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Super H-mode: Theoretical Prediction and Initial Observations of a New High Performance Regime for Tokamak Operation

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A new "Super H-mode"regime is predicted at very high pedestal pressure, enabling pedestal height and predicted fusion performance substantially higher than for H-mode operation. This new regime exists due to a bifurcation of the pedestal solution that occurs in strongly shaped plasmas above a critical density. The Super H-mode regime is predicted to be accessible, and to increase fusion performance, for ITER, as well as for DEMO designs with strong shaping. An initial set of experiments on DIII-D has identified the predicted pedestal pressure bifurcation, and finds pedestal height and width, and their variation with density, in good agreement with theoretical predictions.
The pressure at the top of the edge transport barrier (or "pedestal height") strongly impacts global confinement and fusion performance, with fusion power production expected to scale with the square of the pedestal height. The EPED model predicts the H-mode pedestal height and width based upon two fundamental and calculable constraints: 1) onset of non-local peeling-ballooning (P-B) modes at low to intermediate mode number, 2) onset of nearly local kinetic ballooning modes (KBM) at high mode number. EPED has been extensively tested against experiment, finding agreement to ~20% in both dedicated experiments and broad statistical comparisons. EPED predicts strong dependence of the pedestal height on poloidal field (B_p), toroidal field (B_t) and plasma shape. An important dependence on density derives primarily from the dependence of the bootstrap current on collisionality. For strongly shaped plasmas, a bifurcation into Super H-Mode and H-mode branches is predicted above a critical density. Recent experiments on DIII-D have successfully tested the predicted density dependence at both high and low density, including observations of the predicted bifurcation and access to the Super H-mode regime. Super
H-mode access is also predicted for ITER, and extensive sets of predictions and optimizations will be presented for ITER at a range of densities and plasma currents. We note that collisionality is impacted by impurities as well as density, and present scenarios for improving performance of ITER and existing devices by introducing low Z impurities.

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