Preparing for Burning Plasma Operation and Exploitation in ITER

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It is important for the United States (US) fusion program to prepare for burning plasma operation to ensure that ITER's performance goals are realized and to fully exploit the scientific advancement possible in burning plasma experiments. It is vital to anticipate the different behavior expected in the burning plasma regime in order to have the tools available to interpret the physics and reoptimize scenarios for these conditions. In a burning plasma, heat will come primarily from fusion alpha particles, augmented by radio-frequency heating or high-energy neutral beams, which deposit heat principally on the electrons, drive relatively little torque, and provide little fuel. Dominant electron heating and low-collisionality significantly change turbulent transport and pedestal stability, while low-torque operation challenges edge-localized mode control, error field correction, and magnetohydrodynamic stability. The low energetic particle content in ITER will also impact turbulence through a smaller dilution effect, but the fusion alpha particles and beam ions can drive energetic particle instabilities. ***The US fusion program should prepare for burning plasma operations by augmenting its capabilities for dominant electron heating, low injected torque and control of energetic particle instabilities to study regimes that have dimensionless parameters comparable to ITER (except relative gyroradius) to understand how to re-optimize performance in this regime and develop the scientific understanding to interpret burning plasma behavior.***

All three US tokamak facilities have the ability to contribute to transport and stability studies relevant to burning plasmas. Some highlights are (1) Alcator C-Mod uses (essentially) torque-free ICRF heating; (2) studying energetic particle instabilities from dominant neutral beam injection is a strength of the NSTX Upgrade; and (3) DIII-D has the most extensive suite of turbulence diagnostics, a medium power ECH system and the ability to vary the neutral beam torque. The US fusion program should begin an initiative to significantly increase the amount of torque-free electron heating in experiments to achieve higher beta and lower collisionality to extend studies of turbulence and transport validation and EP instabilities to a wider range of ITER-relevant scenarios with Te=Ti and low (i.e., not artificially increased) plasma rotation. The importance of this initiative can be seen in trapped gyro-Landau fluid modeling that shows electron turbulence is dominated by fine-scale electron temperature gradient modes for high-torque neutral-beam ion heating on DIII-D, whereas low-torque electron heating in ITER favors large-scale ion temperature gradient/trapped electron modes. These changes lead to increases in thermal and particle transport on DIII-D because the ratio of ion to electron heating and torque are reduced. The precise deposition control with ECH will also enable perturbative studies, such as gradient modulation to measure stiffness and probe transport more deeply.

Preparing for the burning plasma era also includes training the US team in the scientific understanding of the burning plasma regime and developing experience in optimizing relevant operating scenarios. This will allow the US to maintain a leadership position in the burning plasma era. The US initiative should also increase the number of scientific staff investigating the burning plasma regime to make optimal use of the new device capabilities.

A major upgrade is proposed for DIII-D to make unique and vital contributions in preparing for burning plasma operating and exploitation in ITER. Upgrades to the DIII-D ECH system (going from 3.5MW now to 7.5MW in 2017 and 10.5MW by 2021) and modifications to the neutral beam system configuration (balanced steering capability at full beam power) will more than double the low-torque heating power and enable DIII-D to access dominantly electron-heated regimes over a range in beta that approach ITER collisionalities. Additionally, DIII-D will be able to vary profiles and the degree of ion-electron coupling to explore trends and underlying transport physics, enabling discovery of the underlying plasma dynamics, testing of emerging theoretical concepts, and validation of state-of-the-art simulations needed to prepare for ITER operation.