Modeling of QUENCH-16 experiment with MAAP4 severe accident code

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Outline

- Context
- Results of QUENCH-16 experiment
- Modeling of QUENCH-16 experiment with MAAP4
- Conclusions & Perspectives

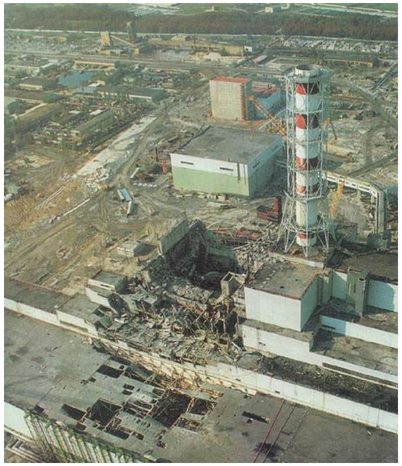
Context

Definition of a Severe Accident (SA)

- Severe Accidents lead to a **significant core degradation** due to an accumulation of multiple failures (human and/or material) and to potential radiotoxic releases into the environment.

- The SA occurrence is at **a low frequency** (≤ 10^{-5} /year/reac), with potentially prejudicial consequences.

TMI-2 (1979)



Tchernobyl (1986)

Fukushima (2011)

Beginning of SA R&D

Context

Issue for severe accident study

- To understand severe accident progression and to control risks and consequences of severe accidents is of first interest.

- EDF uses the MAAP code which is a severe accident simulation code from EPRI where EDF has its own models :

- **implementation** of the state of the art of the international R&D,
- **adaptation** to French PWRs.

Context

Short presentation of MAAP

- Development of the code at the beginning of the 80's following TMI
- Aim to simulate the **overall sequence of a severe accident** for a short running time, thanks to a simplified physics
- **Description of an entire PWR** : primary circuit, safety systems, containment …
- Numerous physical phenomena are modeled and divided into 2 main fields : **thermal-hydraulics and fission products**
- Used by the EDF engineering for probalistic safety studies

Context

Methodology

separate effect tests +
phenomenological study

modelling → MAAP → application

validation

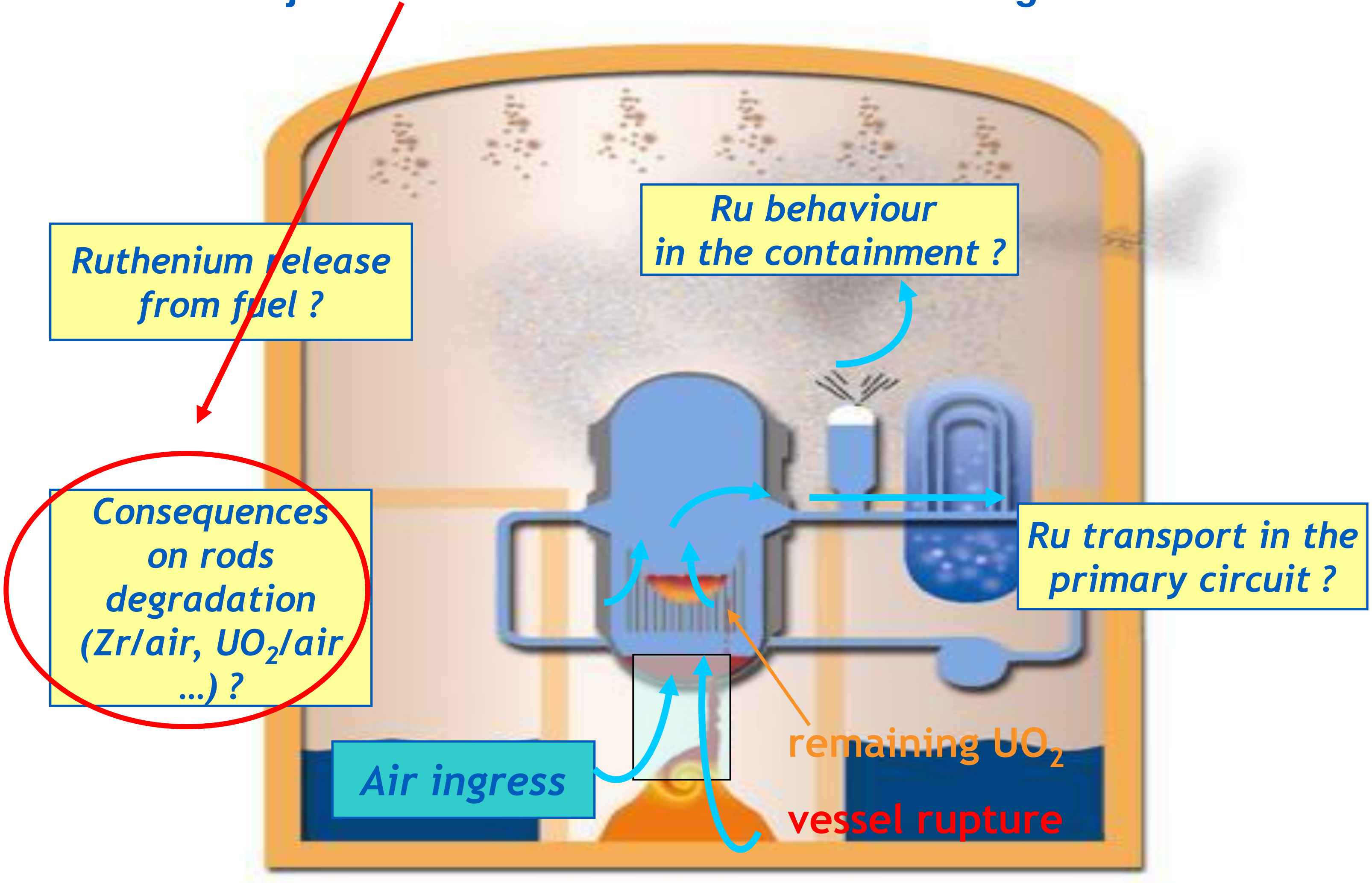
semi-integral experiment

reactor case

[M. Steinbrück et al. : '*Comparison of oxidation kinetics of advanced cladding alloys in steam at temperatures 600-1200°C*', 2008. Proceedings of the 14th QUENCH workshop, ISBN 978-3-923704-67-5.]

