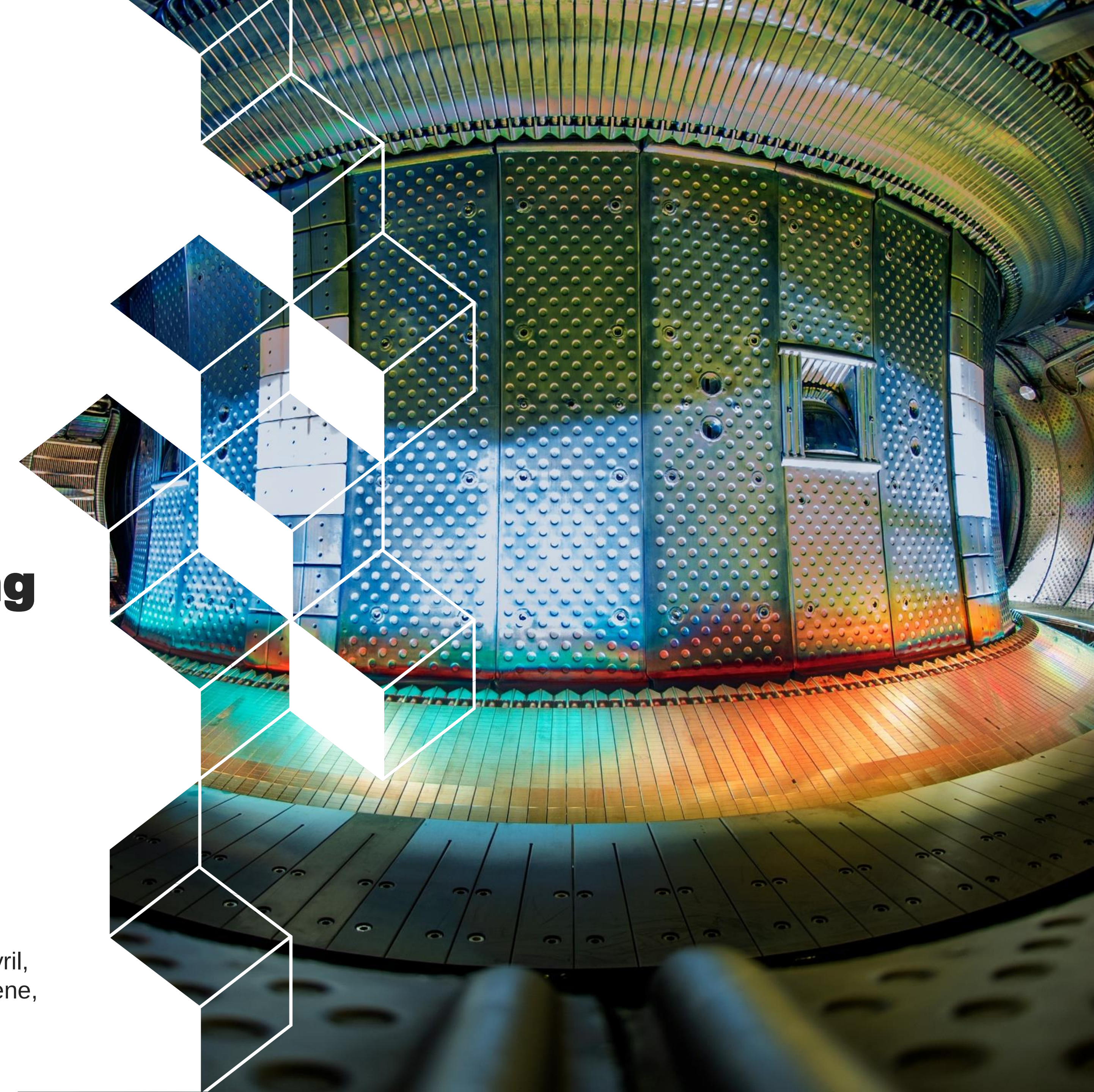
WEST - the challenges of reaching 100% of actively cooled components for long pulse operation

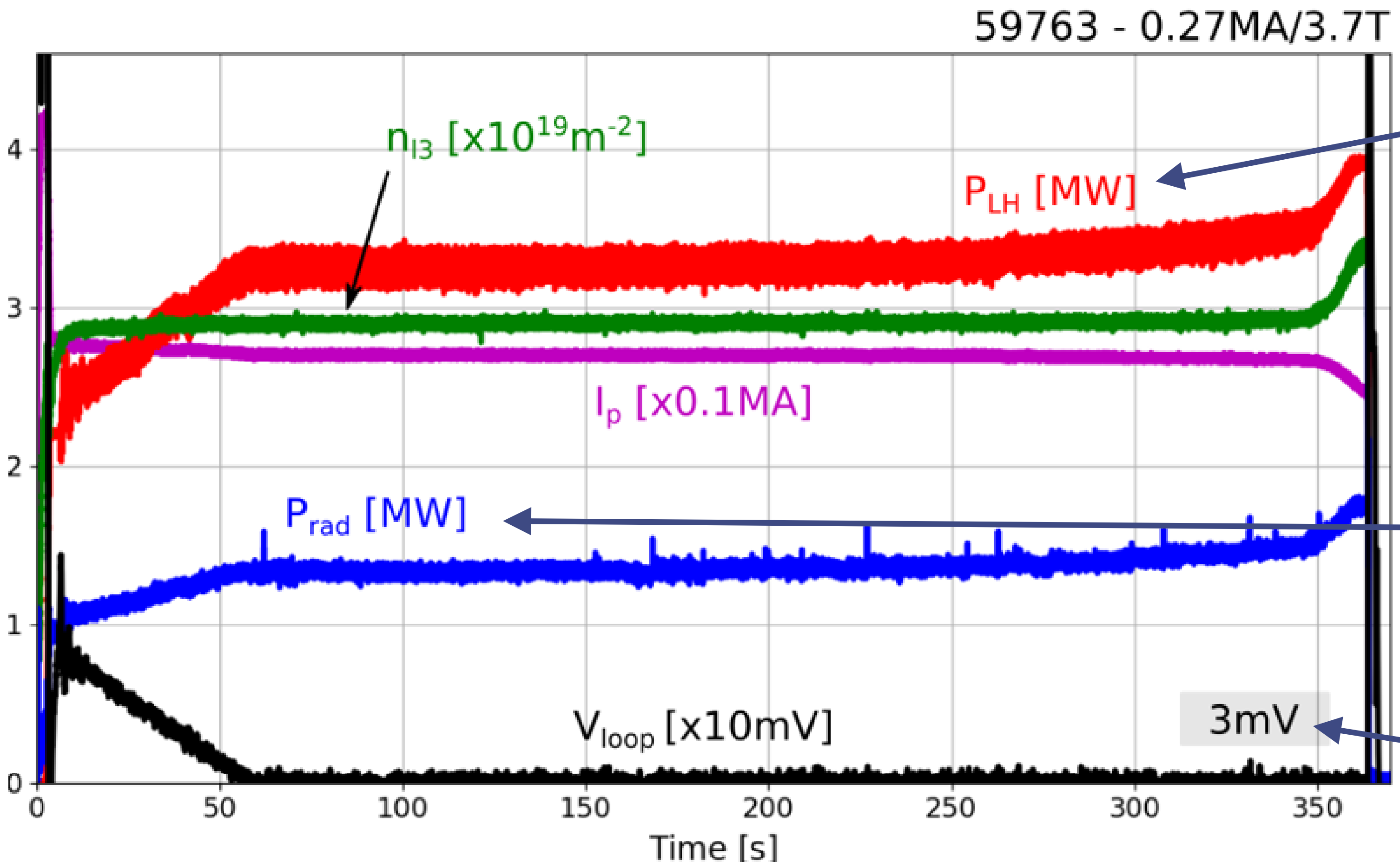
IAEA Technical Meeting

Long-Pulse Operation of Fusion Devices



Lionel MEUNIER, MOREAU Philippe, LAMAISON Valerie, BRUN Cyril, GERARDIN Jonathan, Xavier COURTOIS, AUMEUNIER Marie-Hélène, BATAL Tristan, HOURY Michael and the WEST Team

