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Institute for Magnetic Fusion Research

WEST

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Boron powder

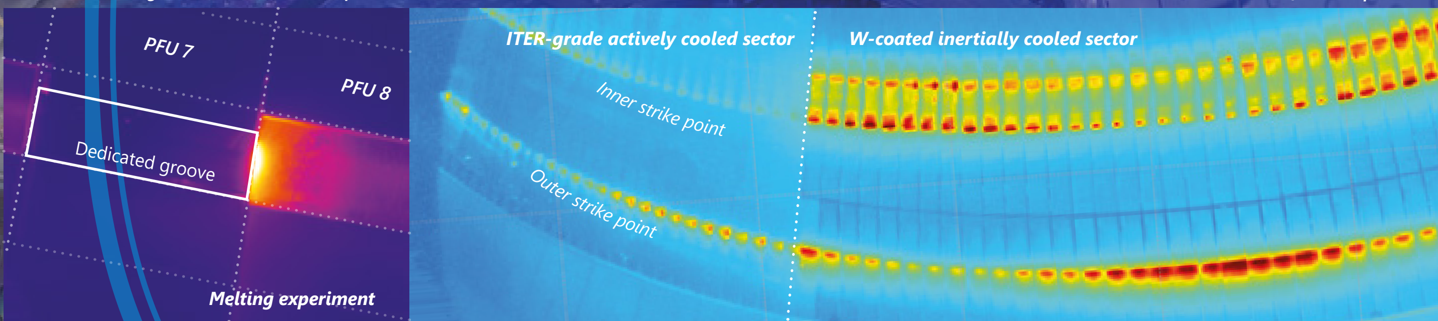
First phase of operation completed!

WEST completed its first phase of operation with a short but intense experimental campaign, carried out from November 27, 2020 until Jaary 27, 2021.

For this last campaign of phase 1, WEST was equipped with 1/6 of its actively cooled ITER like tungsten divertor, putting a significant number of ITER like Plasma Facing Units (PFU) to test. Amongst these PFU, one was dedicated to a melting experiment, in order to better assess these phenomena for next step fusion devices, such as ITER, where localized melting is to be expected in case of PFU misalignment. Another specific feature of this campaign was replacing the central tungsten tiles on the inner and outer start up limiters by tiles made from a low Z material (boron nitride, BN). This was performed to investigate the impact of the material in contact with the plasma in the early phase of the discharge on the global tungsten erosion source behavior.

Despite the COVID-19 pandemics, the experimental sessions dedicated to the characterization of tungsten sources with the BN tiles and PFU melting, were successfully performed in December 2020. In January 2021, a new Impurity Powder Dropper (IPD), provided in the framework of the collaboration between WEST and the US-Department of Energy, was successfully installed and provided right away the first boron powder injections in WEST (see below). While taming the BN tiles took a while, as large outgassing of hydrogen originating from these tiles was observed, a robust start up scenario was established by the end of the campaign.

High resolution infrared top view — *Divertor infrared top view*



Can you clean a tokamak by throwing dust into the plasma? Yes, you can!

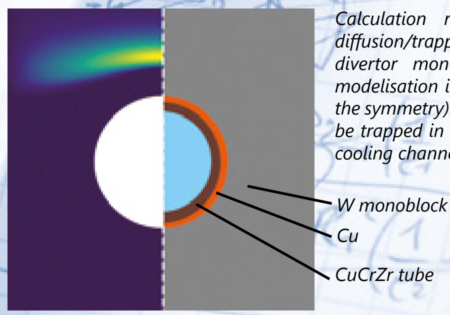
Successful first experiments with the PPPL impurity powder dropper

Keeping magnetic fusion machines clean (or conditioned, as we prefer to say in jargon) is a very big deal. The surface state of Plasma-Facing Components (PFCs) is crucial in controlling both plasma performance and lifetime in fusion devices. In machines with a metallic wall, like WEST with its tungsten (W) armor, conditioning is routinely performed via boronization: in the absence of magnetic field, a boron (B) enriched gas is puffed and ionized by a glow discharge in the tokamak, depositing a nanometric B coating over W PFCs. This usual conditioning technique helps mitigating the penetration of W in the confined plasma and its associated radiative cooling, while improving density control through trapping of hydrogen isotopes into the B layer. However, the coating lifetime is limited to a few minutes of plasmas and real-time conditioning methods are envisioned in view of future, steady-state fusion reactors to maintain the B layer over long pulse duration. With this goal in mind, researchers at the Princeton Plasma Physics Laboratory developed the Impurity Powder Dropper (IPD): this system allows the injection of B powders directly into plasma discharges. Once the powder is ablated and ionized, B is transported by the plasma itself onto the PFCs. This creates coating layers similar to a boronization but only where the plasma-wall interaction actually takes place and, therefore, using smaller amounts of B and, most importantly, without stopping the discharge. After being deployed on several other machines, the IPD was successfully installed on WEST and commissioned by a joint IRFM/PPPL experimental team in January 2021.

