Advanced Tokamak Research in DIII-D*

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Advanced Tokamak (AT) research in DIII-D seeks to provide a scientific basis for steady-state high performance operation in future devices. These regimes require high toroidal beta to maximize fusion output and poloidal beta to maximize the self-driven bootstrap current. Achieving these conditions requires integrated, simultaneous control of the current and pressure profiles, and active magnetohydrodynamic (MHD) stability control. The building blocks for AT operation are in hand. Resistive wall mode stabilization via plasma rotation and active feedback with non-axisymmetric coils allows routine operation above the no-wall beta limit. Neoclassical tearing modes are stabilized by active feedback control of localized electron cyclotron current drive (ECCD). Plasma shaping and profile control provide further improvements. Under these conditions, bootstrap supplies most of the current. Steady-state operation requires replacing the remaining Ohmic current, mostly located near the half radius, with noninductive external sources. In DIII-D this current is provided by ECCD, and nearly stationary AT discharges have been sustained with little remaining Ohmic current. Fast wave current drive is being developed to control the central magnetic shear. Density control, with divertor cryopumps, of AT discharges with ELMing H-mode edges facilitates high current drive efficiency at reactor relevant collisionalities. A sophisticated plasma control system allows integrated control of these elements. Close coupling between modeling and experiment is key to understanding the separate elements, their complex nonlinear interactions, and their integration into self-consistent high performance scenarios. This approach has resulted in fully noninductively driven plasmas with $\beta_N \leq 3.5$ and $\beta_T \leq 3.6\%$ sustained for up to 1 second, approximately one current relaxation time. Progress in this area, and its implications for next-step devices, will be illustrated by results of these and other recent experiment and simulation efforts.

*Work supported by the U.S. Department of Energy under Contract DE-FC02-04ER54698.