Pedestal structure and stability in H and D isotope experiments on JET-ILW

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1. Introduction Understanding the isotope effects of plasma confinement and transport is crucial for the preparation of the non-nuclear phase of ITER (Hydrogen or Helium) and for its subsequent phase of Deuterium-Tritium (D-T) operations. The positive scaling of energy confinement time with isotope mass (A) observed in experiments has not yet been fully understood theoretically and is in contradiction of the gyro-Bohm scaling. Experiments in Hydrogen (H) and Deuterium (D) have recently been executed on JET with the ITER-like wall (JET-ILW) in preparation for the upcoming D-T campaign, providing stringent tests to plasma transport models. This contribution investigates the isotope effects of the pedestal structure, pedestal stability and ELM losses in H and D Type I ELMy H-modes.

2. Energy confinement Comparative type I ELMy H-modes were obtained with both isotopes by means of systematic power and gas scans in JET-ILW (1 MA/1 T and 1.4 MA/1.7 T). The thermal stored energy in H and D at the same neutral gas rate of 8×10^{21} e/s can be seen in figure 1a, showing a reduction in the thermal energy confinement in H compared to D for both I_p/B_t datasets. Figure 1b shows the ELM frequency (f_{ELM}) in H and D for the 1.4 MA/1.7 T dataset. The power threshold for type I/type III ELMs is doubled from D to H. At a given gas rate f_{ELM} is higher in H than in D at the same loss power ($P_{\mathrm{loss}} = P_{\mathrm{heat}} - \mathrm{d}W/\mathrm{d}t$), as observed e.g in JT-60U [1].

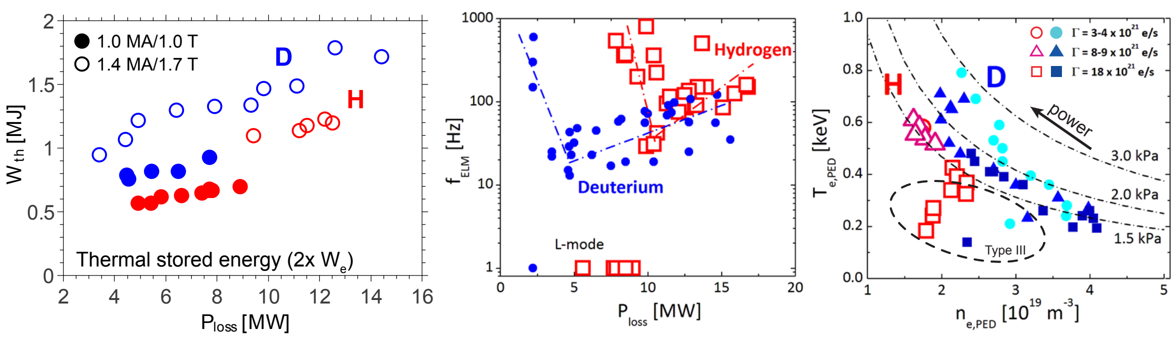

Figure 1: *Comparison of H (in red) and D (in blue) plasmas (a) Thermal stored energy at $\Gamma_{\mathrm{gas}} = 8 \times 10^{21}$ e/s (b) f_{ELM} vs P_{loss} at 1.4 MA/ 1.7 T (c) Pedestal temperature vs density diagram for the 1.4 MA/1.7 T dataset.*

As shown by the n_e-T_e diagram in figure 1c, the pedestals in H evolve along the same isobar with respect to variations in power and gas rate, while D the pedestal pressure increases with power at low gas rate. In H, $n_{e,PED}$ and $T_{e,PED}$ are exchanged at approximately constant pressure at all gas injection levels. This is in contrast to JT-60U experiments, where density and temperature profiles were matched in H and D when the stored energy was matched by raising the H-NBI heating [1] and points to a difference in particle confinement in the two tokamaks.

3. Pedestal structure and stability At 1 MA/1 T the density (n_e) pedestal is narrower than the temperature (T_e) pedestal in H, but n_e and T_e width are similar in D as shown in figure 2a and b. In contrast, at 1.4 MA/1.7 T the n_e and T_e widths are similar in H and D as can be seen in figure 2c and d. The maximum pressure gradient is slightly higher in D, but the peak bootstrap current (j_{BS}) is comparable as the lower collisionality compensates for the lower pressure gradient in H. Similar edge current density, but lower pressure gradient in H than in D is also reflected in the stability analysis.

