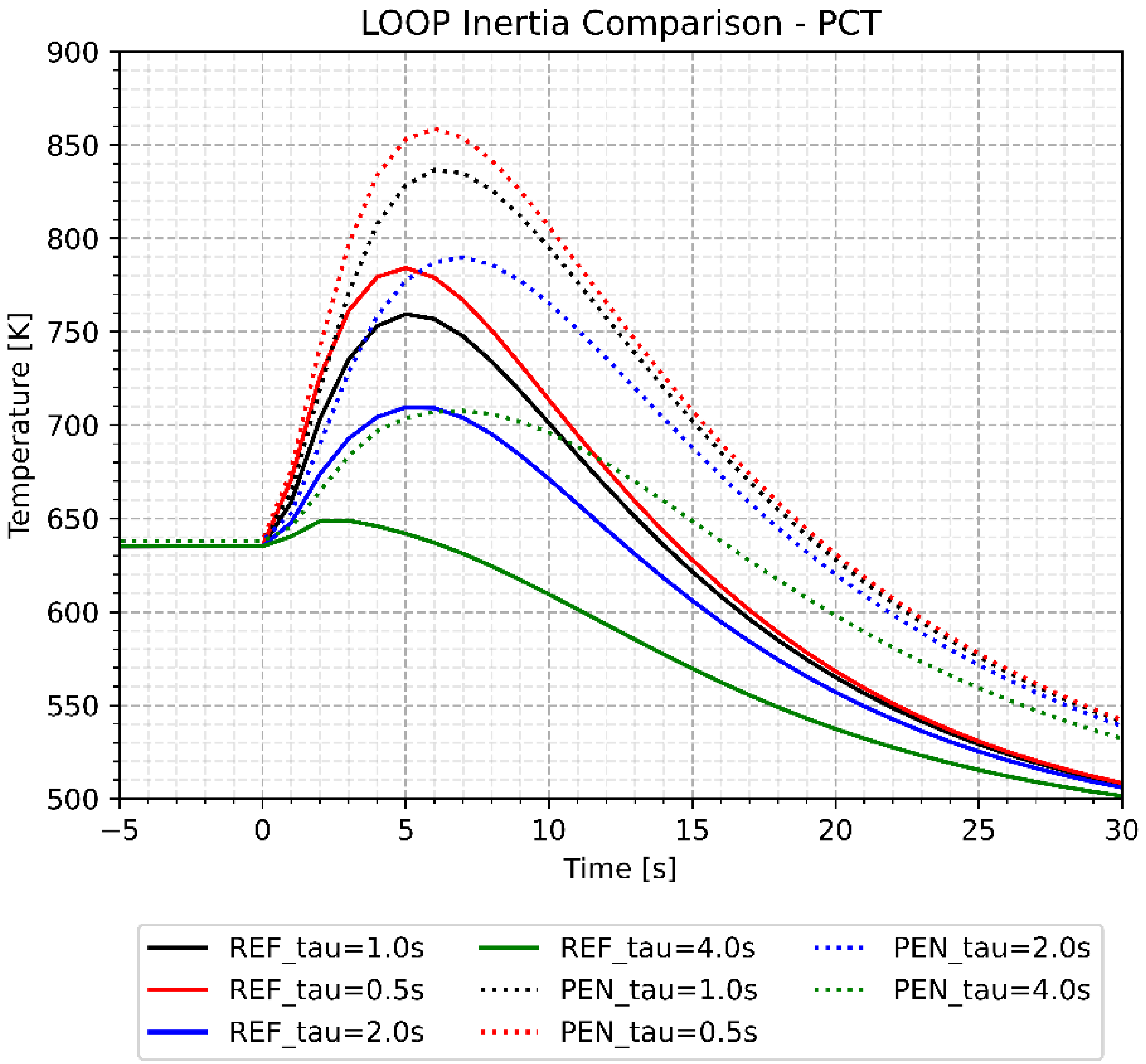
4. **Operational Transients**: RSSIM simulations help in defining procedures, setpoints, and providing an overall overview of reactor operation.

Pump Inertia Requirements

Loss of Off-Site Power

3. Pump Inertia Requirements: Loss of Off-Site Power

Support the definition of the requirement about the primary pump inertia.



	SAFETY CRITERIA	DECOUPLING CRITERIA
DBC1	No open cladding failure	PCT < 700 °C
DBC2	No open cladding failure (except random failure)	700 °C < PCT < 750 °C less than 10'
		750 °C < PCT < 800 °C less than 3'
DBC3	No systematic cladding failure	DBC2 criteria – case by case exceptions
DBC4	Cladding failures accepted consistently with radiological releases criteria	PCT < 800 °C
	No systematic clad melting	
	Fuel assembly allowing cooling function	
DEC – A	No propagation of a fuel melt	TBD

Simulations at different primary pump coastdown and with different penalizations. → Identification of the influence of each penalization, and investigation with different coastdown constants.

Unprotected Transients

Unprotected Transient of Overpower

4. Unprotected Transient Overpower – Reactivity insertion

Initiator: **significant reactivity insertion**

Failure of the shutdown function is postulated

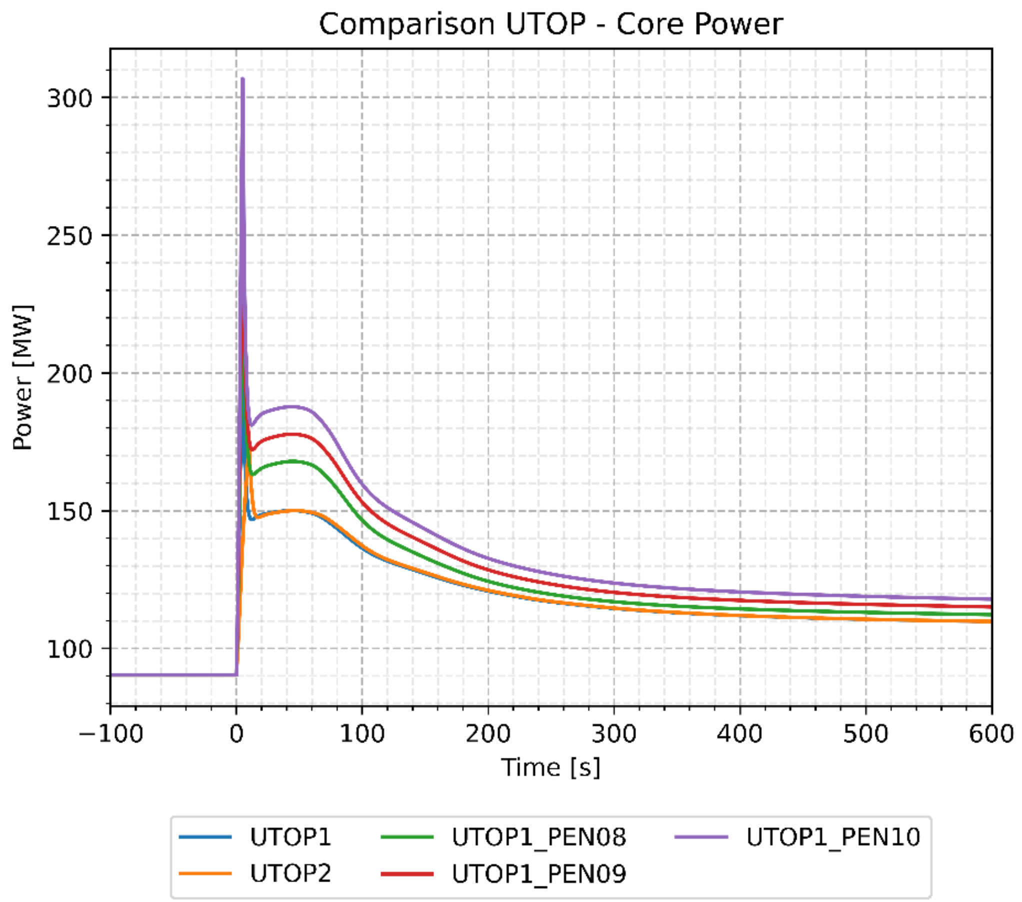
Sensitivity studies to determine the maximum allowable reactivity insertion not causing fuel melting. Penalizations on doppler reactivity coefficients

