



**HAL**  
open science

## Dedicated thermal, thermal-hydraulic and thermal-mechanical analyses in support of DEMO WCLL BB design

Brahim Chelihi, Christophe Garnier, Lionel Cachon, Julien Aubert, P. Arena

► **To cite this version:**

Brahim Chelihi, Christophe Garnier, Lionel Cachon, Julien Aubert, P. Arena. Dedicated thermal, thermal-hydraulic and thermal-mechanical analyses in support of DEMO WCLL BB design. ISFNT 15 - 15th International Symposium on Fusion Nuclear Technology, Sep 2023, Las Palmas de Gran Canaria, Spain. , 2023. cea-04229989

**HAL Id: cea-04229989**

**<https://cea.hal.science/cea-04229989>**

Submitted on 5 Oct 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

B. Chelih<sup>a</sup>, C. Garnier<sup>a</sup>, L. Cachon<sup>a</sup>, J. Aubert<sup>b</sup>, P. Arena<sup>c</sup>

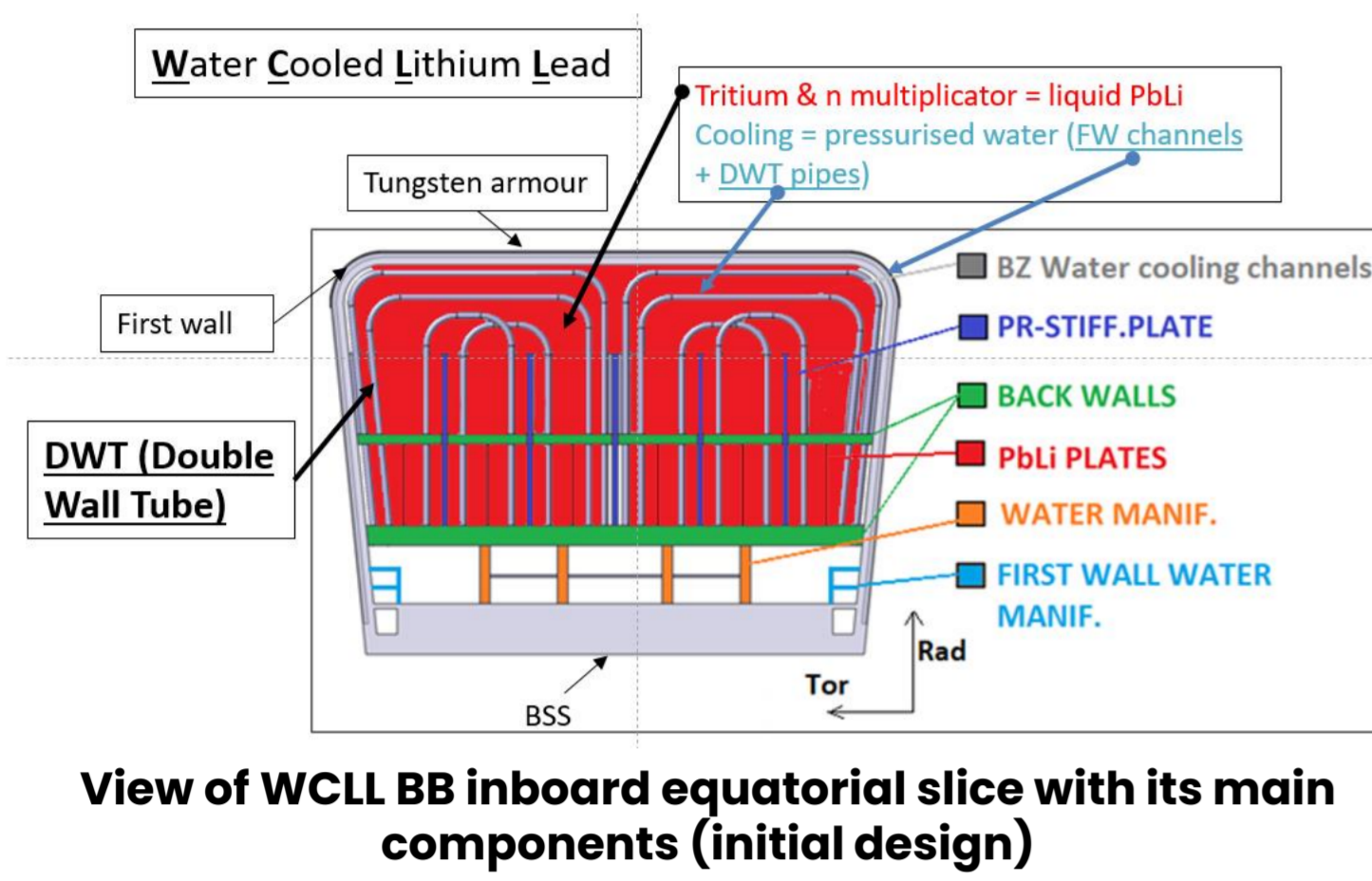
<sup>a</sup>CEA, DES, IRESNE, DTN, STCP, LCIT Cadarache, Saint Paul lez Durance – France

