ITER and future burning plasma experiments require significant radiative dissipation in the edge and divertor plasma to obtain volume recombination and partial divertor detachment. The role of scrape-off layer (SOL) transport, divertor geometry, and magnetic configuration in determining the conditions required to achieve divertor detachment remain uncertain, but has large impact on design and operation of next-step devices. Recent experiments in DIII-D have systematically examined the onset of divertor detachment using a variety of magnetic configurations and new/upgraded diagnostics including divertor Thomson scattering to produce 2D maps of the electron density and temperature.

Detachment onset in H-mode is marked by a sharp drop in divertor temperature ($T_e \leq 1$ eV) and heat flux as core and edge density rises; the divertor target $T_e$ collapse begins near the separatrix, first at the inner and followed by the outer divertor. This H-mode divertor “bifurcation” to detachment is accompanied by little change in midplane $T_{e,\text{sep}}$, $n_{e,\text{sep}}$, or $\lambda_q$, and has a small effect on confinement, with radiative losses peaking in the SOL below the x-point. Reversing $B_{\text{tor}}$ significantly reduces the in/out detachment asymmetry, as shown, likely due to ExB drifts. In detached helium plasmas, HeII replaces C as the main radiator and the $T_{e,\text{div}}$ remains above 2-3 eV.

Our experiments show that the detachment threshold depends most strongly on midplane SOL poloidal heat flux, $q_{\text{pol}}$, rather than parallel heat flux ($q_{\parallel}$). Poloidal heat flux was varied through power and current scans ($P_{\text{sol}}$ and $\lambda_q$), while parallel heat flux was varied by a toroidal field scan at constant $P_{\text{sol}}$ and $\lambda_q$. While the midplane density at detachment onset increases only modestly with $P_{\text{sol}}$, it remained unchanged as $q_{\parallel}$ doubled during the $B_{\text{tor}}$ scan; in either case, the divertor fueling rate required to achieve detachment increased significantly.

The effect of divertor geometry (poloidal length and magnetic flux expansion) was examined by varying the x-point to target-plate distance ($\delta_{\text{pol}}$), and by operating with both snowflake and X-divertor configurations. Increasing $\delta_{\text{pol}}$ resulted in a strong reduction in peak target heat flux at high density as compared to a short divertor and increased the effectiveness of argon injection in reducing peak heat flux. Changing the poloidal flux expansion appears to have a much weaker effect on the threshold density for detachment.

These experiments provide a unique test for SOL model validation based on the systematic parameter variation and comprehensive set of divertor diagnostics. Results will inform design of a new divertor for DIII-D and projections to future burning plasma experiments.

---

*This work was performed in part under the auspices of the U.S. Department of Energy by LLNL under DE-AC52-07NA27344, General Atomics under DE-FC02-04ER54698, and ORNL under DE-AC05-00OR22725.