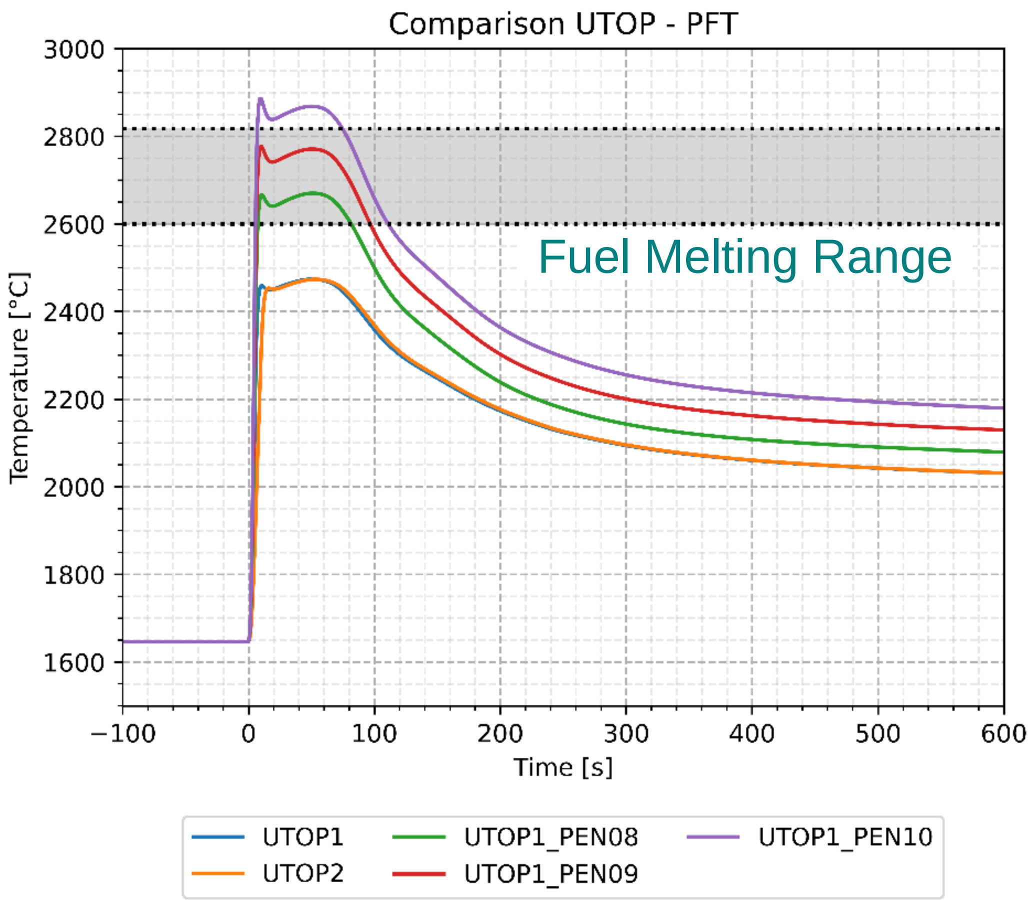
Long-terms conditions (1h) in the reference case (NV=nominal value):

- Core power → 117% NV
- Maximum cladding temperature → 720 °C
- Core outlet temperature → 651 °C

Objectives:

- Demonstrate the favorable intrinsic safety behavior of the system in challenging accidental conditions
  → Practical elimination of generalised core melt scenarios
- Inform the severe accident studies in terms of core state and vessel state





Operational Transients

Steam generator start-up

5. Operational Transient

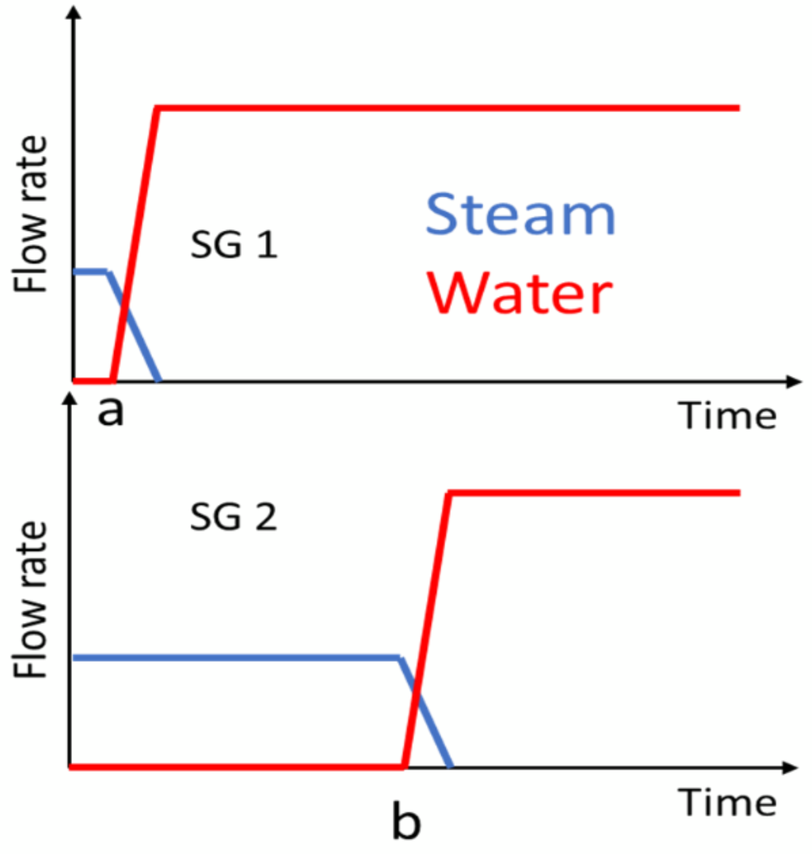
Investigate a **SG start-up procedure** to minimise

