

Overview of Research Results from the Alcator C-Mod Tokamak

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Alcator C-Mod has been the only divertor tokamak in the world capable of operating at magnetic fields up to 8 T, equaling and exceeding that planned for ITER. Because of its relatively compact size, C-Mod accesses regimes of extreme edge power density (1 MW/m² average through the surface of the plasma. H-modes on C-Mod have achieved world-record tokamak volume-average and pedestal plasma pressures ($\langle P \rangle$ above 0.2 MPa, $P_{ped} \sim 80$ kPa). The highest pedestals are obtained by accessing the super H-mode regime predicted by EPED enabling C-Mod to demonstrate P_{ped} at 90% of the ITER target. Data from a multi-machine database shows that the boundary heat flux width scales inversely with B_p , independent of machine size. The most recent data have extended this scaling to $B_p=1.3$ T, beyond that envisioned for ITER, and the $1/B_p$ scaling persists. Based on these results, it is clear that power handling in reactors will be an even bigger challenge than in ITER, arguing for the urgent need for one or more dedicated Divertor Test Tokamaks (DTT). Laser blow-off induced cold-pulses, an enigmatic transient phenomenon that has challenged the standard local-transport paradigm, has been explained by a new local turbulent transport model. Results from the TRANSP power balance code, coupled to the quasilinear transport model TGLF-SAT1, with a new saturation rule that came about from cross-scale coupling physics, and that captures the nonlinear upshift of the critical gradient, are shown to describe the cold-pulse, including the existence of core temperature inversions at low density and disappearance at high density. A Random Forests Machine Learning algorithm, has been trained on thousands of C-Mod discharges to detect disruption events. Disruption evolution time scales on C-Mod are relatively short, and this approach gives reliable warning no more than a few ms before disruption. Warning time-scales on larger plasmas are generally longer, good news for reactor applications. Steady-state tokamak reactors will need high bootstrap fraction, supplemented by RF current drive. Lower Hybrid Current Drive is among the most efficient non-inductive techniques. Recent modeling indicates that moving the launch point to the high field side can have many benefits, including accessibility at lower $n_{||}$ for higher efficiency.

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