<sup>b</sup>CEA, DES, ISAS, DM2S

<sup>c</sup>ENEA/ Department of Fusion and Nuclear Safety Technology, Brasimone Research Centre

## Context

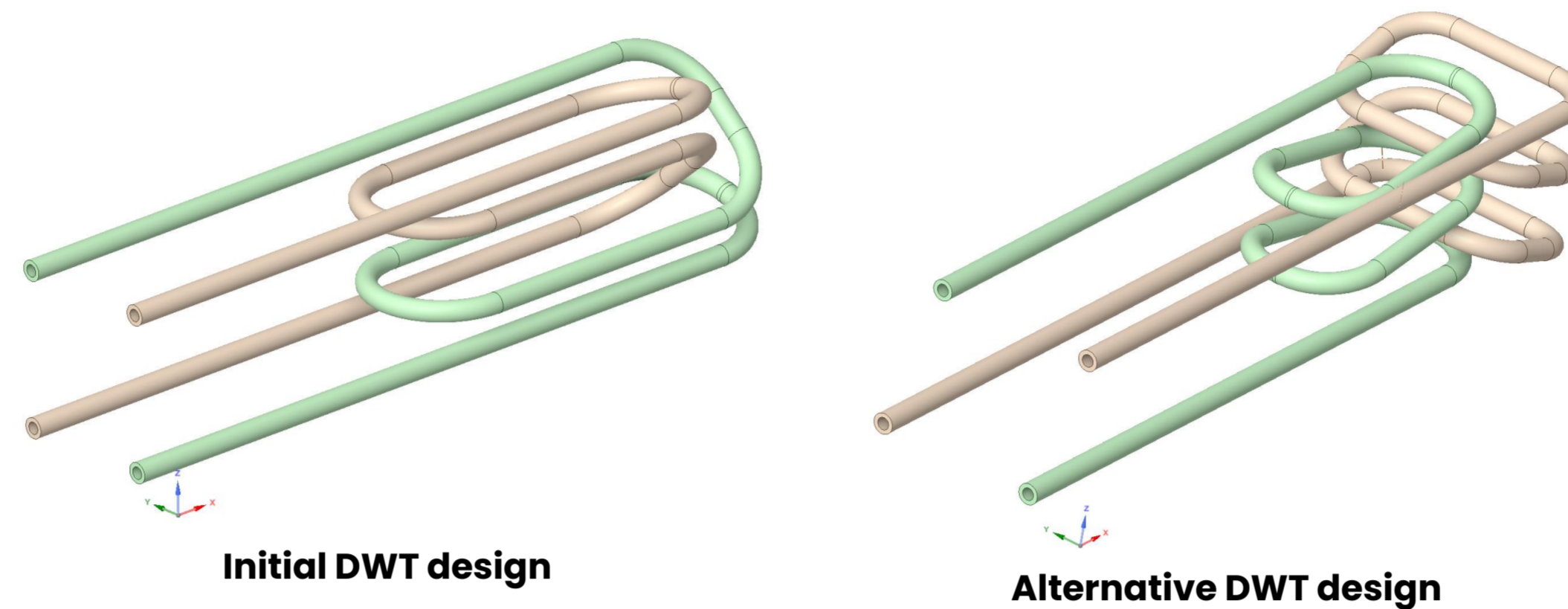
Within the framework of the EUROfusion Work Package Breeding Blanket (WPBB), R&D activities are carried out since 2021 in CEA on the conceptual design of the DEMO Water-Cooled Lithium Lead Breeding Blanket (WCLL BB) for the inboard segment.



