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Experimental characterization and numerical investigation of X-point radiator regime in WEST

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The X-point radiator (XPR) regime, observed in the WEST tokamak, is characterized by the appearance of a stable radiative ring above the X-point with sufficient nitrogen seeding. The transitions from high-recycling regime to the XPR regime usually happen within very short time. XPR regime can significantly mitigating the heat load at the divertor target while maintaining core plasma performance, which offers a promising approach for advanced tokamak operation and control. This study employs the SOLEDGE3X-EIRENE code in transport mode to numerically reproduce the XPR radiation regime under WEST boundary conditions. Simulations were conducted with a constant input power up to 2 MW, deuterium gas puffing combined with nitrogen seeding, and included full drift effects. The simulation results shows that nitrogen seeding, introduced either from the midplane or the private flux region, can lead to the formation of an XPR inside the separatrix, like in experiments. When XPR occurs, one observes a significant reduction in the target temperature, dropping from above 10 eV to 2 eV, while the upstream conditions remain nearly unchanged. The density profile, initially asymmetric with higher values at the inner target and lower values at the outer target, becomes symmetric. As the seeding rate increases, the XPR shifts toward the low-field side along the magnetic field line, consistent with experimental observations. Further analysis indicates that drifts may play a critical role in the formation and dynamics of the XPR. During the onset of the XPR, a potential well develops at the X-point. Changes in the potential map and the leading reversed E×B flux are strongly correlated with the abrupt system transitions observed during the cliff-like behavior associated with XPR onset. The dynamics of the cliff-like transition from an attached plasma to the XPR state is also correctly reproduced and analysed with the help of reduced bifurcation models.

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