Karlsruher Institut für Technologie

Progress of KIT-INR on ASTEC Validation: Application of ASTECV2.1 to the QUENCH-08

(work performed in IRSN Cadarache in frame of CESAM mobility program)

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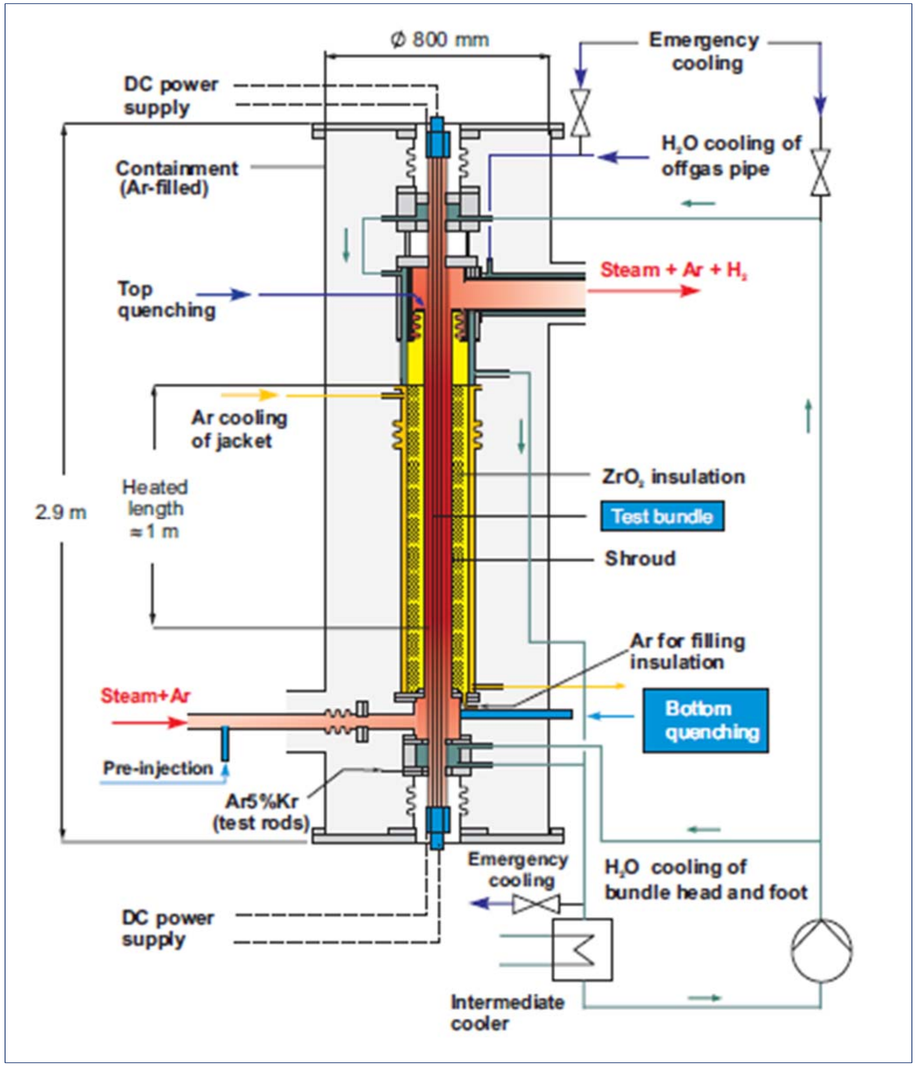
Content

1. Motivation

- Contribute to the validation of the severe accident code ASTECV2.1 using data from QUENCH facility in the frame of the EU CESAM project
- Apply validated ASTECV2.1 code to simulate selected severe accident sequences in a German PWR Konvoi plant
- Use simulation's results as technical basis for the optimization of SAM measures (e.g. re-flooding of an overheated core)