## Presentation

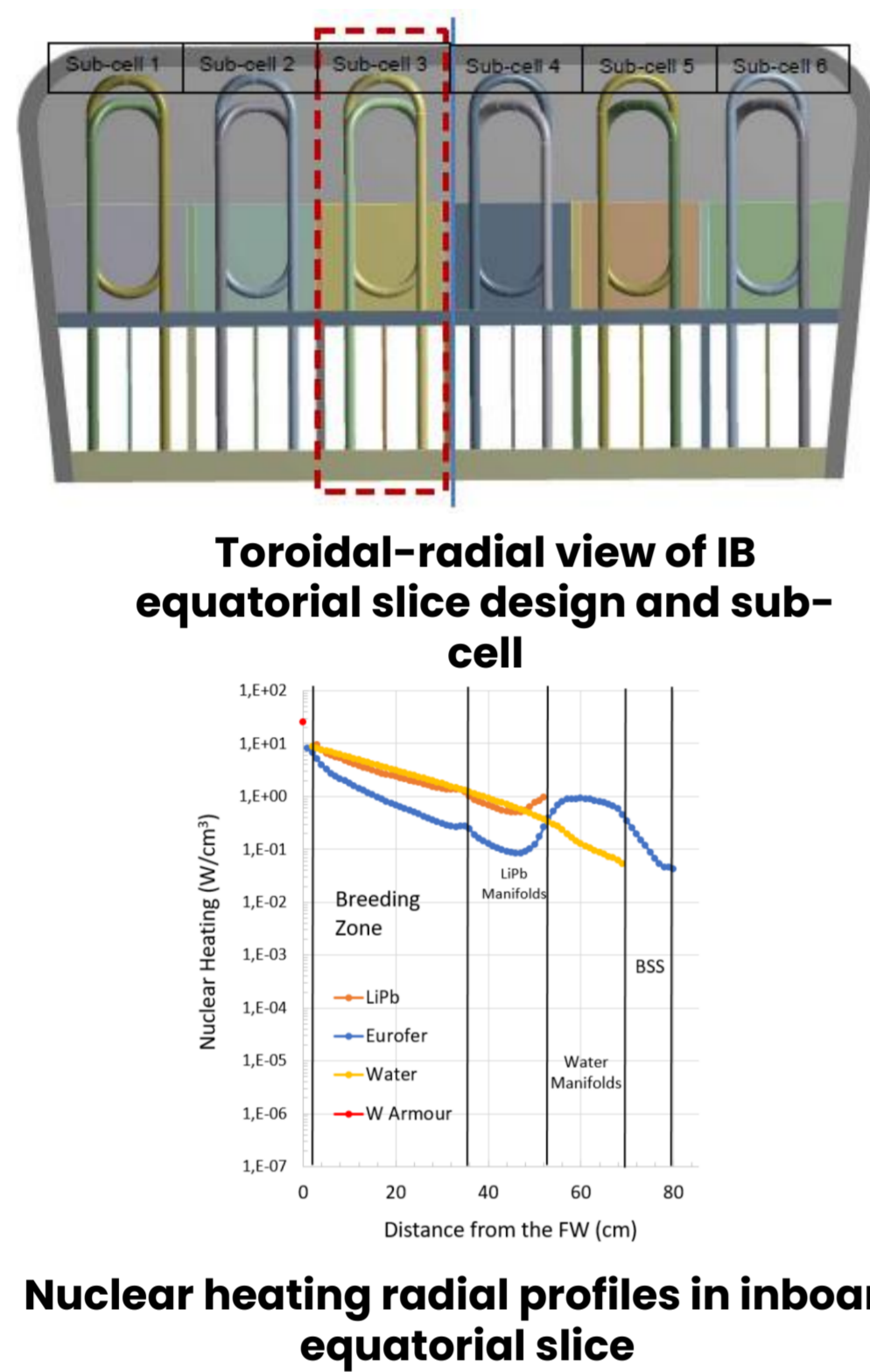
### Objectives

Geometry optimizations have been performed to comply with the RCC-MRx rules (thermomechanical stresses) and the Eurofer maximum temperature criterion of 550°C during nominal operation phases. The initial geometry does not allow the criteria to be satisfied. The geometry of the DWTs must be improved in order to homogenize the temperature field.