Long pulses in WEST



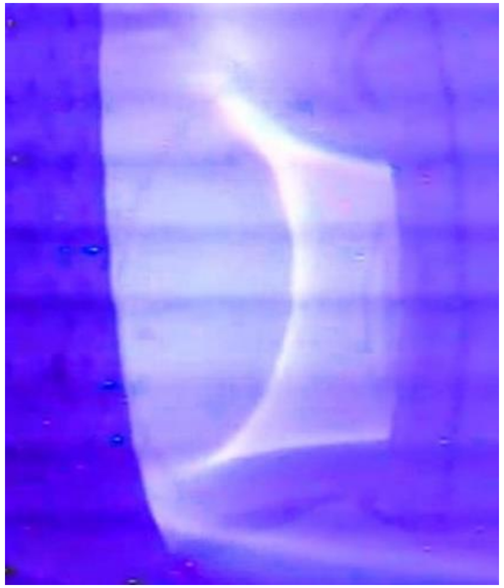
Towards **10MW** steady state power

~50% Radiated power

Vloop = 0 to increase duration above **1000s**

P. Manas – Presentation on Monday

Total energy in a WEST pulse



1000s / 10MW pulse / 50% radiated power
→ 5GJ radiated energy

Enough to warm 10 tons of steel above 2000°C

Most of this energy is extracted with active cooling, but even a small fraction could damage poorly cooled components

1. Thermal Radiations

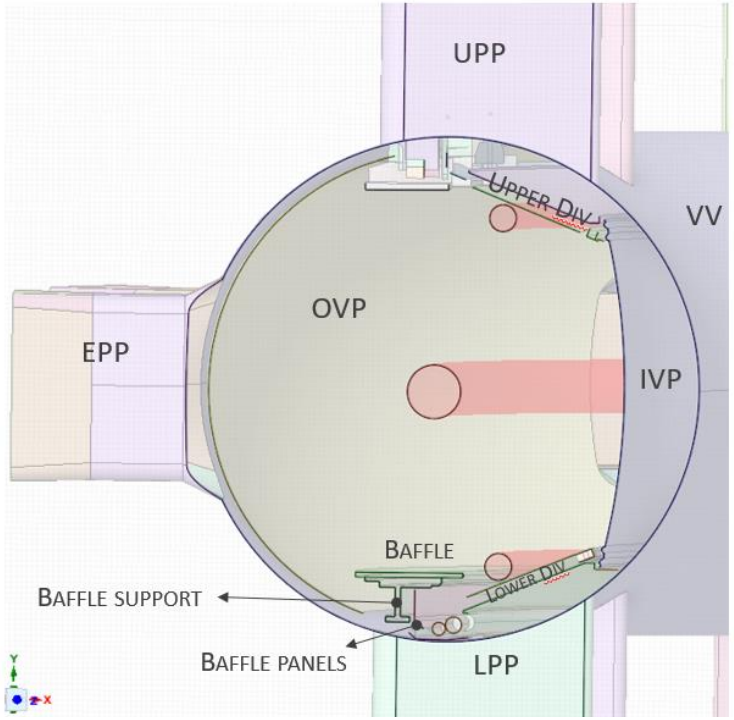
Radiated Power in WEST

Understanding where the power is absorbed in the Vacuum Vessel is important to check that the thermal loads are compatible with the design.

The photonic simulation code is based on a Monte Carlo ray tracing:

- Able to propagate the ray through the **complex geometry of WEST**
- Takes into account multiple **inter-reflections** and custom **reflectivity of materials**

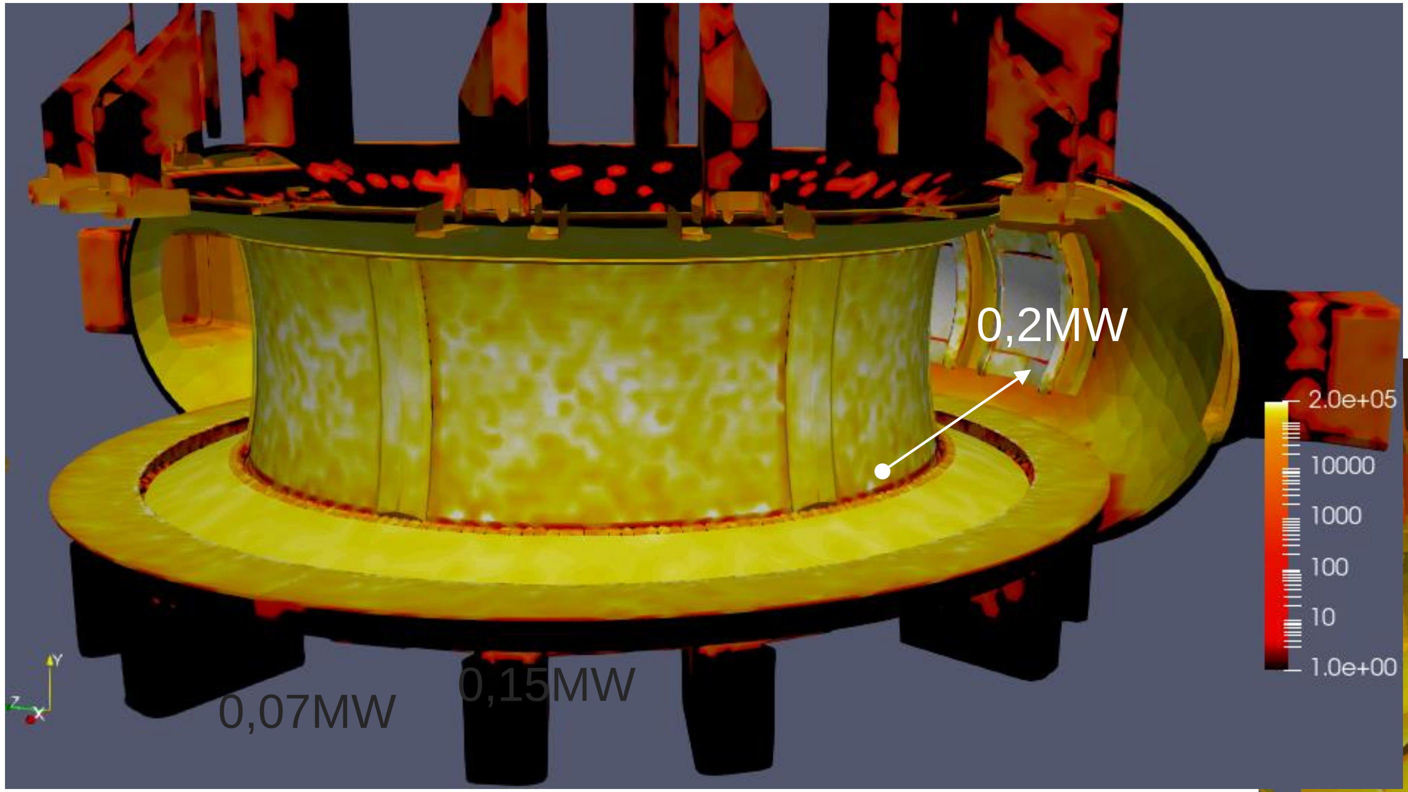
Several plasma scenario are computed : core plasma, lower or upper divertor plasma