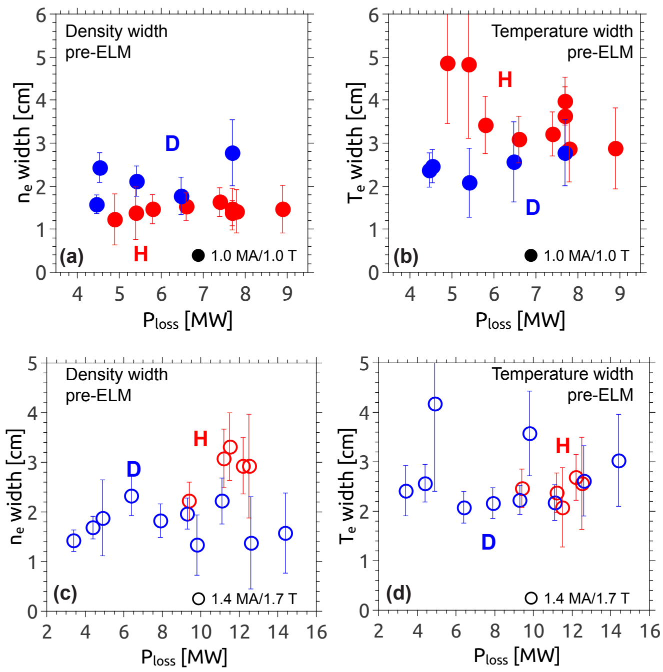

Figure 2: *Pedestal width in H (red) and D (blue) plasmas at* $\Gamma_{gas} = 8-10\times10^{21}$ *e/s gas rate at 1 MA/1 T (a and b) and at 1.4 MA/1.7 T (c and d).*

The pedestal stability has been investigated in H and D plasmas using the ELITE ideal MHD stability code [2], [3]. The inputs for ELITE are the fitted kinetic profiles evaluated from Thomson scattering (HRTS), assuming $T_e = T_i$ (consistent with charge exchange measurements), line averaged Z_{eff} for the calculation of j_{BS}, using Sauter's formula [4], [5]) and the main ion density assuming Be as single intrinsic impurity.

At 1 MA/1 T, $\Gamma_{gas} = 8\times10^{21}$ e/s, the pre-ELM pedestals of H plasmas are shown to be stable to Peeling-Ballooning (P-B) modes both at low and high input power (figures 3a and b). At 1.4 MA/1.7 T (figures 3c, d) operational point (OP) is closer to the boundary at $\Gamma_{gas} = 4\times10^{21}$ e/s gas rate but stable at $\Gamma_{gas} = 8.5\times10^{21}$ e/s at similar P_{loss}. The H stability at 1.4 MA/1.7 T is consistent with findings in D [6], where consistency with the P-B paradigm is found at low gas rates, but not at high power and high gas rates.

4. Isotope identity experiments It is expected that the basic dimensionless plasma physics parameters collisionality ($\nu*$), normalised Larmor radius ($\rho*$), ratio of the kinetic and the magnetic pressure (β) and safety factor (q) can describe the transport in all radial regions of the confined plasma in a tokamak [7], [8]. An isotope identity experiment in H and D on JET with the Carbon wall (JET-C) in H-mode obtained matched H and D plasmas with the same scaled thermal energy confinement times ($B\tau_{E,th}/A$) and scaled ELM frequencies (Af_{ELM}/B) [7].

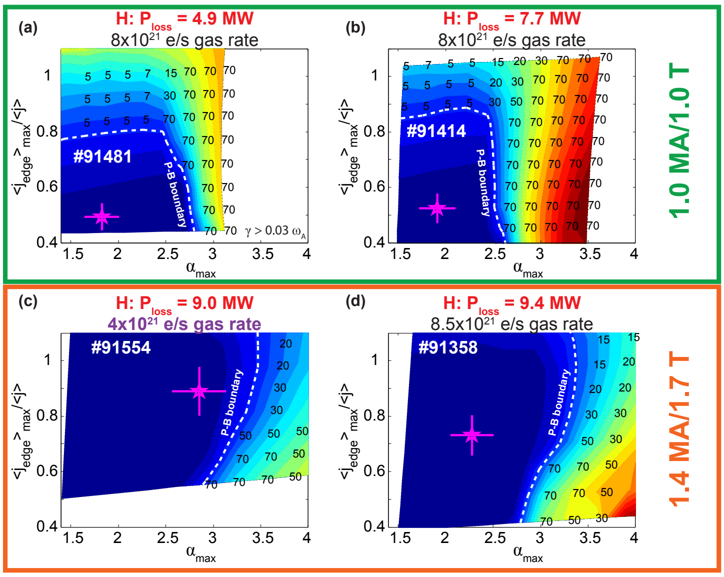

Figure 3: *Pedestal stability analysis with HELENA/ELITE for H.* **Top**: *1 MA/1 T, low vs high power at $\Gamma_{gas} = 8 \times 10^{21}$ e/s. Pedestals stable to P-B modes.* **Bottom**: *1.4 MA/1.7 T at same P_{loss}: "low" vs "medium" gas rate. OP is closer to P-B boundary at lower gas rate.*

The same technique was adopted in recent JET-ILW experiments in H (at 1 MA/1 T) and D (1.7 MA/1.7 T) with type I ELMy H-modes. However, isotope identity with matched ELM averaged profiles of $\nu*$, $\rho*$, β and q has not been achieved. H and D plasmas with matched pre-ELM dimensionless parameters (see figure 4) were obtained, allowing comparison of the ELM behaviour in these discharges. On the other hand, the ELM averaged profiles (and thus $B\tau_{E,th}/A$ and Af_{ELM}/B) were not matched, see table 1.

