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Divertor and Core Plasma Performance Optimization Enabled by Direct Feedback Control of Surface Heat Flux on Alcator C-Mod's High-Z Vertical Target Plate Divertor

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The C-Mod team has developed a new tool for control of plasma conditions at the divertor target. It is the first heat flux mitigation system to employ real-time measurements of surface heat flux to control impurity seeding. Control of the conditions at the divertor surface is one of the remaining challenges to tokamak fusion energy. Active cooling technology limits the surface heat flux to ˜10 MW/mˆ2 or less and erosion of solid, high-Z targets limits the incident plasma temperature <5 eV. Yet, plasma entering the divertor will be intense: The scrape-off layer heat flux width scales inversely with the poloidal magnetic field and is independent of machine size [1]. This results in a parallel heat flux that scales as q||˜PSOL*B/R. Projecting this to ITER results in an unmitigated parallel heat flux of ˜5 GW/mˆ2 and >10 GW/mˆ2 in a DEMO-class device [2]. Seeding of low-Z impurities (N2 and Ne) into the divertor to mitigate the focused plasma heat flux into a uniform photon heat flux is a viewed as a necessity. Yet excessive seeding comes at a cost, lowering pedestal pressures and increasing core dilution.
C-Mod is an excellent test of reactor-relevant plasma control solutions: it has an ITER-like high-Z, vertical target plate and is the only experiment with demonstrated heat fluxes in excess of 1 GW/mˆ2. During FY15 a system for real-time control of heat flux was deployed [3]. The system uses surface thermocouples and an analog computer to output accurate signals of heat flux, which are used to control the injection rate of nitrogen into the private flux region. It has been used to reduce the surface heat flux from >25 MW/mˆ2 (corresponding to an unmitigated parallel heat flux q||˜500 MW/mˆ2) to less than 5 MW/mˆ2 while avoiding degradation of energy confinement, i.e. H98. Yet, even at nearly zero surface heat flux, the divertor Langmuir probes still indicate a plasma temperature too high (>5 eV) to suppress sputtering. In the FY16 campaign a divertor mirror Langmuir probe system [4], which outputs real-time measurements of electron temperature, will be used in an attempt to feedback on the plasma temperature at the divertor target.

[1] T. Eich, et al., Nucl. Fusion 53 (2013) 093031; [2] B. LaBombard et al., Nucl. Fusion 55 (2015) 053020; [3] D. Brunner, et al., Rev. Sci. Inst. 87 (2016) 023504; [4] B. LaBombard and L. Lyons, Rev. Sci. Inst. 78 (2007) 073501.

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