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The Scientific Challenge of Burning Plasmas[1]

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The next frontier for fusion is the study of burning plasmas. The ITER facility, to be operated as an international project, will push research efforts into this new regime. In this tutorial, we will first define a burning plasma and describe its distinguishing properties. One such feature is dominant self-heating (exothermic) by a large population of alpha particles, created from thermonuclear reactions. Fusion self-heating also leads to strongly nonlinear coupling of critical elements in MHD stability, transport, alpha particle losses, edge behavior, and burn dynamics. Also, burning plasmas require robust plasma-wall facing components and diagnostics that can withstand high heat and neutron wall loadings. Next, we will briefly review how previous experiments on JET and TFTR to attain break-even ($Q \leq 1$) have laid the foundation for taking the present step to ITER. Then, we will describe the various physics issues that need to be addressed for burning plasmas, both in preparation for ITER and also when operating at high fusion gain (Q=5-10). Examples of near-term research needs for ITER include the time-dependent study of start-up flexibility to determine whether suitable hybrid and steady-state plasmas can be produced; analysis of the possibility of integrated control of resistive wall modes, ELMs, neoclassical tearing modes, and error field effects; and loss of alpha particles and also beam and RF-heated fast ions due to magnetic field ripple and wave-particle resonances. In high-gain operation, the understanding of pressure limits for stability and turbulent transport for confinement (including pedestal and transport barrier dynamics) must be extended to large size (gyroradius much less than minor radius). Burning plasma operation will also require methods for dealing with tritium retention and replenishment. Other research opportunities will also be described.

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