Context

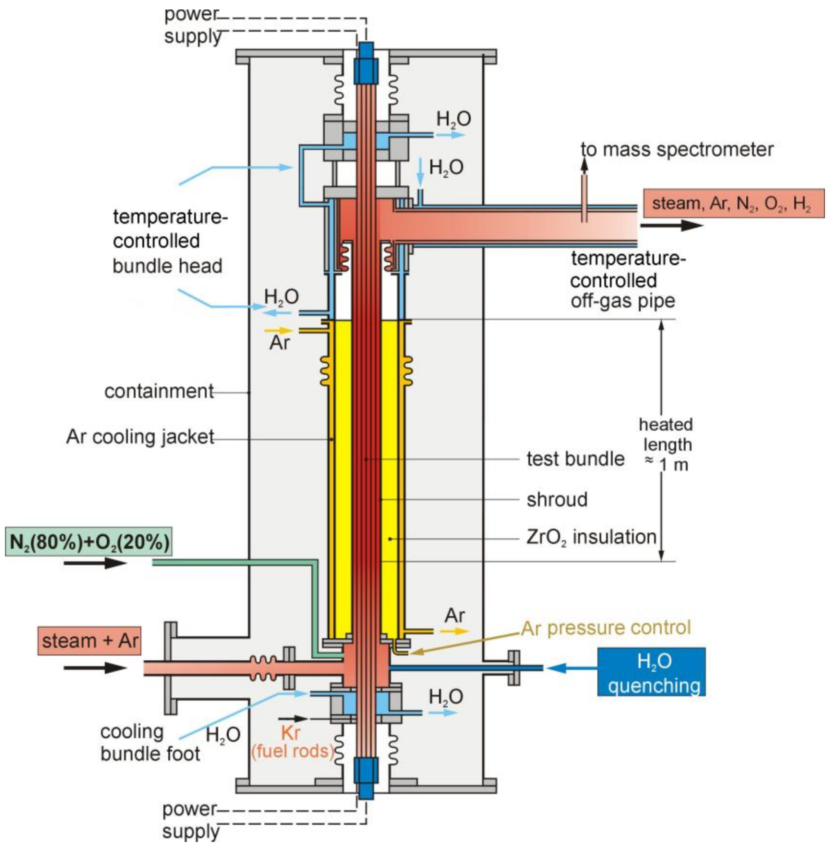
Objectives of our studies : SA with air ingress



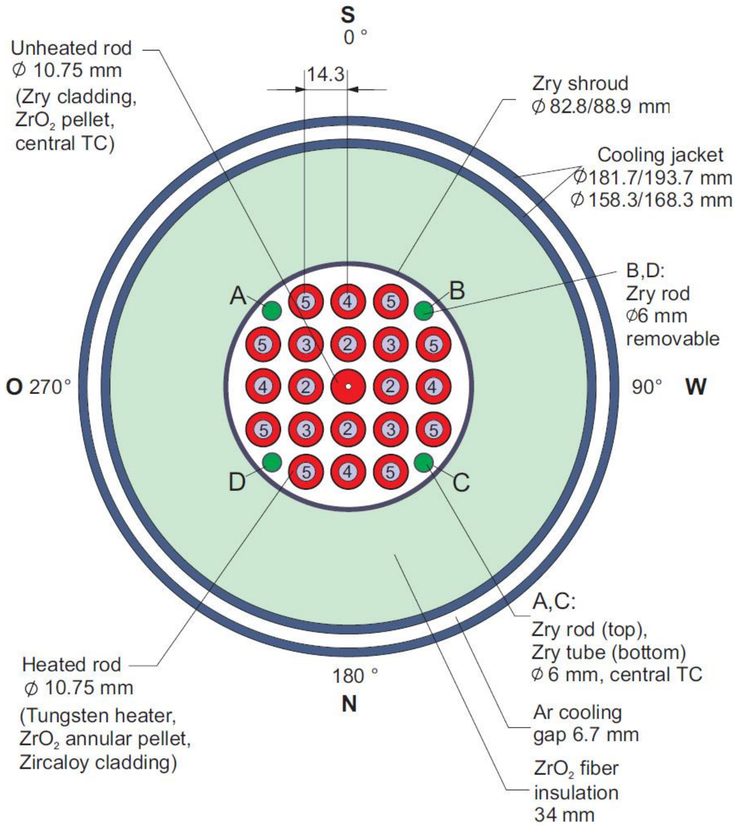
Zr/air reaction as a prerequisite about the fission products release and source term issues in case of an air ingress scenario