Thanks to its long-pulse capabilities, WEST represents the ideal test-bed for qualifying the IPD as a real-time conditioning method in a reactor-like environment. Early results from the deployment of the IPD on WEST are already very encouraging with continuous B powder injections for as long as 16 s at a drop rate of 4 mg/s during 4 MW heated L-mode discharges. A clear reduction of the spectroscopic signals of several impurities, together with a strong increase of the B signal, were observed during the drop phase. A promising reduction of the radiated power and signs of improved energy confinement were also measured. The experiments with the IPD will resume during the next campaign: stay tuned for more cleaning done by throwing powder into WEST!

The fuel in the plasma, not in the wall.

In a deuterium-tritium (D-T) fusion reactor, the first wall – and particularly the divertor – are loaded by the heat and particle fluxes at the plasma periphery. Consequently, the plasma facing components are the site of intense material-particle interactions. Their constituent material, in addition to good thermomechanical properties, must resist erosion by the plasma flux – for avoiding the pollution of the core of the discharge and reduced lifetime – and trap the minimum of isotopes of Hydrogen (D and T), in order to prevent too much Tritium from being stored in the wall. Indeed, in order to limit the Tritium release in the event of a loss of confinement accident, the total quantity of Tritium in the vacuum chamber of the ITER tokamak is limited to around 700g by the Nuclear Safety Authority. If the fusion devices of the last four decades have almost all operated with a carbon first wall (this low Z material does not pollute significantly the plasma), extrapolations to ITER have shown that the retention in the tritiated deposits resulting from the erosion of the carbon wall by the plasma would very quickly exceed this limit of 700g. This is one of the main reasons why carbon compounds were abandoned in the ITER design in favor of the couple beryllium (Be, for the far wall) – tungsten (W, for the divertor, which is the most loaded by the heat and particle fluxes). In fact, tokamaks having operated with metallic walls either close to that planned for ITER (JET, UK), or entirely coated with Tungsten (ASDEX-Upgrade, DE), demonstrated a large decrease of the long term retention of hydrogen isotopes, of almost an order of magnitude. However, these measurements were performed in short pulse devices essentially cooled by radiation in between discharges, the first wall therefore remaining at high temperature during a significant time. This high temperature, by favoring the diffusion of the hydrogen isotopes in the wall, also favors the recovery between discharges of the gas trapped during them. The evaluation of the retention of hydrogen isotopes in conditions that can be extrapolated to ITER is one of the missions of the tokamak WEST. For this purpose, WEST is operated with an actively cooled divertor using the same technology and operating temperature as the ITER divertor and has the potential to perform plasma discharges of the duration of a nominal ITER discharge.



Calculation result of a macroscopic diffusion/trapping model on ITER divertor monobloc (only half of the modelisation is shown on the left due to the symmetry). Hydrogen isotopes tend to be trapped in the coldest parts (near the cooling channel).

ITER-like W monoblocks for the entire WEST divertor is becoming a reality

The 10 remaining sectors are being assembled with their 38 Plasma Facing Unit (PFU) each, before their imminent introduction inside the tokamak to complete the divertor ring with ITER-grade components.

All the 456 actively cooled tungsten Plasma-Facing Units (PFU), necessary to complete the divertor ring, have now been extensively qualified: visual and dimensional inspection, tightness checks, pressure drop, hardness Vickers hardness on tungsten and copper, infrared thermography examination and Hight Heat Flux (HHF) reception testing.

The mechanical process for their assembly onto the 30° divertor sectors was validated with the two first sectors installed in fall 2020 for the C5 experimental campaign. A dedicated production area has been set up at the IRFM and the work for the production of the last 10 sectors is in its full swing. It consists in a sequence of operations performed in an optimized schedule: PFU pipe cutting, mounting, welding, integration of embedded instrumentation, leak detection and metrology.

This assembly phase will have equipped in total 6 sectors with standard PFU (including one sector with the first European components procured by F4E and one sector dedicated to specific experiments observed by the very high resolution infrared camera of WEST) and 6 sectors with specific PFU machined for embedded diagnostics (Langmuir probes, Fiber Bragg Grating and thermocouples).

After a hot helium leak test procedure and last 3D geometry scanning, the sectors will be installed into the WEST tokamak in spring 2021 for a first plasma in the full divertor configuration planned in summer 2021.

The fully actively cooled lower divertor, based on the ITER-grade tungsten monoblock technology , is becoming a reality in WEST, paving way towards steady-state divertor operation in ITER.

PFU cooling pipe welding at IRFM premises

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