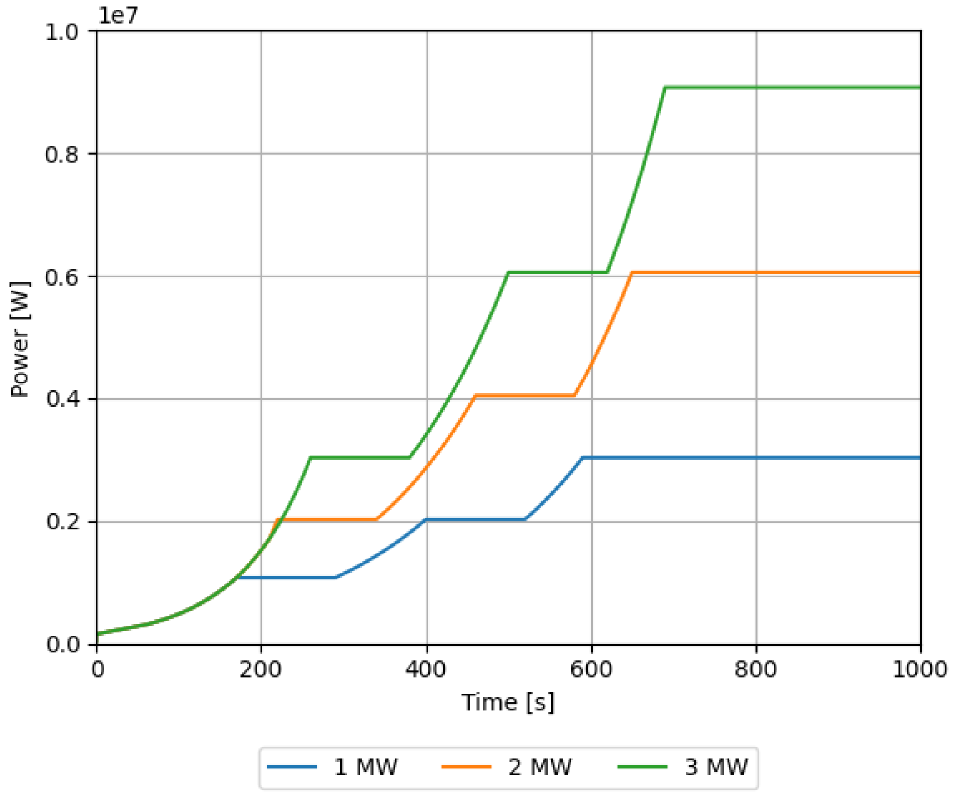
- the water inventory in the SG tubes
- the risk of two-phase flow instabilities
- the risk of flow mal-distribution among the tubes,
- the thermal stress on reactor vessel, SG tubes, etc.

Challenges

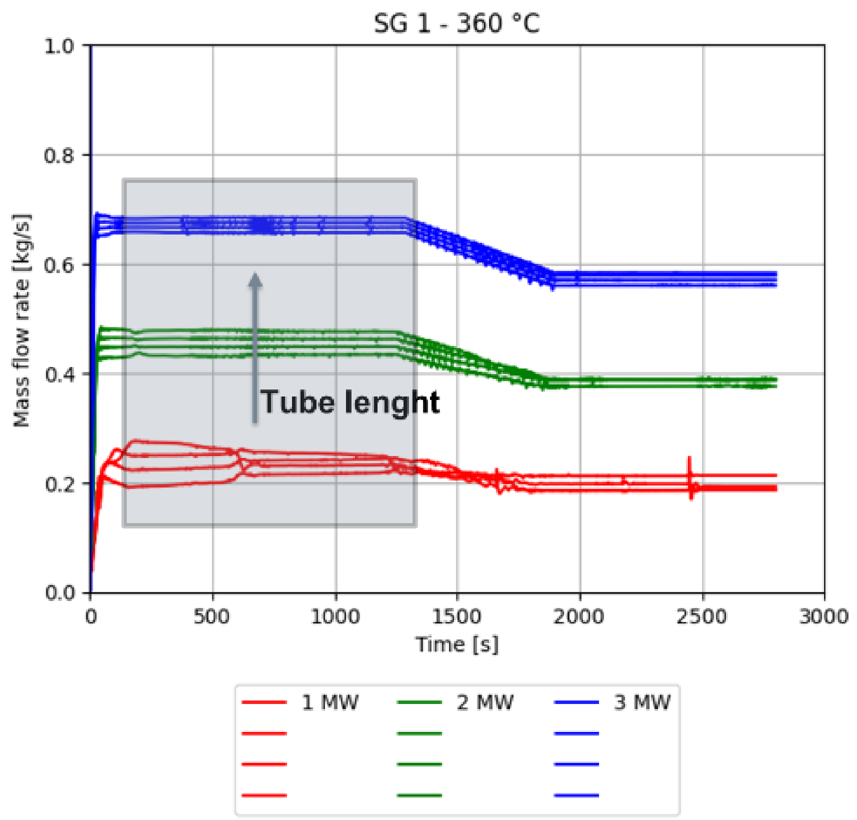
- Impact of numerics, lack of closure laws, presence of non-condensable, lead freezing, ….

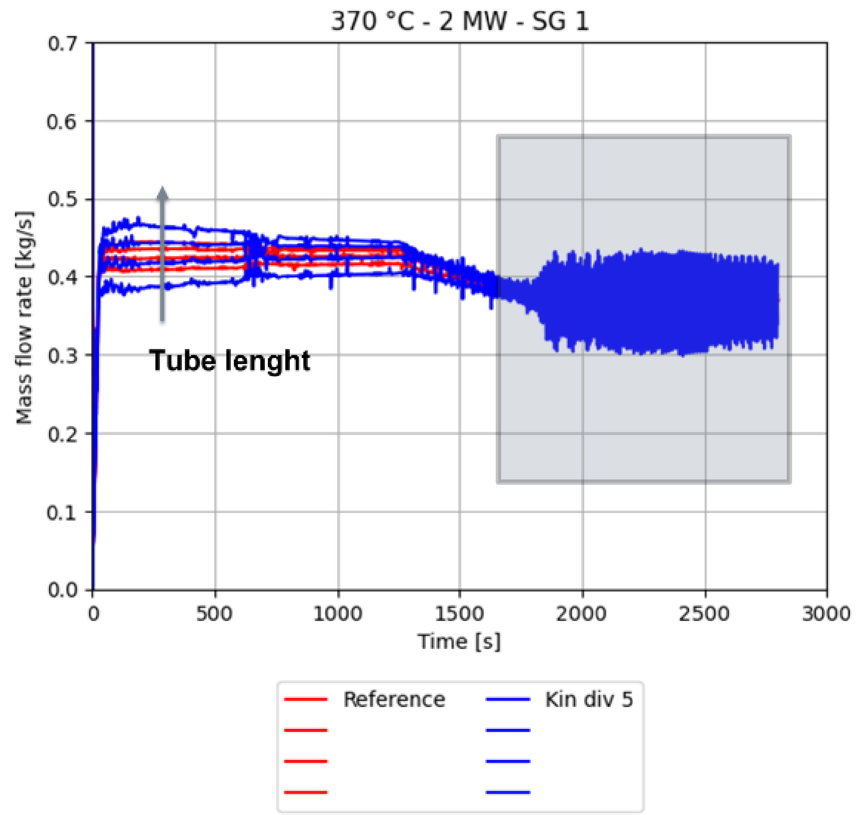
Preliminary procedure – Sequential SG startup