Results of QUENCH-16 experiment

Short presentation of the QUENCH facility and bundle



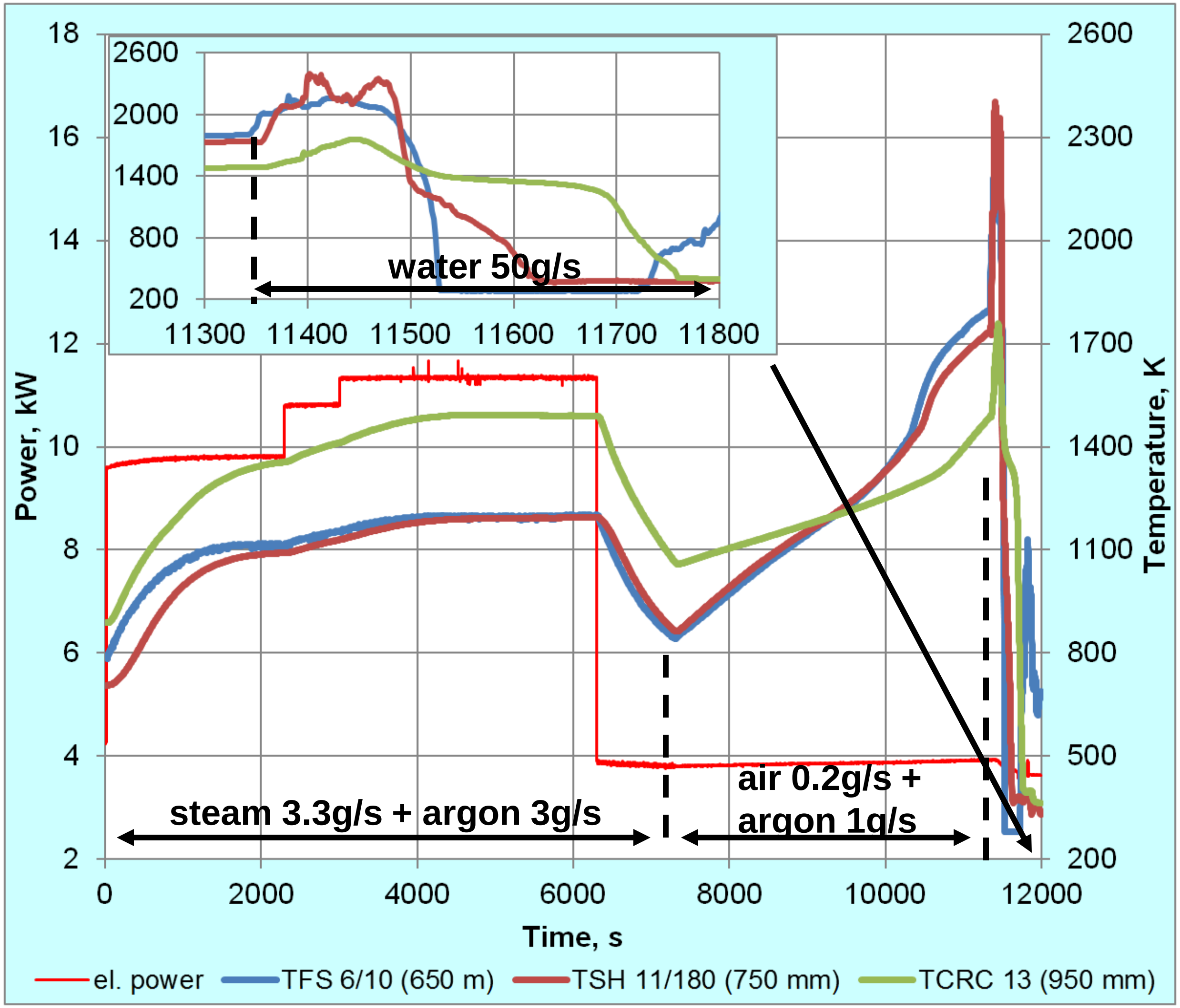
QUENCH facility



QUENCH bundle cross section

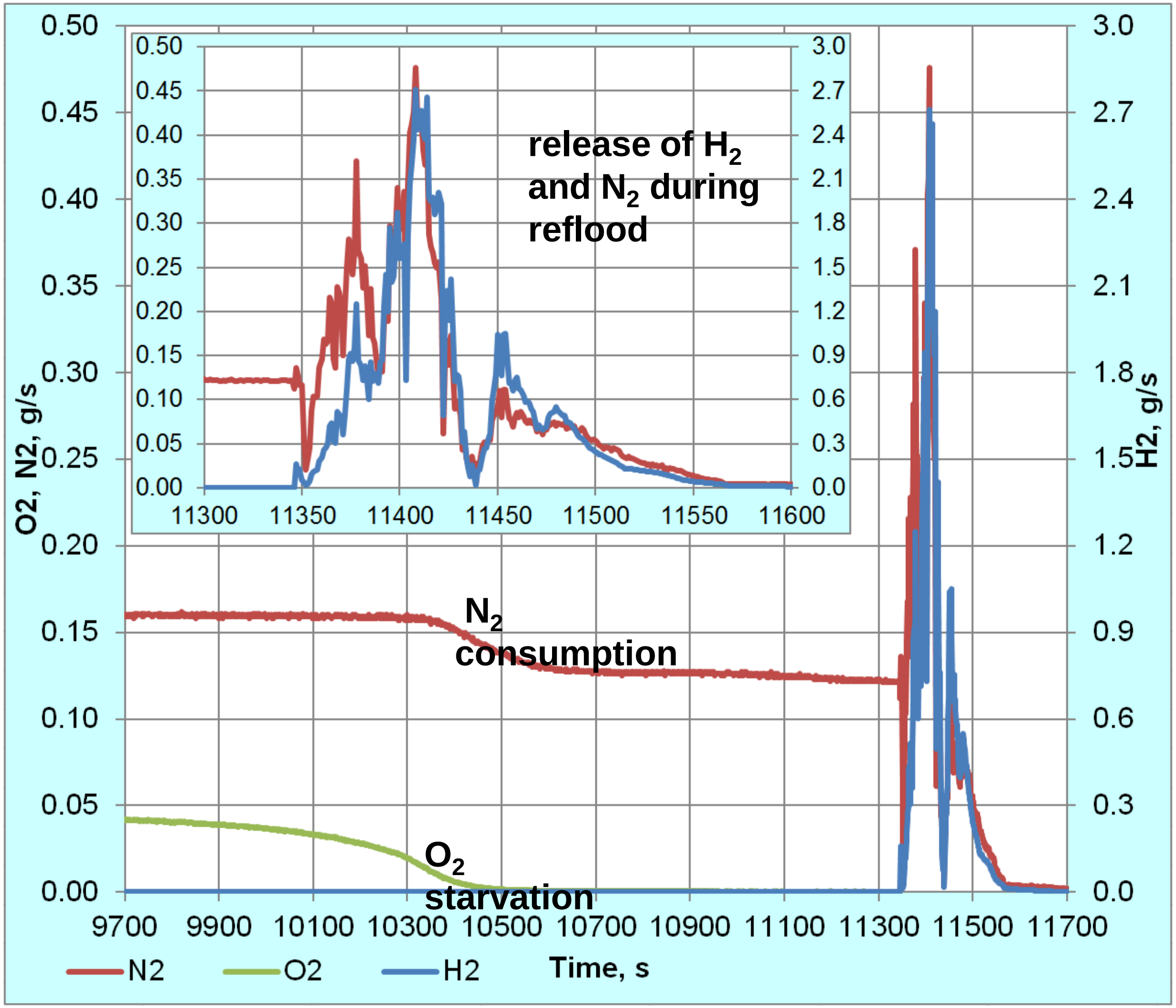
Results of QUENCH-16 experiment

QUENCH-16 transient : electrical power and selected temperatures



Results of QUENCH-16 experiment

Air ingress phase : off-gas composition

