Thermal loads in gaps between ITER divertor monoblocks: first lessons learnt from WEST

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The ITER divertor will consist of tungsten monoblocks (MB) bonded to poloidally-running CuCrZr cooling tubes, with ~0.5 mm gaps between them. Assessing what the thermal loads in gaps could be is a key point for the safe operation of the divertor in ITER because gaps introduce sharp edges onto which plasma influx will be focused, leading to intense local overheating, tungsten recrystallization, melting, and limitations on divertor lifetime [2]. Experimentally evaluating the evolution of ITER-like plasma-facing units (PFU) in a realistic fusion reactor environment, is one of the main missions of the WEST tokamak, and complements both theoretical calculations and tests in high heat flux facilities. The WEST divertor is a flat, open design with no central dome, but exhibits nonetheless features of more sophisticated divertors such as detachment and intense X-point radiation. During the WEST 2018 experimental campaign, one of the lower divertor sectors was partially equipped with 12 actively cooled ITER-like PFUs provided by three different suppliers (Chinese, Japanese, and European domestic agencies), each of which has 35 MBs. They were monitored by a very-high-resolution infrared camera (3.9µm wavelength, minimum temperature threshold ~300°C, 0.1 mm/pixel). The rest of the lower divertor was equipped with inertial graphite PFUs coated with tungsten, some of which were equipped with Langmuir probes, thermocouples, and novel optical fibers equipped with Bragg gratings. This exhaustive suite of diagnostics provides a powerful tool for estimating the heat flux to the divertor. Until now, steady state heat flux to the WEST divertor is about half of what is expected in ITER (10 MW/m^2). MHD crashes and disruptions produced thousands of transient heat load events of order of magnitude 100 MW/m^2 perpendicular to the divertor surface, lasting roughly a few ms each.

Following the 2018 experimental campaign, the ITER-like PFUs were inspected under a microscope. Observations were made of a variety of damage on the PFUs including cracking, melting, crystalline modification to depths significantly below the plasma-wetted areas of exposed leading edges, and in particular clear evidence of optical hot spots (direct plasma impact on poloidal leading edges of MBs through toroidal gaps), predicted to occur in ITER [2]. The damage is observed on the full poloidal extent of the divertor, even on zones that normally receive little heat flux in steady state. High heat flux tests in the JUDITH-1 [3] facility showed that cold tungsten ("cold" meaning surface temperature below the ductile-to-brittle transition temperature) undergoes brittle cracking after only a few pulses delivering heat flux of the same order of magnitude as those occurring in WEST. Transient heat pulses from MHD crashes and disruptions are most likely responsible for the damage.

[2] J. P. Gunn, et al., Nucl. Fusion **57**, 046025 (2017).
[1] R. A. Pitts, et al., Nuclear Materials and Energy **20**, 100696 (2019).
[3] M. Wirtz, et al., Nuclear Materials and Energy **12**, 148 (2017).