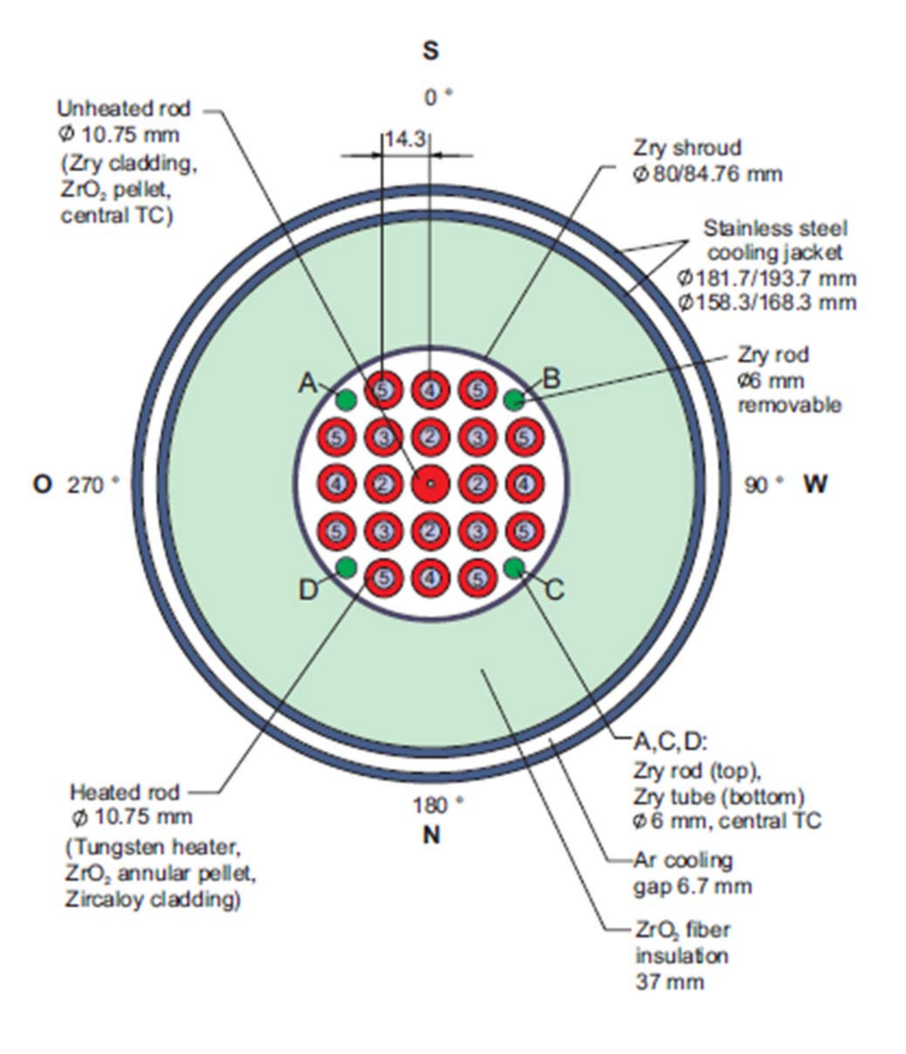
Content

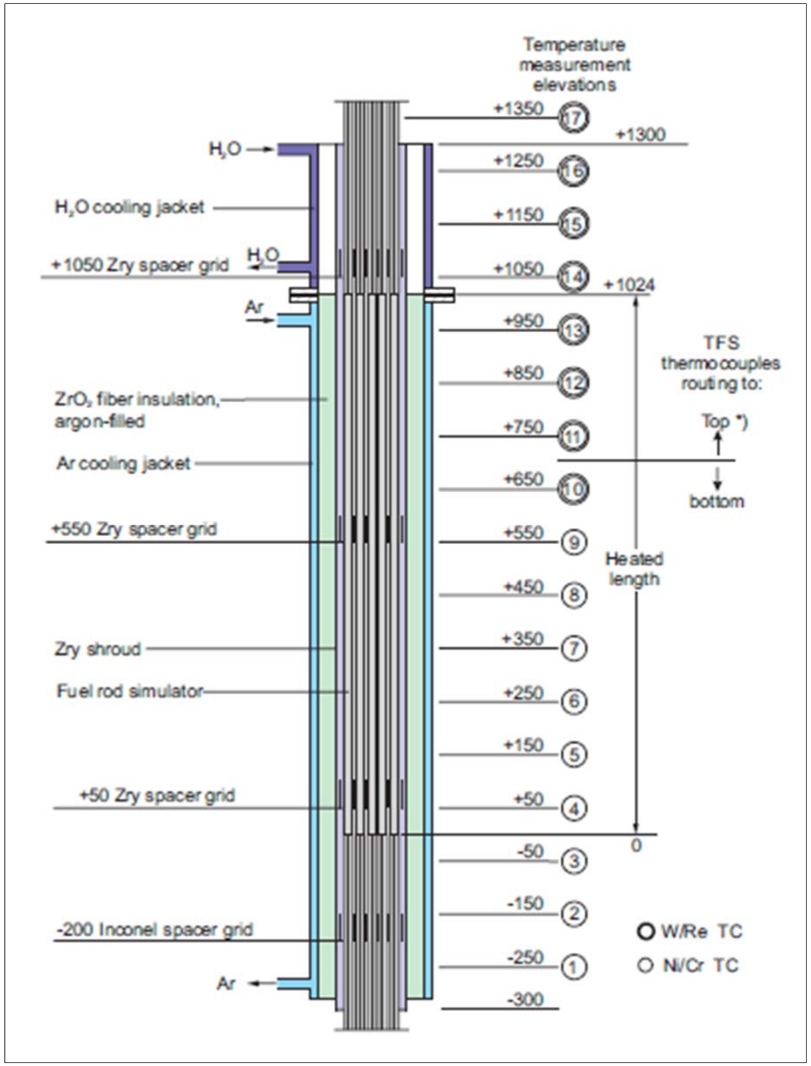
2. The QUENCH-08 Test Facility



- Reference test for QUENCH-07 and QUENCH-09.
- **Goal of QUENCH-07, 08 and 09**: study the influence of boron carbide on hydrogen generation and core degradation.
- Reflooding: saturated steam entering at the bottom.

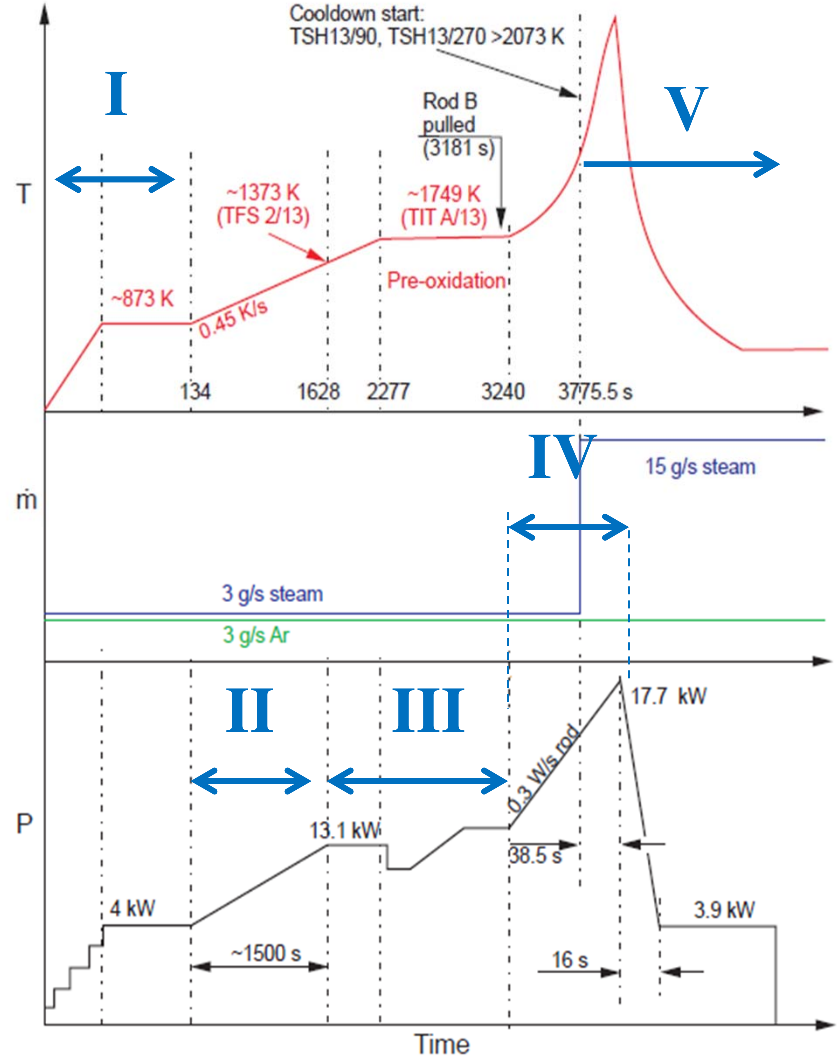
2. The QUENCH-08 Experiment: Test Bundle





