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Compatibility of Internal Transport Barrier with Steady-State Operation in the High Bootstrap Fraction Regime on DIII-D

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A high bootstrap current fraction plasma regime is desirable for steady-state tokamak operation because it reduces the demands on external non-inductive current drive. Typically, this regime is characterized by high βN and an internal transport barrier (ITB), leading to concerns about stability limits and profile control with reduced external input (power). Recent DIII-D research has increased confidence in the potential of the high bootstrap fraction approach for applicability to a steady-state fusion reactor. Fully noninductive plasmas have been sustained for long durations with large-radius ITBs, bootstrap fraction≥80%, βN≥3, βT~1.5%, and with the ITBs and good confinement maintained even with low net torque from neutral beam injection (NBI). Building on earlier DIII-D work [1], the new experiments utilized an approach to fully noninductive operation based on removing the current drive by transformer induction. The plasmas exhibit excellent energy confinement quality, with H98y2~1.5. Similar confinement was obtained after reducing the NBI torque from ~6 Nm to <3 Nm. The excellent confinement is associated with the formation of an ITB at large minor radius in all channels (ne, Te, Ti, rotation). The very broad bootstrap current profile is fairly well-aligned with the total current profile, explaining why the minimum safety factor is high and constant or slowly increasing, and the ITB is maintained at large minor radius for ~4 s, more than three times the current profile relaxation time, τCR estimated to be ~1 s. A further important result, providing evidence of dynamical stability, is that the ITB is maintained at large minor radius despite edge localized mode (ELM) perturbations, which become particularly large at the highest obtained βN~3.5. Stability analysis shows that this βN value is close to the ideal wall MHD stability limit, because a large outer gap was used to reduce wall heating by prompt fast ion losses. However, detailed analysis shows that fast ion losses are anomalously high only during the βN and density ramp-up phase. Future experiments will test an optimized outer gap waveform and methods of ELM control to enable a further increase of βN and thus of the plasma current.

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[1] P.A Politzer, et al., Nucl. Fusion 45 (2005) 417.

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