### Study approach

- 1) Simplified thermal model:
  - Iterative geometry studies
- 2) CFD calculation on global design:
  - Validation of the thermal model
- 3) Simplified mechanical model:
  - Calculation of elastic thermo-mechanical stresses



## 1) Thermal modelisation

### Thermal Model

Iterative geometry studies are carried out using a simplified thermal FE model on one sub-cell

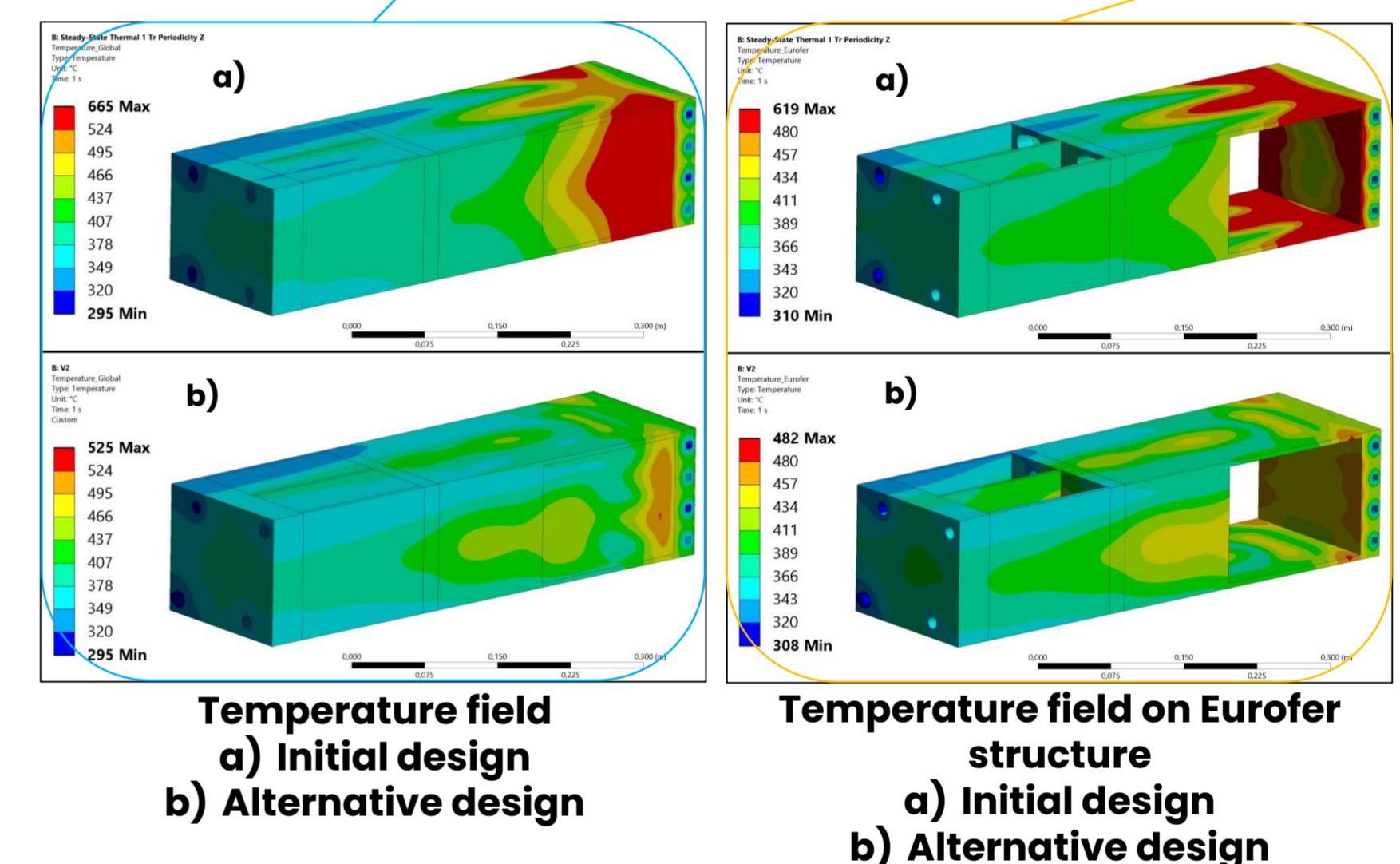
- Strong assumption of periodicity condition
- Plasma heat flux on FW face (0.19 MW/m<sup>2</sup>)
- Heat generation loads
- Cooling by fluid-type elements