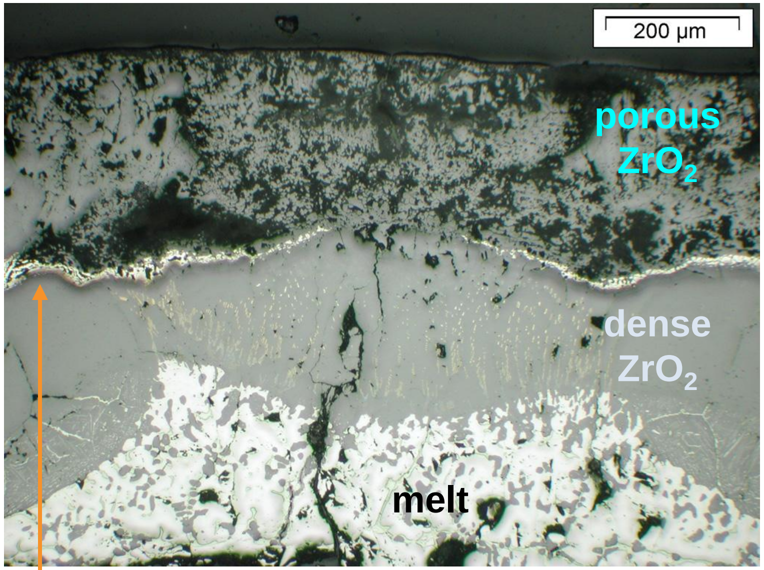


[J. Stuckert et al., Proceedings of the 17th Int. QUENCH Workshop, ISBN 978-3-923704-77-4.]

Results of QUENCH-16 experiment

Post-test appearance of the bundle

Bundle cross section at 430 mm:
frozen melt relocated from upper elevations

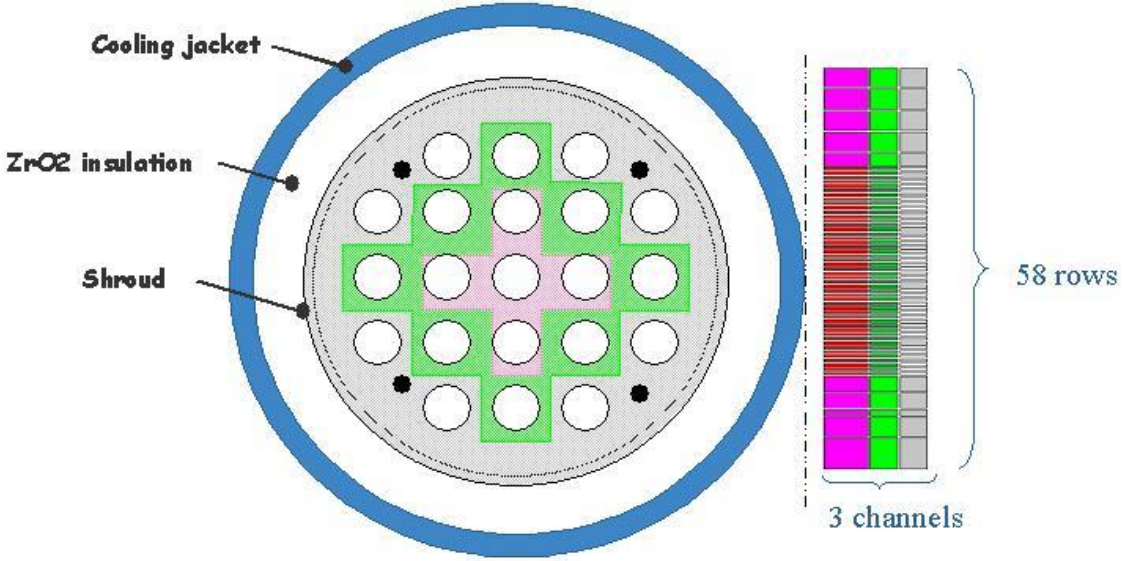


Cladding structure elevation 550 mm:
nitrides between inner dense and outer porous oxide layers