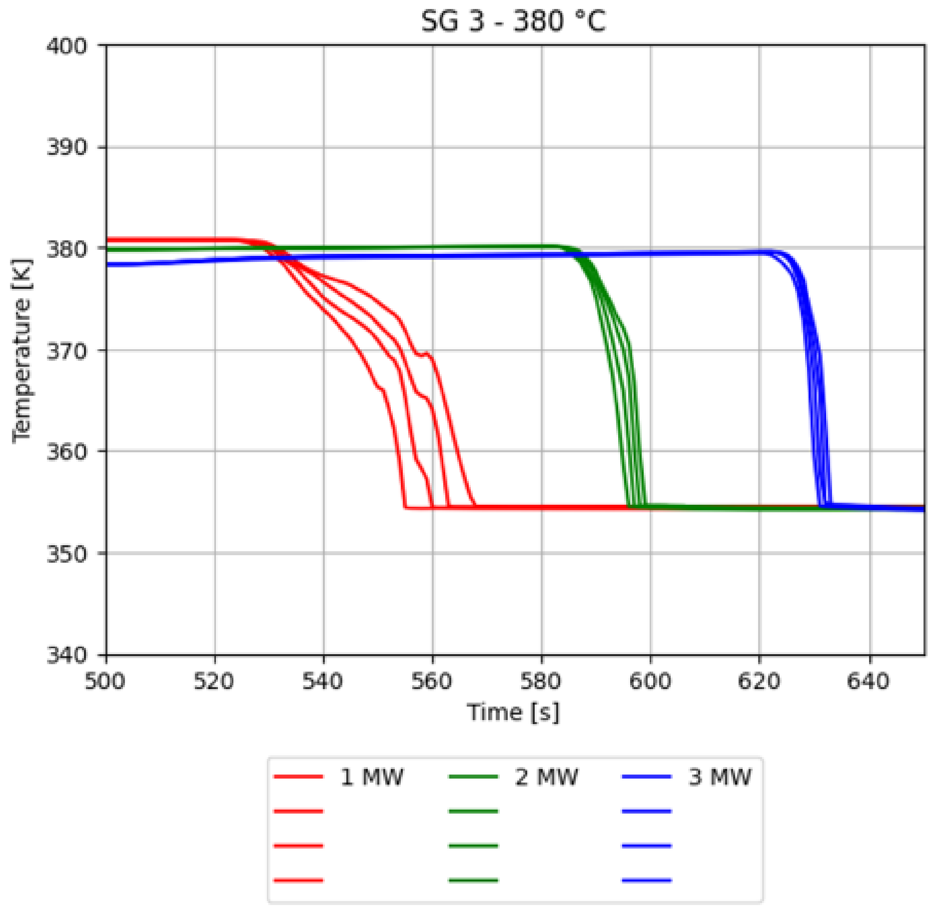


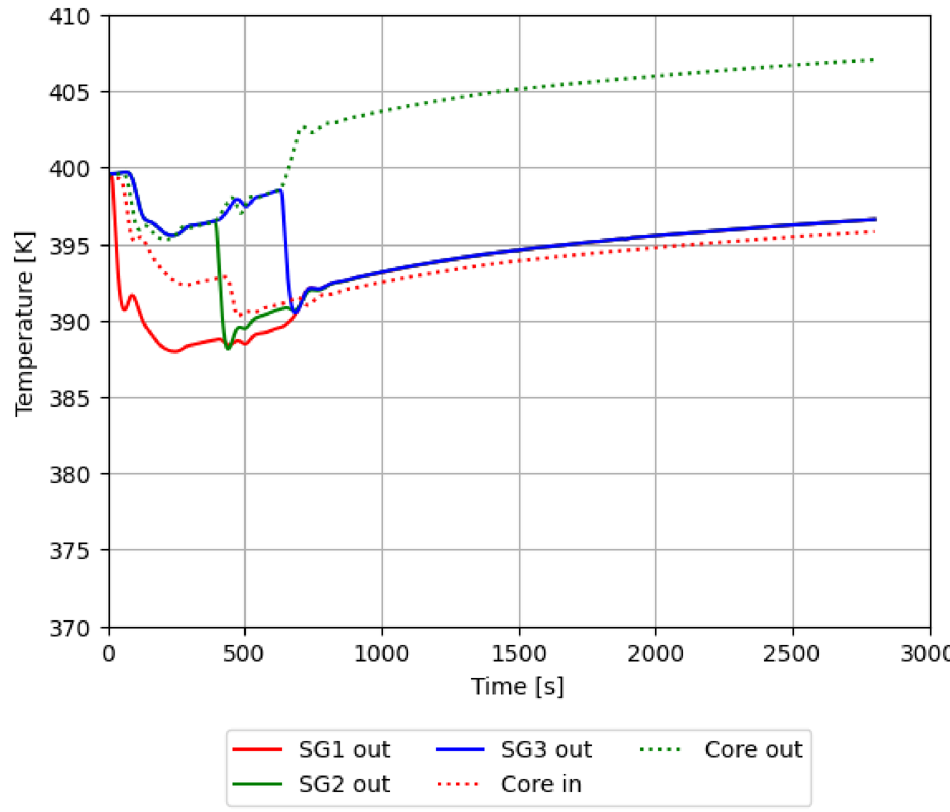
Address the onset of two-phase flow instabilities & SS flow maldistribution