The ELM energy losses (dW_{ELM}) have been evaluated from two semi-independent measurements: a) the stored energy from EFIT equilibrium reconstruction (dW_{EFIT}) and b) HRTS profiles (dW_{HRTS}). A comparison of ELM losses evaluated from the two methods on a subset of JET-ILW H and D type I ELMy H-modes is shown in figure 5. The ELM losses given by the two different measurements are broadly consis-

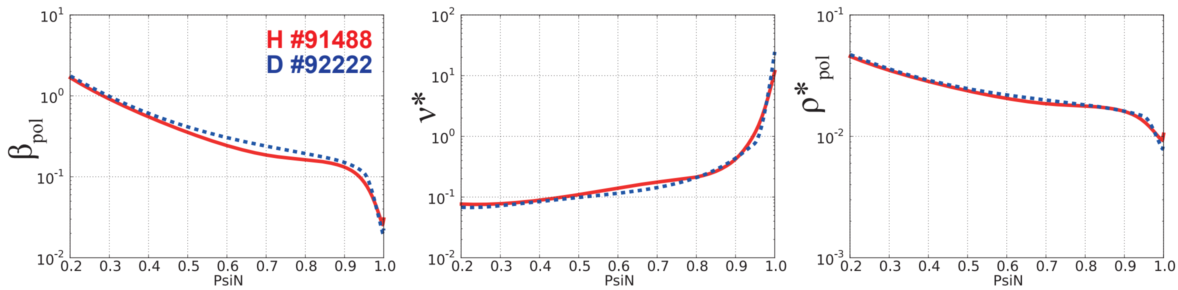

Figure 4: *Matched dimensionless plasma parameter profiles in the pre-ELM phase in H (red) and D (blue) plasmas. (a) the ratio of the kinetic and the magnetic pressure (β), (b) collisionality ($\nu*$), (c) the normalised Larmor radius ($\rho*$).*

tent, especially in controlled scans, but differences between individual discharges can be as high as a factor of 2 due to intrinsic difficulties of these measurements. The ELM losses normalised to the pedestal stored energy (dW_{ELM}/W_{ped}) are significantly higher in the H counterpart of the matched pair from both measurements as shown in table 1. The fact that an isotope identity match cannot be obtained simultaneously with pre-ELM and

ELM averaged profiles suggests that the ELM behaviour is very different in the H and D plasmas and implies that additional physics (e.g. atomic physics) may be playing a role at the pedestal, which is not captured by the basic dimensionless plasma physics parameters.

	I_p [MA]	B_t [T]	Gas rate [e/s]	P_{loss} [MW]	W_p [MJ]	Af_{ELM}/B [Hz/T]	$B\tau_{E,th}/A$ [Ts]	dW_{EFIT}/W_{ped}	dW_{HRTS}/W_{ped}
H #91488	1.0	1.0	4.5e21	8.6	1.03	40	0.102	0.189	0.184
D #92222	1.7	1.7	1.5e22	16.6	3.41	58	0.148	0.116	0.088

Table 1: *Parameters of the H and D plasmas where pre-ELM dimensionless parameter profiles were matched.*

5. Conclusions A reduction in the thermal energy confinement time in H with respect to D is observed in type I ELMy H-modes in JET-ILW, in contradiction of the gyro-Bohm scaling. The power threshold for type I/type III ELMs doubled from D to H and f_{ELM} is larger in H at the same input power in type I ELMy H-modes. H-modes in H and D at the same pedestal stored energy do not have matched density and temperature profiles, with lower density being compensated by higher temperature in H compared to D. The effect of the isotope mass on the pedestal structure can also be influenced by the current and field in the given plasma, as we observed narrower n_e than T_e pedestals in H at 1 MA/1 T, but similar pedestal widths both in H and D at 1.4 MA/1.7 T. The pedestal stability in H is qualitatively consistent with results found in D for JET-ILW, but an isotope effect through the bootstrap current is not excluded and will be investigated. H and D discharges with matched $\nu*$, $\rho*$, β and q profiles in the pre-ELM phase indicate larger ELM losses dW_{ELM}/W_{ped} in H than in D, suggesting different ELM behaviour with different isotope mass.

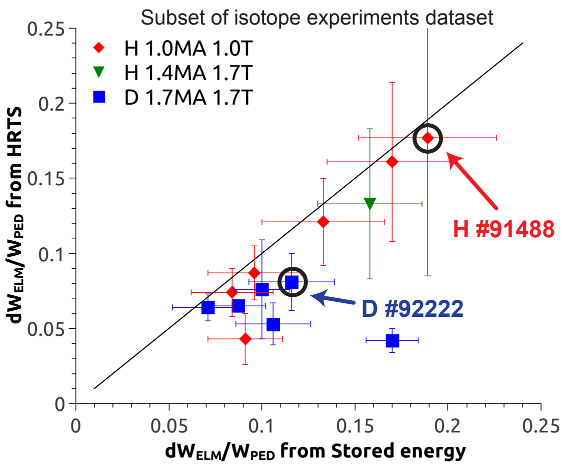

Figure 5: *Comparison of ELM losses evaluated from EFIT stored energy and HRTS profiles on a subset of JET-ILW H and D type I ELMy H-modes.*

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