Research Needs Workshop (ReNeW)

White Paper: Some issues related to core and divertor control for ITER

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Issues

Successful ITER operation requires independent means of achieving and maintaining favorable performance characteristics in both plasma core and divertor. Simultaneous and independent control over three of these performance characteristics ("markers") would be particularly positive in terms of sustaining a successful burn phase.

(1) Active control over the fusion power output, as quantified, for example, by the neutron production rate R_N, is needed.

(2) The divertor structure must be protected against excessive local heating from the power outflow from the main plasma; this would necessitate a means of maintaining an acceptable level of divertor heating at the divertor targets, as quantified by the peak heat flux Q_{TAR}.

(3) Access into the H-mode energy confinement regime, as well as maintaining adequate confinement throughout the burn cycle requires control over the power flow through the pedestal into the scrape-off layer P_{SEP}.

Because these three markers play a central role in established tokamak performance, achieving simultaneous and independent control over each of them in real time is a very relevant component of the fusion program. This is due not only does it have direct near-term application ITER, but also because it would be a key step toward demonstrating the practicality of having active control over fusion output in a future DEMO or commercial fusion tokamak. Hence, the focus here will be on this issue.

Each of these performance markers can be controlled by a variety of actuators, although feedback control over one marker may well lead to a reduced control over other markers, which is an issue in need of resolution before ITER comes on-line. During the past two decades, for example, considerable effort has been devoted to various ways of controlling localized heating at the divertor targets. One approach that is under consideration by ITER involves actively "seeding" the divertor with impurity particles. These impurities can then radiate a significant fraction of the plasma-conducted power before it can reach the divertor surfaces. Peak heat flux reductions ($\geq$ 3.0 times) were demonstrated with argon as the seed impurity in attached H-mode plasmas [1] and even higher reductions in detached plasmas. Leakage of the injected impurities into the main plasma was controlled by changing the flow of deuterium ions into the divertor, and the radiated power (and Q_{TAR}) was controlled by changing the impurity injection rate. However, the core density and the energy confinement time were uncontrolled and the thermally-produced fusion production rate was insignificant.

One actuator that can be used to control fusion power output depends strongly on the density in the main plasma n_{DT}. Density can be controlled in several ways, such as:

(1) by changing fuel gas puff rate,
(2) by changing the D/T pellet injection rate,
(3) by changing the particle exhaust rate (e.g., moving the divertor strike point location relative to the pumping plenum entrance), and
(4) possibly by changing the ergodic nature of the edge plasma, i.e., ITER is expected to have an array of coils designed to suppress ELM pulses by adding an ergodic component to the pedestal.

In addition, the fusion power may have an additional knob related to pellet injection. Baylor [2] has pointed out that, in addition to using pellet injection as a primary fueling source in ITER, adjusting the D and T ratio of the pellet provides another way to control the fusion power production of ITER. The variety of the above density control methods either singly or in combination offer the possibility of independent control over the fusion output without significantly affecting other controlled key characteristics P_{SEP} and Q_{TAR}.

Although "core" and "divertor" physics are often treated as separate studies, in reality they are entwined. Noting that actuators used to control one marker can destabilize control over other markers, any solution to the issues related to independent control over R_N, P_{SEP}, and Q_{TAR} for ITER requires a comprehensive approach. Waiting for dedicated experimental time on ITER before seriously addressing these control issues would be expensive and risky.

Technical Requirement for Resolution to bridge the gap to ITER

Present understanding of the particle and energy transport physics inside the ITER core plasma, and particularly in its scrape-off layer and divertor, is incomplete at present, although it is reasonable to expect that the gaps in knowledge of ITER-relevant transport will close significantly in the next decade. Of particular interest with regard to active control of an ITER burning plasma as outlined above, are:

(1) A quantitative and predictive understanding of particle and energy transport in the presence of an ergodic plasma edge. This is important not only in "ELM suppression", but also in controlling particle and energy transport through the pedestal.
(2) A quantitative and predictive understanding of the role that particle drifts play in the distribution of (injected) impurities in the divertor, scrape-off layer, and core plasmas. The success or failure of ITER's radiating divertor solution to controlling the heat flux at the divertor targets may hinge on how well these drifts are understood.
(3) A quantitative and predictive understanding of particle transport during gas injection and pellet injection.

With progress on the above issues, an experimental program is still needed to develop a plausible algorithm for individual and simultaneous control over the designated performance markers. Dedicated experimental time and manpower are needed to test out control scenarios, to assess their effectiveness, and to follow up on the most promising scenarios. A credible control scenario for ITER needs to be identified and successfully tested prior to ITER startup.

Research thrust elements

In addressing these issues, a dedicated experimental and theoretical effort is required. Several tokamak programs can make valuable contributions to this effort, particularly those (1) that have a full array of core and divertor diagnostics, particularly those providing information on density, temperature, impurity density, divertor heat flux and neutron production, as well as the computational power to effectively act on the data from these diagnostics in real time, (2) that have an adequate selection of candidate actuators, including active pumping, (3) that can achieve and maintain operating regimes of interest to ITER (e.g., 'hybrid'), (4) that have the power input significantly above that needed for the L-H transition, and (5) that have sufficient plasma shaping capability to approximate the ITER configuration. The JET, Asdex-U, C-MOD, and DIII-D programs would be well-positioned to collaborate on this effort. EAST and K-STAR, are now on-line, and may also be in position to help..

References

[1] T.W. Petrie, *et al.*, J. Nucl. Mater. **363-365** (2007) 416.

[2] L.R. Baylor, P.B. Parks, T.C. Jernigan, et al., Nucl. Fusion **47** (2007) 443.