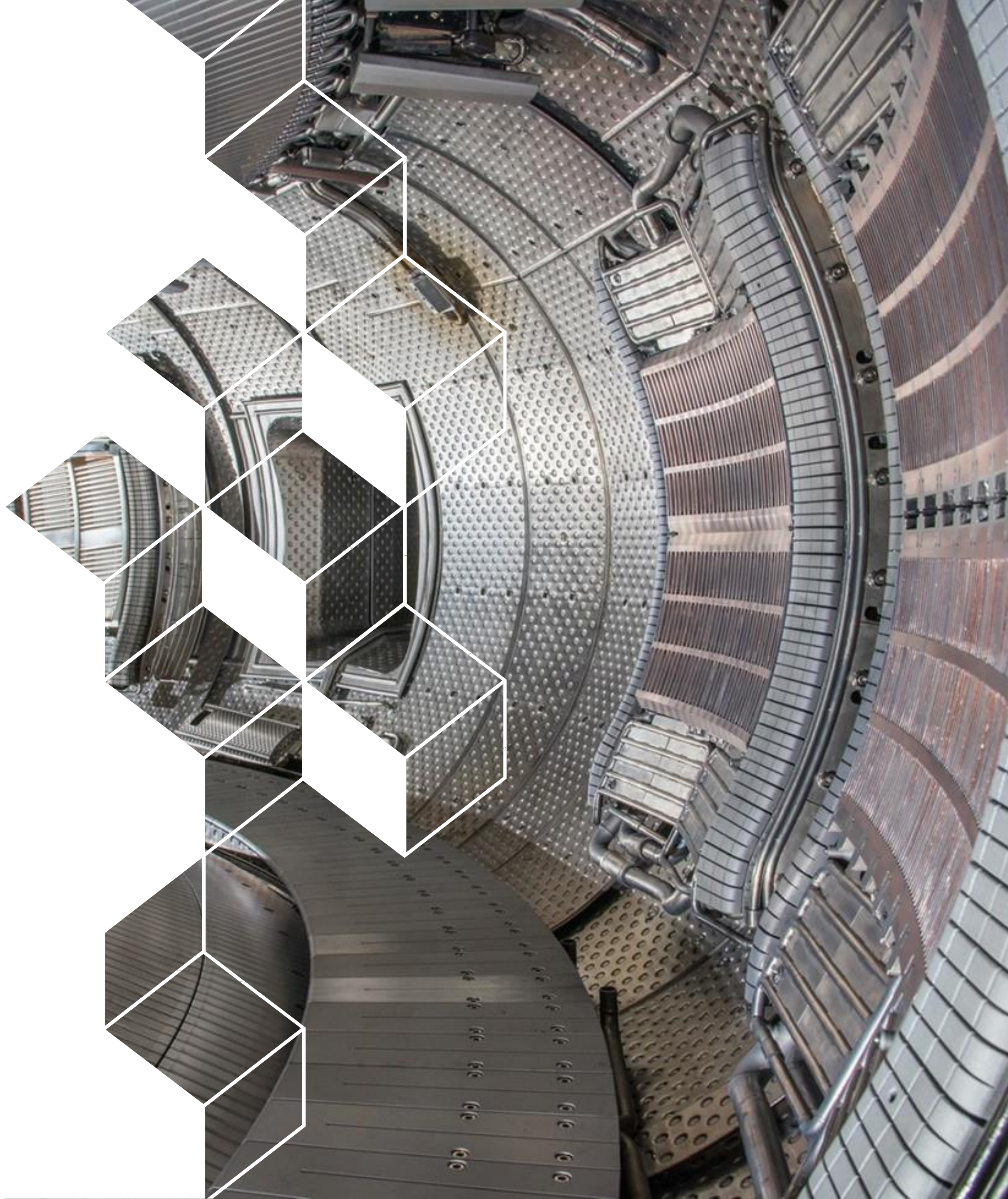
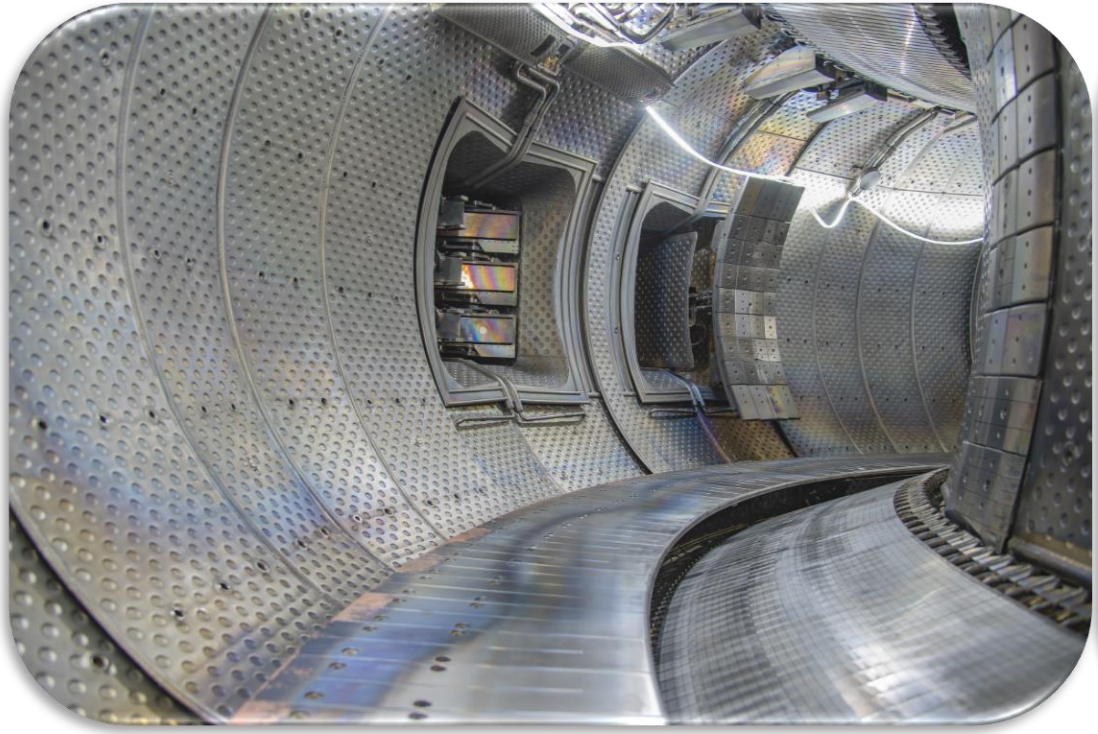
WEST Operation Reliability and Availability of a Long Pulse Tokamak