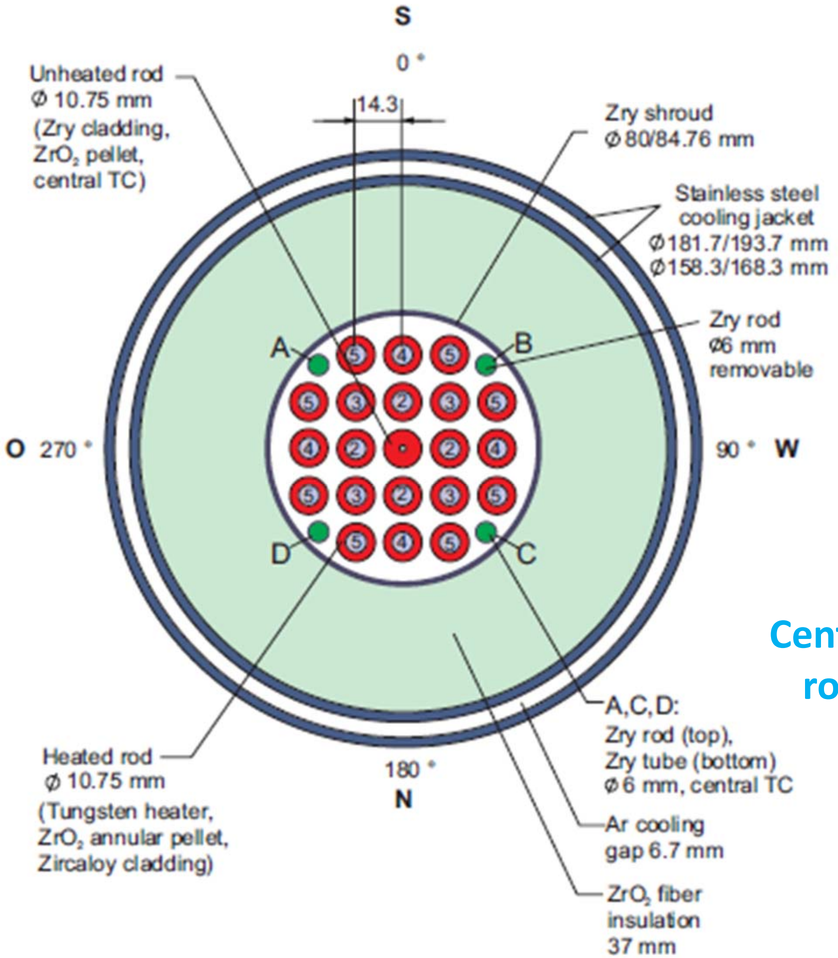
2. The QUENCH-08 Experiment: Phases

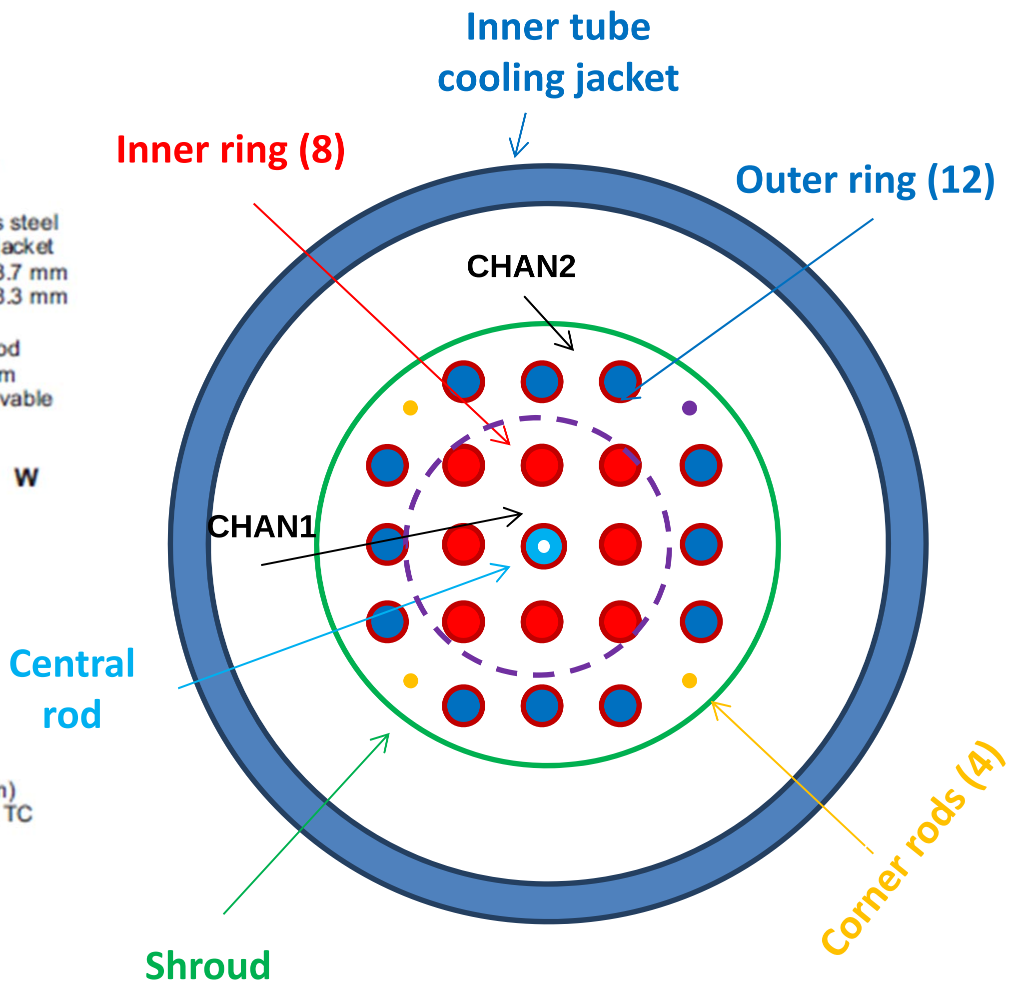
Phase	Specifications	Time (s)
I	Heat-up to 873 K and stabilization	0-134
II	First heat-up: 873 K to 1700 K	134-1628
III	Pre-oxidation at 1700-1740 K	1628–3240
IV	Second heat-up: 1740 K to 2200 K	3240-3814
V	Quenching	3775-4650



Content

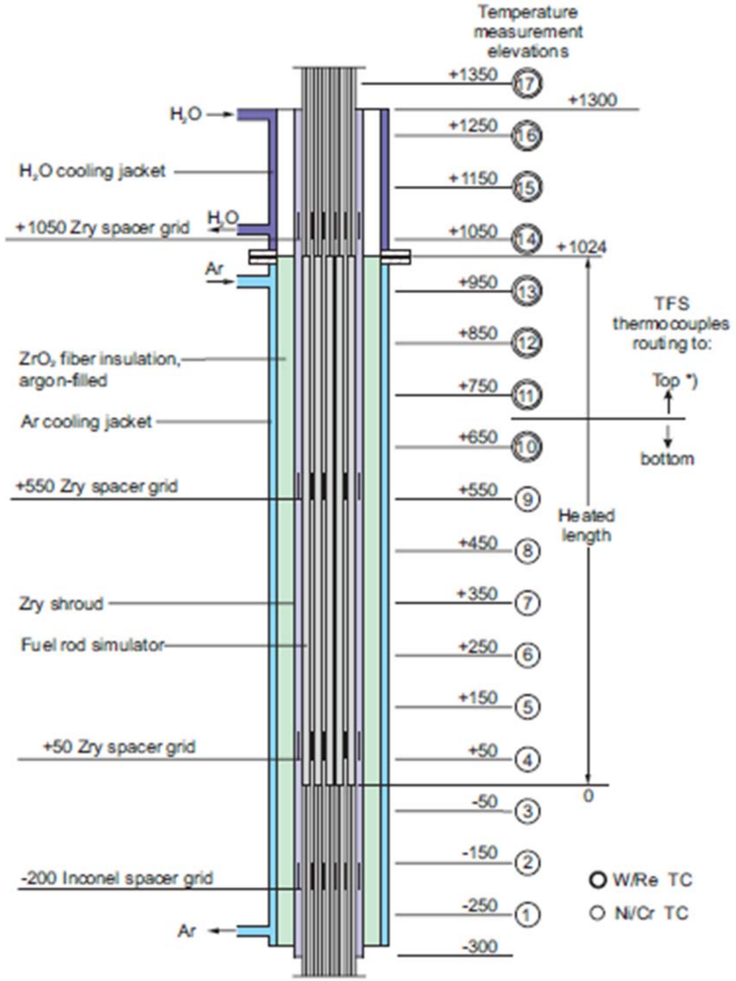
3. ASTECV2.1 Model of QUENCH-08: Radial View