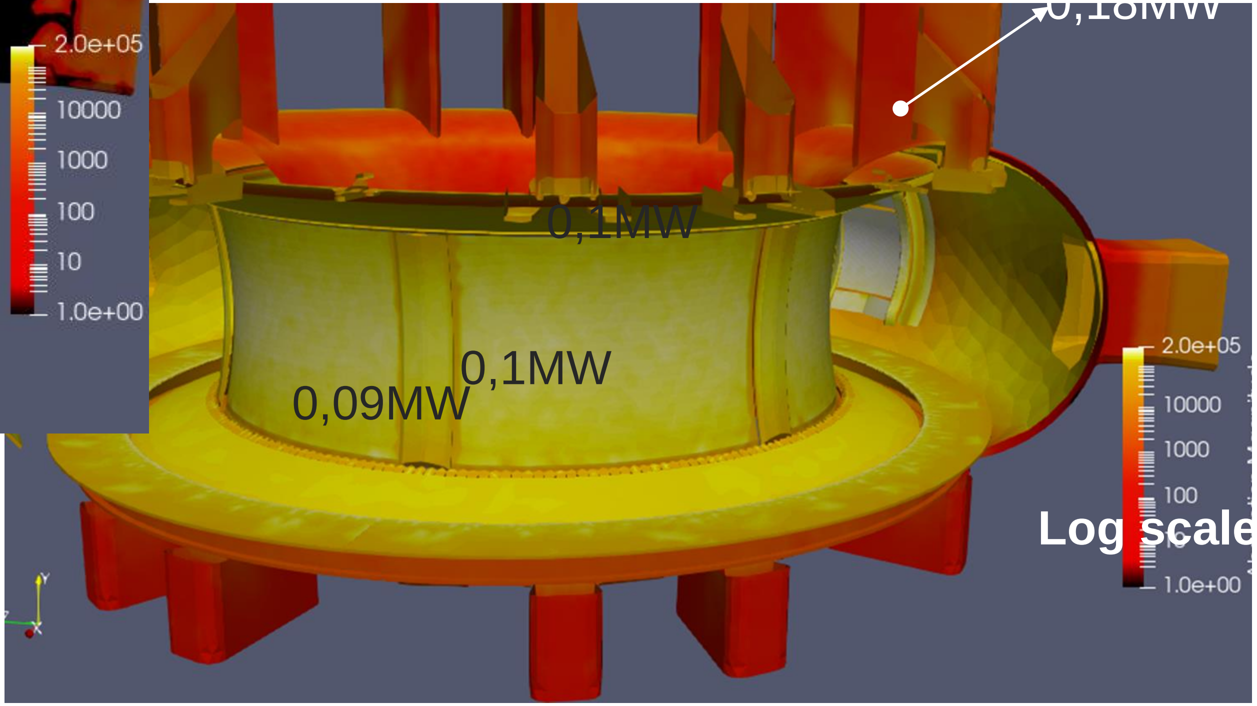
Aumeunier et al. 2016

Exemple of results - 10 MW in core plasma

- Fully absorbing materials



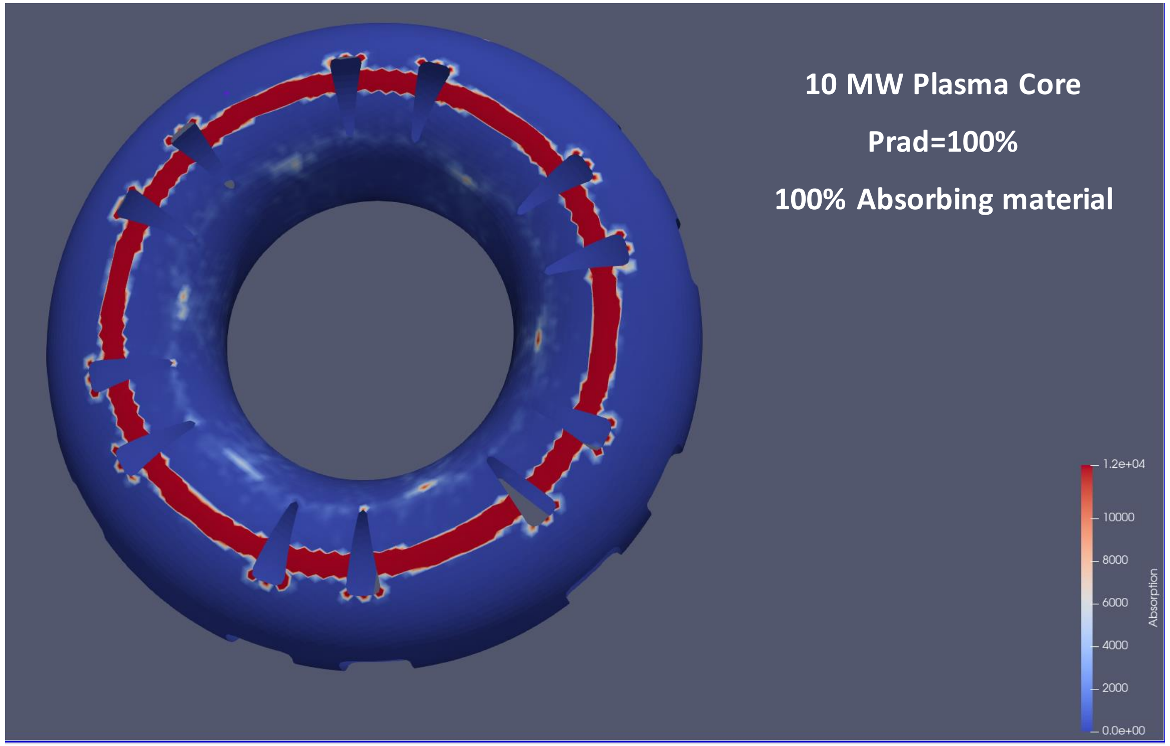
- Specular reflectance materials

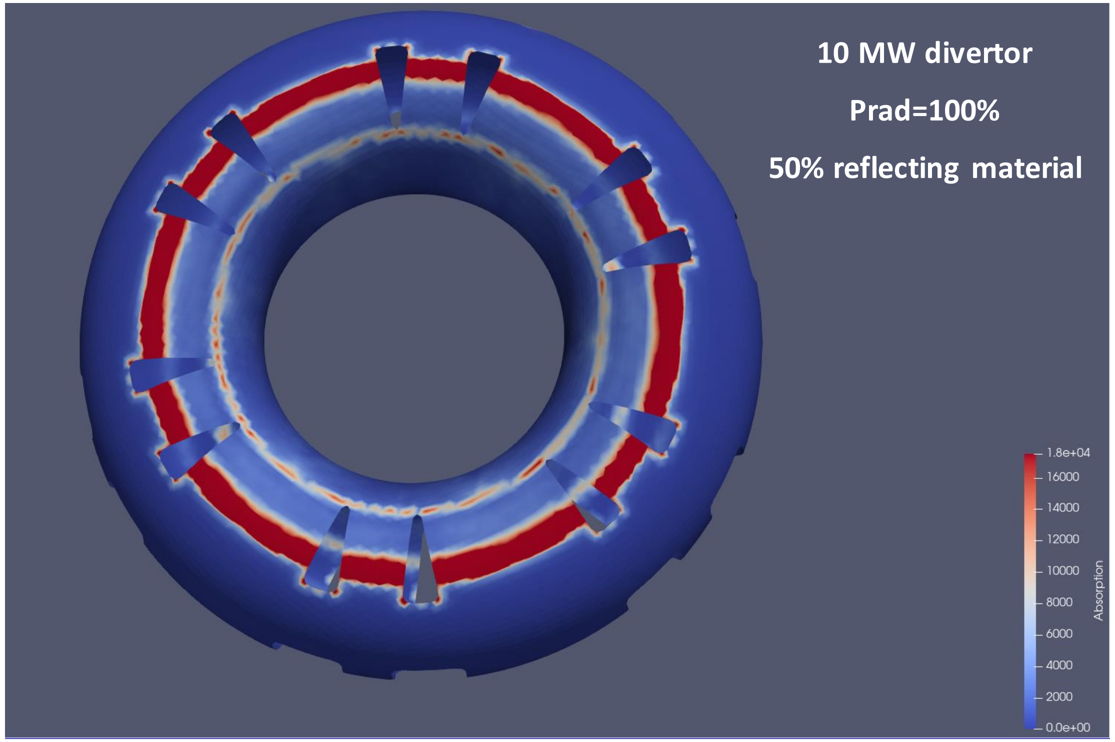


Around 10 kW/m² on internal uncooled structures

Thermal loads on Vacuum Vessel

Up to 15kW/m² on large wetted areas in the upper divertor region