V. Lamaison, C. Brun, E. Corbel, A. Ekedahl, L. Gargiulo, S. Hacquin, M. Houry, L. Meunier, P. Moreau, L. Toulouse and the WEST Team

30th IAEA Fusion Energy Conference (IAEA FEC 2025), Chengdu, China



WEST: a Full Tungsten Superconducting Tokamak



Plasma current	1 MA (q95~2.5)
Toroidal field	3.7 T @ R=2,5m
Major radius (R)	2.5 m
Minor Radius (a)	0.5 m
Aspect ratio (A=R/a)	5-6
Elongation	1.4
Triangularity	0.5-0.6
Plasma volume	15 m^3
Greenwald density (at 1MA)	1.5 10^{20} m^{-3}
P_{ICRH}	9 MW
P_{LHCD}	7 MW
P_{ECRH}	3 MW (≥ 2026)
Flat-top duration	> 1000 s

WEST main goals

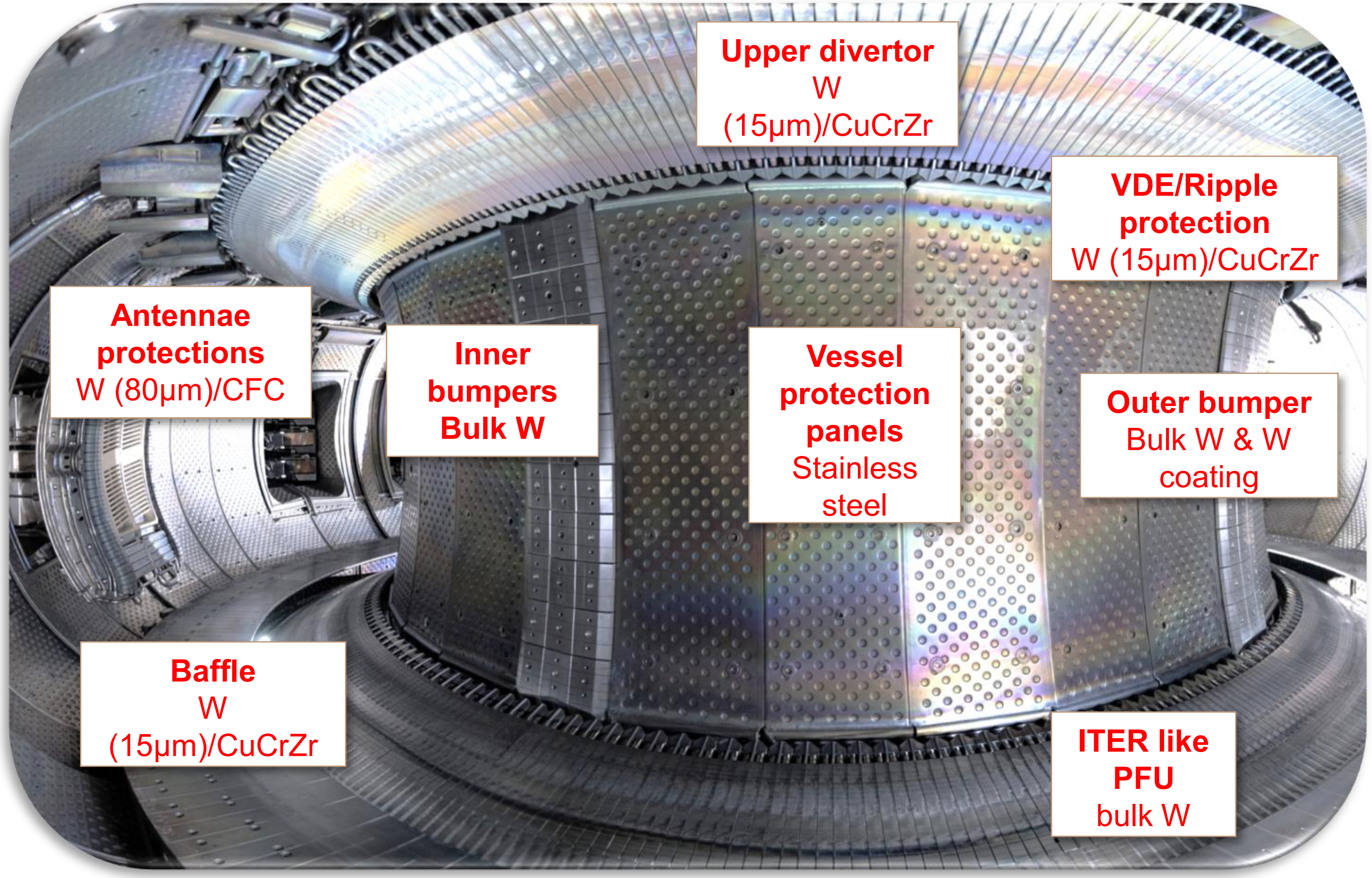
- **Test the ITER divertor technology at high heat loads/particle fluence**
- **Explore plasma operation scenarios in full tungsten environment**
  - Full tungsten actively cooled environment
  - Flexible magnetic configuration (LSN, USN, DN, Negative Triangularity)
  - Large current drive capability
  - Long pulse operation > 1000 s

OUTLINE

- WEST Long pulse Tokamak requires …
- WEST Long Pulse Achievements
- WEST Operation : Machine Availability and Downtimes analysis

