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The "Chimney"divertor: A closed divertor with mid-leg pumping for core-edge integration in DIII-D

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DIII-D is planning to install a new baffling and pumping structure in the upper divertor to test the concept of mid-leg pumping as a mechanism to passively stabilize the detachment front, maintaining a hot X-point ($T_{e,Xpt} \sim T_{e,sep,OMP}$) simultaneously with a detached divertor target ($T_{e,targ} < \sim 5$ eV). Adopting this innovative pumping concept has the potential to be a new paradigm for addressing the integrated tokamak exhaust and performance challenge with reduced requirements for divertor volume and radiating impurity injection.

This "Chimney"design employs a closed divertor structure along an extended outer leg with a pump duct opening positioned vertically upstream from the target on the common flux side. A 4.5 cm deep volume at the end of the divertor slot acts as a neutral reservoir surrounding the outer target to dissipate plasma thermal exhaust via neutral friction, charge exchange and recombination downstream of where neutral particles are removed by the pump. While positioning the pump upstream of the target reduces the fraction of fast reflected particles captured on their first flight by the pump opening, a high fraction of thermalized neutral particles is still removed by the pump before they reach the main chamber where they can ionize on closed flux surfaces and increase the core plasma density. The hypothesis is that this also stops the neutral dissipation processes from propagating further upstream, thereby stabilizing the detachment front. The width of the divertor slot opening is designed to accept the majority of exhausted plasma flux while remaining narrow enough to minimize leakage of neutral particles back to the main chamber, with room for experimental testing and optimization.

Behavior of the chimney pump design is predicted with 2D boundary fluid plasma and neutral modeling using both UEDGE [1] and SOLPS-ITER [2]. These simulations predict that positioning the pump duct upstream from the target in the divertor slot reduces the upstream separatrix density at the onset of detachment. They also find that the location of the 10 eV front along the outer divertor leg is stabilized poloidally near the pump duct opening over an experimentally attractive range of injected power and D2 gas puffing. Plasma control analysis finds a realizable equilibrium with a $\leq$ 44 cm outer leg poloidal length using 1.8 MA of plasma current, resulting in an edge safety factor q_{95}=3.3. This equilibrium is calculated to have sufficient flexibility to scan the length and position of the outer leg.

A comprehensive set of diagnostics is planned to be installed to monitor plasma conditions and dissipation processes in the new divertor. Tiles will be instrumented with 44 in-situ Langmuir probes, 22 surface-eroding thermocouples, 6 ASDEX-style neutral pressure gauges, and 2 in-situ Penning gauges. New Thomson scattering measurement positions will enable diagnosis of Te near the X-point, and new in-vessel fiber optic views will complement an existing tangentially-viewing camera to diagnose impurity radiation profiles along the outer leg.

[1] A. Holm et al., Nuclear Materials and Energy 41 (2024), 101782.
[2] J. H. Yu et al., Nuclear Materials and Energy 41 (2024) 101826.

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