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Implications of JET-ILW L-H Transition Studies for ITER

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Unraveling the conditions that permit access to H-mode continues to be an unresolved physics issue for tokamaks, and accurate extrapolations are important for planning ITER operations and DEMO design constraints. Experiments have been performed in JET, with the ITER-like W/Be wall, to increase the confidence of predictions for the L-H transition power threshold in ITER. These studies have broadly confirmed established dependencies of P_{LH}, reduced uncertainties in extrapolations, and highlighted the largest remaining sources of uncertainty. We have also obtained unexpected results with direct relevance for lowering P_{LH} during the non-active phase of ITER operation, when limited heating power will be available. We will summarize results across all JET-ILW P_{LH} data and the implications of the conclusions for ITER.

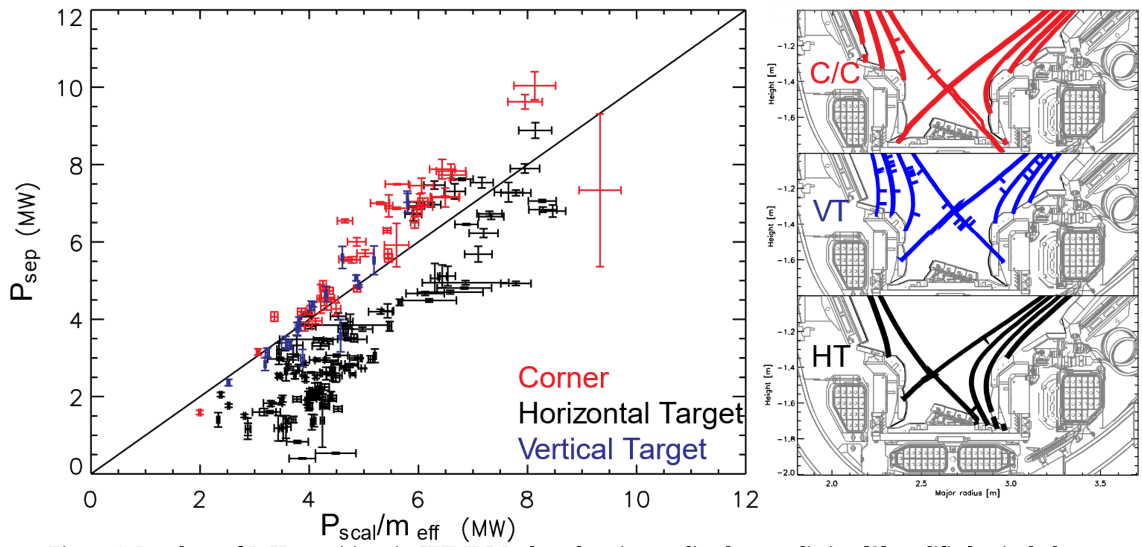

Figure 1. Database of L-H transitions in JET-ILW, plotted against scaling law prediction [8] modified to include mass dependence and colored by divertor configuration, pictured at right. Both high and low density branch data are included.

Figure 1 shows the result for all available JET-ILW P_{LH} measurements, about 200 in total and expanding from previous studies[1-7], spanning a range of plasma magnetic geometries, density and toroidal magnetic field values, hydrogen isotopes, ion species mixtures, effects from impurity seeding, and differences in heating and momentum sources. The scaling prediction is taken from Ref. [8] adding a $1/m_i$ dependence [9] using measurements of the ratio between hydrogen and deuterium in the plasma such that m_{eff}=1 for pure deuterium (*D*) and 0.5 for hydrogen (*H*). The radiated power is subtracted from the thermal loss power to yield the power across the separatrix, $P_{sep}=P_L-P_{rad}$. The data in Fig.1 are colored according to the location of the outer strike point, whether on the horizontal target (HT), vertical target (VT), or in the 'corner' (C/C) near the pump throat. It is notable that VT and C/C have about the same threshold, which is roughly a factor of two larger than HT. VT and C/C have very different pumping characteristics and different X-point height, which are thought to cause changes in P_{LH} on other experiments.