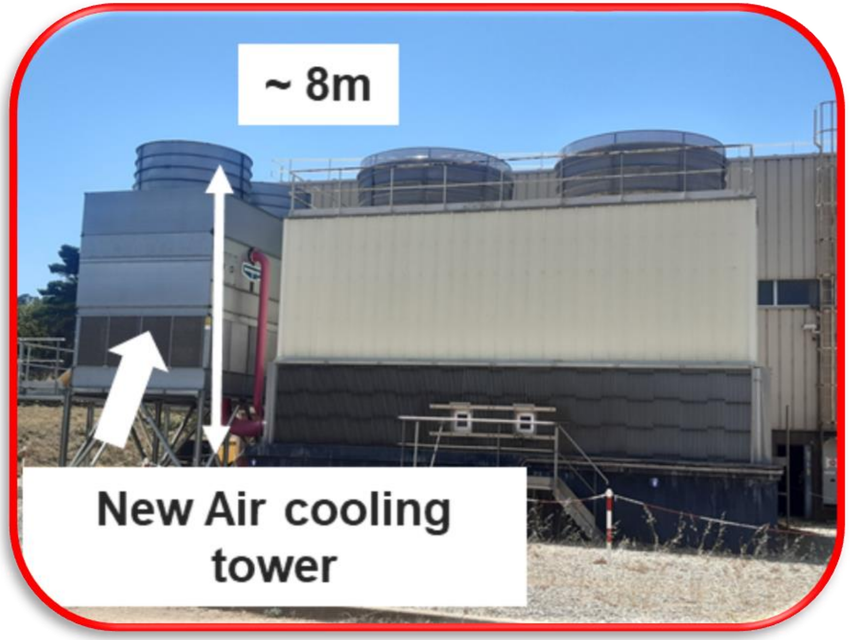
WEST long pulse Tokamak requires ...

Actively cooled Plasma Facing components



- **High pressure / temperature primary water loop (30m^3, 40 bar, 200°C)**
- Complex cooling circuit networks
- **Heat exchangers and Air cooling tours**

10MW + 5MW recently installed

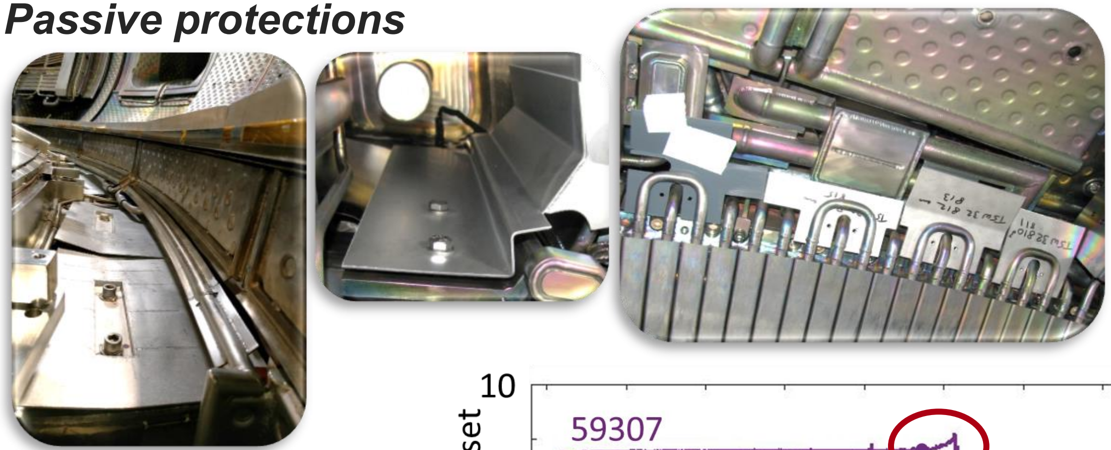


WEST long pulse Tokamak requires ...

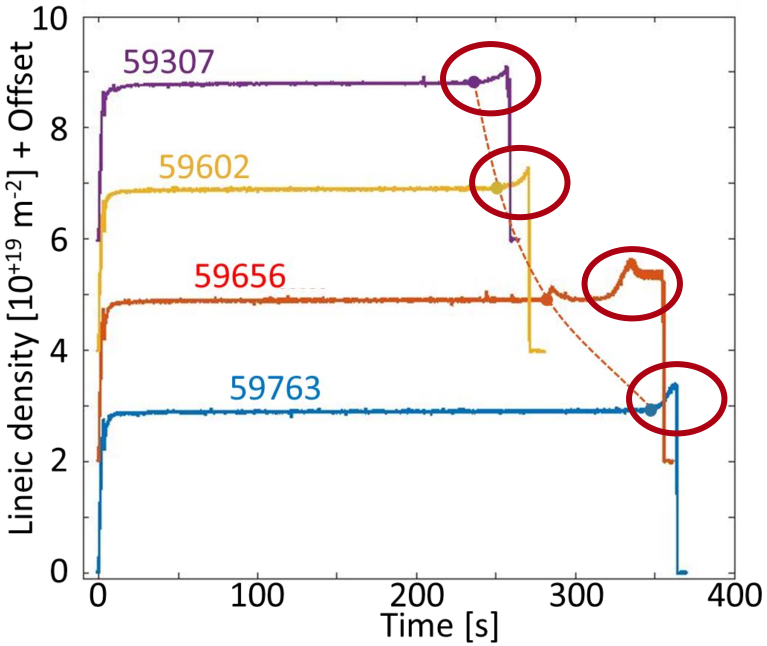
Full gaps cooled

- Passive protections to avoid heating of critical components
- Outgassing due to uncooled surfaces

