Impact of small ELMs on the divertor heat flux width scaling

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The BOUT++ simulations of C-Mod, DIII-D, and EAST H-mode discharges follow the Heuristic-Drift-based (HD) empirical divertor heat flux width scaling of the inverse dependence on the poloidal magnetic field. The BOUT++ simulations for ITER and CFETR indicate that divertor heat flux width q of the future large machines may no longer follow the 1/Bpol,OMP scaling, while the HD model gives a pessimistic limit of divertor heat flux width. The simulation results show a transition from a drift dominant regime to a fluctuation dominant regime from current machines to future large machines such as ITER and CFETR for two reasons. (1) The magnetic drift-based radial transport decreases due to large CFETR and ITER machine sizes and strong magnetic field. (2) the SOL fluctuation-driven thermal diffusivity increases due to larger turbulent fluxes ejected from the pedestal into the SOL when operating in a small and grassy ELM regime.

BOUT++ turbulence simulation further shows that peeling-ballooning modes dominate in the linear stage for CFETR & ITER Fusion Power Operation (FPO) scenarios and eventually evolve into various type ELMs. (1) The divertor heat flux width broadens with fluctuations. Small/grassy ELM broadening is much more effective. Ballooning critical gradient scale length near separatrix is a good proxy for heat flux width in small ELMs. (2) micro-turbulence broadening from resistive ballooning modes and drift-Alfven instabilities is very little for ITER, CFETR, and SPARC due to their low scrape-off layer collisionality. Divertor heat flux will pose a significant challenge for compact Fusion Pilot Plant (cFPP). A proper machine design for the combination of the total magnetic field B, the poloidal magnetic Bp or the current Ip, the major radius R, and the separatrix temperature Tsep could significantly alleviate the challenge for cFPP.