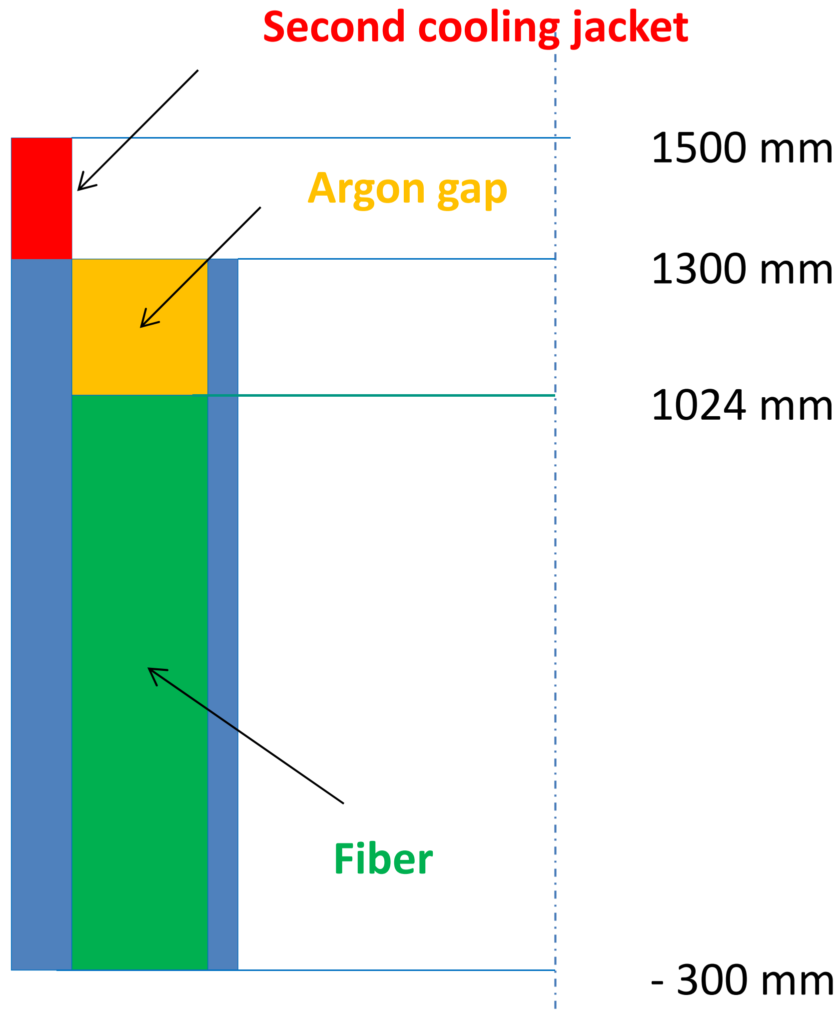




Test Facility → ASTECV2.0 Model

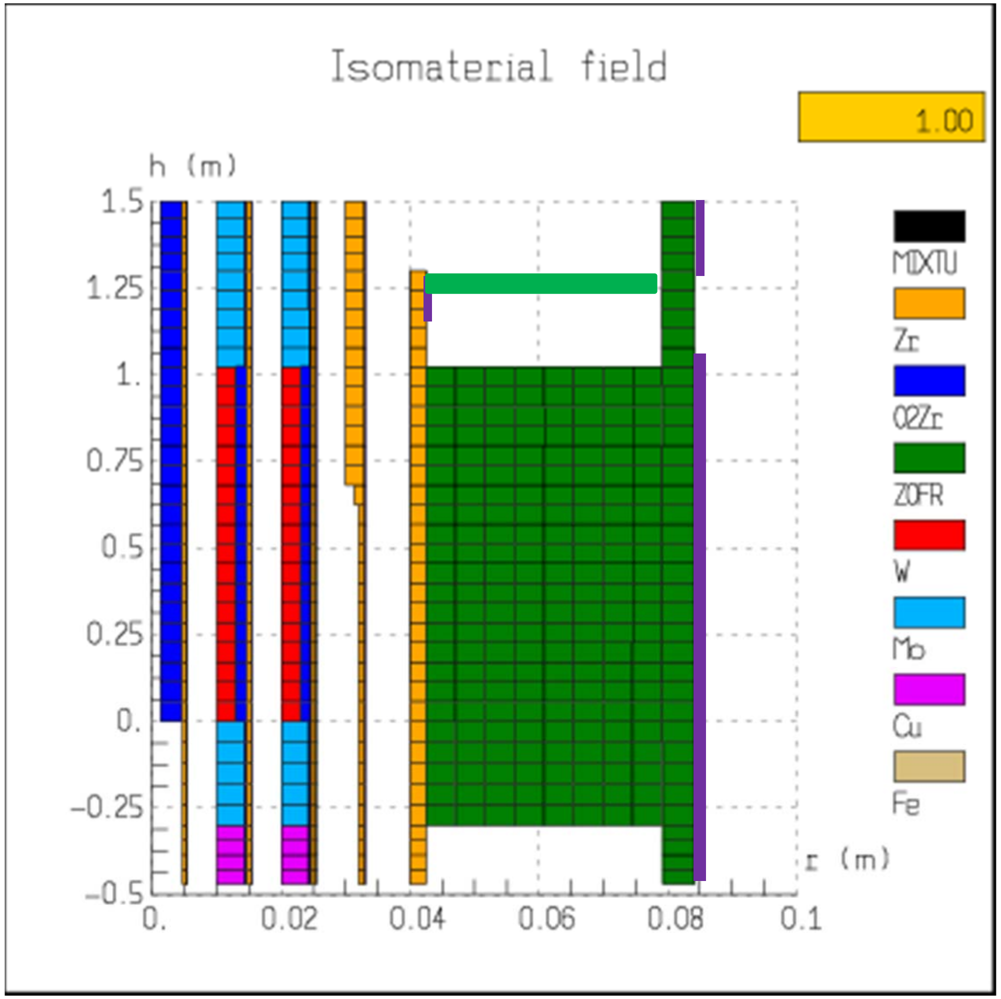
3. ASTECV2.1 Model of QUENCH-08: Axial View





Test Facility → ASTEC Model

3. ASTECV2.1 model for QUENCH-08: Geometry



ASTEC: axial and radial Nodalisation

2-D configuration for the fuel bundle:

- Central, inner and outer ring
- Corner rods
- Shroud and Cooling Jacket
- Fiber and Argon gap
- Grid spacers

Boundary conditions:

- T: outer surface of cooling jacket (experiment) and shroud
- P: system 1.9 bar
- Q: inlet mass flow rate

Axial mesh size:

- Active zone and upper part: 50 mm
- Lower part 100 mm

3. ASTECV2.1 model for QUENCH-08: Physical model parameters

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- Oxidation of solid Zircaloy-4 by steam (ZROX): claddings, grid spacers, shroud
  - Best-fit correlation
- Loss of integrity criteria for Zirconia layer (INTE) for thin oxide layers
  - T > 2300 K, and
  - Oxide thickness < 300 µm
- Decanting of molten material towards outer surfaces (DECA)
  - Shroud not allowed to decant → blockages → convergence problems
- Relocation of molten material downwards (MOVEMAG)
  - MAGMA model → 2D relocation
- Oxidation of molten material (UZOXMAG)

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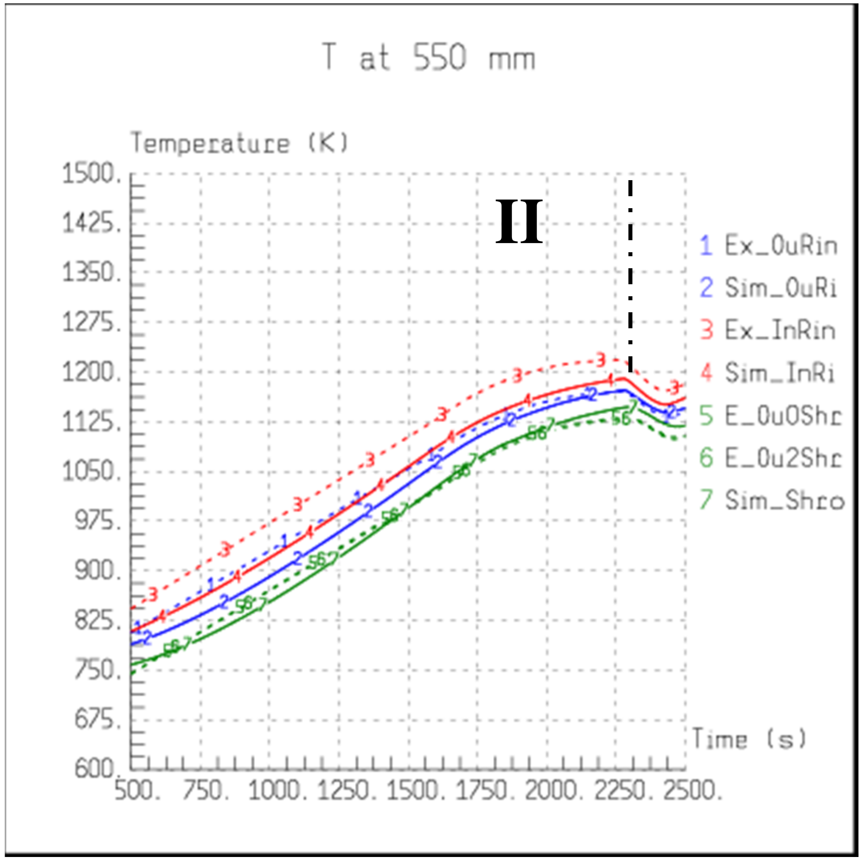
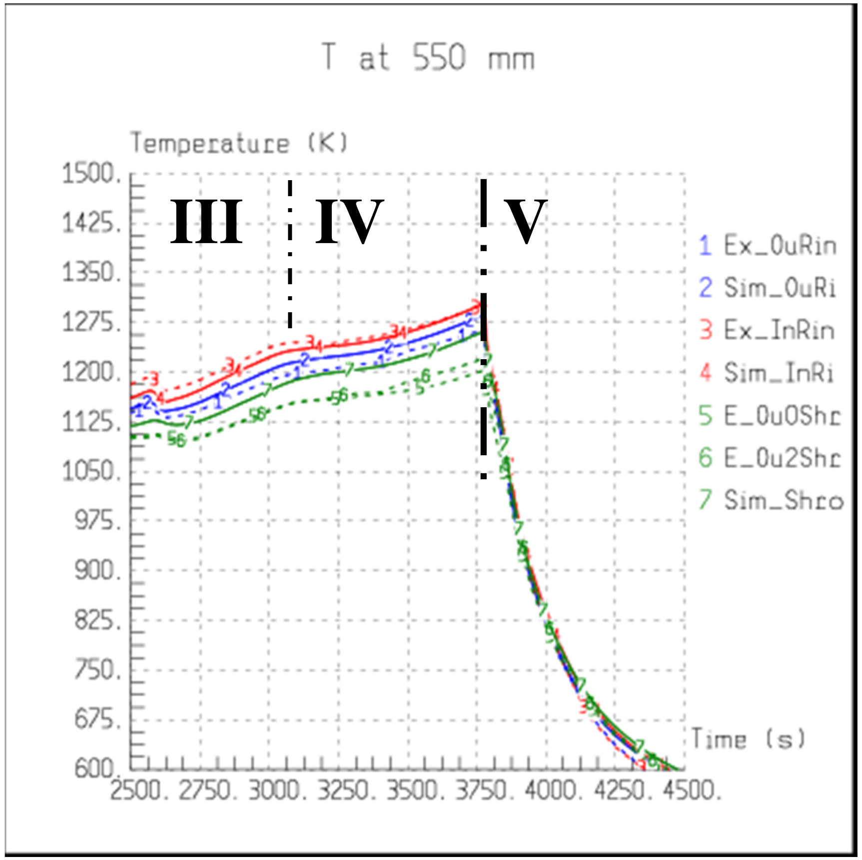
1. Motivation
2. The QUENCH-08 experiment
3. ASTECV2.1 model of the QUENCH-08
4. **Comparison between Data and Predictions**
5. Conclusions
6. Future works

