Mixed Hydrogen-Deuterium plasmas on JET ILW: H-mode confinement and isotope mixture control

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Previous results on fusion experiments have shown that plasma properties such as confinement and ELM frequency depend on the isotopic mass [1]. However, the behaviour of mixed isotope plasmas is less understood, particularly in JET-ITER Like Wall (JET-ILW). A study of hydrogen-deuterium (H-D) H-mode plasmas in JET-ILW strengthens the physics basis for extrapolations to JET deuterium-tritium (D-T) operation, supports the development of strategies for isotope ratio control for the future D-T campaign and provides stringent tests for plasma transport models. Beyond JET the fuelling behaviour of mixed isotope plasmas and the behaviour of hydrogen majority plasmas is relevant for ITER.

Experiments in mixed hydrogen-deuterium (H-D) plasmas have been performed on JET to study the effect of isotope composition on plasma properties, in particular the H-mode confinement. This work is part of a wider study of the isotope effect on JET including the confinement of pure H and D plasmas [2] and the effect of isotope on L-H transition in [3].

In order to carry out the experiment it was necessary to develop a method for controlling the isotope ratio. On JET the fuelling actuators are gas puffing, neutral beam injection (NBI), pellets and wall recycling. A control method using feedback and feedforward gas injection was developed with edge diagnostics based on Balmer-Alpha emission as the sensor.

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To estimate the core isotope mixture a relationship between the neutron rate and core deuterium content was developed. This was done by analysing pure deuterium pulses over a range of densities and temperatures then scaling the neutron rates from these pulses according to the deuterium content. It can be seen in Fig. 1 that the core isotope ratio is within 10% of the measured edge ratio (which is the estimated error of the core isotope calculation).

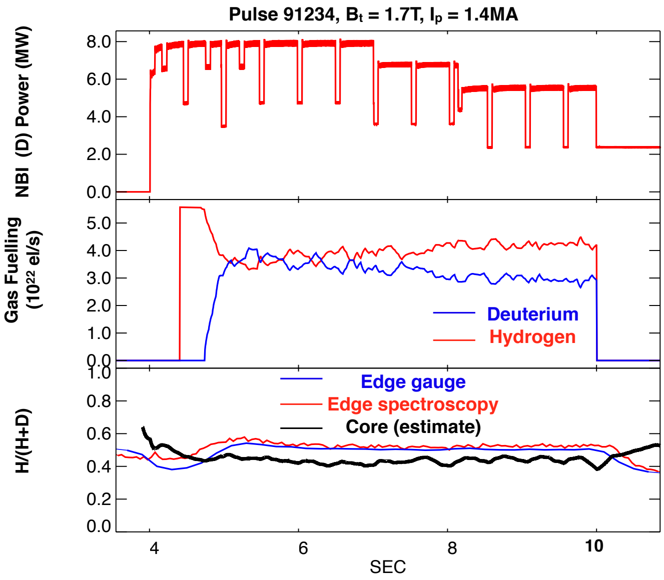

Figure 1: *Real time control of isotope ratio in edge and core*

Scans of isotope mixture were performed in plasmas of fixed plasma current (1.4MA), toroidal field (1.7T), total gas fuelling rate (1-1.1x10^{22}el/s) and plasma shape (with strike points in the corner of the divertor) using predominantly NBI heating of either deuterium or hydrogen. These parameters were chosen so that comparisons could be made with other, pure isotope experiments. Type-I ELMy H-mode pulses of this type were successfully performed with the isotope ratio varying from 1.05< M_{eff}<1.8 and 8MW<P_{input}<10MW. Data from pure isotope plasmas is available from [2] to complete the full range of isotope ratio. The dependence of thermal stored energy vs effective mass is shown in Fig.2.

Figure 3 shows the n_e-T_e diagram for various isotope ratios at one gas puff level (1-1.1 × 10^{22} el/s). The NBI power varied between 8 and 10 MW. As the isotope ratio changes from predominantly D (H/(H+D) < 0.25) to predominantly H (H/(H+D) > 0.75) the datapoints move along constant pressure, exchanging density and temperature. This is consistent with the findings in full D and full H plasmas [2]. Note that the full D and H plasmas indicated in figure 3 have been performed at a wider range of NBI power (6-13MW) and gas fuelling of 0.8 × 10^{22} el/s. At constant gas, H plasmas feature lower

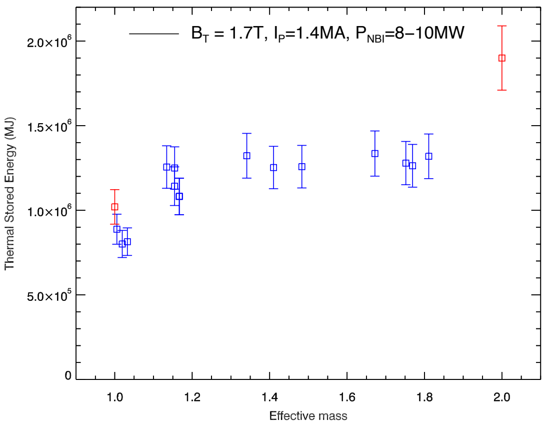

Figure 2: *Thermal stored energy calculated by TRANSP vs effective mass for mixed isotope plasmas (blue) and pure isotope plasmas (red)*

density and need a much larger gas puff to reach the same pedestal density, consistent with results on ASDEX Upgrade [4]. As shown in figure 3, for the power range specified above the temperature in D is higher compared to H, indicating that in order to achieve similar pedestal temperatures more power is required in H.

