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The X-Point radiating regime at JET in D and DT plasmas with mixed impurities

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Power exhaust is a crucial issue for future fusion reactors. To reach the required 95% dissipation of the exhaust power, impurities must be injected into the plasma. With strong impurity seeding the radiation concentrates in a small region inside the confined plasma, forming the X-point radiator (XPR). The XPR is observed in almost all currently operating tokamaks and was, in JET, first observed in 2016. In the recent campaigns, which culminated in the last DT campaign of JET (DTE3) and the subsequent shutdown of the machine, the XPR was investigated in detail.

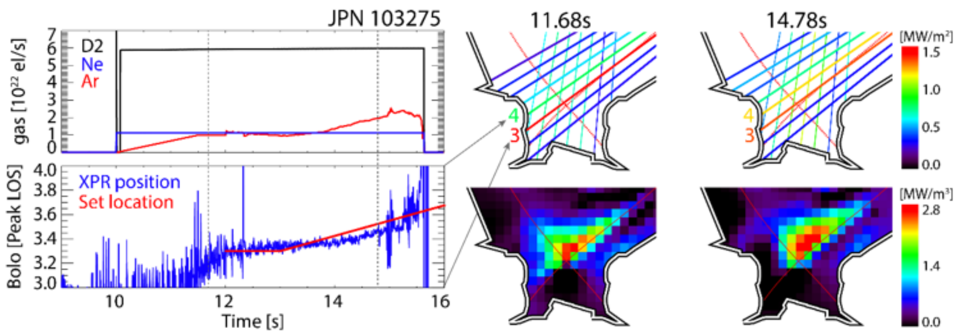

Figure Left: Time traces of gas injection (top) and XPR position (bottom), controlled in real time. Right: Bolometer LOS measurements and tomography for two time points with a low (11.68s) and high (14.78s) XPR.

Figure 1: Left: Time traces of gas injection (top) and XPR position (bottom), controlled in real time. Right: Bolometer LOS measurements and tomography for two time points with a low (11.68s) and high (14.78s) XPR.

Several seed impurities were injected in order to trigger an XPR, such as nitrogen, neon, argon, and combinations thereof. With pure neon or argon seeding the plasma exhibits dithering between H- and L-mode, even at heating powers of up to 26 MW. The dithering is suppressed and the plasma stays in H-mode when combining two impurities or with pure N2 seeding. As the use of N2 was not permitted in the DT campaign, the mixture of Ar and Ne performed best while still being compatible with DT operation. The impact of the seed impurities used and the benefits of the mixed seeding are presented. With the help of SOLPS modelling the effect of the impurities is analysed in terms of their impact on access to the XPR regime, radiative capability, H-mode stability, and plasma performance.

For the first time at JET, a movement of the XPR inside the confined region was observed (see Figure 1). This movement was tracked by the horizontal bolometer camera, using the algorithm developed at AUG, with the XPR moving mainly between lines of sight 3 and 4. The XPR location is detected to a sub-channel accuracy of 4 mm (with a channel spacing of about 8 cm) and can be provided in real time to the control system. A PI controller is implemented using Ar seeding as actuator (while the Ne injection is pre-programmed). The controller gains were optimized using system identification experiments. The reaction time of the XPR location to a change in the seeding rate is in the range of 1s, which presents a significant restriction for the control of the XPR. However, external perturbations, such as drops in heating power or pellet injection, are first buffered by a movement of the XPR, and can then be effectively counteracted by the slower control. These dynamics will be compared to the faster reaction times of the XPR in AUG.

The active control of the XPR helped to efficiently establish the same power exhaust conditions when moving from pure D plasmas to DT plasmas. The overall performance of the scenario, though initially low without seeding (H98≈0.65), does not decrease with the impurity injection, and increases slightly for the seeded and unseeded case when going to DT. Notably, the edge kinetic profiles are not observed to be affected by the strong seeding, while ELMs become fully mitigated.

The successful demonstration of the XPR in D and DT plasmas at JET, combined with its stable operation, makes a strong case for incorporating XPRs into future fusion devices. This scenario meets several requirements of a reactor, including high power dissipation, control of full detachment, and effective ELM heat load mitigation, though not at highest confinement yet.

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