Projecting High Beta Steady-State Scenarios from DIII-D Advanced Tokamk Discharges*

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Fusion power plant studies based on steady-state tokamak operation suggest that normalized beta in the range of 4-6 is needed for economic viability. DIII-D is exploring a range of candidate high beta scenarios guided by FASTRAN modeling in a repeated cycle of experiment and modeling validation. FASTRAN is a new iterative numerical procedure coupled to the Integrated Plasma Simulator (IPS) that integrates models of core transport, heating and current drive, equilibrium and stability self-consistently to find steady state (d/dt=0) solutions, and reproduces most features of DIII-D high beta discharges with a stationary current profile. Separately, modeling components such as core transport (TGLF) and off-axis neutral beam current drive (NUBEAM) show reasonable agreement with experiment. Projecting forward to scenarios possible on DIII-D with future upgrades, two self-consistent noninductive scenarios at $\beta_N>4$ are found: high q_{min} and high internal inductance ℓ_i. Both have bootstrap current fraction $f_{BS}>0.5$ and rely on the planned addition of a second off-axis neutral beamline and increased electron cyclotron heating. The high $q_{min}>2$ scenario achieves stable operation at β_N as high as 5 by a very broad current density profile to improve the ideal-wall stabilization of low-n instabilities along with confinement enhancement from low magnetic shear. The ℓ_i near 1 scenario does not depend on ideal-wall stabilization. Improved confinement from strong magnetic shear makes up for the lower pedestal needed to maintain ℓ_i high. The tradeoff between increasing ℓ_i and reduced edge pedestal determines the achievable β_N (near 4) and f_{BS} (near 0.5). This modeling identifies the necessary upgrades to achieve target scenarios and clarifies the pros and cons of particular scenarios to better inform the development of steady-state fusion.

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