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## DISCLAIMER

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# Demonstration of ITER Operational Scenarios on DIII-D EX-C

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The DIII-D program has recently initiated an effort to provide suitably scaled experimental evaluations of the primary ITER operational scenarios. New and unique features of this work are that the plasmas incorporate as constraints leading operational features of the ITER scenarios, such as the design values for the ITER plasma cross-section and aspect ratio, and that all four primary ITER scenarios have been evaluated on a single device, enabling direct cross-comparisons. Key aspects of the ITER baseline or reference scenario (Scenario 2), steady-state (Scenario 4), hybrid (Scenario 3), and “advanced inductive” plasmas have been replicated successfully, providing an improved physics basis for transport and stability modeling and performance extrapolation to ITER. In all four scenarios performance equals or closely approaches that required to realize the physics and technology goals of ITER.

Utilizing a version of the ITER plasma scaled by a factor of 3.7, and with aspect ratio of 3.1 [Fig. 1(b)], conventional ELMy H-mode baseline scenario plasmas have been operated at the target *I/aB* value of 1.415, corresponding to $q_{95}$~3, with $\beta_N$ of 1.8-2.0. Figure 1(a) shows an example of operation at the higher $\beta_N$=2.0 level, where normalized fusion performance as measured by the parameter $G \equiv \beta_N H_{89}/q_{95}^2$ is close to the level required for $Q$=10 operation on ITER. The 3 s H-mode period illustrated in Fig. 1(a) corresponds to ~3$\tau_R$. For the steady-

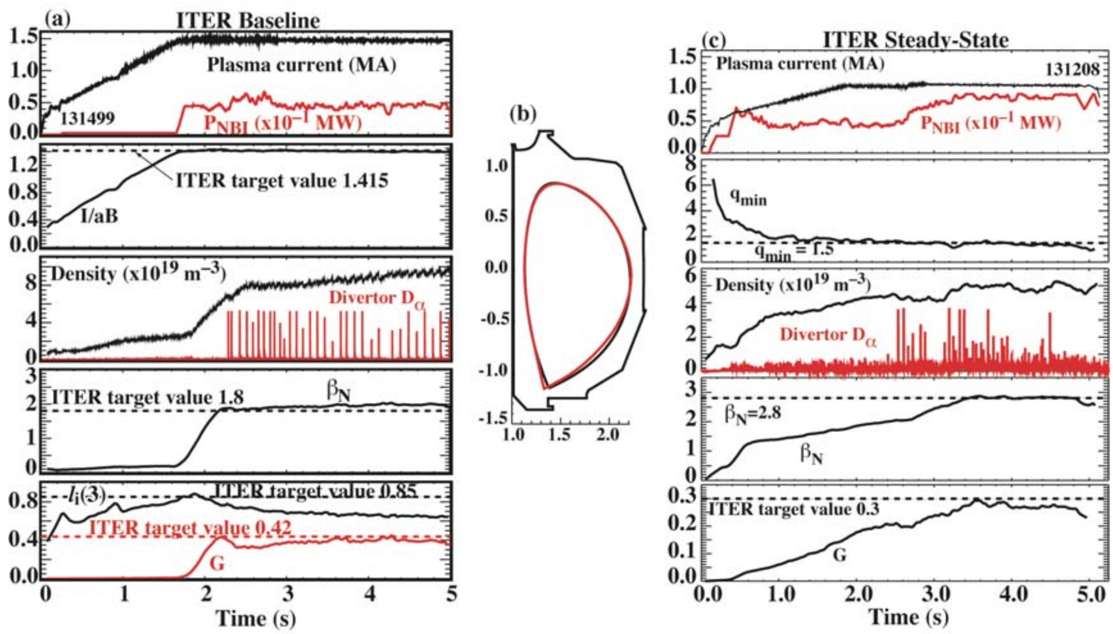


Fig. 1. (a) Key parameters for an ITER baseline scenario demonstration discharge, (b) scaled ITER Scenario 2 plasma shape, preserving aspect ratio of 3.1 (black), and experimental DIII-D shape (red), and (c) key parameters for ITER steady-state scenario demonstration discharge.