Modeling of QUENCH-16 experiment with MAAP4

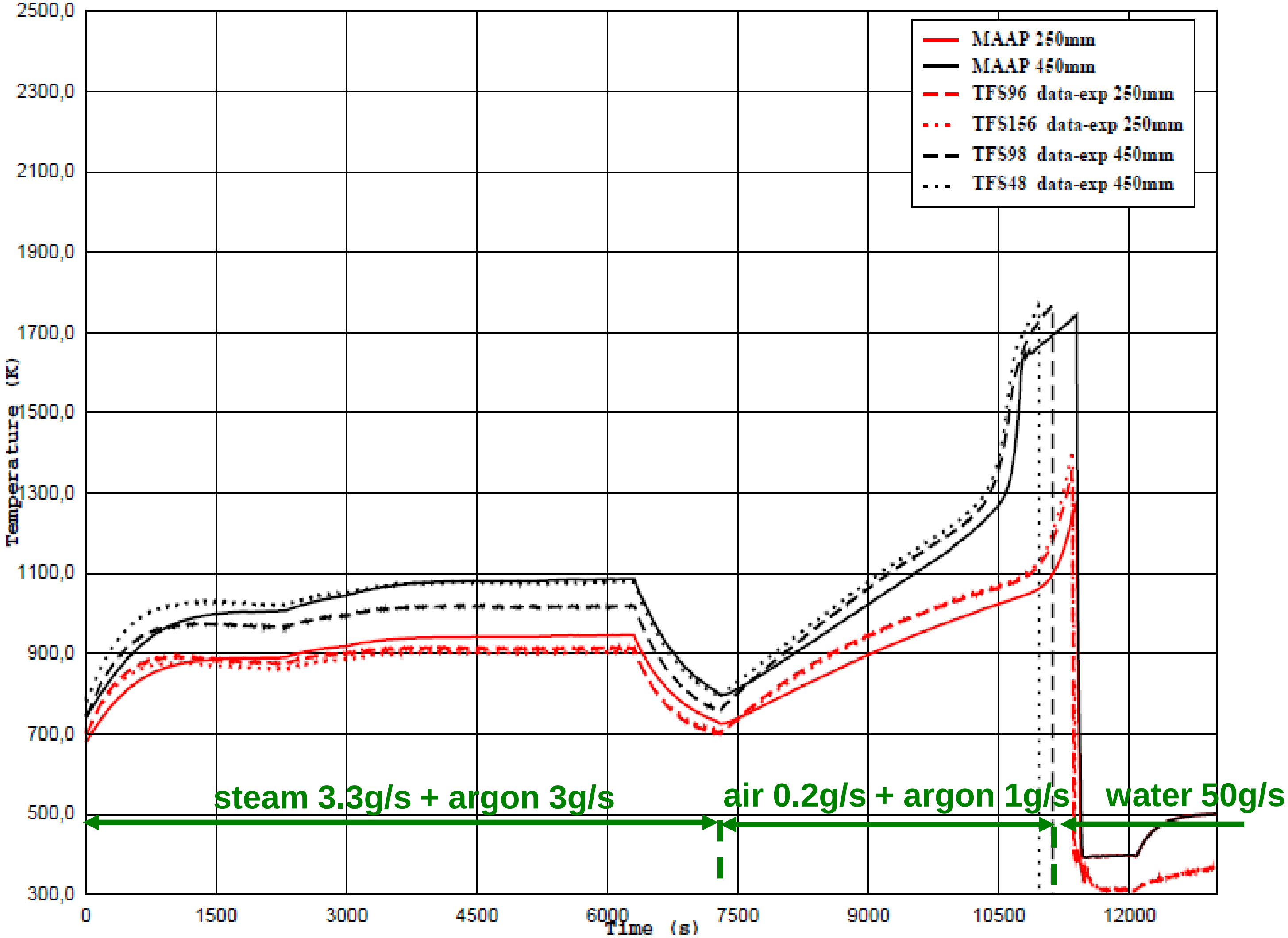
Main modeling parameters

- **Steam oxidation: Cathcart - Urbanic** with an external resistance of **4.5 mΩ/rod**
- **Air oxidation: NUREG** with an external resistance of **6.5 mΩ/rod**
- **3 rings of 4** rods / **8** rods / **8** rods (+ 1 unheated rod in the center)
- **58 meshes of 5** for the lower plenum / **48** for the core / **5** for the upper plenum