Address the thermal stress on metallic structures

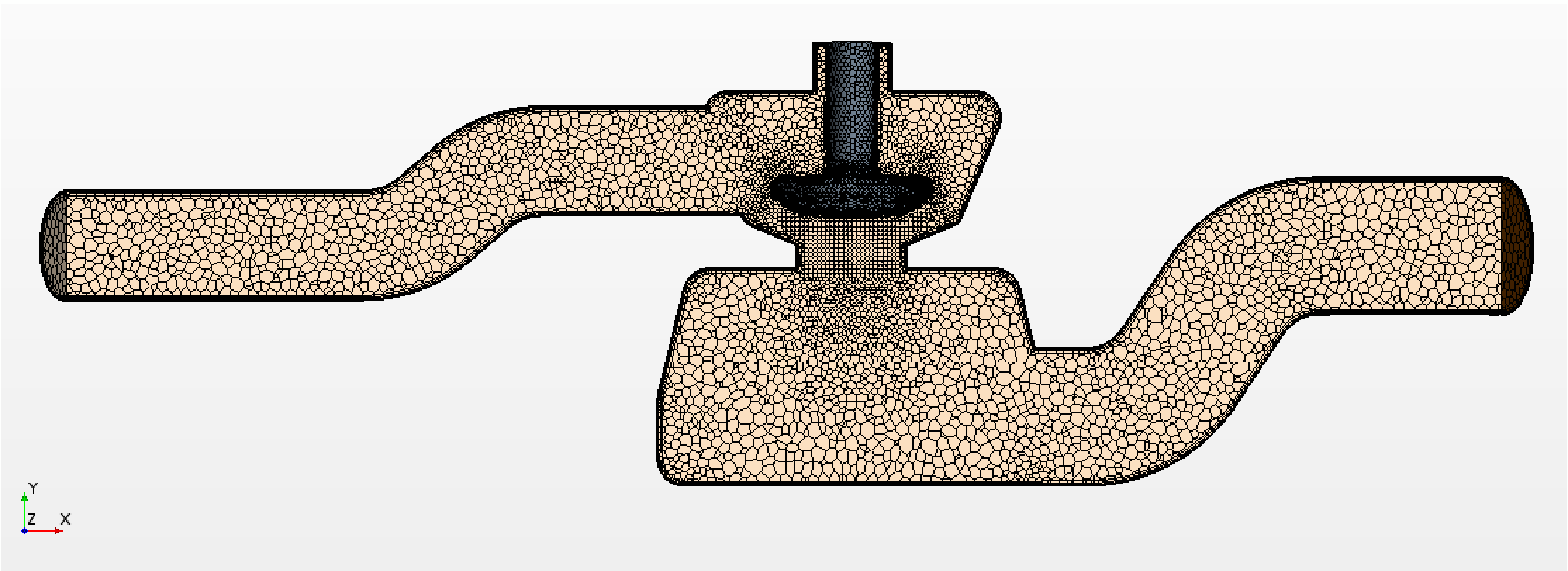


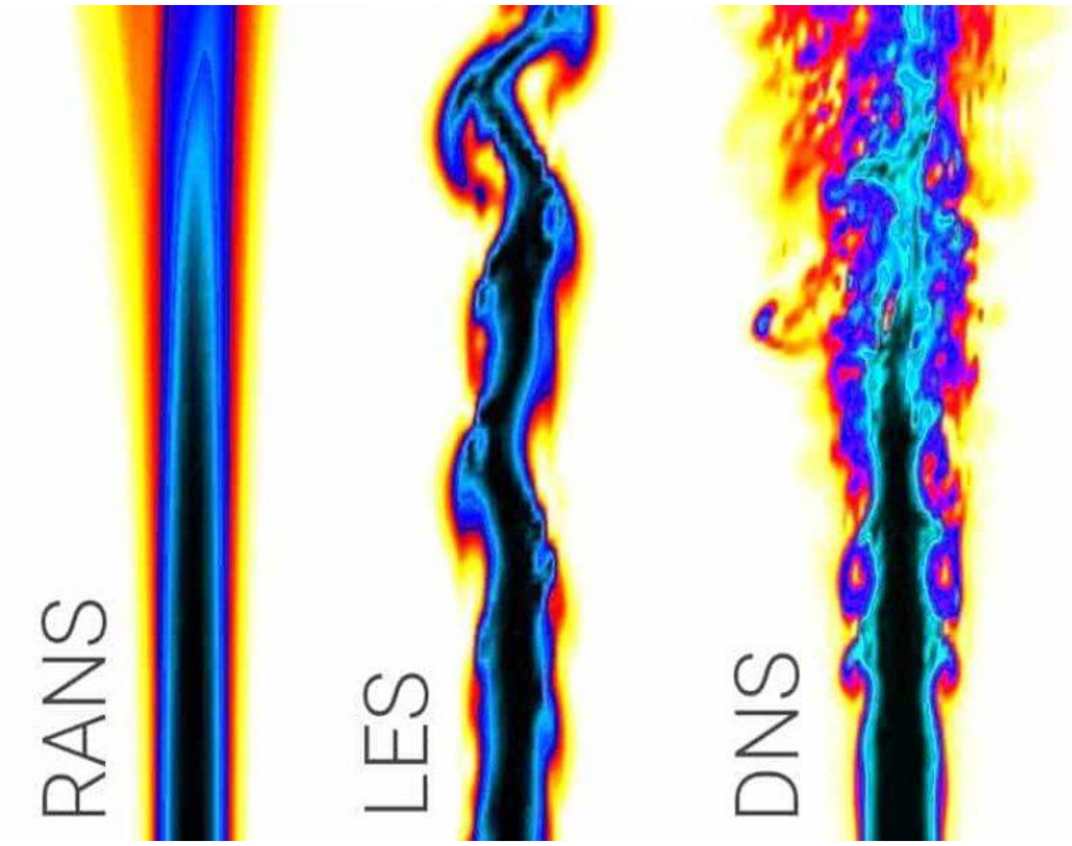


CFD studies

6.a CFD studies for plant thermal-hydraulics

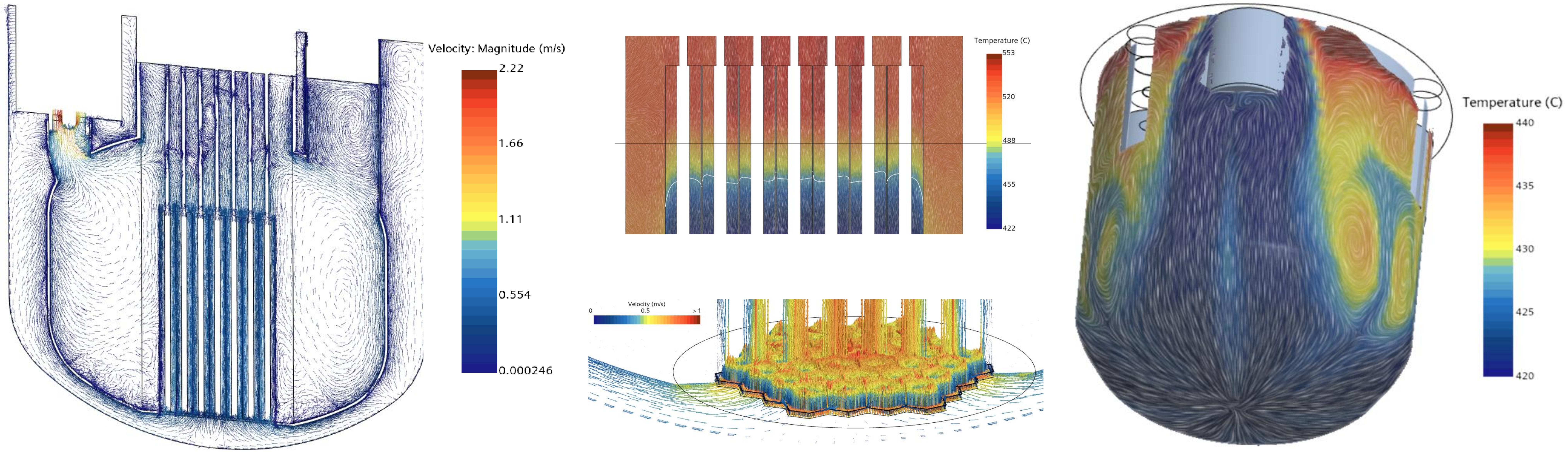
- CFD = Computational Fluid Dynamics
  - Allow to solve the conservation equations of mass, momentum and energy on discretised geometries thanks to numerical alogorithms
  - Several approaches to deal with the turbulence
    - Reynolds Average Navier Stokes (average values and turbulence models),
    - Large Eddy Simulation (eddies larger than the mesh and models for smaller eddies),
    - Direct Numerical Simulation (all scales solved).
  - Steady state and transient analyses