4. Comparison between Data and Prediction: Cladding temperature evolution at 550 mm

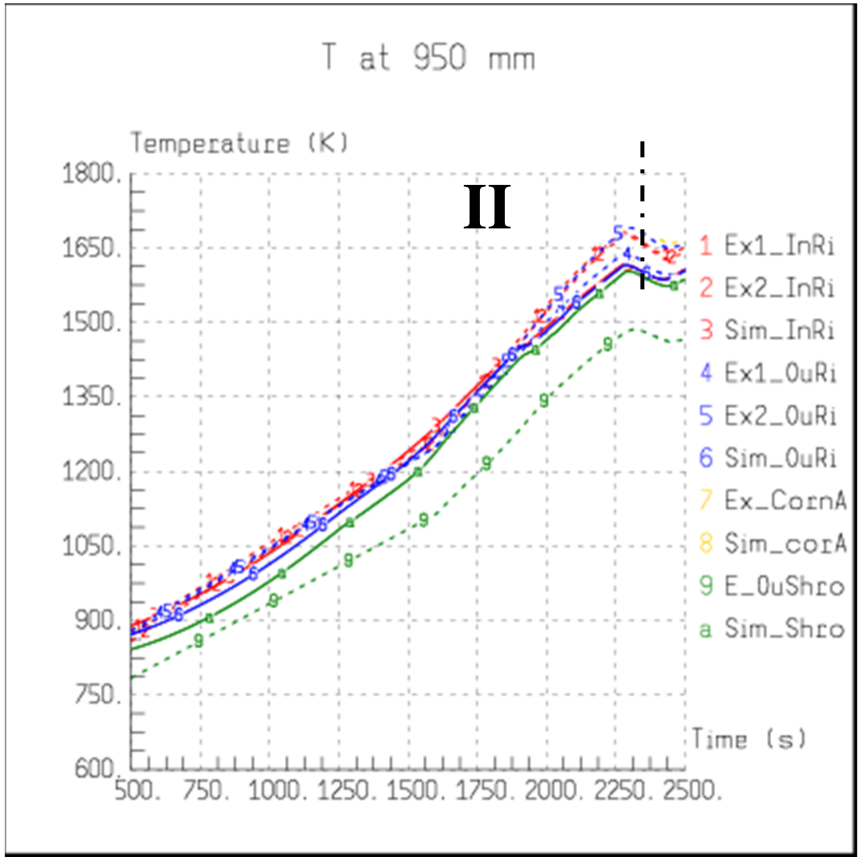


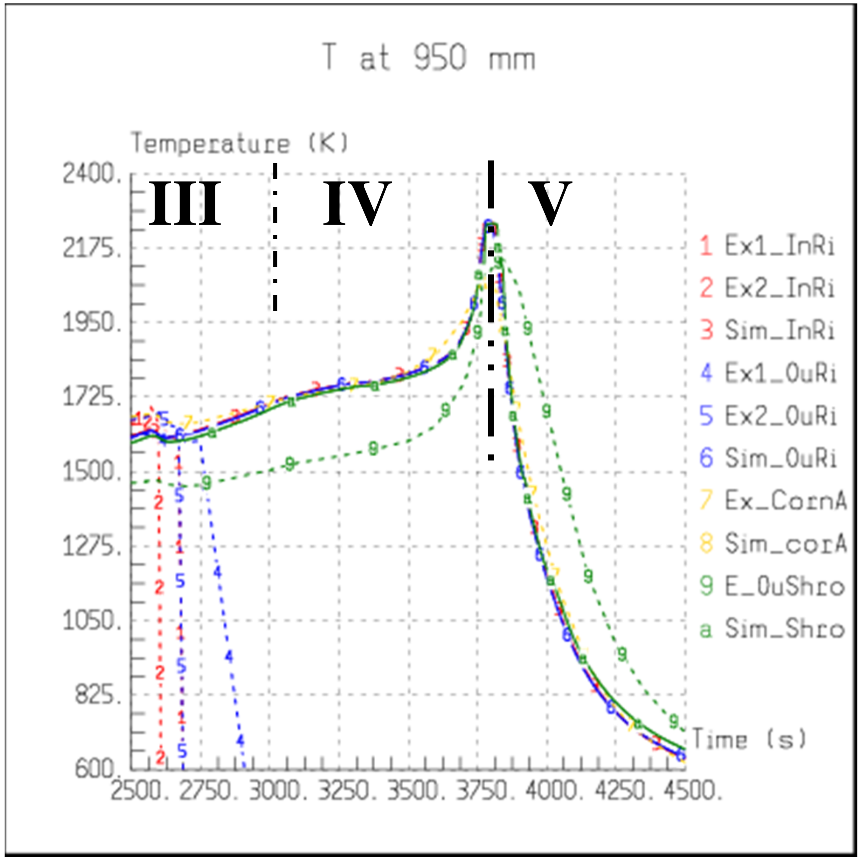


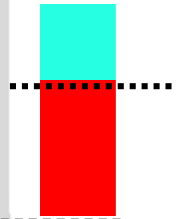
Good qualitative prediction throughout the transient