state scenario, plasmas were run with the same ITER-like shape and aspect ratio, but with $q_{95}$~4.7, $q_{min}$~1.5 and $\beta_N$ of 2.7-3.0. Discharges with $\beta_N$ of 2.7-2.8 ran through for 1.5 s or ~0.7$\tau_R$, with normalized performance factor *G* close to the 0.3 target required for *Q*=5 operation on ITER, Fig. 1(c). At $\beta_N$=3.0, performance matched the *G*=0.3 target, but discharges were terminated by fast growing internal modes after ~0.8 s, indicating a beta limit. Hybrid plasmas have also been run in the ITER shape, with $q_{95}$~4.1, $q_{min}$ slightly above 1, $\beta_N$~2.8, and $H_{89}$=2.5, achieving normalized performance close to the level required for *Q*=10 operation on ITER. In addition, a fourth operating regime has been demonstrated, the full-current "advanced inductive" (AI) scenario, which targets the ITER *Q*=30 physics goal. This scenario operated with $q_{95}$~3.3, $\beta_N$~2.8 and $H_{89}$=2.2, resulting in *G*=0.52, well above the level required for *Q*=10 operation in ITER.

The ITER demonstration discharges provide critical new information and advances, including timely information that may impact the detailed ITER design. One significant result is the fact that the value of the internal inductance $l_i$(3) in all scenarios is below 0.7 [e.g. bottom box in Fig. 1(a), with current fully penetrated], outside the present ITER plasma shape control system design range of 0.7-1.0. A second area where the design may be impacted is plasma shaping, which is known to play a key role in determining H-mode pedestal parameters and global stability limits. Differences in lower triangularity and squareness between the ITER design and experimental DIII-D shapes in Fig. 1(b) form part of a scan of these parameters around the nominal ITER shape, as part of an ongoing shape sensitivity study. Initial data show variations in plasma performance as the lower plasma triangularity is varied.

In addition to providing the basis for an improved performance projection capability for ITER, these discharges also enable a direct comparison of the performance and operating characteristics of the different ITER scenarios on a single current device without the issues and uncertainties associated with a projection forward to ITER. Key ITER issues encountered in the demonstrations include, in the baseline scenario discharges, very large, infrequent ELMs [third box in Fig. 1(a)], often coupled to sawteeth. Such infrequent ELMs lead to poor density regulation, while the large energy release per ELM would be detrimental to the ITER divertor. More rapid, smaller ELMs with improved density regulation have been obtained both by adding a proportion of counter neutral beam heating, and by applying edge magnetic perturbations. The baseline discharges operate at high density, up to $1\text{x}10^{20}$ $m^{-3}$, matching the absolute ITER operating density, but with $n/n_{GW}$~0.65 as compared to 0.85 on ITER, and with higher collisionality. The presence of sawtooth triggered 3/2 tearing modes results in a confinement factor $H_{89}\leq 2$ when operating at $\beta_N$=1.8, such that the normalized fusion performance parameter, *G* was ~0.37 rather than the target value of 0.42 for *Q*=10 operation on ITER. However, increasing $\beta_N$ to 2.0 increased *G* to ~0.4, close to the ITER requirement [bottom box in Fig. 1(a)]. Another well-known ITER issue is that many of these plasmas develop a 2/1 tearing mode and disrupt. With regard to the steady-state scenario plasmas, early NBI heating was utilized in these discharges [e.g. top box in Fig. 1(c)], in order to obtain an early (~0.45 s) H-mode transition and elevated *q* profile [second box in Fig. 1(c)].

In addition to global parameters, the demonstration discharges also provide more realistic experimental profiles to use in transport and stability modeling for ITER, which will be presented at the IAEA meeting. In the baseline scenario plasmas, $T_e \sim T_i$ is obtained across the entire profile as a result of the high density. However, unlike the present standard ITER model, the density profile is not flat, but weakly peaked in the center. The edge pedestal conditions have been characterized and show a relatively wide pressure pedestal full-width of ~5% in $\psi$. In performing this work it is recognized that present devices cannot simultaneously replicate all of the anticipated ITER plasma parameters, e.g. $\rho^*$ cannot be matched, and it is difficult to simultaneously match core and edge parameters. Additional experiments scheduled for later in 2008 will improve the ITER demonstrations by further addressing the sensitivity of performance to changes in plasma shaping, etc.

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