### Thermal Results

- ✓ The maximal temperature is reduced by 140°C
- ✓ The maximum Eurofer temperature is below 500°C
- ✓ The maximum DWT temperature exceeds 345°C, which could result in boiling

	Maximum temperature on whole model	Maximum temperature on Eurofer Structure
Initial DWT design	665°C	620°C
Alternative DWT design	525°C (-140°C)	482°C (-138°C)

Temperature results



## Thermal-hydraulic Model

Full CFD thermal-hydraulic calculations have been carried out to validate the thermal model (sub-cell model with initial design)

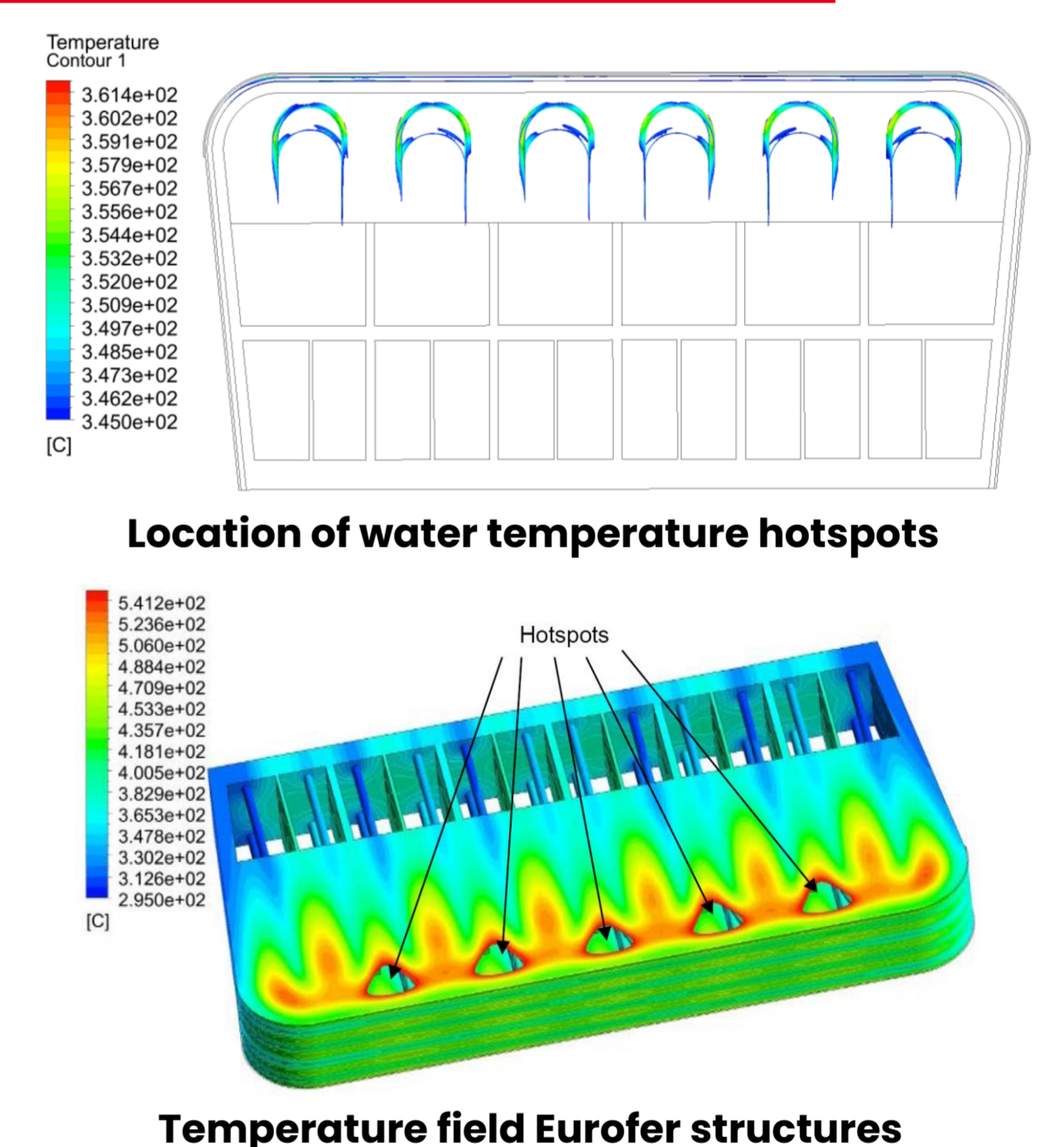
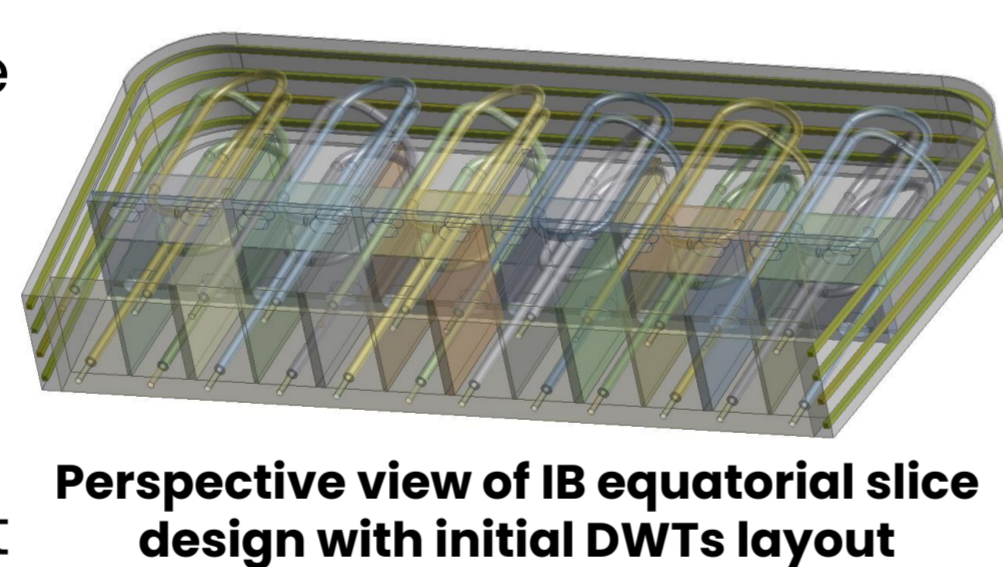
Aims: calculate the thermal field and validate the periodicity assumption

- k-w SST turbulence model
- Heat generation loads
- Cooling rate such that inlet and outlet temperature are 295°C and 328°C

## 2) Thermal-hydraulic modelisation

### Main Thermal-hydraulic Results

- ✓ The maximum temperature difference between the thermal and the CFD models is very low ( $\pm 2\%$ ):
  - Thermal model considered as validated
- ✓ Fluid temperature in all pipes > 345°C
  - Risk of local nucleate or sub-cooled boiling
- ✓ The temperature criterion of 550°C is achieved in all structures except the Eurofer