6.b CFD studies for plant thermal-hydraulics

- Primary lead pool studies: to assess the coolant behavior in the reactor

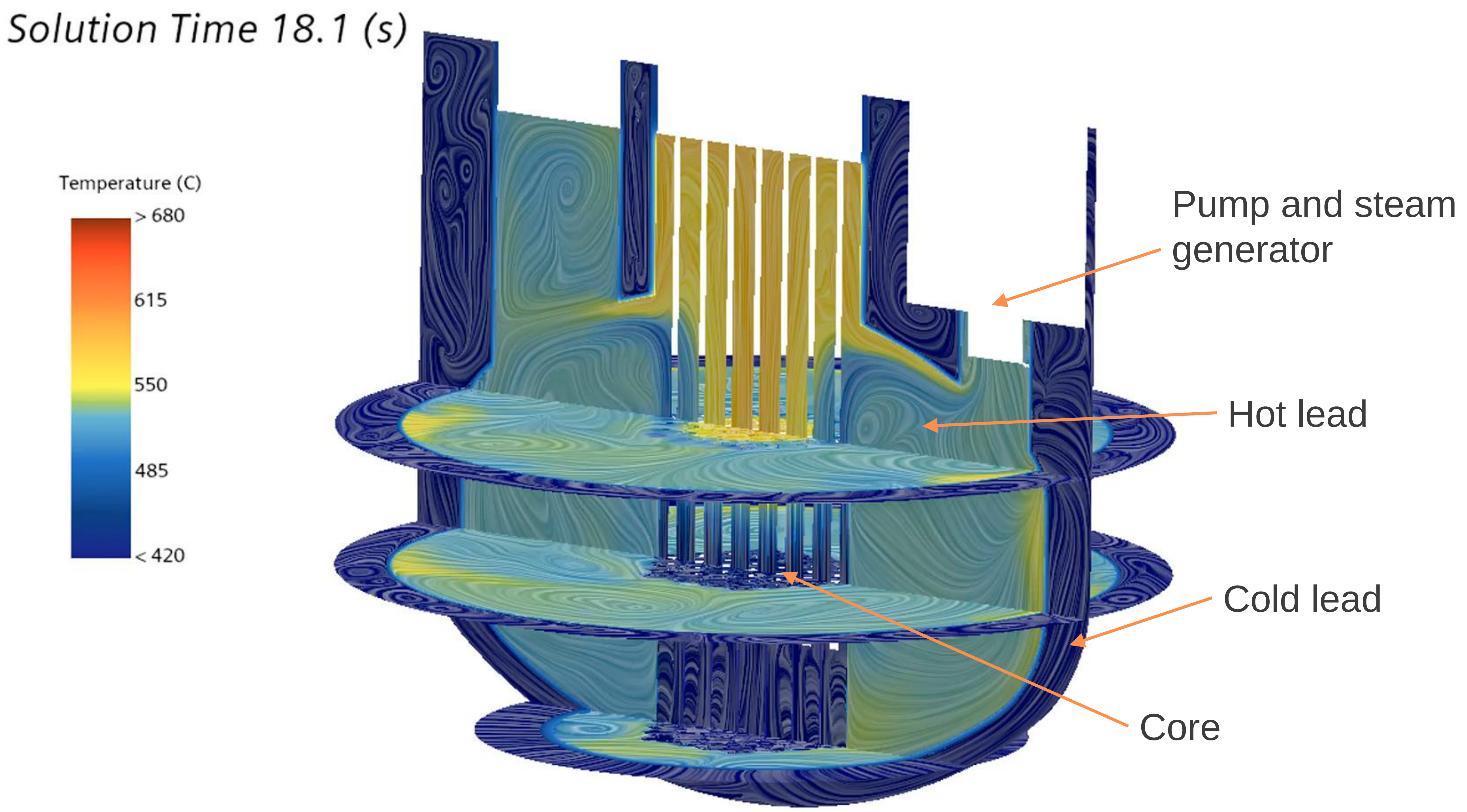


Mass flow and temperature distribution

→ Allows improve the conception, to optimise the reactor operation and to assess the plant behaviour during normal operation or accidental conditions

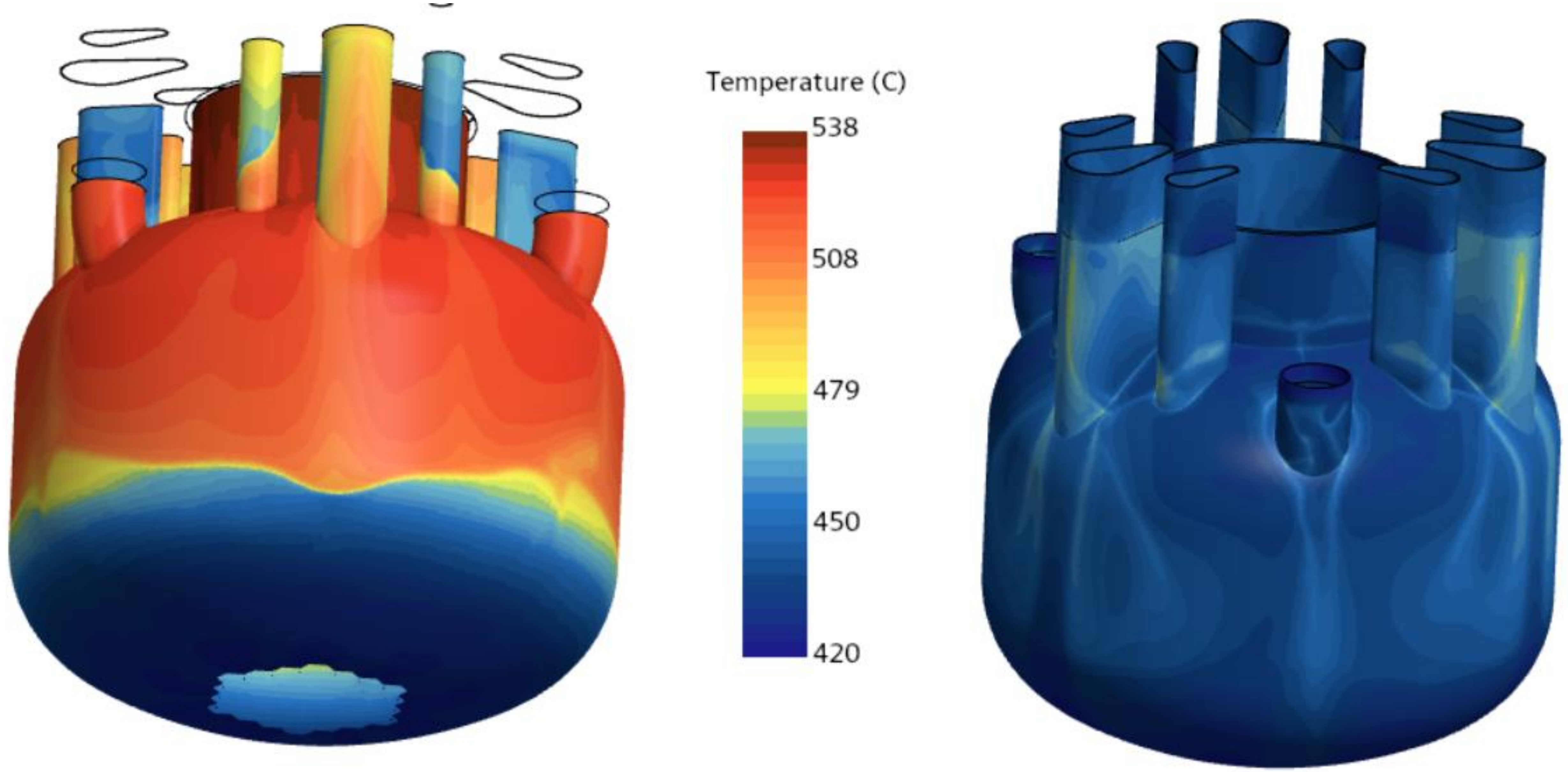
6.c CFD studies for plant thermal-hydraulics

