Overview of Recent Results from the Alcator C-Mod Tokamak


There are four key areas of investigation on the compact, high magnetic field, Alcator C-Mod tokamak. Transport studies on C-Mod provide critical tests of empirical scalings and theoretically-based interpretations of tokamak transport at unique dimensional parameters, but with dimensionless parameters comparable to those in larger experiments. Divertor research on C-Mod takes advantage of the advanced divertor shaping, very high scrape-off layer power density, high divertor plasma density, unique abilities in diagnosis and neutral control, and a high-Z metal wall. Ion cyclotron radio frequency power provides the auxiliary heating on C-Mod, and is exploited for research into wave absorption and parasitic losses and mode conversion processes. Advanced tokamak research on C-Mod proposes demonstrating fully relaxed current profile control and sustainment through efficient off-axis current drive by Lower Hybrid waves.

In the area of transport research, we have continued investigations of the L/H threshold, with emphasis on local measurements. Trends demonstrating a temperature threshold have been elaborated and compared to high beta edge-turbulence simulations; reasonable agreement has been obtained. New ultra high spatial resolution (~1 mm) measurements of the H-Mode edge pedestal show features with scale lengths as short as 2 mm. We have begun to gain an empirical understanding of the enhanced D_e (EDA) H-mode regime, which is unique in its combination of good energy confinement (H_{T,EB}=2), finite particle confinement (\tau_p \sim 3-6), and the absence of type-I ELMs, thus producing no transiently high heat loads onto the divertor. We have found that lower plasma current, high divertor densities, and strong triangularity favor creation of EDA over ELM-free discharges. Strong on-axis toroidal flows are observed in C-Mod during ICRF heating, and scalings of these flows with density, current and confinement properties have been measured. The flow is fastest in discharges with high stored energy (H-Modes) as well as those with core transport barriers (PEP mode). For a given stored energy, the flow speed is reduced as the plasma current is increased.

In divertor research, we have implemented impurity injection feedback techniques to achieve quasi-steady-state detached divertor operation during EDA H-Mode plasmas. Using nitrogen, the peak divertor plate heat flux was reduced by about an order of magnitude. These results are highly promising: the core perturbation is small (\Delta B_{pe} \sim 0.4, H_{T,EB} \sim 1.6) and the upstream parallel heat fluxes are reactor-like (q_p \sim 0.5 GW/m^2). The minimal effect on the core is due, at least in part, to the high divertor compression of impurity gases (C_{EP} = n_{EP}/(n_{EP},core)). C_{EP} increases with plasma density, giving high density operation an advantage. Parallel flows in the scrape-off are measured and appear to play a role in keeping C_{EP} high. We have developed an analysis technique for determining the local recombination rate in detached regions, using the deuterium Balmer and Lyman series intensities. Opacities for the Lyman lines are measured, and the opacity effects reduce the overall radiation rates. The results show that, while recombination is still significant, it is sufficient to explain the magnitude of the divertor plate current reduction seen during detachment. Instead, this appears to be consistent with a reduction in the ionization source, along with plasma pressure loss along field lines by ion-neutral friction. The importance of ion-neutral friction has been verified from parallel flow measurements of ionized and neutral species in the divertor using spectroscopic techniques. A new 2D interpretational analysis code (Edgefit) has been developed and used to confirm our earlier 1-D onion-skin modelling: \chi_L does not depend on magnetic field, and it increases slowly with \rho_i, typically in the range from 0.1 to 1.0 m^2/s. In H-mode, \chi_L is strongly reduced within the first few mm outside the separatrix.

Radio frequency heating experiments have been concentrated on studying fixed frequency operation at 80 MHz, measuring heating efficiencies for two heating scenarios, hydrogen minority (D(H)) at 53 Tesla and He minority (D(He)) at 7.9 Tesla. Recent D(He) experiments have shown good total power absorption (up to 80%) when the D concentration was optimized (between 2% and 4%). A weaker dependence on minority fraction is seen for the D(H) case.

Modeling of possible advanced tokamak operation on C-Mod has been undertaken with the ACCOME current drive and equilibrium code, combined with the PEST-II stability code. Starting with ICRF heated target plasmas characterized by inductively driven current profiles (q_n < 1), it is found that reverse shear current density profiles can be created and maintained using off-axis Lower Hybrid Current Drive (LHCD). Reversed shear plasmas at the \beta limit can be produced in C-Mod at B_0 \sim 4.5 Tesla, I_p \sim 0.8 MA, and (n_e) in the range from 1 \times 10^{19} to 2 \times 10^{19} m^{-3}, with pulse length of about 10 skin times and 2 L/R times. These plasmas are sustained by a high bootstrap current fraction (\gtrsim 0.7). The shaped C-Mod geometry (\kappa \sim 1.7, \delta \sim 0.7) results in high ideal MHD \beta-limits, even in the absence of a conducting shell (\beta_N \sim 3.5).

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