## Thermal-mechanical model

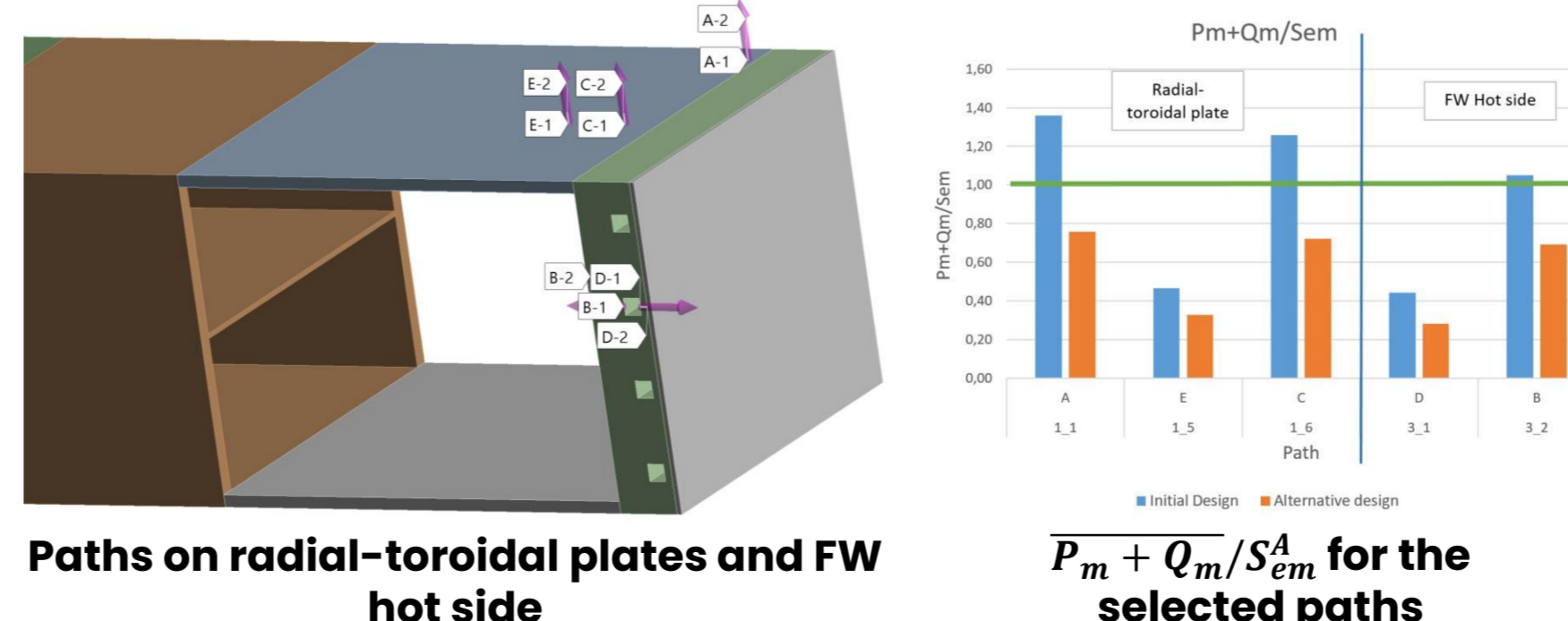
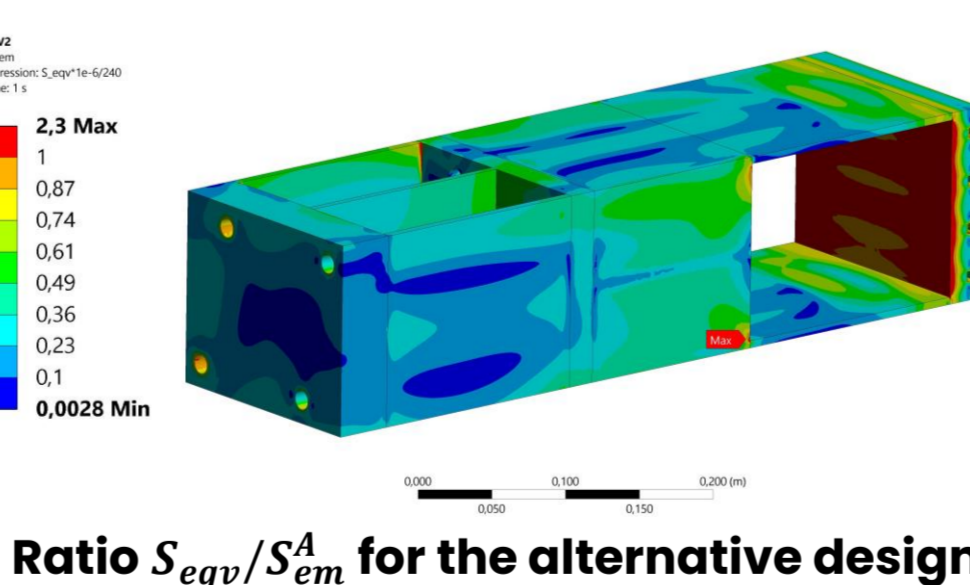