- Example: loss of one primary pump transient (temperature and velocity streamlines)



6.d CFD studies for plant thermal-hydraulics

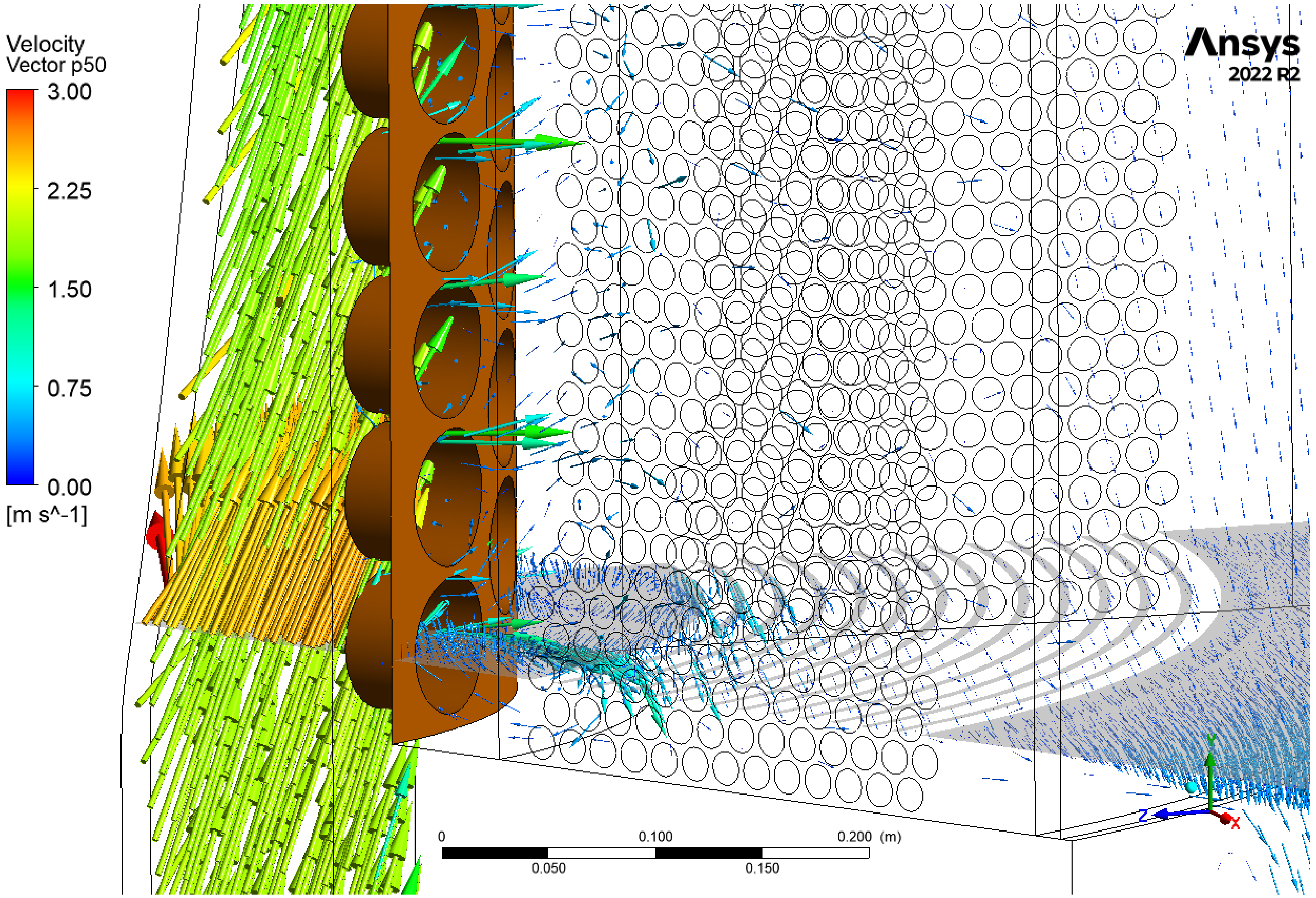
- Simulation for mechanical analyses: to provide thermal loading and assess the mechanical constraints during the reactor operation