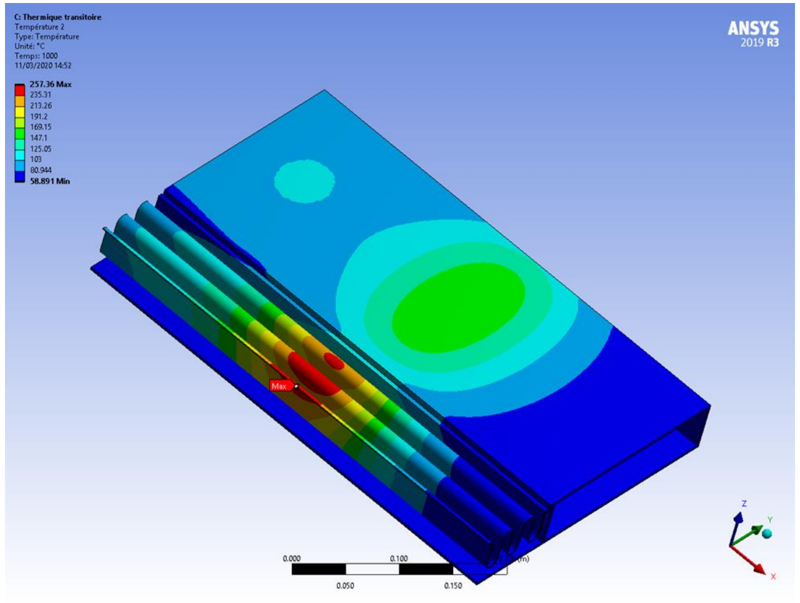


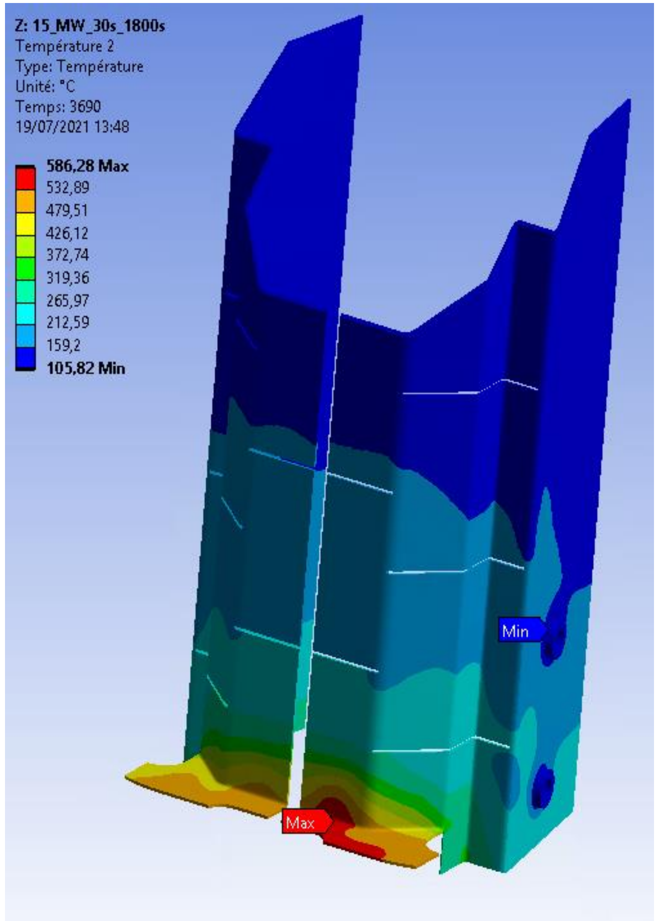
2. Component protections

Thermal analyses

With the thermal loads, thermal analyses were performed to assess the impact on various components

- Vacuum Vessel inner shell
- Vacuum Vessel belows
- Upper Divertor support structures
- Upper and equatorial ports flanges
- …