Passive protections



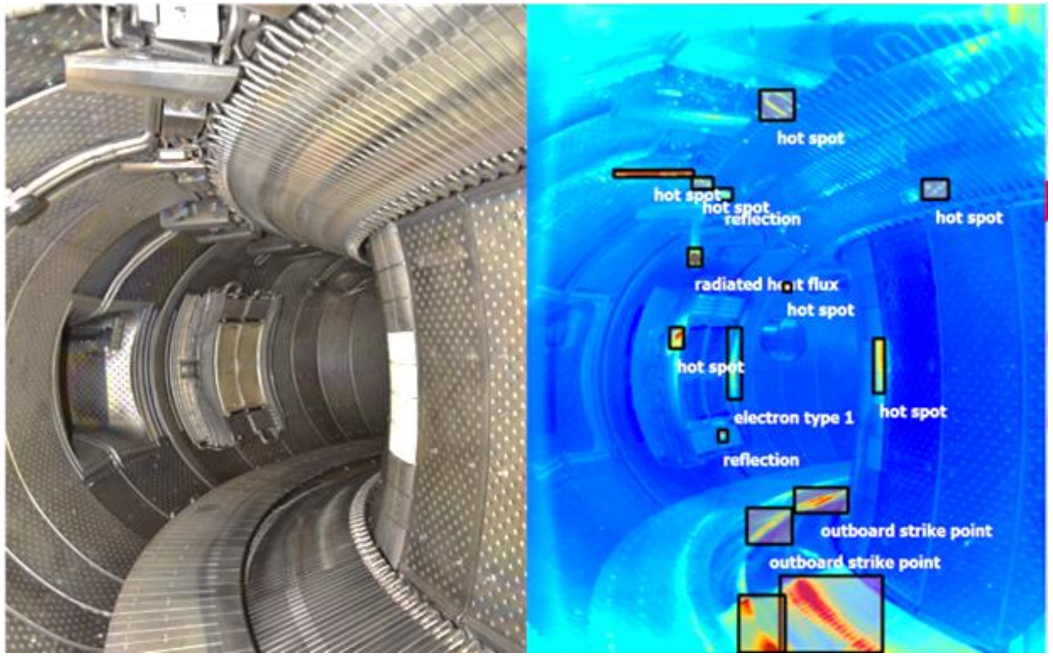
Density variation
Surface Outgassing



Real time PFC protection

- Avoid damage on the material/water leak
- Advanced wall protection by **Infrared real time diagnostic**

WEST IR Mapping
52% of 1st wall
85% of Lower Divertor



Y. Corre, this conference, EX-M 3487

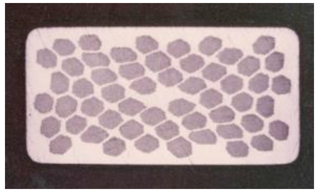
R. Mitteau, this conference, TEC-ICV P7 3049

WEST long pulse Tokamak requires ...

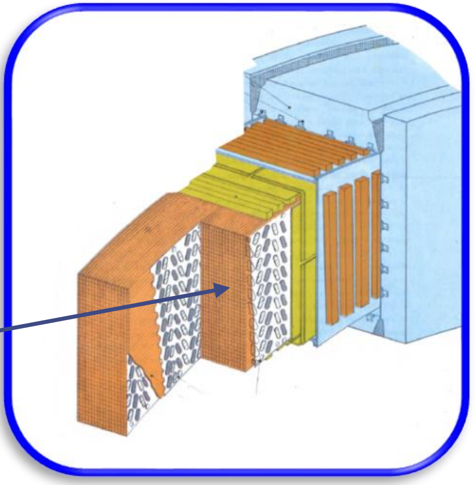
Permanent Toroidal Magnetic Field

Superconducting Strand
(Helium II – 1.8K – 1.3bar)

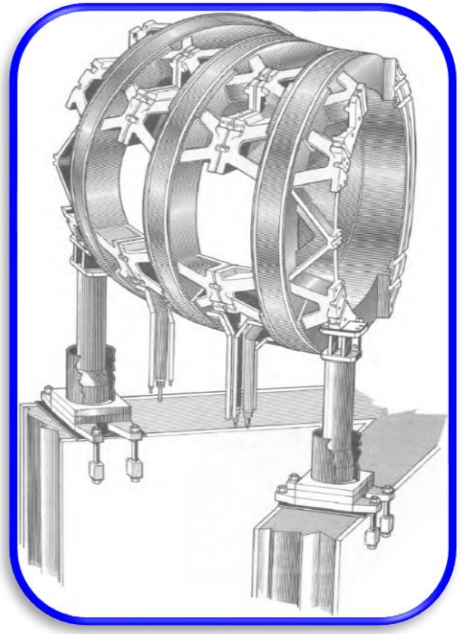
2.8 mm



5.6 mm



- 18 Toroidal Field NbTi Superconducting Magnets



- Cryogenic system

- $\varnothing_{average}$ = 2.6 m
- Toroidal field = 3.65 T @ R=2.5m
- Stored energy = 500 MJ (1250A)

- **~ 3 weeks cool down** : Magnets (160 tons), Thermal Shields (20 tons)
- **Cryogenic power : 3kW @ 4.5K (1/3 of JT-60SA cryogenic system)**
- 3.5 tons of helium inventory
- Gas helium (200 bar) and Liquid helium storage