Modeling of QUENCH-16 experiment with MAAP4

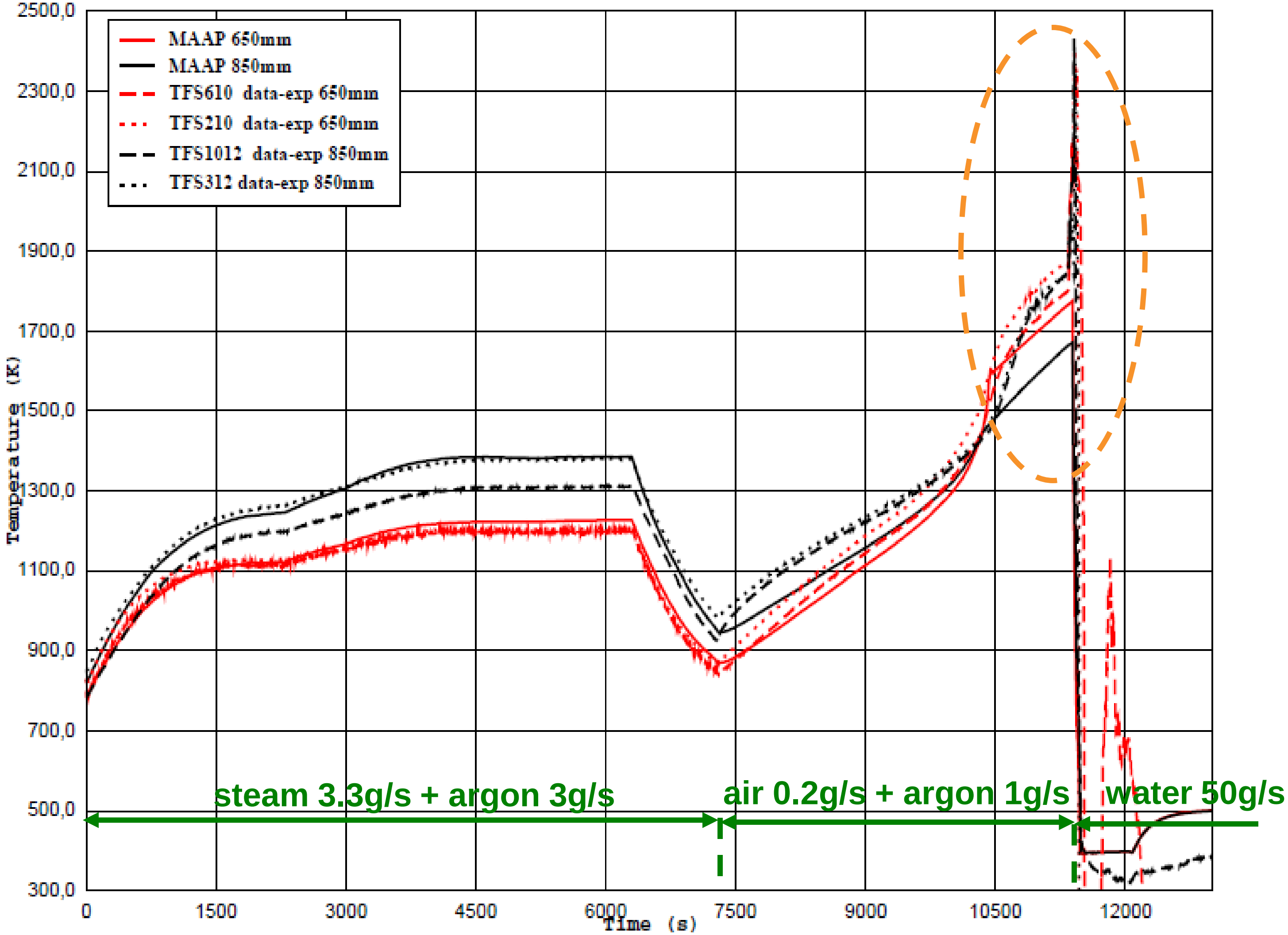
Main results of the simulation – T in K at 250mm and at 450mm



Lower part of the bundle comparatively well reproduced for both steam and air phases

Modeling of QUENCH-16 experiment with MAAP4

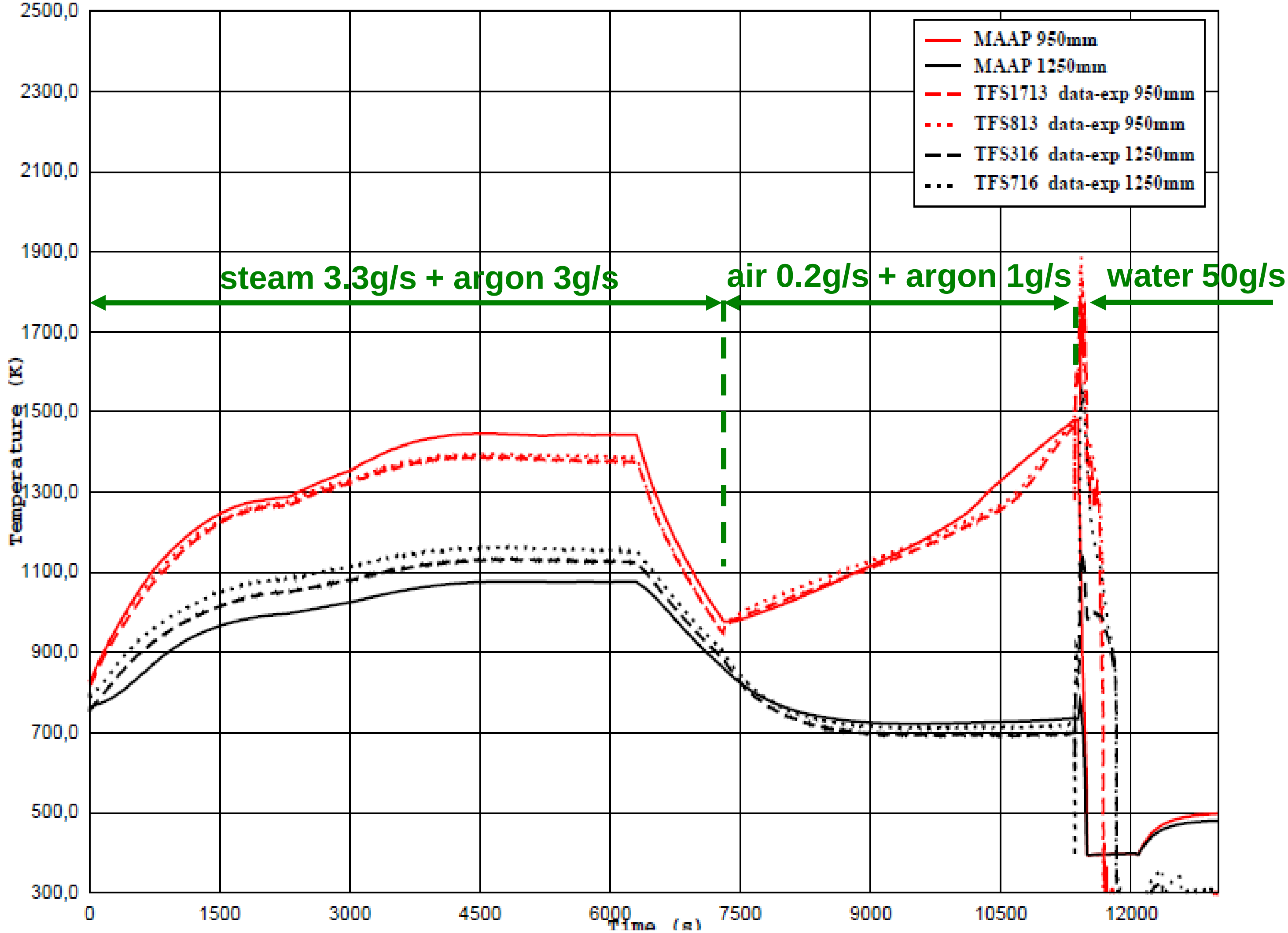
Main results of the simulation – T in K at 650mm and at 850mm



