Demonstration of the ITER Ignition Figure of Merit at q_{95} > 4 in Stationary Plasmas in DIII-D*

M.R. Wade,[1] T.C. Luce,[2] P.A. Politzer,[2] J.R. Ferron,[2] A.W. Hyatt,[2] J.T. Scoville,[2] R.J. La Haye,[2] C.J. Lasnier,[3] M. Murakami,[1] J.G. Watkins[4]

[1]*Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee, 37831 USA*
[2]*General Atomics, P.O. Box 85608, San Diego, California, 92186-5608 USA*
[3]*Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551 USA*
[4]*Sandia National Laboratories, P.O. Box 5800, Albuquerque, New Mexico 87185*

Recent experiments on the DIII-D tokamak have demonstrated the feasibility of stationary (> 6 s), high normalized performance conditions ($\beta_N H_{89}$ = 7.0) such that the ignition figure of merit (given by $\beta_N H_{89}/q_{95}^2$) is comparable to the ITER baseline scenario but at considerably higher q_{95}. This increase in q_{95} (q_{95} = 4.5 compared to q_{95} = 3.0 in the ITER design) has far-reaching implications since present experimental evidence indicates that the probability of a disruption increases with plasma current. The reduction in plasma current afforded by the improved performance in these discharges can lead significant reductions in not only the probability of a disruption but also the damage to vessel components should such a disruption occur. These discharges have been shown to be stationary on the thermal, resistive, and wall time scales and involve feedback control only of global quantities rather than profiles.

The best performing discharges have sustained $\beta_N H_{89}$ = 8.5 for ~4 energy confinement times (τ_E). At a value of 3.4, β_N exceeds 90% of the expected no-wall ideal β limit. At a value of 2.5, H_{89} exceeds standard ELMing H-mode confinement. Longer duration discharges (~35 τ_E) can be produced reliably with $\beta_N H_{89}$ ~ 7. These discharges are generally terminated by hardware limitations, not by evolution of the plasma profiles or plasma instabilities. The key to the highfusion performance in this type of discharge appears to be achievement of a stationary current profile with q_{min} > 1. Motional Stark effect (MSE) measurements indicate that after 2 s of the high power phase, the current profile is stationary, consistent with an estimated current profile relaxation time of 1.8 s. Reconstructions of the magnetic equilibrium using the MSE data indicate that the q profile is monotonic with $q(0)$ ~ 1.05. No sawtooth or fishbone instabilities are observed. Equilibration of the current profile with q_{min} > 1 is correlated with an apparent voltage source of ~10 mV at the location of an m=3/n=2 tearing mode. While this mode has a small effect on confinement (~ 10%), the small non-inductive voltage source associated with it appears to be essential in obtaining a stationary current profile with q_{min} > 1.

Global particle balance calculations based on experimental data indicate that the wall also comes into equilibrium (i.e., $dN_{wall}/dt = 0$) within 2 s of the beginning of high power phase. This balance is achieved through tight coupling of the divertor plasma to the two upper divertor pumps in DIII-D. In fact, the particle exhaust efficiency is of such good quality that gas puffing is required to maintain a constant line-averaged density ($n_e = 3.5\text{x}10^{19}$ m^{-3}).

Projecting these discharges to burning plasmas, one finds that $\beta_N H_{89}/q_{95}^2$ in the best case ($\beta_N H_{89}$ = 8.5 at q_{95} = 4.5) is comparable to that in the ITER baseline scenario ($\beta_N H_{89}$ = 3.6 at q_{95} = 3.0). A further consideration is that $T_i > T_e$ and $n_e = 0.35\ n_{GW}$, where n_{GW} is the Greenwald density, in the present discharges. It will be necessary to demonstrate similar confinement quality with $T_e = T_i$ and $n_e \sim n_{GW}$ to qualify this as a burning plasma scenario.

In conclusion, a stationary scenario with significant benefits for a burning plasma experiment has been demonstrated in the DIII-D tokamak. Normalized performance ($\beta_N H_{89}$) has reached 7.0 for 35 τ_E and 8.5 for 4 τ_E, both limited by hardware. This level of performance approaches that of the standard low-*q* ELMing H-mode scenario envisioned for ITER and other burning plasma experiments. The advance in normalized performance is due both to higher β_N and higher H_{89} than that anticipated for low-q ELMing H-mode.

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