Experiments in VT and C/C configurations were consistent with the other experiments finding P_{LH} in *H* is about twice that in *D*, for the high-density branch. Variations were found for HT data, where it was possible to access the low-density branch in both *H* and *D*, and significant differences depending on heating method were identified. Fig. 2 shows the results in *H*, *D*, and 50/50 mixtures, all with the same shape, toroidal magnetic field, and plasma current. We find an isotope dependence for the value of the density at the minimum of the P_{LH} dependence on density, due to a stronger isotope dependence in the low-density branch, also studied in AUG [10,11]. This could affect extrapolation of the density minimum for ITER. Fig. 2 also show that in *H*, P_{LH} is much higher with NBI than ICRH, while there is little difference in *D*, which is similar to DIII-D results on the effect of torque [12]. Experiments in H were also performed at higher magnetic field, but were unable to access H-mode due to limited power, staying in L-mode with up to 18 MW total input power at B_t=3.2 T, even though the input about was above the scaling [8], likely due to the heating source effect in Fig. 2.

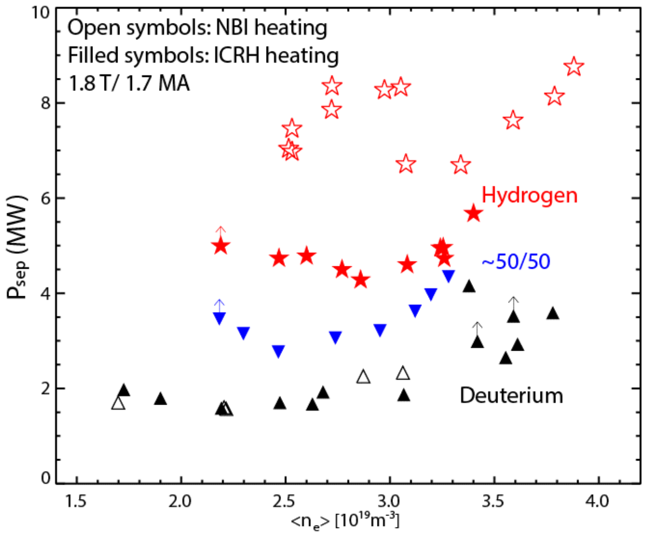

Figure 2. Power across separatrix at time of L-H transition for hydrogen, deuterium, ~50/50 H-D mixtures, with either ICRH-only or NBI-only heating at different values of line-averaged density. Upwards arrows indicate maximum power in pulses that remained in L-mode.

The dependence of P_{LH} was also studied in mixed species plasmas, yielding unexpected results. It was found that most of the variation in *H-D* mixtures was at less than 20% or more than 80% H concentration, with little variation in between. Helium-4 fuelling into *H* plasmas was also performed, resulting in a ~25% reduction of the threshold with up to about 10% helium concentration. This reduction in L-H threshold in H-He mixtures may have application for the non-active phase of ITER operations. Detailed hydrogen and helium concentration analysis, transport simulations, and ICRH power deposition calculations have been performed to constrain interpretation of the mixed ion species effects, excluding several possible interpretations of the mixed isotope results.

Regression analysis of the database in Fig. 1 has been performed. In comparison to [8] and to JET-C results, P_{LH} is lower for matched density and magnetic field as shown in [1]; however, the exponents for density and magnetic field are larger, resulting in possibly reduced threshold at low magnetic field operation in ITER, but increased values at full field operation. As highlighted by the data in Fig. 1, the single largest uncertainty in extrapolating to ITER is the effect of the divertor configuration, a factor of two difference in JET alone.

Further experiments are planned at JET to investigate isotope effects, including experiments in tritium and mixed species plasmas, and to test hypotheses on the origin of the divertor effect and relationship to the near SOL E_r [13].

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