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Divertor leg length considerations for testing detached divertor operation compatibility with a high-performance core plasma

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Divertor leg length requirements for testing divertor detachment compatibility with a hot X-point plasma and robust H-mode pedestal is examined with DIII-D data and modeling. Poloidal Te gradients consistent with this requirement are found to be determined by convective energy transport and particle balance constraints. These considerations provide estimates of divertor leg length requirements for existing and planned facilities that aim to test a Fusion Pilot Plant (FPP) divertor design and operation for issues such as integration of divertor heat flux control with core plasma operational scenarios.

Measurements from the divertor Thomson scattering (DTS) diagnostic on DIII-D indicate average poloidal electron temperature gradients of up to 200 eV/m through the dissipative region of a detached outer divertor leg with the radiating front mid-way up the leg. These gradients imply a minimum leg length of 15-20 cm in DIII-D for the dissipative region, Te ≤ 20 eV, to remain below the X-point. The spatial extent of the radiating region implied by the measured gradient is confirmed with visible imaging of the carbon impurity radiating state.

The observed divertor poloidal Te gradients are found to be consistent with convective energy transport through the divertor dissipative region, Te ≤ 40 eV, while transport dominated by conduction would imply much steeper gradients than observed experimentally. For transport dominated by convection, the characteristic Te poloidal scale length can be estimated as $L_{Te} \approx T_e/(dT_e/ds_{pol}) \approx v_{pol} q_e T_e / L_z f_z n_e$ where v_{pol} the effective plasma poloidal velocity from parallel convection and ExB poloidal flow, L_z is the radiative loss parameter and f_z is the radiating impurity fraction. For carbon impurity radiation peaking near 10 eV, $n_e \sim 2x10^{20} m^{-3}$, a measured impurity fraction of ~ 0.2

The implications for DIII-D divertor upgrades and future tokamak divertor design will be explored. For DIII-D high performance Advanced Tokamak (AT) scenarios with 10 MW of injected power and a requirement for maintaining the X-point region at T_e 80 eV robust pedestal pressure, a divertor leg length of 50 cm is indicated. This is a factor of 2-3 longer than the typical DIII-D configuration and would present a target for future divertor upgrade design. For future tokamaks the scaling appears to be favorable with larger size, higher field and higher density, but will also depend on the scaling of radial transport and plasma drifts.
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