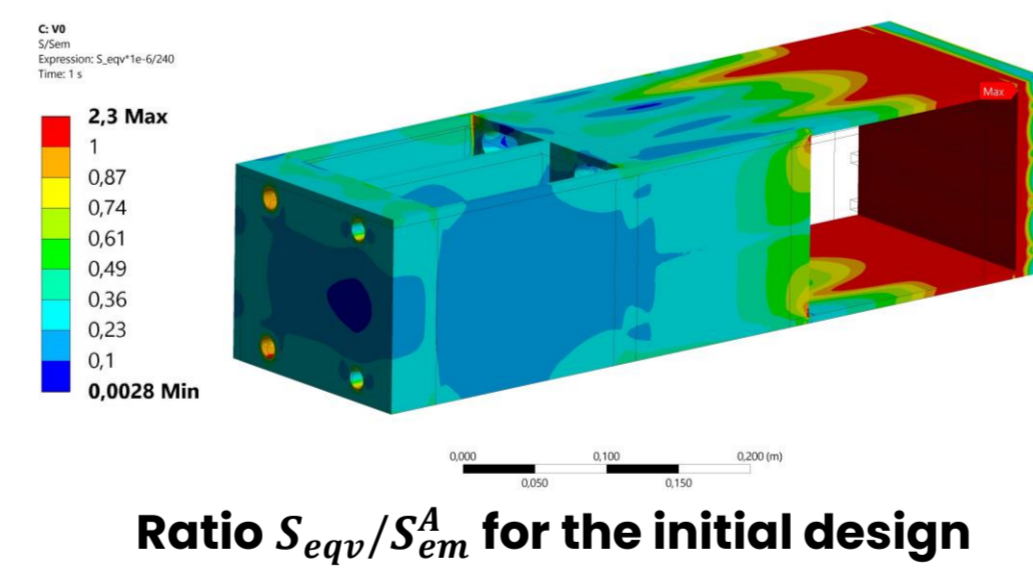
## 3) Thermal-mechanical modelisation

