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# Characterization of X-point radiation operational space and performance impact in DIII-D H-mode discharges

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X-point radiation experiments in the DIII-D tokamak explored stable X-point radiating (XPR) conditions with mitigation of edge localized modes (ELMs) potentially relevant to steady-state divertor operation in future devices while collecting detailed local measurements of plasma parameters and species-resolved radiating emissivities for model validation. Regimes with X-point radiation [1] are being pursued to simultaneously achieve deep detachment to maintain manageable target heat fluxes and intrinsic mitigation of ELMs. While such regimes have been achieved in many tokamaks (JET, ASDEX Upgrade, TCV, DIII-D), an improved understanding of operational access requirements, radiation stability as well as impact on overall confinement and impurity dilution are critical for the extrapolation of these regimes to future devices.
Dedicated experiments (H-mode, favorable ion B×∇B drift direction, $I_p$=1.3 MA, $P_{INJ}$= 6-12 MW) were performed in the DIII-D tokamak for a broad characterization of access to X-point radiation regimes, validation of radiation stability models including dependence on radiating species, and assessment of the impact of X-point radiation on pedestal and confinement. Stable X-point radiation was accessed from deeply detached conditions via feedforward impurity seeding from the private flux region (deuterated methane $CD_4$, and nitrogen $N_2$). Access to XPR regimes was accompanied by a reduction in confinement up to 20% compared to deeply detached conditions, with a decrease in pedestal temperatures at nearly unchanged pedestal densities. Deeper X-point radiation resulted in a back-transition to L-mode while maintaining radiation inside the X-point, without unstable evolution into a MARFE. A narrower operating space was observed with only C as the dominant radiator, consistently with theory [2]. While theory predicts more restrictive conditions for X-point radiation due to unstable MARFE evolution, experimentally the limited operating space was identified in terms of a narrower window of access to X-point radiation before back-transition to L-mode. Radiated power densities remained concentrated in the last 5% of normalized poloidal flux $\psi_N$ in the confined plasma. Divertor Thomson scattering measurements inside the X-point indicate Te ∼1-2eV with up to a $5-10\times$ reduction in electron pressure with respect to upstream pressure in the confined plasma in the last 1% of $\psi_N$. Penetration of the radiation front inside the X-point was accompanied by ELM mitigation from $\Delta W_{ELM}/W \sim 1.2-1.5\%$ to $\Delta W_{ELM}/W \sim 0.3-0.5\%$ with an increase in ELM frequency from 100 Hz to ∼300Hz. While the power lost to the scrape-off layer (SOL) via ELMs remained on the order of 10-20% of $P_{SOL}$, the energy lost per ELM and the peak divertor heat fluxes were largely reduced by $4\times$ and $10\times$ respectively, indicating increased ELM buffering. At the largest seeding rates (∼20 Torr l/s), dilution measured at the pedestal top can become large with both carbon ($f_C$) and nitrogen ($f_N$) concentrations simultaneously up to 3%. Work is ongoing to compare detailed local measurements of plasma parameters and impurity concentrations to simple models and edge fluid codes to contribute to the physics basis of X-point radiating regimes towards establishing their potential as core-edge integration solution for future devices.
[1] M. Bernert et al 2021 Nucl. Fusion 61 024001
[2] U. Stroth et al 2022 Nucl. Fusion 62 076008

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