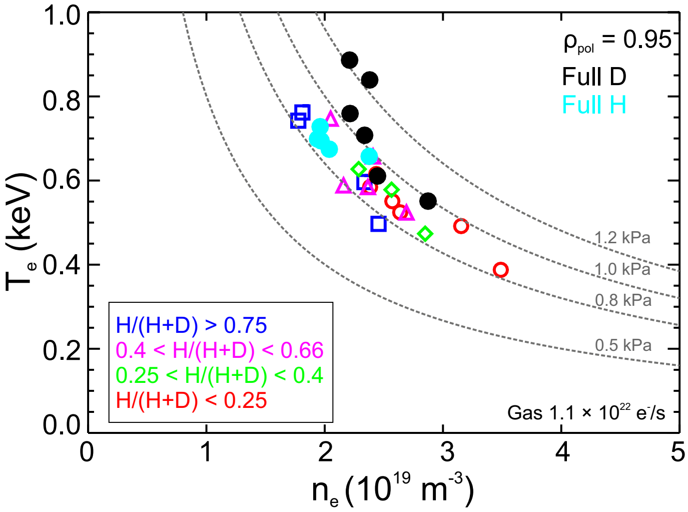

Figure 3: *Pedestal density and temperature for pulses across range of isotope ratio and pure isotope pulses across a range of input power and gas fuelling.*

To determine the rate at which the core and edge isotope ratio could vary a discharge was performed where the gas fuelling was switched from D to H during the type-I ELMy H-mode phase, while other parameters were kept the same as in the isotope ratio scan. This test was performed with both divertor and main chamber gas fuelling. It can be seen from Fig 4 that in both cases the core isotope ratio closely follows the edge isotope ratio. The main chamber case appears to change more rapidly but this could be due to the proximity of the diagnostic to the divertor gas puff. This pulse also contains 20% H NBI power so the difference could either be related to diagnostic, gas fuelling position or beam fuelling. It takes ∼ 10 energy confinement times (calculated using TRANSP [5]) for the plasma composition to change from ∼ 5% to ∼ 50% hydrogen.

When changing gas species the effect on the plasma behaviour is much faster than the effect on overall plasma composition. Fig. 4 also shows the ELM behaviour (from Beryllium emission) when the gas isotope is changed. The valve response is 100ms and within 200ms of the gas switch there is a change in ELM behaviour, the ELM frequency changes from 70Hz to 50Hz. This could either be related to the small change in isotope ratio or the effect of neutrals.

It has been shown that the plasma confinement in mixed isotope plasmas does not vary significantly with isotope ratio between 1.2< M_{eff}<.1.8 and that the density and temperature vary across this isotope range. There is a more significant change in confinement near pure isotopes (consistent with [2]), this is also supported by the change in ELM frequency for small change in isotope ratio in the pulse with changing gas fuelling. Due to the proximity to the L-H threshold (expected to be 8-9MW for pure hydrogen at these parameters) it is still unclear whether the stored energy variation is a change in the confinement behaviour or due to the changes in L-H threshold power as seen in [3]. The strong effect of small amounts of minority isotopes shows how it is vital for isotope studies to be carried out at high isotope purity.

It has been demonstrated that isotope control in JET ILW can be successfully performed and that many confinement times were required to fully change the isotope ratio. This could have consequences for potential burn-control methods on fusion reactors. Finally, it has been shown that gas fuelling dominates the core isotope composition of these pulses with beam fuelling a much smaller effect. Further experiments in H-D at higher input power and plasma current would allow extrapolation to higher performance JET-ILW plasmas and to larger plasmas such as ITER.

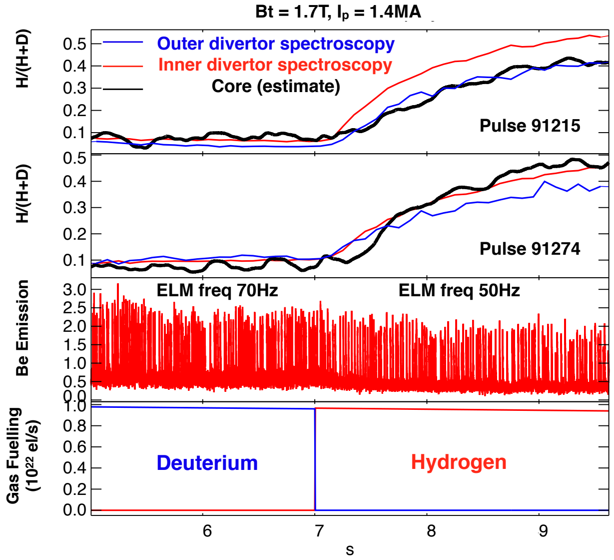

Figure 4: *Change in isotope ratio with gas fuelling using divertor fuelling (first pane) and main chamber fuelling (second pane), ELM behaviour with isotope change for divertor fuelled discharge (third pane) and gas fuelling level (bottom pane).*

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