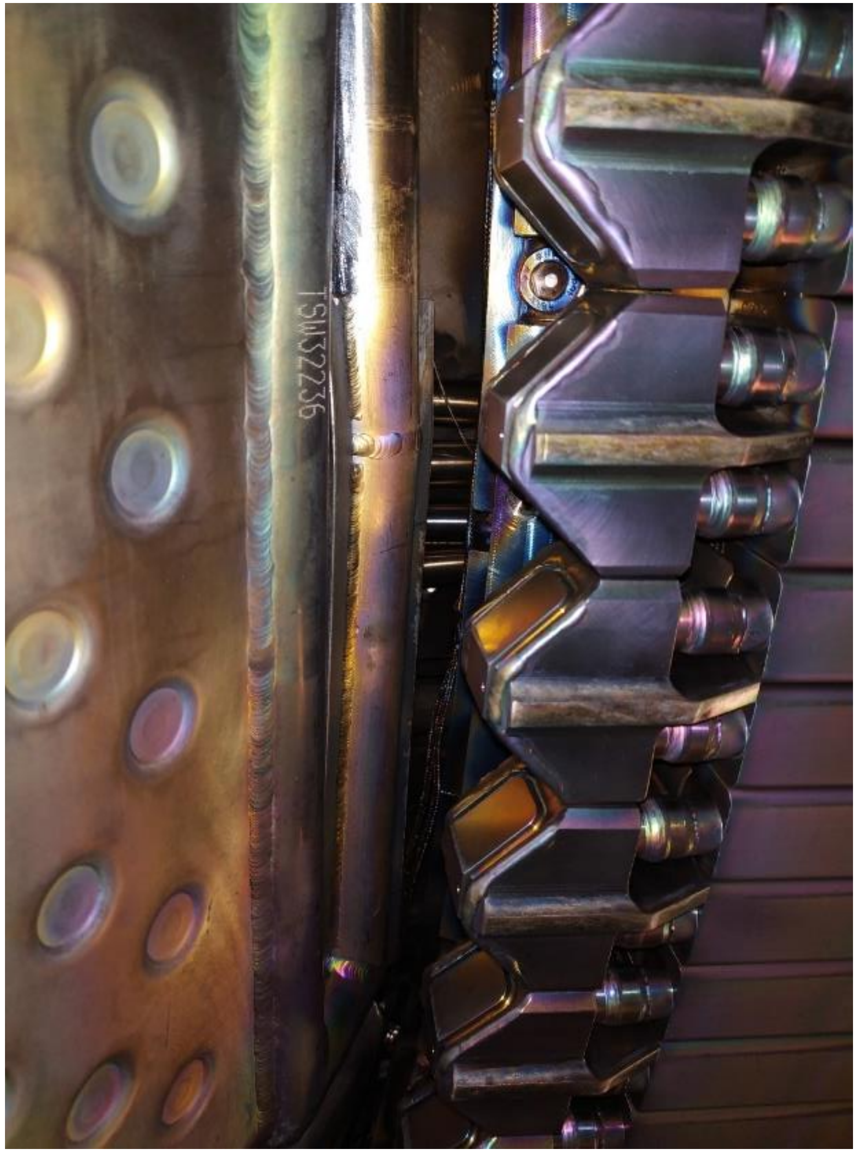




Thermal analyses

Results showed **high temperature**

- On critical components: vacuum vessel bellows
- On components with extremely complex maintenance: upper divertor support structures
- In small gaps: vacuum vessel

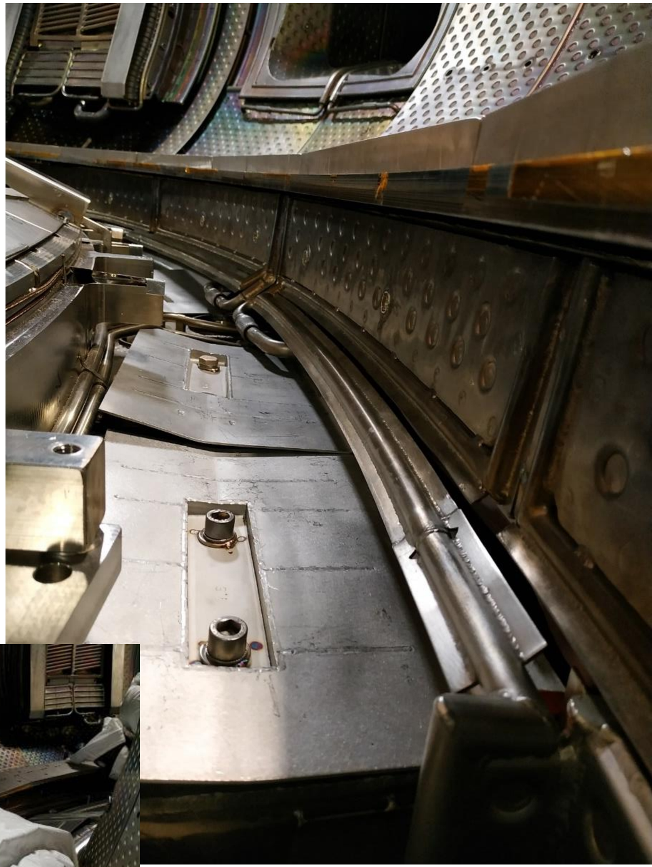


Protection panels

Wherever it was possible, active cooling was added. This was in particular the case of the Lower Baffle support Beam

But requires

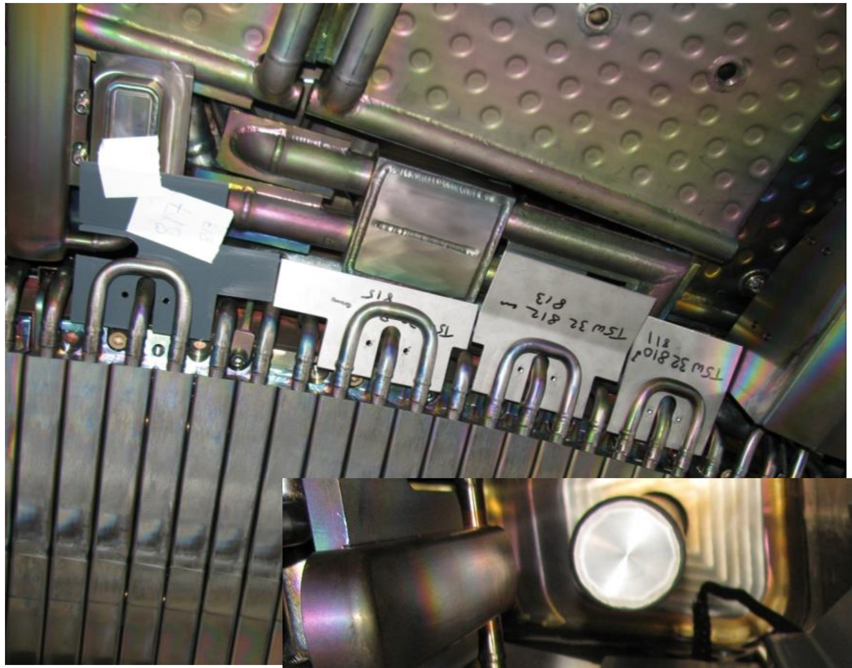
- Space : for components, for assembly and welding
- Pipe routing

