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

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An X-point radiator (XPR) features a stable, cold, and dense plasma surrounded by a highly radiative mantle above the X-point inside the confined region, providing a dissipated power fraction larger than 90%, fully detached divertor targets, and ELM mitigation, and is considered a potential solution for the power exhaust challenge in future fusion reactors. The XPR-like regime is observed in almost all currently operating tokamaks and was, in JET, first observed in 2015 [1]. In the recent JET campaigns, which culminated in the final DT campaign (DTE3) and the subsequent shutdown of the machine, the XPR, along with its stable control, was successfully demonstrated and investigated in detail.
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. SOLPS-ITER simulations were conducted using N2, Ne, Ar, and a Ne+Ar mixture. XPRs were achieved with all impurity options; however, the Ne case, compared to N2 and Ar, exhibited less impurity compression in the XPR region and a broader distribution of the radiative mantle, as well as a less bifurcation-like transition when entering the XPR regime. The XPR access conditions, radiative capabilities, stability, and impact on upstream parameters for different impurities were compared and analyzed using a combination of theoretical models [3,4] and SOLPS-ITER simulations.
For the first time at JET, a movement of the XPR was tracked by the horizontal bolometer camera and provided in real time to the control system, using the algorithm developed at AUG [2]. A PI controller is implemented using Ar seeding as actuator (while the Ne injection is pre-programmed). The reaction time of the XPR location to a change in the seeding rate is in the range of 1 s, much slower than at AUG, which presents a restriction for the XPR control. 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. The active control of the XPR helped to efficiently establish the same power exhaust conditions when moving from D to DT plasmas. The overall performance of the scenario, though initially low without seeding (H98≈0.65), increases slightly when going to DT and does not decrease with impurity injection. Notably, the edge kinetic profiles are not observed to be affected by the strong seeding, while ELMs become fully mitigated.

[1] M. Wischmeier, et al., J. Nucl. Mater. 463, 22-29 (2015).
[2] M. Bernert, et al., Nucl. Fusion 61, 024001 (2020).
[3] U. Stroth, et al., Nucl. Fusion 62, 076008 (2022).
[4] D. Morozov and A. Pshenov, Plasma Physics Reports 41, 599 (2015).

Speaker's title

Mr

Speaker's Affiliation

Max-Planck-Institut für Plasmaphysik, Garching

Member State or IGO

Germany

Author: PAN, Ou (Max-Planck-Institut für Plasmaphysik)

Co-authors: BERNERT, Matthias (Max-Planck-Institut für Plasmaphysik); BOSMAN, Thomas O.S.J. (DIFFER); CEELEN, Lennard (DIFFER); FOX, Peter (UKAEA); SIEGLIN, Bernhard (Max-Planck-Institut for Plasma Physics); LOWRY, Christopher (European Commission); LENNHOLM, Morten (UKAEA); SUN, Hongjuan (UKAEA/CCFE, Culham Science Centre); JACQUET, Philippe (UKAEA); KIROV, Krassimir (UKAEA); MENMUIR, Sheena (UKAEA); BRIDA, Dominik (Max-Planck-Institute for Plasma Physics); HENDERSON, Stuart (UKAEA); REIMERDES, Holger (Ecole Polytechnique Fédérale de Lausanne (EPFL), Centre de Recherches en Physique des Plasmas); VIANELLO, Nicola (Consorzio RFX, ISTP-CNR Padova)

Presenter: PAN, Ou (Max-Planck-Institut für Plasmaphysik)

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