WEST OPERATION – RELIABILITY AND AVAILABILITY OF A LONG PULSE FUSION TOKAMAK

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

CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France
*See http://west.cea.fr/WESTteam
Corresponding author: valerie.lamaison@cea.fr

Since 2016, the WEST tokamak has demonstrated its capability to perform long plasma discharges [1] approaching 1000s in a fully metallic environment. WEST is a long pulse machine, and presents the specific features of a permanent magnetic field of up 4T during operation with its 18 Superconducting Toroidal Field coils cooled at 1.8K supplied by a helium cryogenic system. Since 2021, all plasma facing components (PFCs), including the tungsten ITER grade divertor, are actively cooled by a pressurized water loop. WEST is representative of the type of technical and operational environment of future superconducting devices such as ITER, BEST, DTT and DEMO.

From 2022 to 2024, the experimental campaigns have been very successful and performance continuously improved. Key indicators are displayed in Table 1. The WEST tokamak confirmed its capability to operate routinely long pulse discharges: The number of discharges lasting more than 100s and achieved thanks to the non-inductive current drive capability from the Lower Hybrid Current Drive (LHCD) system, were increased by a factor of three between the four months plasma campaigns in 2023 (C6&C7) and 2024 (C8&C9). This was continued over the two months of the C10 campaign at the end of 2024 which produced a new record plasma duration of 824s with 1.93GJ (injected energy). The WEST performance is also demonstrated by the total plasma duration reached over the last two campaigns reaching more than five hours. In addition, more than 70% of pulses have been successful and EUROfusion Work Package Tokamak Exploitation (WPTE) programme on WEST was completed as planned.

Campaign	Nb Plasma	Ip max (kA)	Max plasma duration (s)	Integrated plasma time (s)	Nb plasma > 100s	Total plasma duration (h:mm)	Successful pulses (%)	Nb WPTE pulses planned	Nb WPTE pulses performed	LHCD Injected Energy (GJ)	Campaign availability (%)
C6 & C7 Dec 2022-April 2023	**1420**	**807**	**101**	**19960**	**10**	**05:32**	**72%**	**335**	**382**	**43**	**79%**
C8 & C9 Dec 2023-April 2024	**1478**	**730**	**364**	**20733**	**27**	**05:45**	**77%**	**313**	**301**	**38**	**75%**
C10 Nov-Dec 2024	**576**	**714**	**824**	**7614**	**8**	**02:06**	**71%**	**58**	**73**	**13**	**60%**

Table 1. *Summary of experimental campaign key indicators*

These results have been made possible thanks to a close monitoring of the campaign, commissioning and shutdown phases with the target of operating the machine during 50% of working days in a year (Figure 1). WEST machine availability of 42% in 2024, reflects the quality controlled management of maintenance and evolution plans put in place by the operation teams. In addition, the subsystems

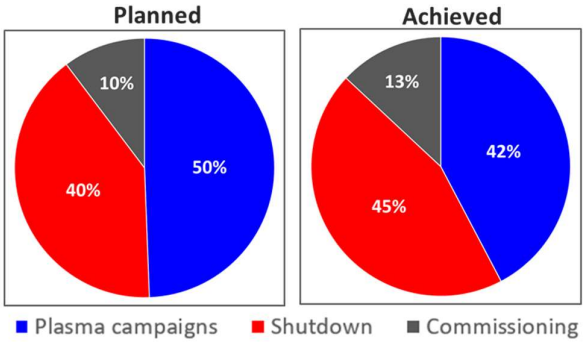

Figure 1. *Distribution of plasma campaigns, shutdown and commissioning days on 2024.*

availability, exceeding 70% achieved during both four months experimental campaigns offers a large time for plasma even though machine availability during C10 campaign was impacted for a week, by an incident on the cryogenic system.

The main factors that influence WEST tokamak availability:

1- A targeted maintenance plan of sub-systems based on the monitoring and analysis of operation downtimes encountered during experimental campaigns. Figure 2 presents, for the C8&C9 campaigns, the distribution of system-related downtimes which represent 160 hours of the 670 hours of the complete campaign.
2- The ability to recover nominal conditions after unplanned interventions.
3- The capability to ensure that sub-systems are operating within their limits during long steady state discharges, especially Plasma Facing Components (PFC).

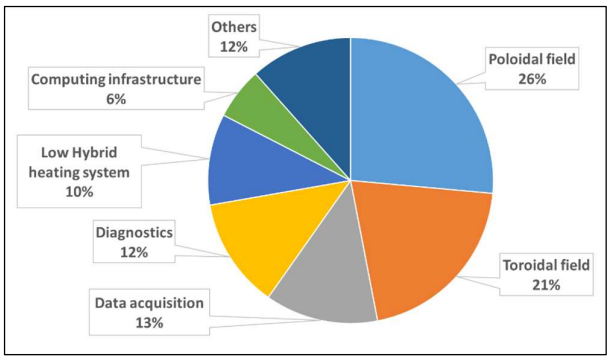

Figure 2. *Operation downtimes: Time contributions (%) of sub-systems, total = 107h*

In addition, to optimize daily plasma session, a study focusing on indicators such as operation day starting time (WEST ready to perform plasma), first plasma with heating systems coupled to the plasma, plasma pulse frequency, has led to improvements, especially in operation team organisation and training resulting in increased available time for experiments.

From this operational experience, several lessons can be drawn for the next step of fusion devices:

- In the commissioning phase, toroidal field coils cool down requires a careful monitoring of the temperature of the magnets and thermal shields. Related to this, the reliability of the cryogenic system is also critical as a failure can significant delay a superconducting device.
- Technical intervention downtime has been reduced in case of water leaks by carefully segmenting the complex water cooling network. As this point is crucial for the safe operation of future machines, advanced detection techniques had to be developed, such as infrared water leak detection and remote sniffing inside the vacuum vessel.
- Actively cooled PFC protections are essential and based on a comprehensive set of infrared (IR) real time diagnostics [2], providing a large thermal mapping with 52% of the first wall of the vacuum vessel. During plasma operation, this IR system provides temperature values to the plasma control system that can adjust the additional heating power if the temperature is approaching a threshold defined in accordance with the engineering limit of the component. If temperature exceeds the threshold, the IR system triggers an interlock that stops the plasma. In addition, an extensive calorimetry diagnostic [3] deployed on the cooling pipes of PFC is essential to check that all PFCs are actively cooled and to analyze the energy dumped in each of them.
- With this large set of diagnostics, the capabilities of the data acquisition must also be adapted to cope with the large amount of data produced during long pulses.

All these operational features are representative of the complex tools needed for the operation of a full tungsten next step devices like ITER.

References

[1] WEST Overview, Bucalossi and al., IAEA-FEC 2025
[2] WEST advanced wall protection achievements toward long pulse operation, Mitteau and al., IAEA-FEC 2025
[3] Calorimetry measurement for energy balance and energy distribution in WEST for L-mode plasmas, Gaspar and al., Nucl. Fusion 64 (2024) 036018