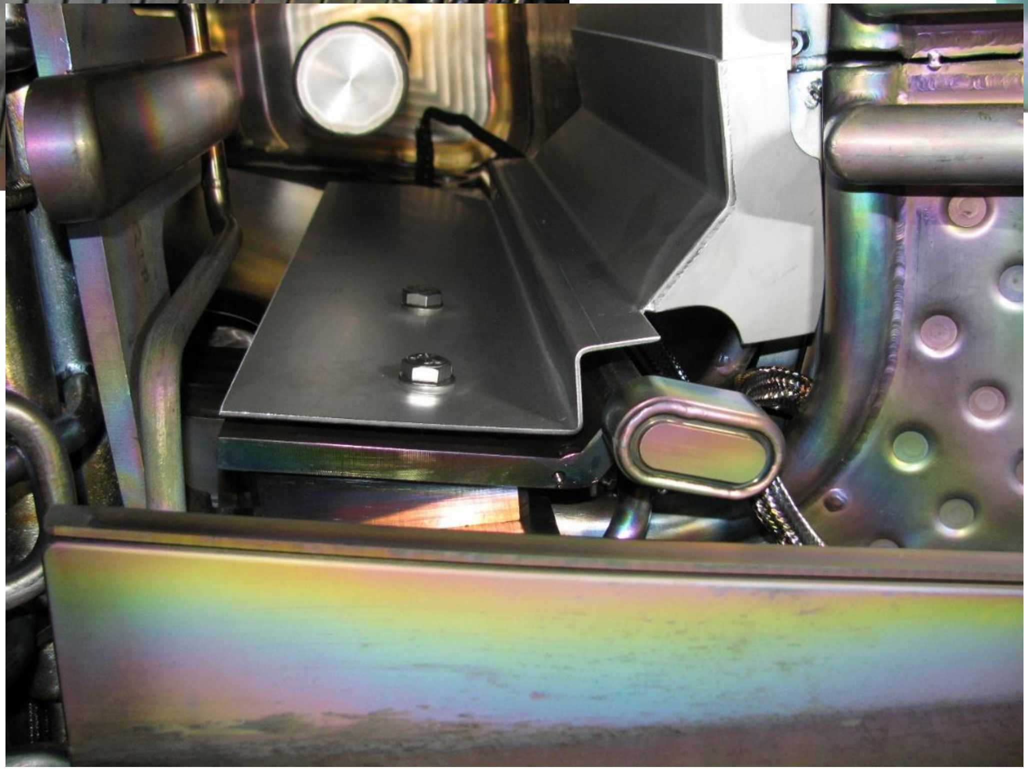


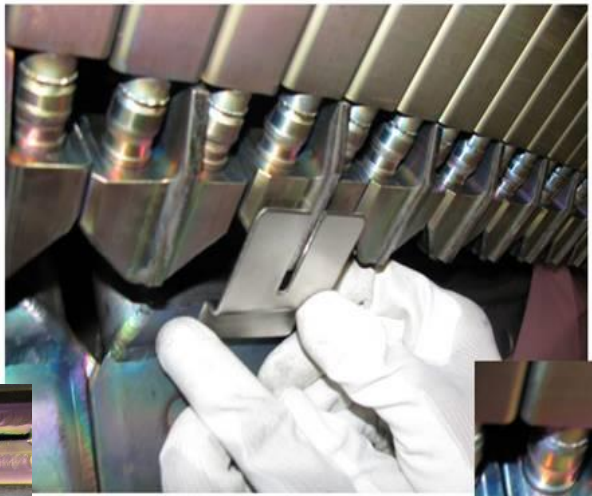
For the smallest gaps, very complex rooting of water pipes imposing the dismantling a large number of critical components (such as the divertor), and the number and complexity of water tight welds to be performed

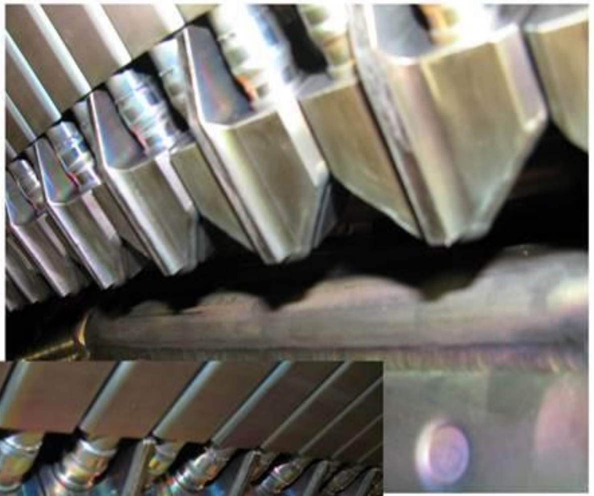
→ **High risk of water leaks**

→ **Only passive protections were included**







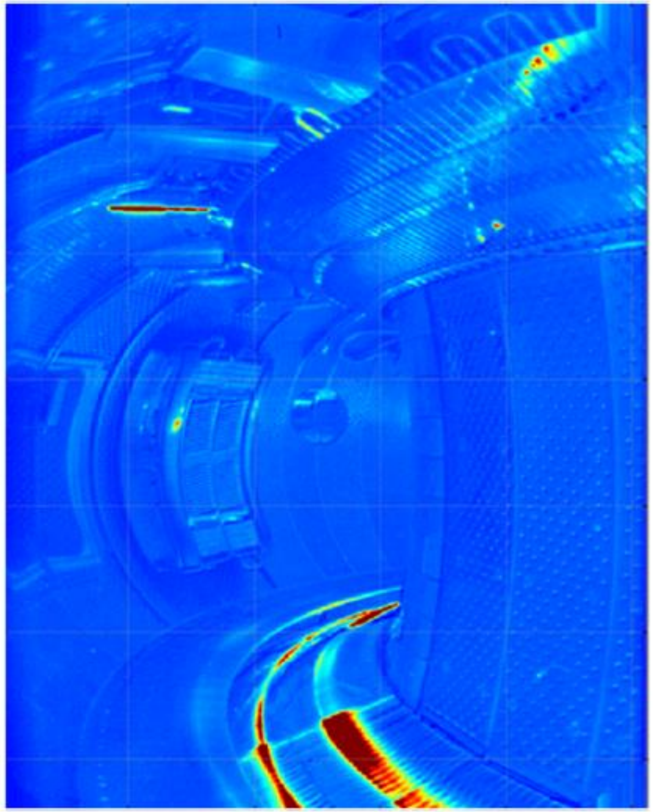


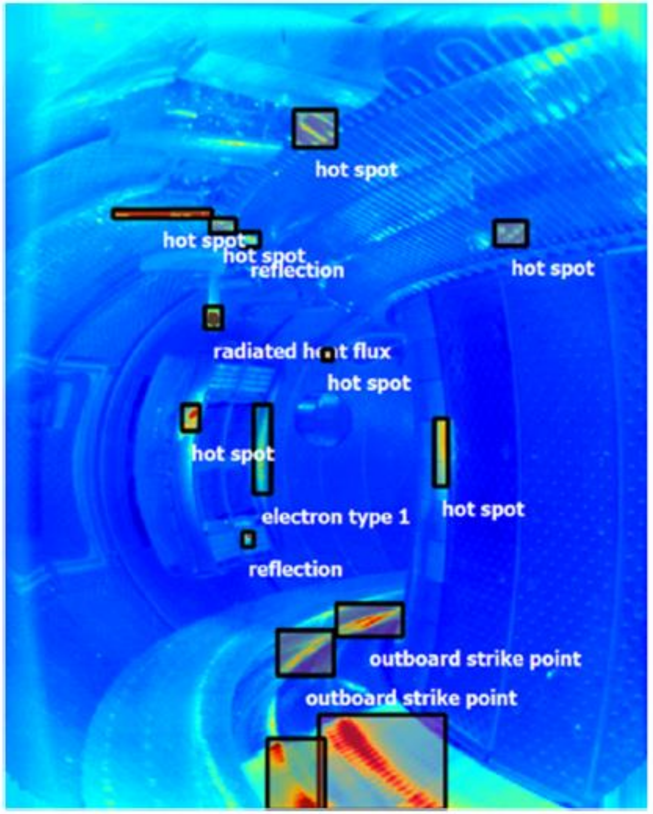
3. Components Monitoring

IR Monitoring

WEST IR system is mainly designed to monitor the lower divertor and heating systems

