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High Internal Inductance for Steady-State Operation in ITER and a Reactor

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Increased confinement and ideal stability limits at relatively high values of the internal inductance (l_i) have enabled an attractive scenario for steady-state tokamak operation to be demonstrated in DIII-D. The potential of the scenario was shown in high elongation and triangularity double-null divertor discharges in which β_N>4.5 was achieved at l_i≈1.3. This high value of β_N just reached the ideal n=1 kink stability limit calculated without the effect of a stabilizing vacuum vessel wall, with the ideal-wall limit still higher at β_N>5.5. Confinement is above the H-mode level with H_98≈1.8. This type of discharge is a candidate for a reactor that could either operate stably at β_N≈4 without the requirement for a nearby conducting wall or n≥1 active stabilization coils, or at β_N≈5 with wall stabilization. With the high β_N and relatively high q_95=7, the discharge in the experiment is overdriven with bootstrap current fraction f_BS≈0.8, noninductive current fraction f_NI>1 and negative surface voltage. For ITER, operation at l_i≈1 is a promising option. Improved core confinement at high li could compensate for reduced H-mode pedestal confinement if a low pedestal height results from pedestal physics and/or ELM-stabilization using 3D fields. At l_i≈1, f_BS would be ≈0.5 with the remainder from external current driven efficiently near the axis. This scenario has been tested in the ITER shape in DIII-D at q_95=4.8, so far reaching f_NI=0.7 and f_BS=0.4 at β_N≈3.4 with performance appropriate for the ITER Q=5 mission, H_89 β_N/q_95^2 >0.3. High l_i discharges thus far take advantage of inductively driven current density near the axis as a partial substitute for externally-driven current. Studies with the FASTRAN transport code using the TGLF energy transport model explored how increased current drive power for DIII-D, 9 MW electron cyclotron current drive (ECCD) and 13 MW off-axis beam power, could be applied to maintain a stationary, fully noninductive high l_i discharge. Solutions are found at β_N=4, l_i=1.07, and f_BS=0.5 calculated stable without a conducting wall with ECCD and neutral beam current drive near the axis and at β_N=5 calculated to be stable with the vacuum vessel wall.

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