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X-POINT TARGET RADIATOR AS A POTENTIAL REACTOR EXHAUST SOLUTION

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Experiments on the TCV tokamak have enabled the identification and detailed characterization of a novel X-point radiator regime, the X-point target radiator (XPTR) [1], which forms at a secondary X-point embedded along the outer divertor leg in the X-point target divertor geometry [2]. Unlike the conventional X-point radiator regime, the XPTR spatially decouples the radiator from the confined plasma core, effectively preventing radiative edge cooling. This spatial separation promises attractive core–edge integration, avoiding proximity to operational limits and possible degradation of core performance. A comprehensive diagnostic suite, including high-resolution spectral imaging, bolometry, Langmuir probes, and Thomson scattering, reveals the two-dimensional structure of the XPTR. In Ohmic plasmas, compared to standard single-null (SN) configurations, detachment access is significantly facilitated, with divertor target heat fluxes reduced by more than a factor of five. This is accompanied by the formation of a stable, localized radiative zone, exhibiting a marked insensitivity of the radiator position to upstream density changes, increased by a factor >5 compared to the SN, facilitating detachment control.

Following the initial demonstration of the XPTR in [1], its excellent exhaust performance has also been confirmed in scenarios with high levels of second-harmonic ECRH, with values of the detachment accessibility metric $PB/R/n_{sep}^2$ comparable to those predicted for SPARC. While nitrogen seeding in this scenario does not lead to detachment in SN, it triggers early XPTR onset and associated detachment in the X-point target divertor. These studies, initially focused on the lower divertor, are now being extended to up–down symmetric (double-null) geometries and are supported by reduced analytical models and first SOLPS-ITER simulations with full drift effects included.

Overall, the XPTR offers several compelling advantages for reactor applications, particularly supporting the planned integration of the X-point target divertor in the SPARC reactor [3] and the ARC pilot plant. These advantages include the realization of a robust detached divertor regime with reduced reliance on impurity seeding, simplified control requirements, and minimal risk of confinement degradation from excessive radiative edge cooling.

[1] K. LEE, C. THEILER, M. CARPITA et al., Phys. Rev. Lett. 134, 185102 (2025)
[2] B. LABOMBARD et al., Nucl. Fusion 55, 053020 (2015)
[3] A. Q. KUANG et al., J. Plasma Phys. 86, 865860505 (2020)

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