The Wide Angle IR system allows IR monitoring of some non critical systems: upper divertor, VV protection panels, ripple and VDE protections…





Components	IR %
Lower Divertor	80%
Upper Divertor	**16%**
Antennas	100%
Baffle	**16%**
Ripple and VDE protections	**25%**
Inner Bumpers	**16%**
Outter Bumper	**0%**

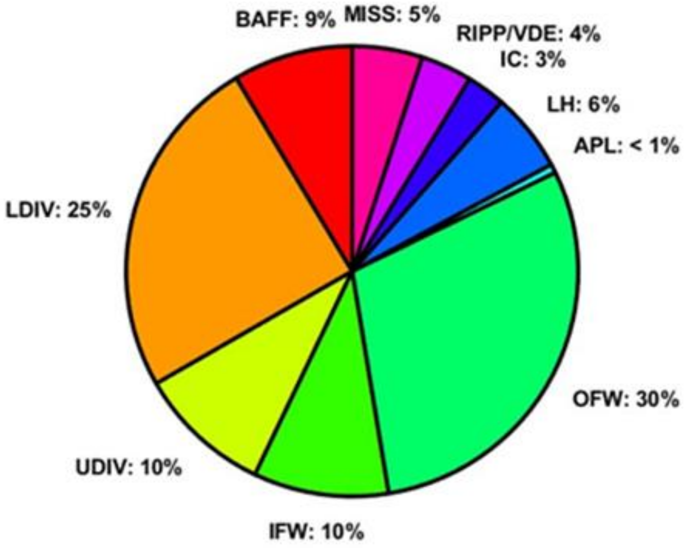
Houry et al. 2023

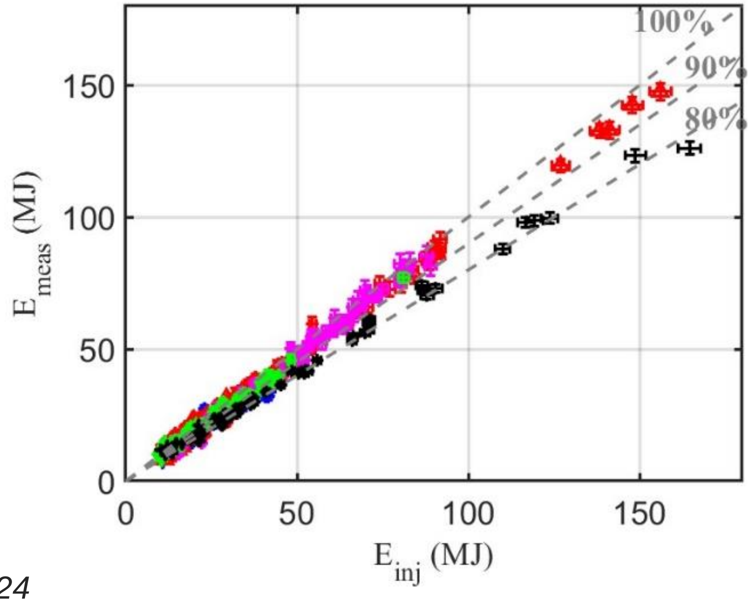
Calorimetry

The Calorimetry Diagnostic, based on thermocouples and flowmeters measurements, is a good complement to IR monitoring for actively cooled components.

- Energy balance closed in the range of 10%
- Energy distribution characterized:
  - OFW about 30% due to his high surface
  - LDIV or UDIV depending on magnetic equilibrium with more than 25%
  - IFW about 10% for all campaign and magnetic equilibrium
  - Ripple losses evaluated in the range of 4 to 5%

Coupled with bolometry measurements, the BOLO2wall code allows to evaluate the radiation contribution to local energy loads on different wall elements and check it against predictions and design data





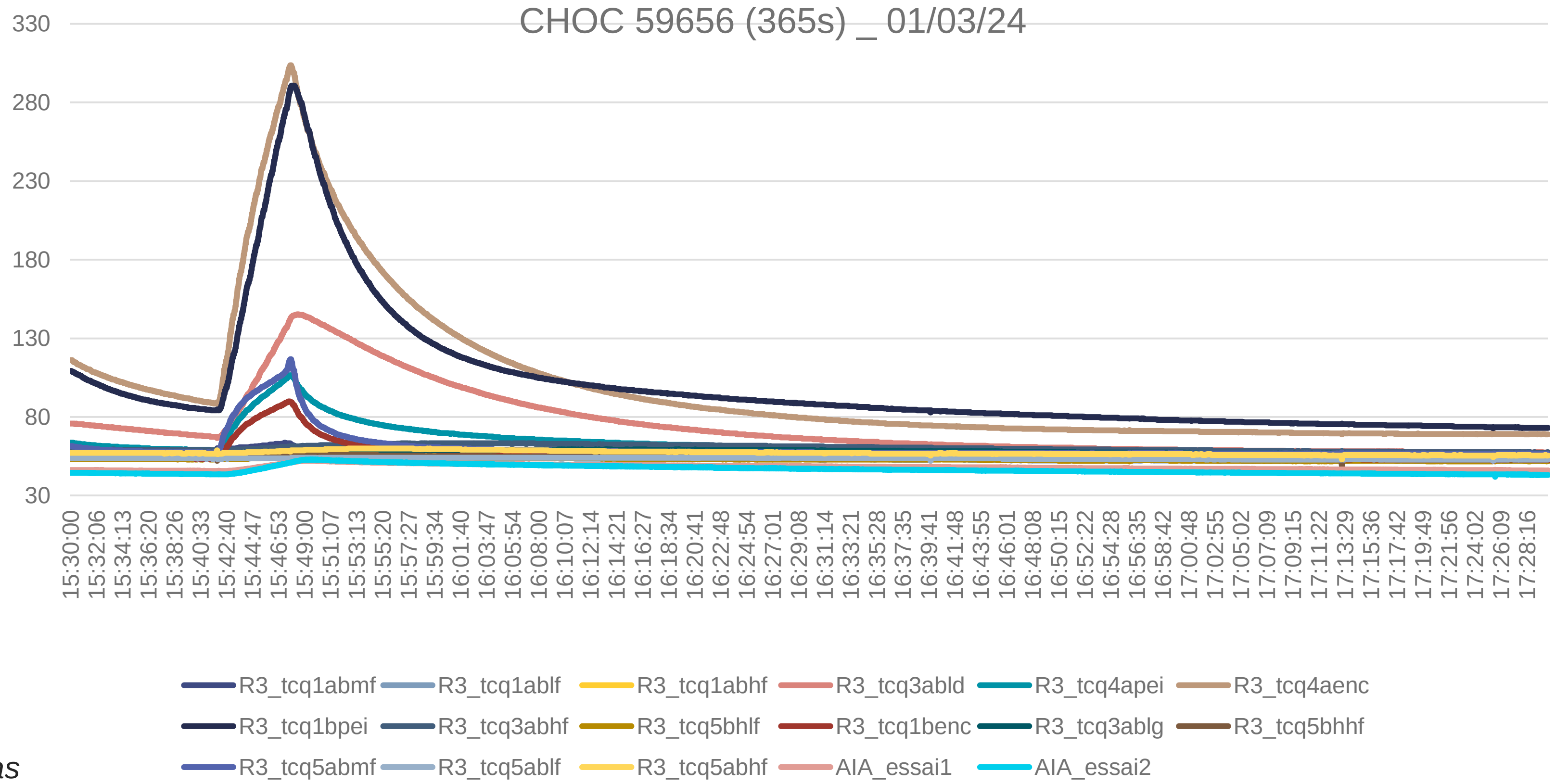
Gaspar et al. 2024

Components temperature

In addition to Calorimetry thermocouples, measurements have been added on inertial components when possible.