A thermomechanical analysis of the sub-cell was carried out

- RCC-MRx elastic rules applied to the Eurofer structure, Type P damages, case significant irradiation and creep
- DWTs not included in the model (no impact on Eurofer structure)
- Simplified boundary conditions: infinite repetitions
- Normal Operating conditions (NO) with internal pressure (sub-cell casing and FW channels) and thermal field

### Thermal-mechanical Results (Type P damages, case significant irradiation and negligible creep)

- ✓ Significant improvements with DWT design evolutions: lower thermal stress due to a reduced maximum temperature and enhanced homogenization of the thermal field
- ✓ The lower margin is reduced from 1.38 to 0.96 (must be <1)
- ✓ All the analyzed paths of the alternative design respect the criteria



## Conclusion

Iterative geometry studies on DWTs have significantly improved the results/behavior:

- ✓ The RCC-MRx rules are respected in terms of thermomechanical stresses (for NO, negligible creep and significant irradiation)
- ✓ The Eurofer maximum temperature criterion of 550°C is satisfied

## Perspective

- ✓ A CFD study is underway to investigate potential local nucleate or sub-cooled boiling problems and validate results from thermal simplified model
- ✓ Mechanical analysis on full slice (RCC-MRx)
- ✓ Calculation on full segment including curvature of the BB
- ✓ Type S damages (ratcheting, fatigue)