Temperature overestimation of shroud (25 C) at end of second heat-up phase

4. Comparison between Data and Prediction: Cladding temperature evolution at 950 mm



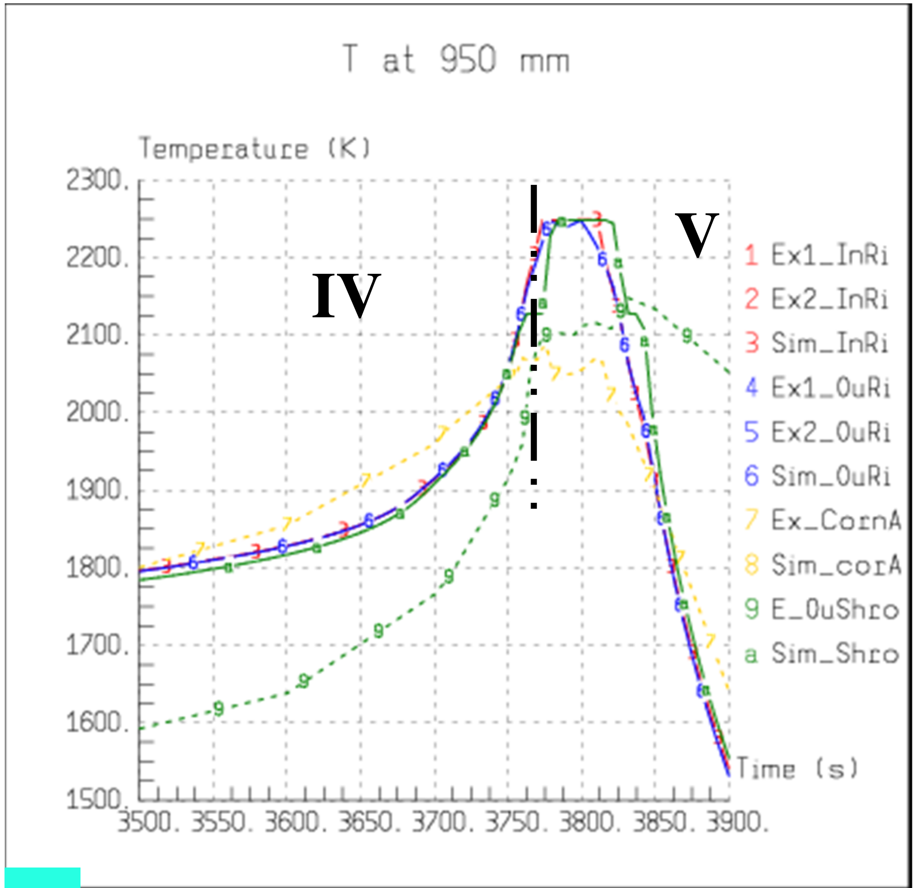


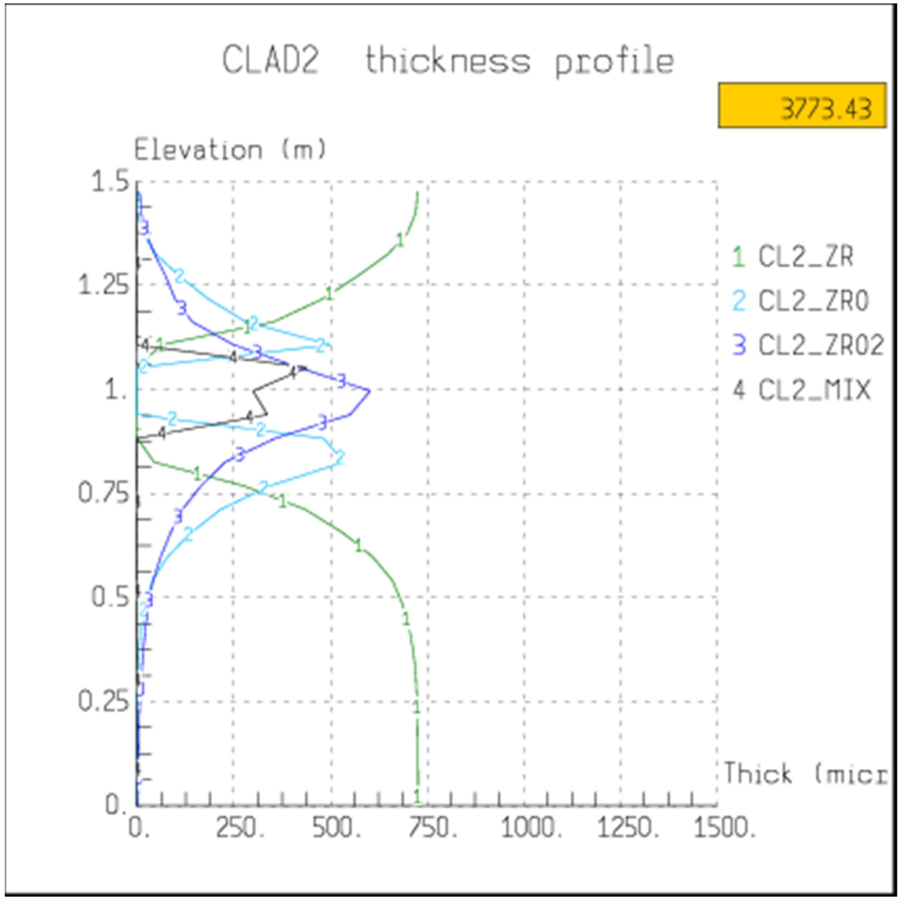


Trends are very well predicted by ASTEC in fuel rod simulators until quenching

Shroud temperature is poorly calculated → argon gap just above

4. Comparison between Data and Prediction: Cladding temperature evolution at 950 mm (quenching)

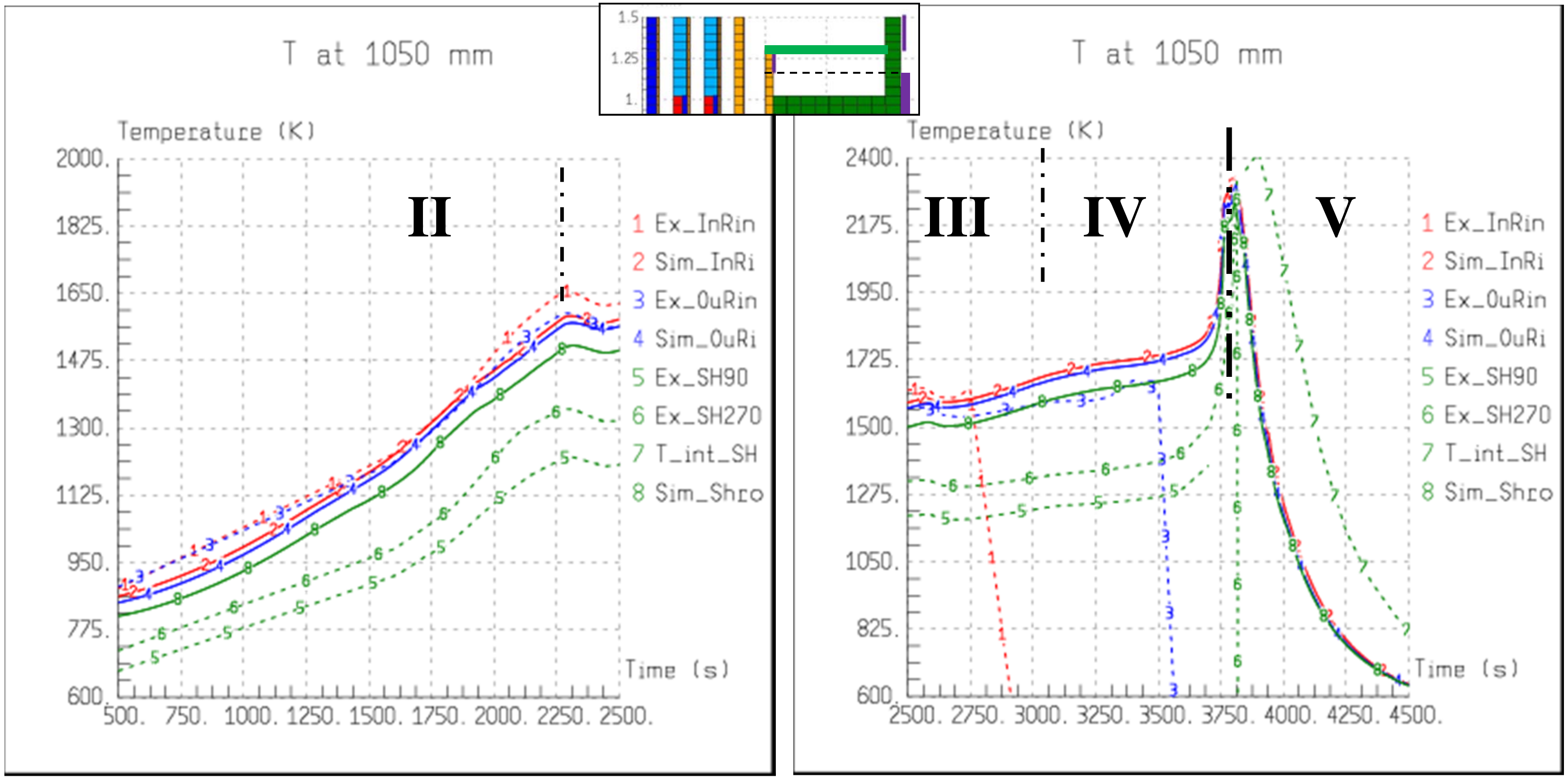


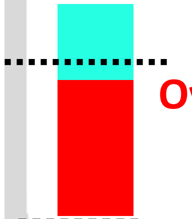


Predicted temperature escalation in fuel rod simulators shows a similar trend than experimental corner rod A

