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Realizing Steady State Tokamak Operation for Fusion Energy[1]

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Continuous operation of a tokamak for fusion energy has obvious engineering advantages, but also presents physics challenges beyond the achievement of conditions needed for a burning plasma. The power from fusion reactions and external sources must support both the pressure and the current equilibrium without inductive current drive, leading to demands on stability, confinement, current drive, and plasma-wall interactions that exceed those for pulsed tokamaks. These conditions have been met individually in the present generation of tokamaks, and significant progress has been made in the last decade to realize scenarios where the required conditions are obtained simultaneously. Tokamaks are now operated routinely without disruptions close to the ideal MHD pressure limit, as needed for steady-state operation. Scenarios that project to high fusion gain have been demonstrated where more than half of the current is supplied by the "bootstrap" current generated by the pressure gradient in the plasma. Fully noninductive sustainment has been obtained for about a resistive time (the longest intrinsic time scale in the confined plasma) with normalized pressure and confinement approaching those needed for demonstration of steady-state conditions in ITER. One key challenge remaining to be addressed is how to handle the demanding heat and particle fluxes expected in a steady-state tokamak without compromising the high level of core plasma performance. Rather than attempt a comprehensive historical survey, this review will start from the plasma requirements of a steady-state tokamak powerplant, illustrate with examples the progress made in both experimental and theoretical understanding, and point to the remaining physics challenges.

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