Middle part of the bundle not quite caught for the air phase : nitriding not taken into account in the model

Modeling of QUENCH-16 experiment with MAAP4

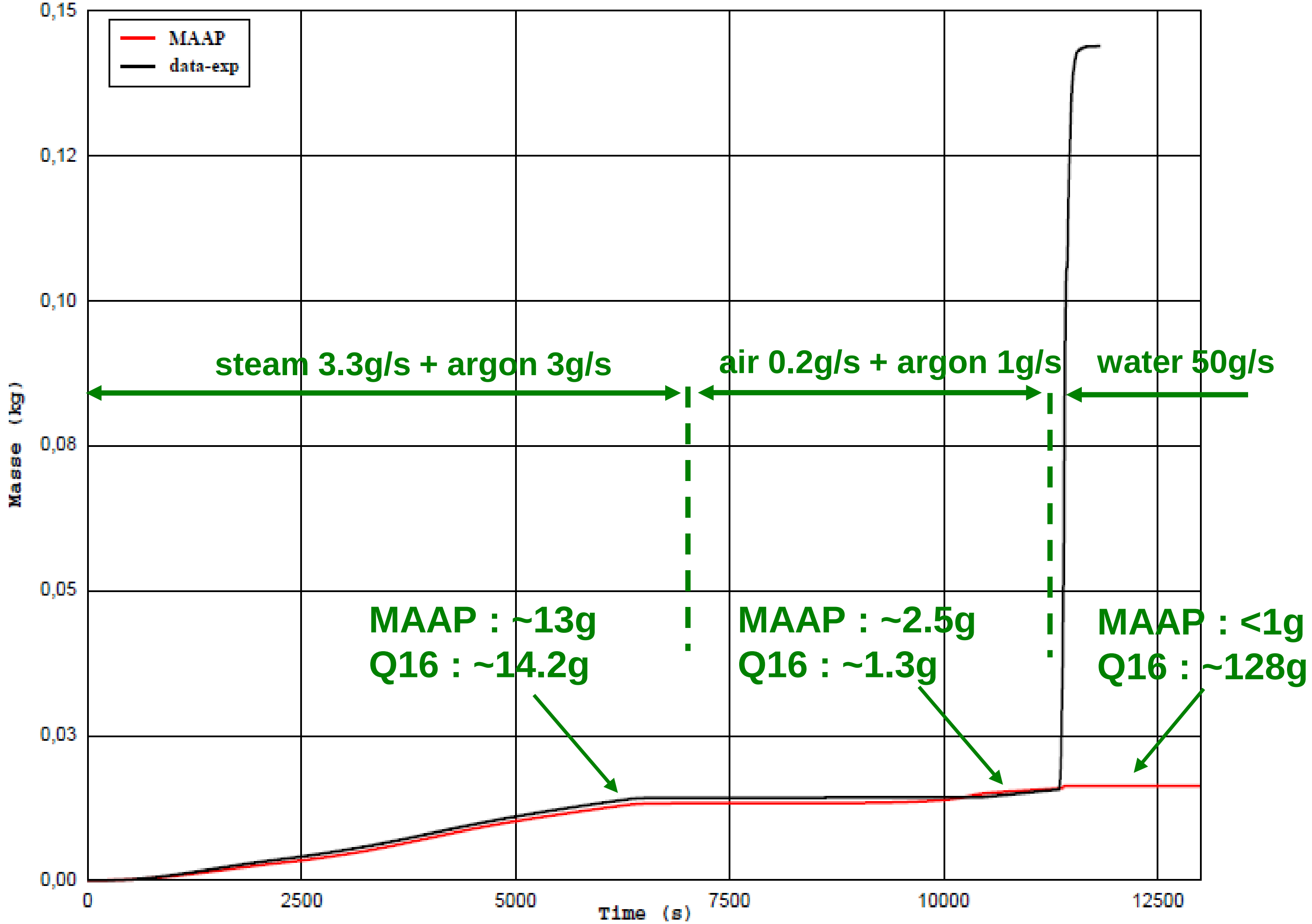
Main results of the simulation – T in K at 950mm and at 1250mm



