PLASMA-WALL INTERACTION IN W7-X OPERATING WITH GRAPHITE DIVERTOR

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Abstract The world largest stellarator W7-X finished successfully its first phase in island divertor configuration. Plasma-facing components (PFCs) made of fine grain graphite (carbon C) were used to exhaust the plasma particle and power load the toroidal device with five-fold symmetry. No significant damage occurred to the 10 divertor modules in the executed 3.6h of integral plasma operation in hydrogen (H) and helium (He). The adiabatically cooled divertor with an area of 25m^2, received peak heat loads up to 10MWm^{-2} in ECRH-heated plasma discharges with maximum duration of 100s in attached conditions. With the aid of improved wall conditioning (boronisation), W7-X superseded the expected plasma performance combining high central density (n> 1.5x10^{20}m^{-3}) operation with stable, detached divertor conditions (P_{div}<1MWm^{-2}) for 30s in H with 5MW input power. Peak particle fluxes up to few 10^{23}ions s^{-1}m^{-2} to the divertor and 1x10^{22}ions s^{-1}m^{-2} to the first wall - consisting of graphite heat shields, baffles, and stainless steel panels - resulted in a manifold of plasma-surface interaction (PSI) in the 3D geometry. Important with this respect is (i) the C balance, namely the identification of erosion and deposition areas as well as the material transport paths between those in W7-X; (ii) the balance of fuel in W7-X, namely the balance of injection, retention, release, and recycling. In view of upcoming long-pulse operation, these PSI processes will determine the lifetime of divertor PFCs, the fuel cycle and plasma control, as well as the dust production.

Access to these processes is given by the combination of in-situ analysis via spectroscopy, IR thermography, residual gas composition, etc. during plasma operation and ex-situ analysis of PFCs after extraction from the vessel by a variety of techniques including nuclear-reaction analysis, scanning electron microscopy, laser-induced break-down spectroscopy etc. The post-mortem analysis revealed the main C migration paths in W7-X for dedicated plasma configurations, the peak C erosion rates of more than 5nm/s, as well as the net C erosion source of about ~50g in the ~2500s long operational phase prior to boronisation. The peak erosion rates dropped substantially after application of the boronisation confirming the dominant role of oxygen (O) in the PSI in the first phase of W7-X operation with Z_{eff} of ~3.5 and the excellent O gettering with boron (B) associated with a reduction of Z_{eff} to ~1.5 in H plasmas with residual C radiation. Dedicated PSI modelling with the 3D codes ERO2.0 and WallDYN-3D are applied to describe the PSI processes for the standard configuration where both codes are able to describe the main C erosion, transport, and deposition areas. A final benchmark of the codes is presently done using a $^{13}CH_4$ injection through one single divertor module in more than 330s accumulated plasma seconds to mimic the material migration for one single plasma condition. The corresponding PFCs for ^{13}C surface analysis have been extracted after the experiment that no mixture with other plasma conditions perturb the interpretation.

These PSI processes in the full-C W7-X device will be discussed in detail and predictions towards single steady-state plasmas of up to 1800s will be made with the aid of experimental data and PSI modelling. Consequences for operation and the need to control. PSI processes in the novel and actively cooled carbon-fibre composite divertor in W7-X by adapting the divertor plasma solution with enhanced input power capability will be drawn.