Temperature field on internal and external parts of the inner vessel

6.e CFD studies for plant thermal-hydraulics

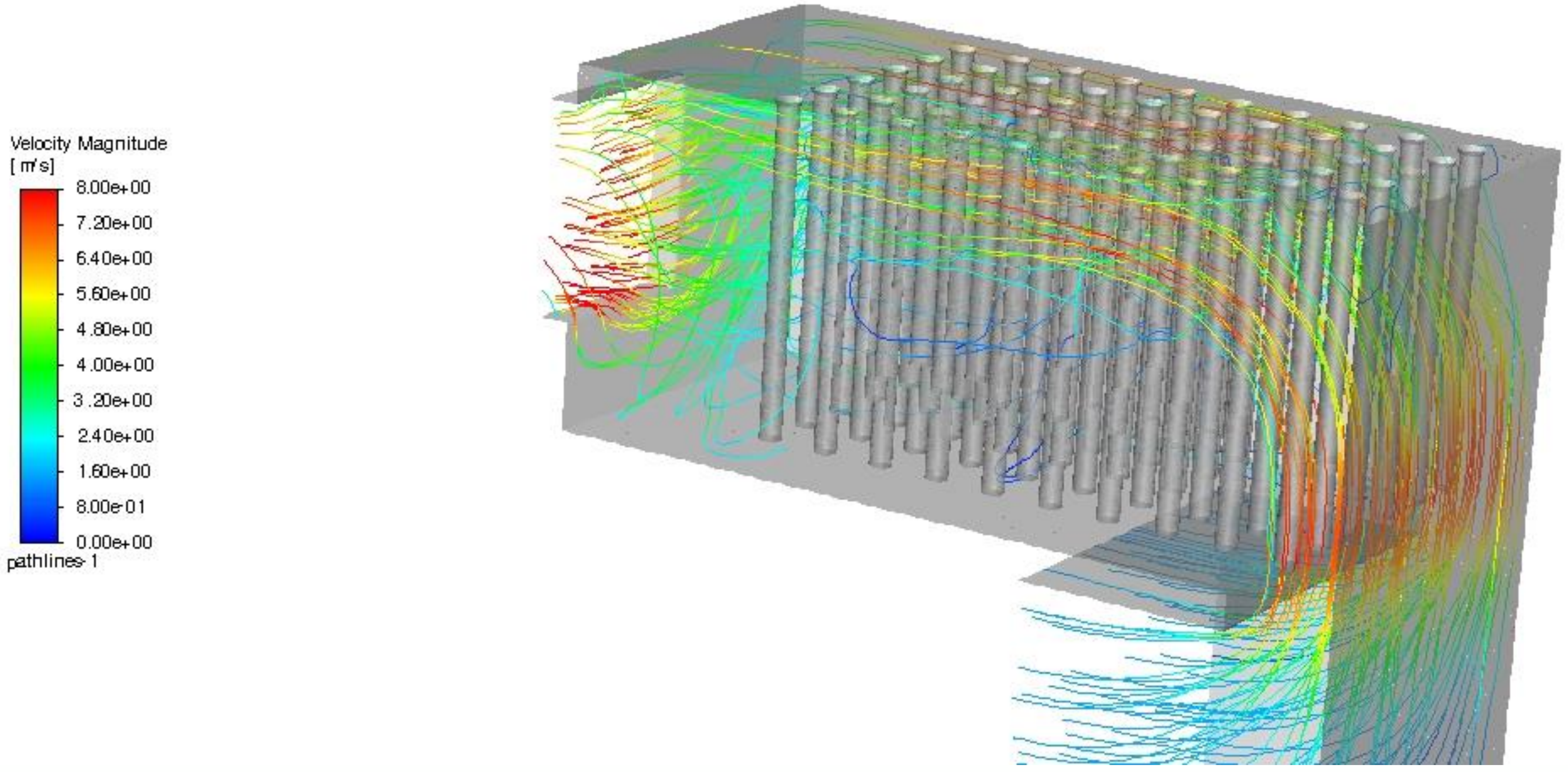
- Pump and heat exchangers analyses: to assess their performance, mechanical constraints, …



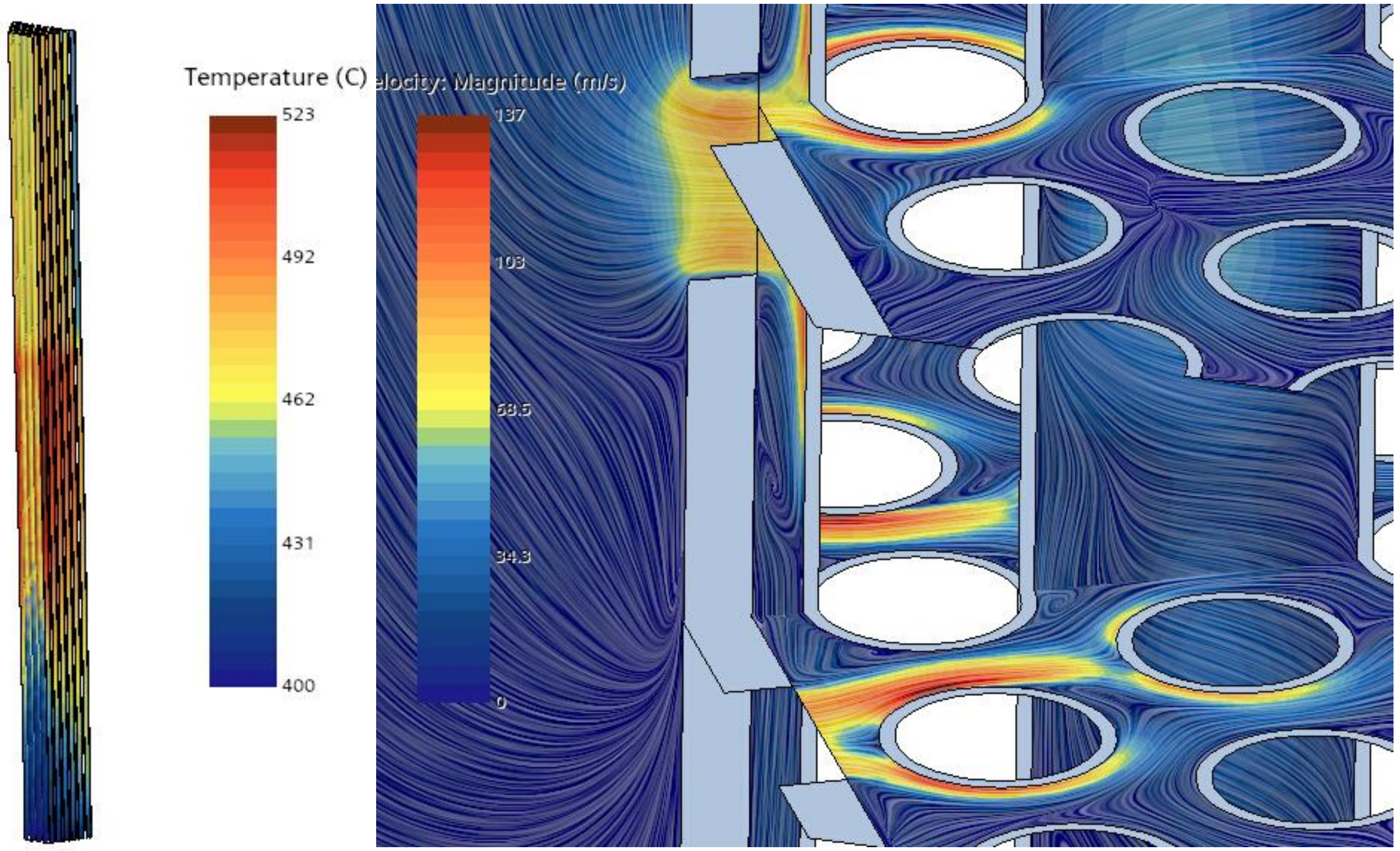
Velocity field at the steam generator inlet

6.f CFD studies for plant thermal-hydraulics

- Fuel handling studies: to assess the thermal behavior of fresh and spent fuel assemblies for safety analyses



Cooling of spent fuel assemblies in the storage room



Temperature and gas flow inside a spent fuel assembly

6.g CFD studies for plant thermal-hydraulics

- Other possible applications:

  - Coupling CFD / system code for better accuracy
  - Transport of species to assess the concentrations inside the primary coolant (radioactive activation products, chemical species for corrosion risk,…)
  - Atmospheric dispersion (radiological emissions)
  - Artificial intelligence
  - …

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Futurable Energy

Thank you