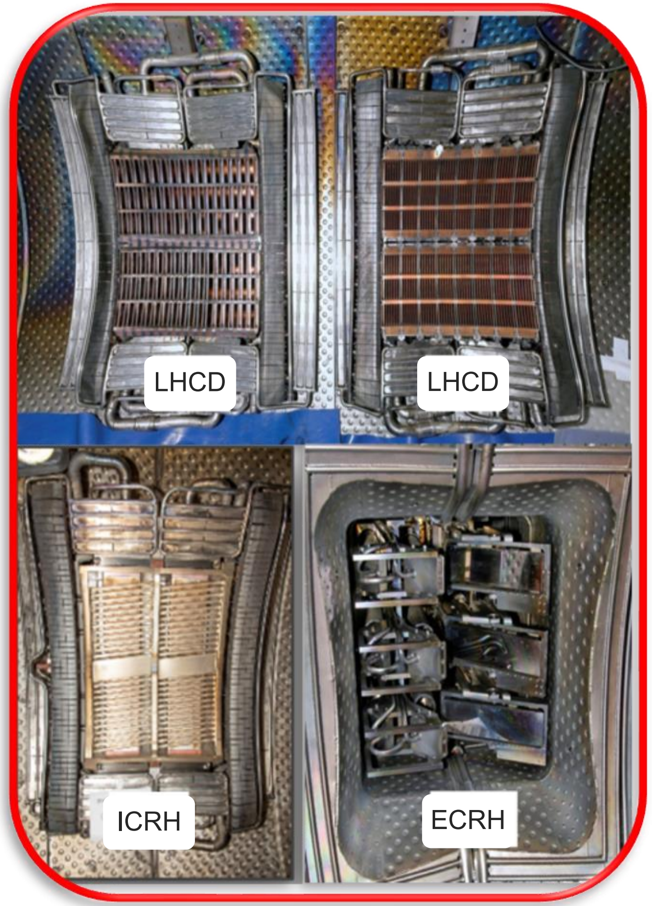
cea irfm

WEST long pulse Tokamak requires …

Vacuum System

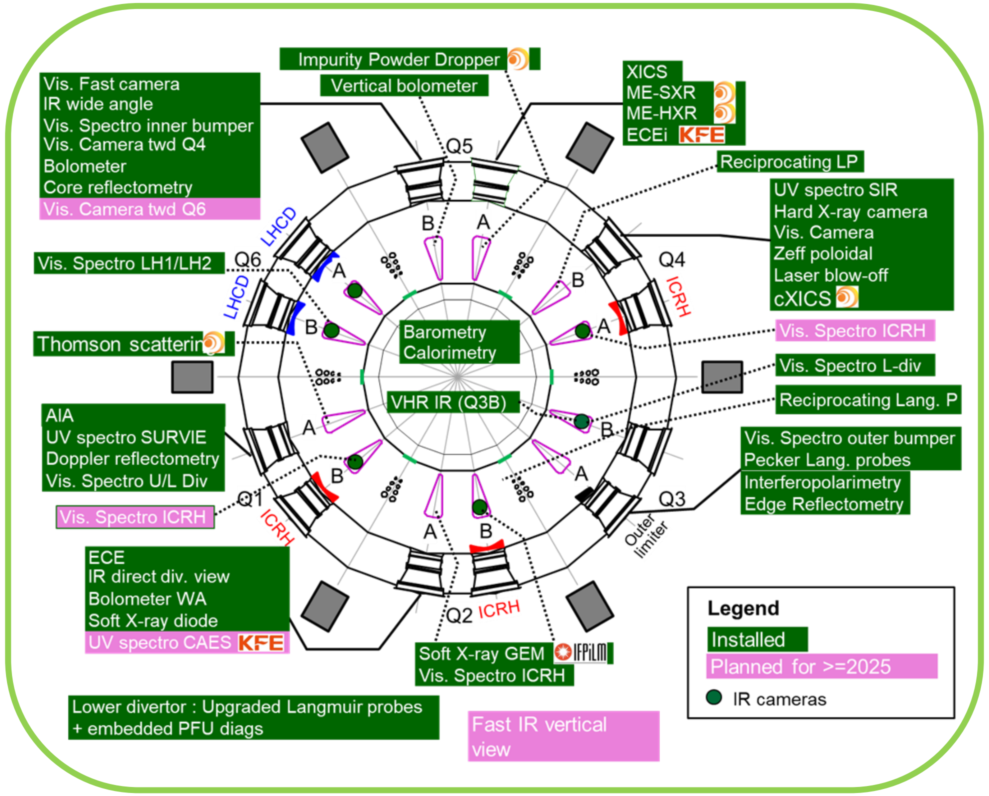
- Pressure 10^{-5}Pa
- Turbo molecular pumps
- Pumping speed $15 m^3/s$ ($50 m^3$ vacuum vessel)

Heating and Current Drive



- LH: 7MW
- ICRH: 3MW
- ECRH: 3MW (2026)

Diagnostics and Control System

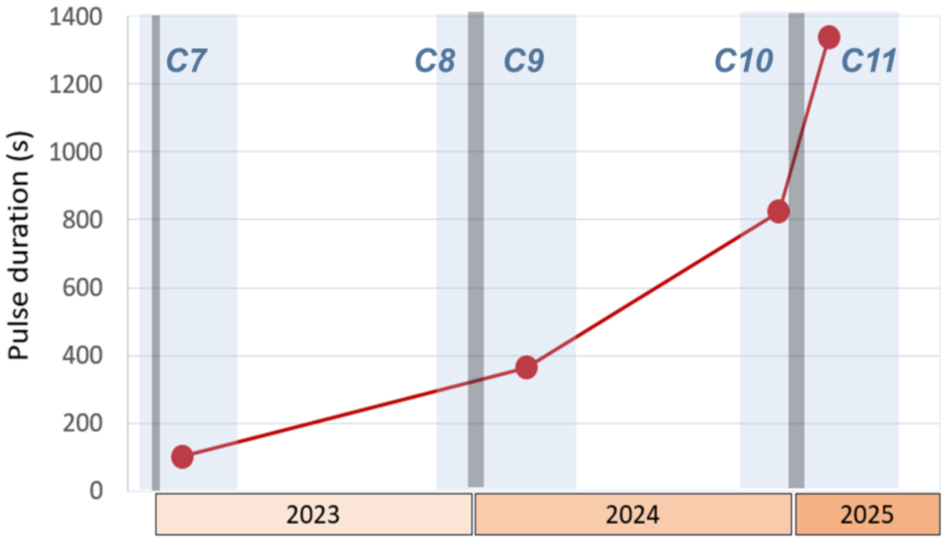


- ~ 40 diagnostics to measure plasma and Tokamak features for Operation Safety and authorities regulation, Magnetic and fueling Control, Physics