Temperature reaching ~300°C on plates protectind the VV bellows in the upper divertor region

As expected



Possible source of degassing causing the end of long pulses

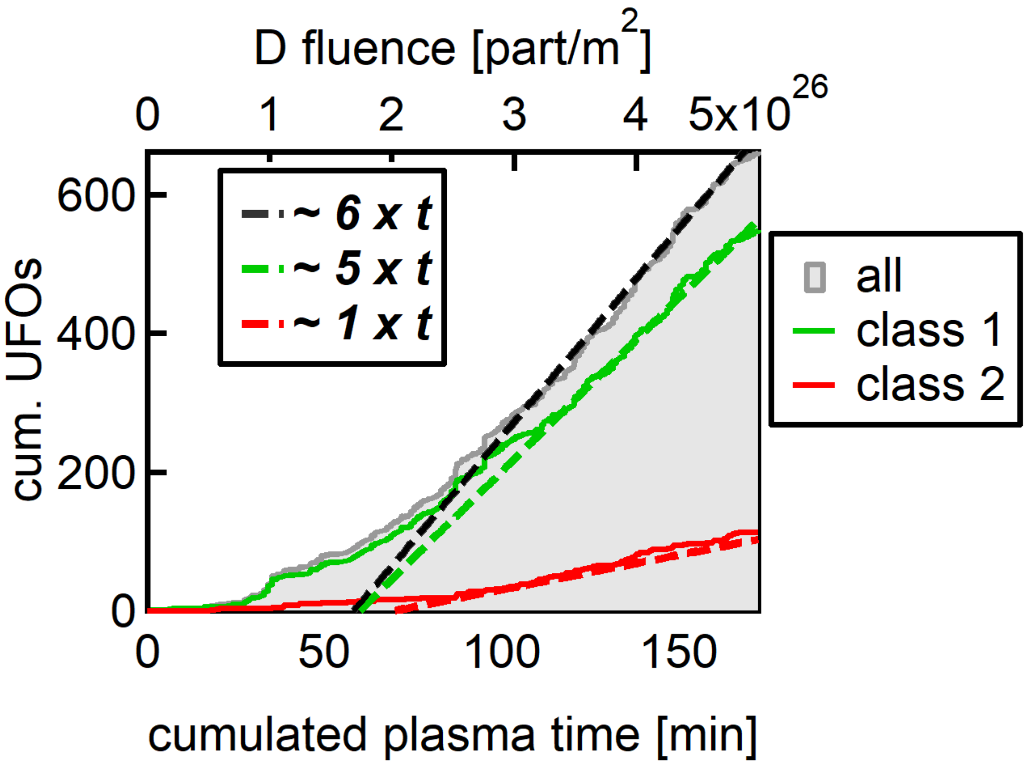
Presentation by P. Manas and R. Nouailletas

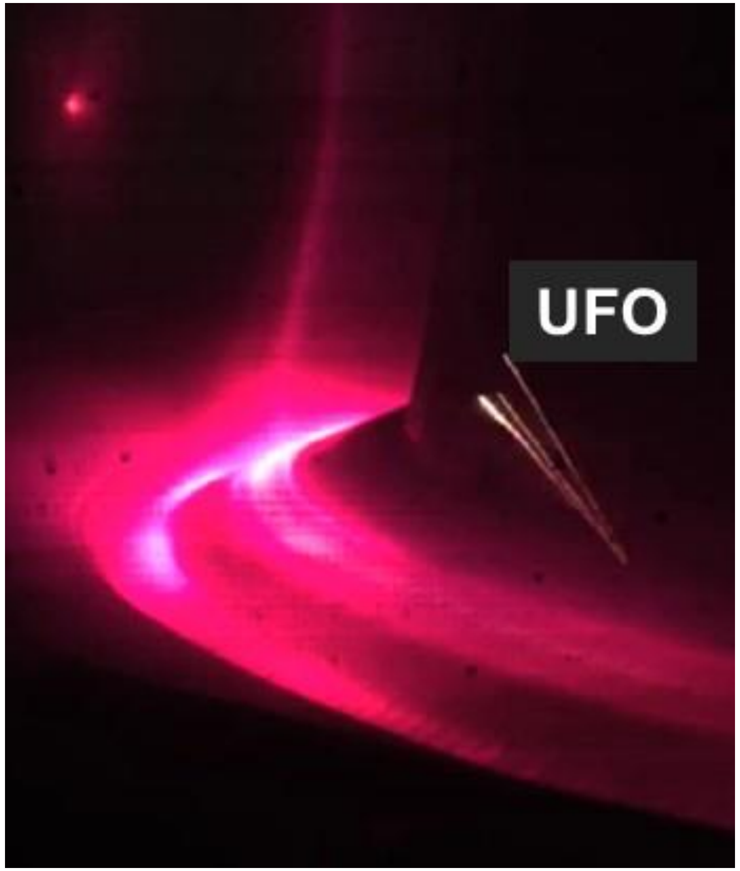
4. Tungsten UFOs

UFOs in long pulses

- High Fluence campaign performed generates deposits, flakes and UFOs on the W divertor
- Short peaks of radiated power, becoming more and more frequent ⇨ impact on plasma operation

→ Impact on repetition of long pulses can be dramatic





Quantify UFOs

1st analyses of UFO

- Peaks of radiated power
- 100% Manual identification on the IR movies – tedious frame by frame task
- Manual cleaning of divertor monoblocks

Developments performed

- AI based automatic detection
  - Detects 96% of dataset UFOs – also detects UFO missed by experts
  - Ready for next campaign for after pulse analysis
- Laser cleaning of divertor

Prospects near future

- Real time implementation of UFO IR detection
- In situ laser cleaning

E. Grelier et al.

■ Conclusions

Long pulses challenges

- Long pulses with High Power radiate large quantities of energy to poorly cooled components in WEST
- Improving cooling is a technical challenge → pipes routing / weld quality
  → not fully satisfying technical solutions

1 - None of the components in the Vacuum Vessel should be left aside during the design of long pulse Tokamaks.

This is emphasized in DT Tokamaks where improvements of the configuration is more complex.

2 – There are events affecting plasma

with time constants in the order of hundreds of seconds – degassing,

Or thousands of seconds - flakes/UFOs

Long pulses challenges

- Formation of flakes when repeating the same plasma scenario
- UFOs triggering disruptions

3 – Need for better understanding of flakes

formation, detachment, trajectory, sources, impact on plasma, cleaning…

Other issues will be discovered by accumulating experience in long pulses