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Compact radiative divertor experiments at ASDEX Upgrade extrapolated to DEMO

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One of the most promising approaches to tackle the power exhaust problem in a divertor tokamak is the so called X-point radiator (XPR). By the controlled injection of impurities into the plasma a radiation cloud localized in the vicinity of the X-point is formed. It was shown that up to 95% of the power absorbed in the plasma can be dissipated before reaching the divertor targets [1]. Recent experiments [2], an analytic model [3] and numerical simulations with SOLPS-ITER [4] have shown that the temperature at the X-point under these conditions can become as low as a few eV,similar to the conditions in a detached divertor. We here report on experiments that demonstrate,that with an XPR long divertor legs and complicated divertor geometries may not be needed anymore. After establishing an XPR via nitrogen seeding in an H-mode with up to 15 MW of total heating power the X-point was moved towards the tungsten target surface such that the divertor legs become as short as 5 cm and the poloidal flux expansion as large as $f_x = ds_t/dr_u = 50$. We also refer to this configuration as a 'compact radiative divertor' (CRD). The energy confinement remained constant during the movement. The challenge of this configurations is that the (projected) field line incidence angle $\theta_\perp$ is inversely proportional to f_x and therefore $\theta_\perp$ very small. Commonly it is assumed in the community that $\theta_\perp$ must be kept above $\sim 2^\circ$ otherwise magnetic error fields or small misalignments of the divertor tiles could lead to strong toroidal asymmetries in the power deposition pattern or even to the formation of hot spots. At least with respect to the error fields it has recently been found in 3D transport simulations that the shallow angles might not be as problematic as assumed [5] when detachment can be guaranteed. The experiments presented here now confirm this finding: Despite of values for $\theta_\perp$ in the order of 0.2° in the CRD configuration no hot spots were observed in the near-SOL region observed by the camera. Even with the X-point located exactly on the target surface and even without density or impurity feed-back control the discharge remained stable, hot spots absent and the divertor in a detached state. The maximized volume of the confined plasma, the smaller poloidal field coil currents and the increased vertical stability of the CRD are all very attractive properties for DEMO. In DEMO the XPR volume is of far higher relevance for power exhaust due to the enhanced ratio a/λ_q, compared to AUG. Further research will be devoted to the question on how to realize a pumping concept for He-ash removal and on how to access the high power CRD without passing a phase with harmful divertor conditions. At least at very high densities, an L-H transition with a detached CRD was observed indicating a possible path to this configuration without attaching the divertor.

[1] Bernert, NF 2020
[2] Cavedon, NF 2022
[3] Stroth, NF 2022
[4] Pan, to be submitted to NF 2022
[5] Lunt, Nucl.Mat.Energ. 2021

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