Upper part of the bundle comparatively well reproduced for both steam and air phases

Modeling of QUENCH-16 experiment with MAAP4

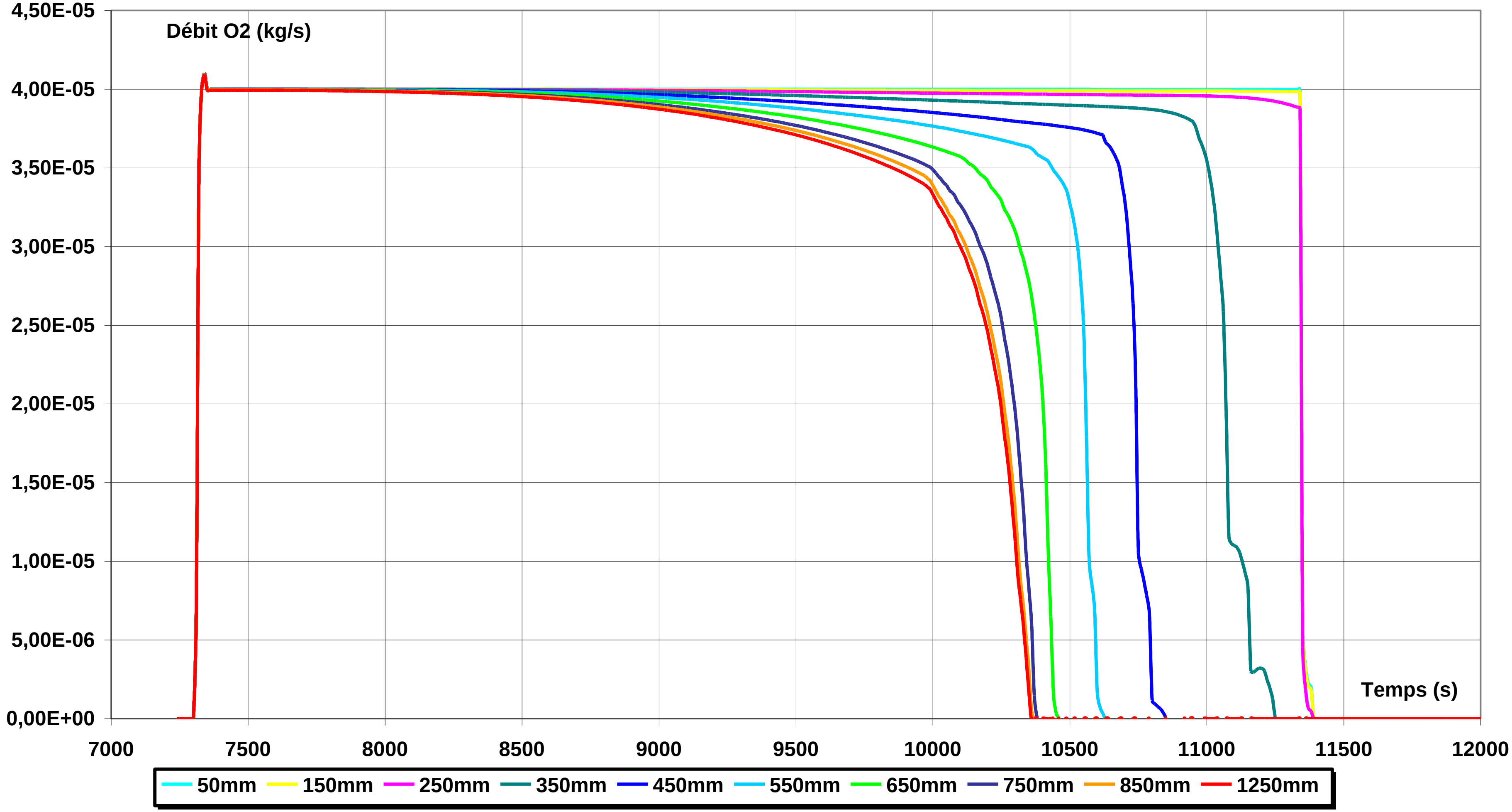
Main results of the simulation – H_2 production



Conclusions from the bundle thermal behaviour confirmed by the H_2 production

Modeling of QUENCH-16 experiment with MAAP4

Main results of the simulation – O_2 consumption



Consumption of 49g of oxygen and oxygen starvation at 10360s for MAAP (for 58g and 10200s during the experiment)

Conclusion & Perspectives

- Supported by the pre-test calculations by MAAP and other codes, the experimental conditions have been met as previously defined, namely **low cladding pre-oxidation and a period of oxygen starvation during the air phase**. The QUENCH-16 experiment **constitutes a <u>case for modeling nitrides formation and its impact on cladding degradation and hydrogen release during reflood</u>**.

- The **simulation** of the QUENCH-16 experiment with MAAP4 is **satisfying for the <u>steam phase</u>**.

- The **simulation of the <u>air phase</u> shows the need for model improvements for the oxidation-nitriding kinetics under oxygen starvation conditions** in order to reproduce properly the thermal behaviour of the bundle.

- Furthermore, MAAP showed neither a temperature escalation nor an increased hydrogen production, which were both observed during the **<u>reflood</u>**: this can be directly related to the **not modeled 1) intensive steam oxidation of nitrides and subjacent cladding metal as well and 2) oxidation of melt developed due to temperature escalation**.

- The treatment of the **nitriding in MAAP is the subject of ongoing investigation.**

Acknowledgments

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Thank you for your attention !