Quantitative analysis cannot be done for claddings due to failure of THCs

4. Comparison between Data and Prediction: Cladding temperature evolution at 1050 mm

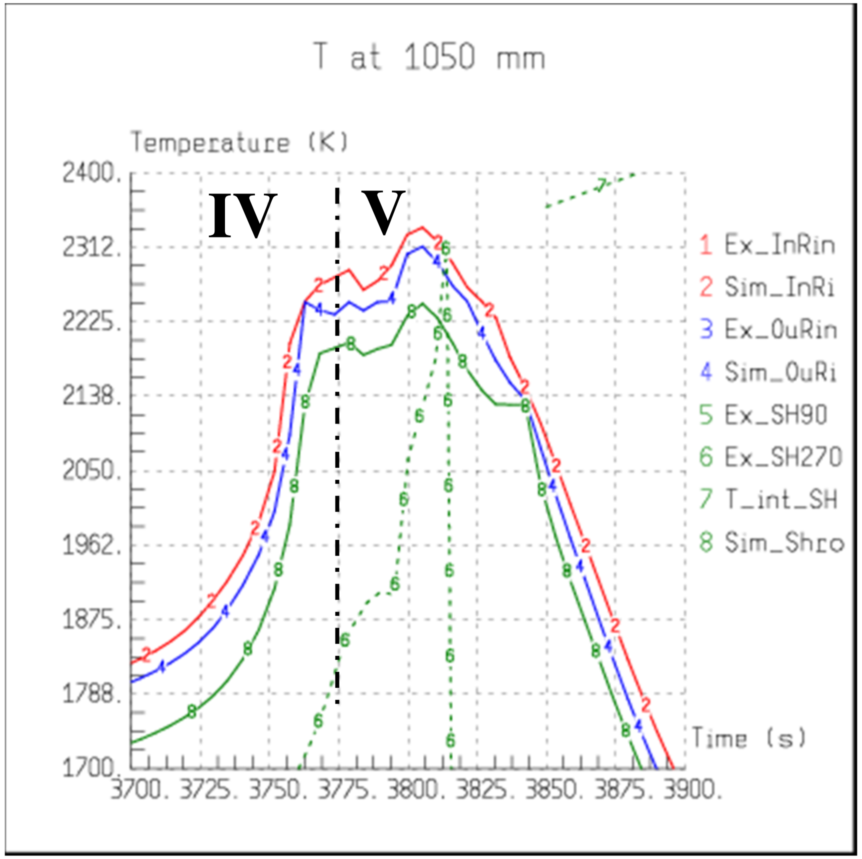


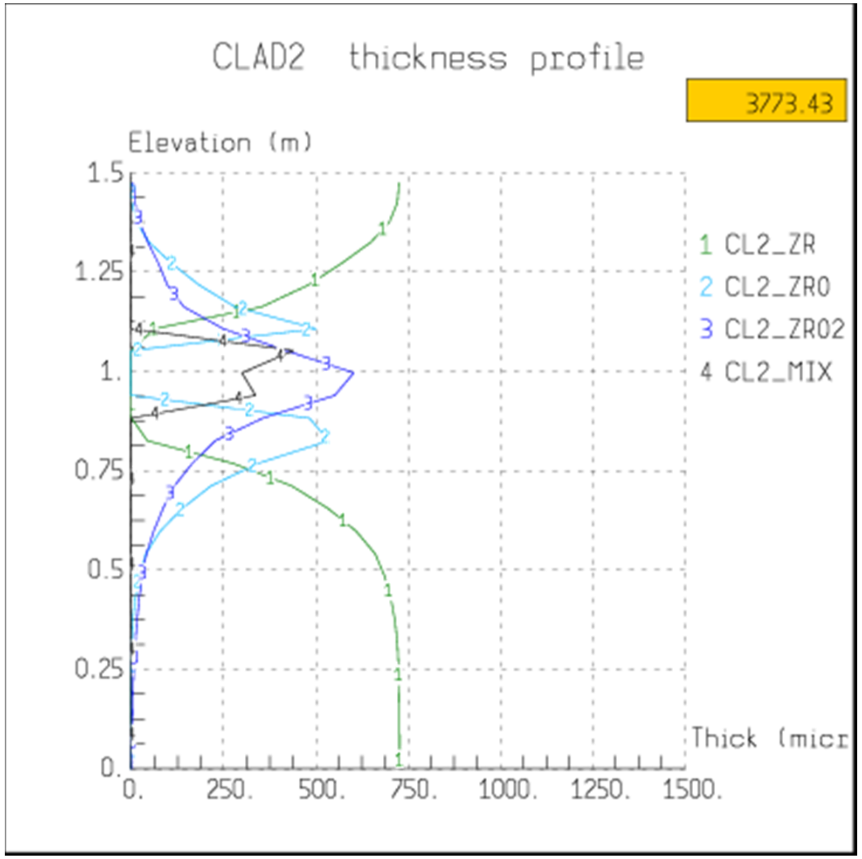


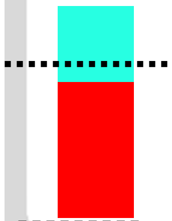
Temperature escalation occurred at 950 mm propagates upwards → T runaway

Overestimation of shroud temperature → difficulty treating argon gap → underestimation of heat losses

4. Comparison between Data and Prediction: Temperature evolution at 1050 mm (quenching)





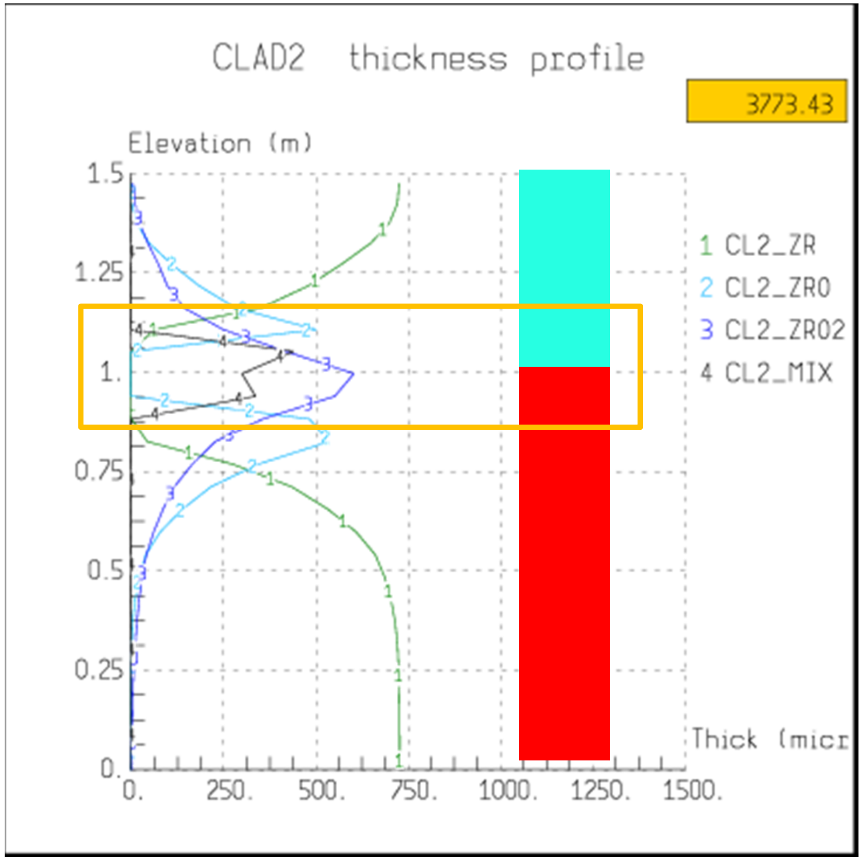
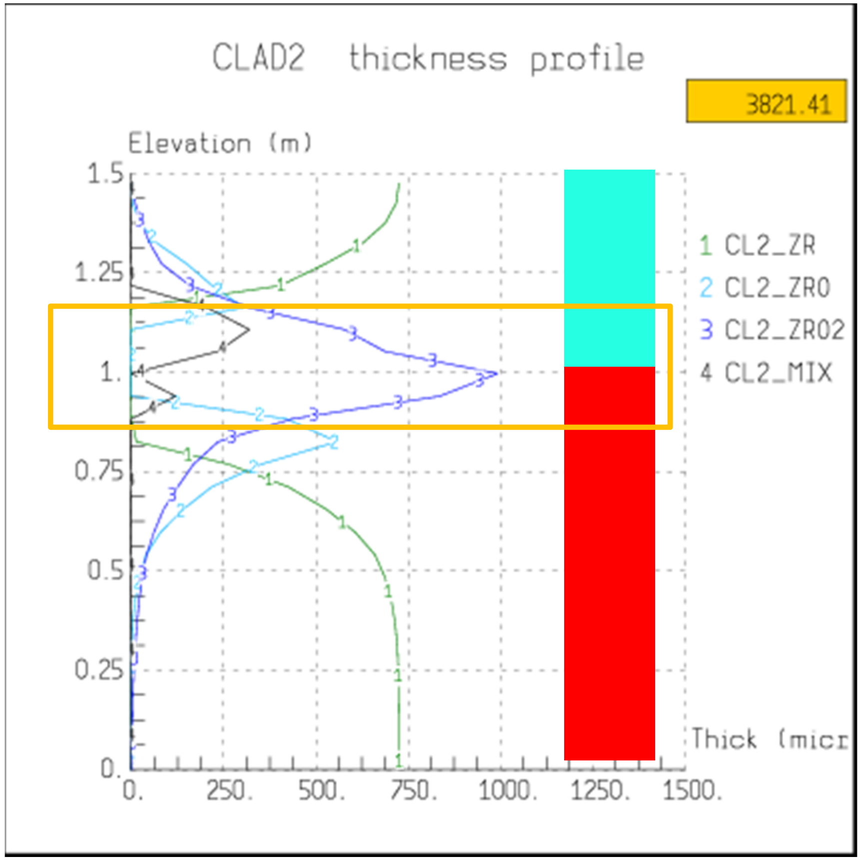