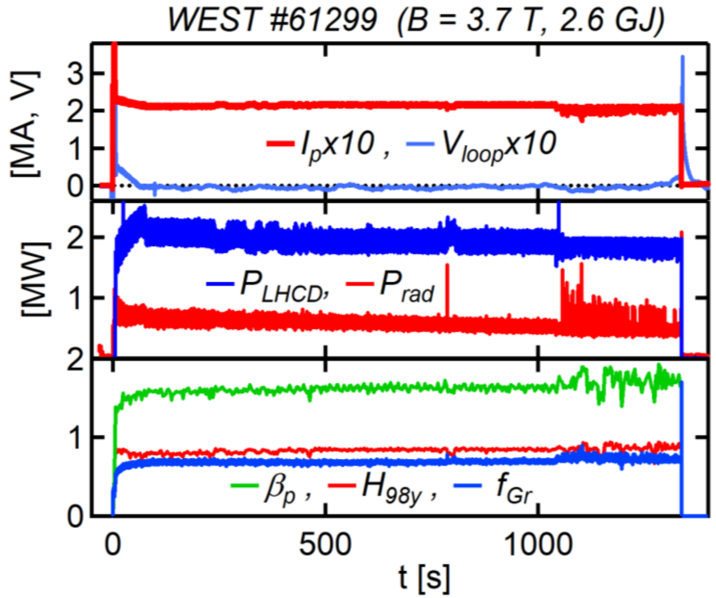
cea irfm

Main achievements on Long Plasma Pulses

Progress in Long pulse duration



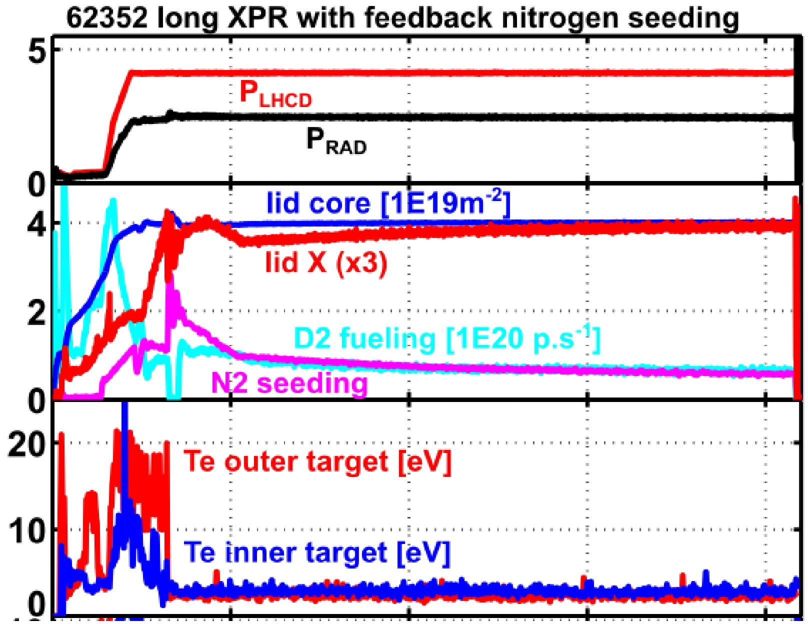
WEST long pulse record : 22 minutes / 2.6GJ



High Fluence campaign in 2023 (4 weeks)

- Repetition of 50s-100s long plasma pulses
- 3 hours of plasma and 30 GJ of injected energy
- Fluence ~ a few ITER pulses

