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First results from operating an ITER-grade divertor in the full tungsten actively cooled tokamak WEST

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The mission of WEST (tungsten-W Environment in Steady-state Tokamak) is to explore long pulse operation in a full W environment for preparing next-step fusion devices (ITER and DEMO) with a focus on testing the ITER actively cooled W divertor in tokamak conditions. After successfully having completed phase 1 of WEST (2016-2021) [1], phase 2 started in December 2022, with the lower divertor entirely composed of ITER-grade actively cooled tungsten mono-blocks [2]. Fast progress towards long pulse operation was achieved, resulting in discharges of 100 s pulse length and injected energy of ~300 MJ per discharge (Figure 1). In total, the cumulated injected energy during the campaign reached 43 GJ and the cumulated plasma time exceeded 5 hours.

Tungsten contamination can lead to 50% radiated power fraction in standard attached WEST plasmas, making the transitions into H-mode challenging. Conventional boronisation can decrease this level to about 20-30%, but only for a few discharges. Two alternative routes are explored. Firstly, encouraging results have been obtained with boron powder injection during the plasma discharges, with beneficial effects on both machine conditioning and core plasma performance. Secondly, experiments with nitrogen seeding have demonstrated that the W divertor sources can be extinguished and that a transition to an X-point Radiator (XPR) regime is obtained, similar to earlier results from AUG [3]. A stable radiating regime has been maintained for 19 s in WEST, with real-time control using nitrogen seeding as an actuator for 12 s (Figure 2). An increase in core performance by 20% was observed during the XPR phase.

Efforts to develop robust plasma scenarios, conciliating edge and core plasma constraints in a full W environment, have been pursued. Plasma start-up assisted by Ion Cyclotron Resonant Heating (ICRH) was successfully performed to assess the conditions for breakdown at low electric field in ITER. The analysis of W accumulation events [4] confirms the need for a large core electron heat source in a tungsten environment. This allows maximising ion temperature screening effect by equipartition, thus limiting the W peaking [5]. The installation of a 3 MW Electron Cyclotron Resonant Heating (ECRH) will consolidate plasma scenarios in this respect [6].

The last part of the experimental campaign in 2023 was devoted to a high fluence campaign in deuterium, with the goal to reach a cumulated particle fluence exceeding an ITER discharge in the Pre-Fusion Plasma Operation phase. Repetitive discharges of ~60 s pulse length were carried out during one month of operation, with a plasma scenario giving a divertor heat load of 4 MW/m^2 and electron temperature on the target of ~20 eV, leading to a cumulated particle fluence in the range 5×10^{26} D/m^2.

No boronisation or boron powder injection was carried out during the last 7 weeks of operation. Only glow discharge cleaning was performed once or twice per week. An increasing number of radiative events appeared towards the end of the campaign, becoming significant once the cumulated injected energy had reached ~20 GJ. These radiative events could be related to dust from thin, redeposited layers near the inner strike point on the divertor. Post-mortem analyses are now being carried out on selected tungsten plasma facing units to quantify the composition of the redeposited layers.

References
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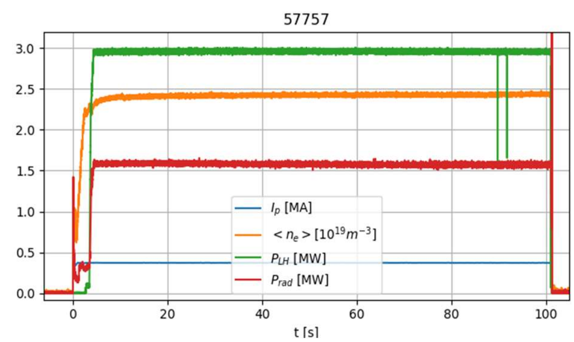

Figure 1: Main parameters of a 100 s long discharge with ~300 MJ injected energy, performed in WEST phase 2.

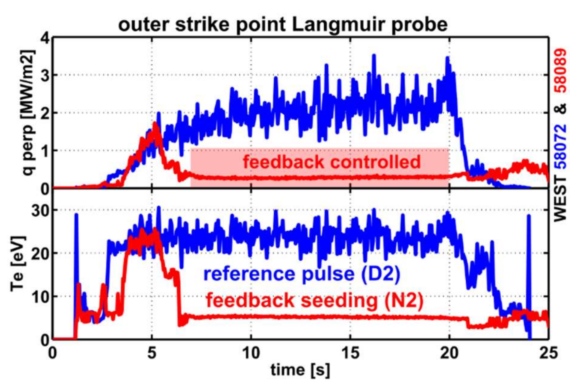

Figure 2: X-point radiator experiment in WEST, with feedback control using nitrogen injection.