ASTEC predicts temperature escalation due to reflooding at 1050 mm

Quantitative analysis cannot be done for claddings due to failure of THCs

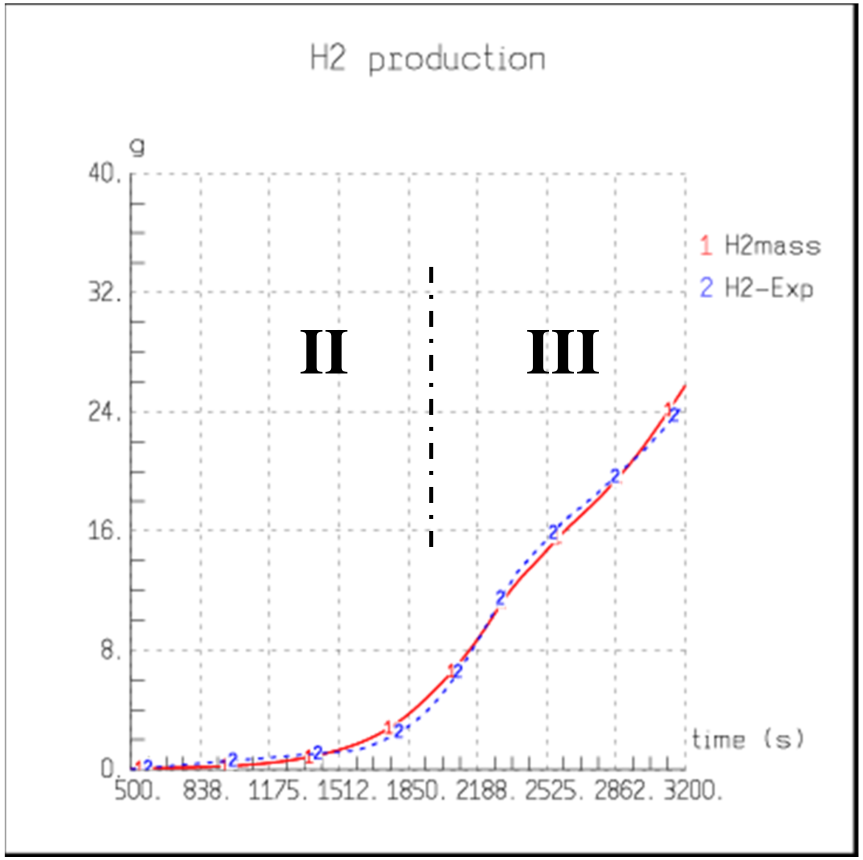
6th ASTEC Users Club/ 2. CESAM Workshop, February 23 – 26.2015, Bologna, Italy

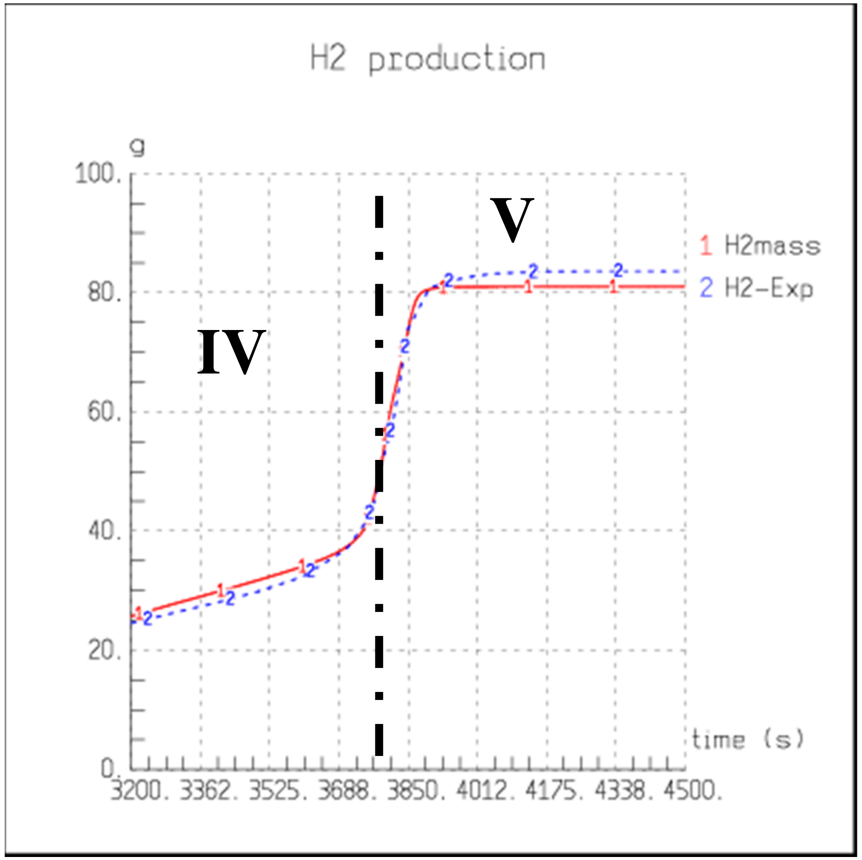
4. Comparison between Data and Prediction: Oxide layer evolution during quenching

Just before reflooding	50 sec after reflooding
	

The upper part of the active zone and the lower part of the heated zone are further oxidized during re-flooding

4. Comparison between Data and Prediction: Hydrogen generated





Very good agreement in total hydrogen production → temperature agreement active zone
Very good agreement in hydrogen production during reflooding → temperature agreement in hottest zones (900-1200 mm)

Content

5. Conclusions on Q-08 modelling with ASTECV2.1

- Difficulties concerning modelling of heat transfer through the argon gap leads to fix the boundary condition on shroud temperature from 1150 mm to 1300 mm.

- Behavior of the bundle throughout the active zone is properly tracked by ASTEC for each experimental phase (first heat-up, pre-oxidation, second heat-up and quenching)

- Overestimation of shroud temperatures within 950-1150 mm due to the poor modelling of the heat transfer through the gap → complex geometry

- Hydrogen production is similar to the experimental, both during reflooding (33.7 g ASTEC vs 36.8 g Exp), and globally (80 g ASTEC vs 83 g Exp).

- ASTECV2.1 is able to model the integral experiment QUENCH-08

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6. Future work

- Analyze how to work out the problem of the heat transfer through the argon gap of the QUENCH test facility
- Uncertainty and sensitivity analysis of the QUENCH-08 model in ASTECV2.1 using SUNSET
- Applicability of results to the reactor scale

Acknowledgement

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- IRSN Cadarache for the support and the giving the oportunity to perform a delegation with the ASTEC team
- Program Nuclear Safety Research of KIT for the financial support of the research topic “severe accidents for LWR”
- EU CESAM project

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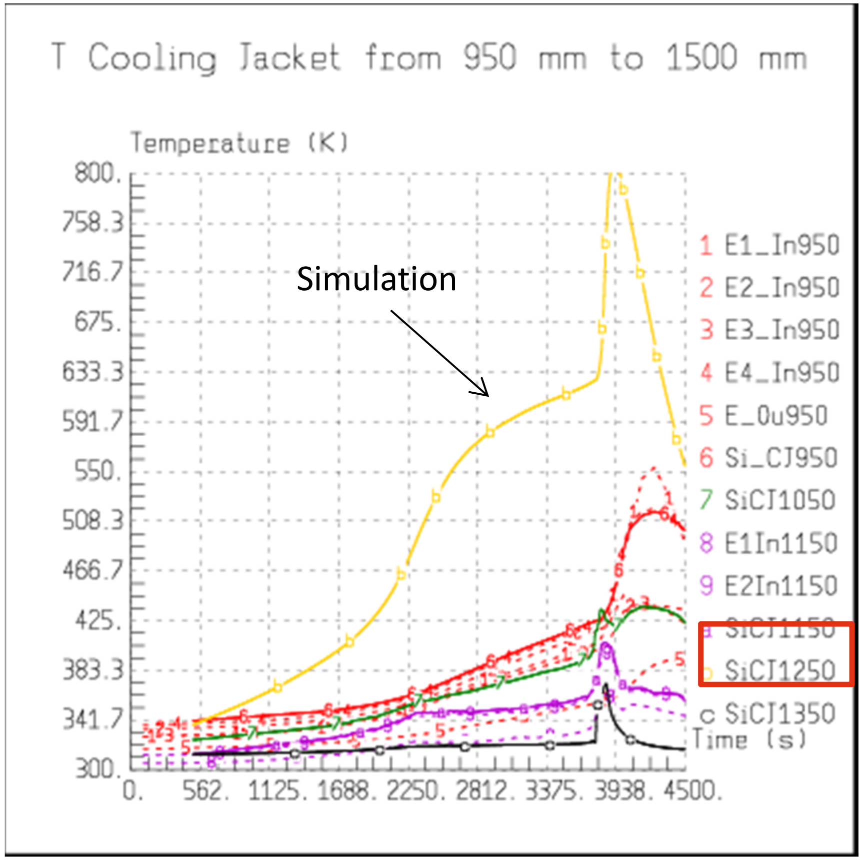
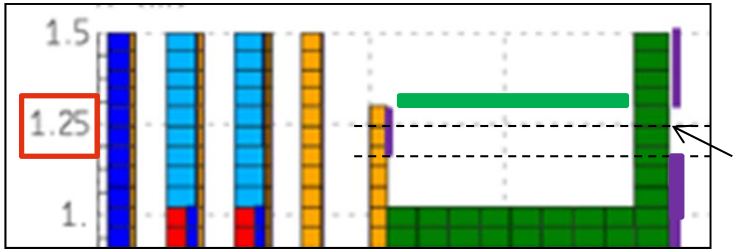
Thank you for your attention

Heat transfer through the gap





Axial conduction profile along cladding and shroud