X Point Radiator regime extended to 35s



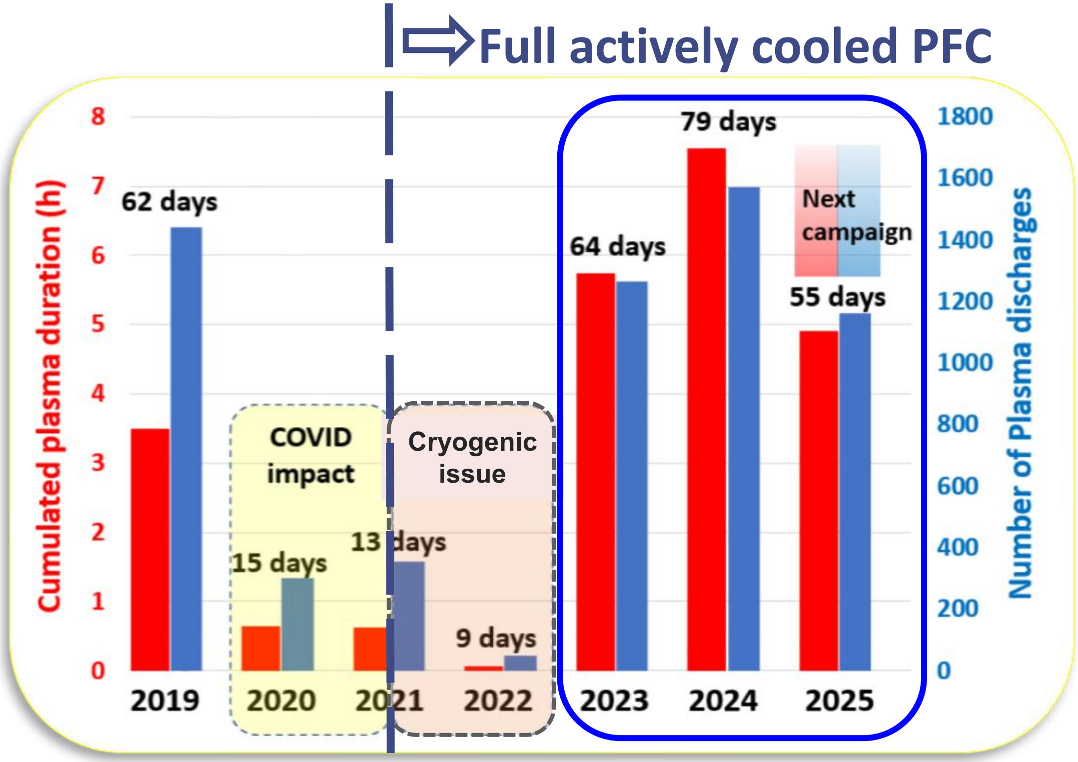
R. Dumont, this conference, EX-C 3420

N. Rivals, this conference, EX-D P2-3067

➢ **WEST operate routinely long pulse discharges**

Plasma campaign Key indicators since 2023

Cumulated plasma duration
Number of Plasma pulses



Plasma pulses

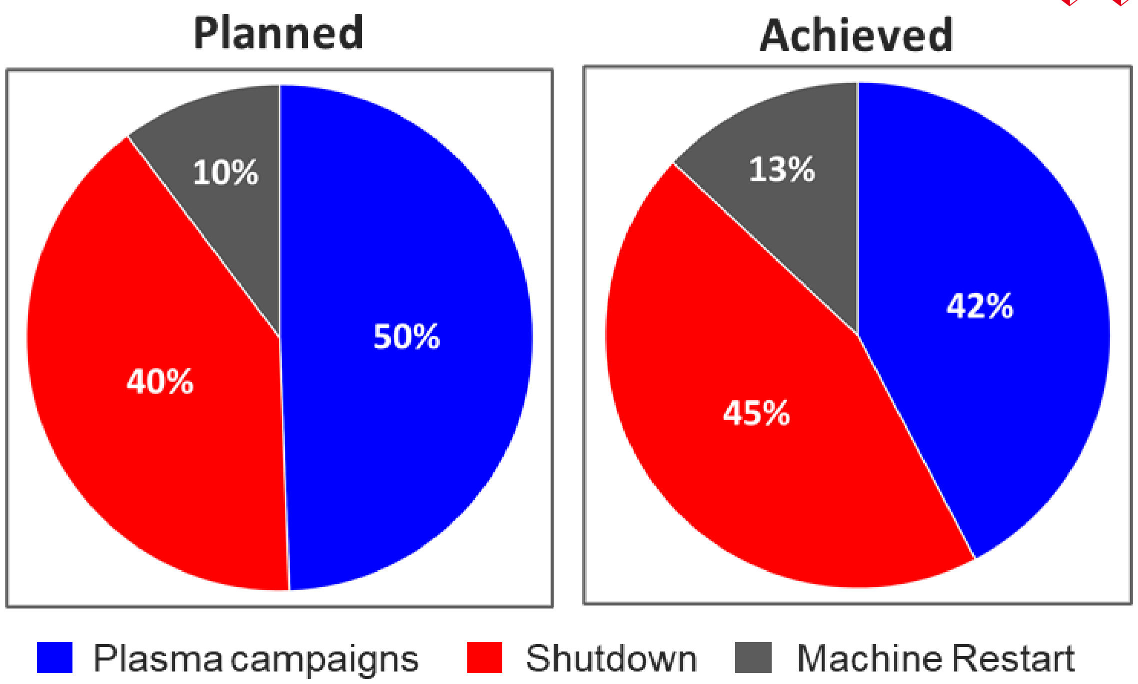
Year	Nb plasma pulses	Successful Plasma pulses %
2023	1264	**89**
2024	1570	**92**
2025 (first campaign)	1161	**91**

Successful: no technical issue

- **More than 5 hours cumulated plasma duration per year**
- **More than 1200 plasma pulses per year**
- **High success rate of plasma pulses : 90% successful pulses**

WEST Yearly Schedule

Yearly Distribution on 2024



Yearly schedule target

- Plasma campaigns ~ 6 months
- Shutdown for maintenance and evolutions ~ 5 months
- Machine Restart before campaign (vacuum pumping, baking …) 1 month

Yearly schedule management

Shutdown & Machine restart

- Preparation of Machine Configuration for the next experimental campaign
- Integrated Schedule taking into account co-activities, availability of systems, and safety regulations
- Daily briefings for seamless team coordination

Campaign

- Experiment Timeline for each plasma session
- Training of operation teams (~90 staff members: 25 trainees, 65 fully qualified)

WEST Plasma Campaign Operation

Weekly operation

- Monday dedicated to Maintenance/Boronisation
- 4 operation days in two shifts
  (2 days 8:45am-6:00 pm + 2 days 8:45am-9:00pm)

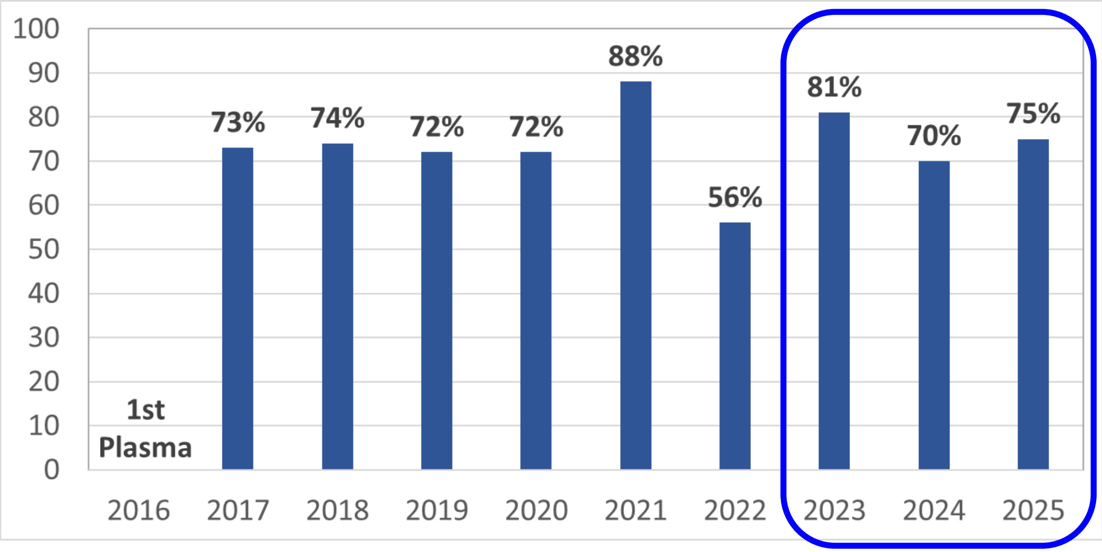
➢ **Machine availability = 75% achieved**

Operation downtimes (2023-2024-2025)

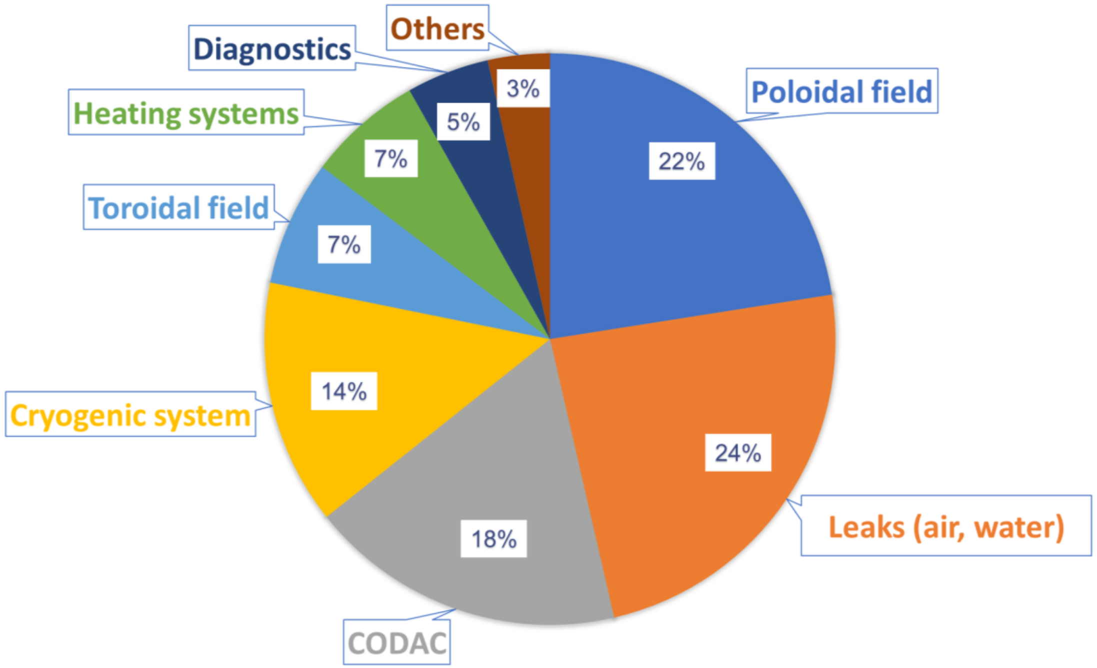
Record of operation downtimes in a dedicated database

- A total of ~ 40 days on the last three years
- **80% of the operation downtimes result from 4 main systems**
  - Leaks in vacuum vessel
  - Poloidal field system
  - CODAC (Control, Data Acquisition and Communication)
  - Cryogenic system

Availibility during experimental campaign



Operation downtimes: Time contributions (%) of systems



cea irfm

Downtime analysis (1/2)

Poloidal field system (22% downtimes)

- Multiple short shutdowns and a few longer shutdowns with interventions lasting up to one day
- **A targeted yearly maintenance plan** on specific components

CODAC (Control, Data Acqusition and Communication) (18% downtimes)

- Minor issues fixed during commissioning phase
- **Integrated CODAC tests** : Rehearsal sessions before beginning of the experimental campaign

Cryogenic system (14% downtimes)

- Single event can result in 2 months of shutdown due to warm-up and cool down of the magnetic system
- **A targeted yearly maintenance plan**
- Ensure safety operation of the superconducting coils
- Control cryogenic temperature of coils in case of cryogenic system failure → **backup strategies to operate the cryoplant**

Thyristor bridge

Helium storage

Downtime Analysis (2/2)

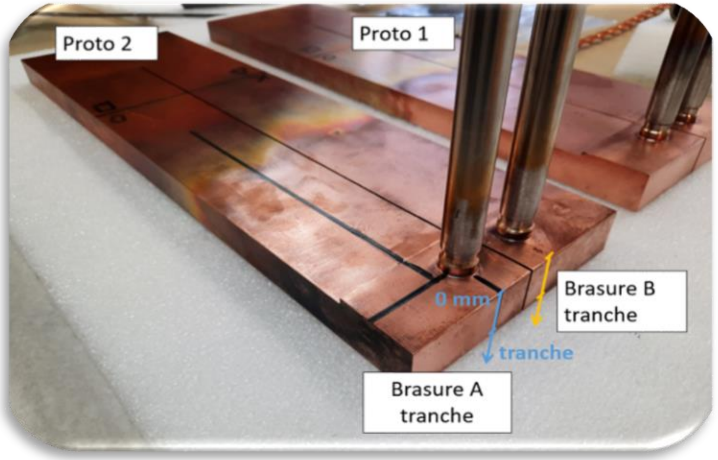
Leak management (24% downtimes)

- Water Leaks

  7 events since the beginning of WEST

  3 due to design issue on baffle
  4 due to aging components

Induction brazing on Baffle connections



Repair of panel protection inside vacuum vessel

- Typical duration : 5 weeks (Localization, Opening vacuum vessel, Repair, Closing & Pumping vacuum vessel)
- **Specific tests performed** on any actively cooled components **before integration** in the vacuum vessel : pressure and temperature cycling and helium leak test
- **Leak localization → Dedicated procedure**

  → Valves to isolate hydraulic circuits → faster leak localization with ~1-2 weeks saved

> ➢ **Leak management will be crucial for future machines so advanced detection techniques had to be developed** (visible spectroscopy, sniffing inside the vacuum vessel …)

cea irfm

Summary

- WEST long pulse Tokamak requires **complex systems**: actively cooled plasma facing components, superconducting magnets, cryogenic system, water cooling system, heating systems, power supplies …)
- WEST Long pulse achievements
  - New record with **22minutes plasma duration and 2.6GJ injected energy**
  - WEST **operate routinely long pulse discharges** and plasma scenario in attached and detached regime relevant for future machine
  - More than **5 hours cumulated plasma duration per year, more than 1200 plasma pulses per year**
  - High success rate of plasma pulses : **90% successful pulses**
- WEST Machine Operation
  - **Machine availability** 2023-2024-2025 = **75% achieved**
  - Downtimes analysis : identification of main systems involved, **Leaks, Poloidal field, CODAC, Cryogenic system**
  - Action plan to improve system reliability and availability

Thank you for your attention