Recent results from Helium plasma operation in JET

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Introduction. To assess the suitability for ITER of operation during the low activation phase in ELMing H-mode helium plasmas and to investigate in detail areas in which the underlying physics differs from operation with hydrogenic isotopes as the main plasma species, pure He discharges have been explored in JET during a three week period at the end of first experimental campaign in 2001. As many as possible of the principal operating regimes in D (eg. L and H-mode and OS plasmas) have been explored with the aim of improving understanding in confinement, the L-H transition, ELMs and edge physics. With regard to the latter, particular topics of interest include atomic physics and impurity production and their influence on divertor radiation, detachment and density limits.

Experimental and operational conditions. For much of the He campaign both JET beam boxes were converted for pure helium injection using Ar frosting on the NI-cryopumps. During D to He changeover using a fixed magnetic equilibrium and a reproducible ICRH power ramp to investigate L-H transition thresholds, He/D ratios > 85% were obtained after only 10 discharges. Changing the configuration increased the D plasma content even after relatively long term operation in He, demonstrating that a significant D reservoir exists in surfaces not previously exposed to direct He ion fluxes. Although the lack of active He pumping in most discharges often yielded uncontrolled increases in core and edge densities with subsequent influence on, for example, confinement, ELMs and access to OS scenarios, a few discharges with divertor cryopump Ar frosting were performed in which steady state H-Mode conditions were achieved.

Confinement and L-H transition. For the first time a set of quasi steady state ELMy-H mode shots have been achieved with He-NBI injection up to 12 MW in discharges with I_p, B_T and the ratio He/D in the range 1-2 MA, 1-2T and 70-90% respectively. Without active He cryopumping, the density rise leads in general to a type I-III ELM transition as shown in fig1. Although the effect of D in He plasmas is still to be assessed, preliminary analysis shows that the L-H threshold is about 50% higher with respect to that in D, with a similar dependence on

I_p and B_T. The energy confinement decreases by ~15-20% (see fig. 2) compared with equivalent D plasmas, which would result in a confinement dependence of $Z^{0.55}$ assuming a positive mass dependence ($\sim M^{0.2}$) as measured in previous JET isotope measurements (1).

Impurity production and divertor physics. In comparison with similar D plasmas, the carbon impurity release in He discharges changes significantly for all conditions studied. This highlights the importance of chemical erosion and charge exchange (CX) neutral fluxes, both of which change considerably during He operation. Fig. 3 compares the CIII light emission integrated over the inner and outer divertor legs and that along a midplane horizontal chord from two similar L-mode density limit shots (a) and two 11 MW H-mode discharges at the same density (b) in He and D. There is a large (by factors 3-10) decrease in the inner divertor carbon source, an observation common to all plasma conditions studied. In the outer divertor the carbon release changes little at lower plasma densities but, in contrast to D operation, decreases steadily with increasing density. A horizontal spectroscopic view recorded similar CIII light emission during the limiter phases, but a dramatic reduction in the carbon light during the diverted phase in He. Other C-ionisation states behave similarly in the different plasma scenarios. The data demonstrate that in the inner divertor chemical erosion largely dominates the carbon source in deuterium plasmas. By contrast, at the outer divertor physical sputtering dominates at low density, with chemical erosion becoming increasingly important as density increases. In the main chamber the reduction of the carbon source in helium plasmas is mainly due to reduced CX fluxes.

In L-mode He plasmas, the reduced carbon influx results in a considerable reduction in main plasma carbon content. This is clearly illustrated in fig. 3a by the strong decrease in the incremental Z_{eff} compared with a similar D plasma and also by the carbon concentrations from CX spectroscopy which are below the detection limit at higher plasma densities in He. In H-mode, the carbon source reduction is similar but this is not manifest in a reduced Z_{eff} (fig 3b). Such different behaviour is surprising since it implies an increasing influence of the outer target carbon source on the main plasma C content during H-mode conditions.

Helium operation and the consequent reduced carbon influxes lead to L-mode density limits about a factor of two higher than those found for identical D plasmas (fig. 3a). Increasing the density in a deuterium discharge leads to detachment of the inner divertor leg with subsequent strong X-point radiation and finally to the development of an inner wall MARFE resulting in a density limit disruption (2). In helium, the L-mode density limit is characterised by an almost poloidally symmetric radiative collapse ($P_{rad} = P_{in}$), which results also in a different disruption behaviour(3).

The longer He ionisation mean-free-path allows neutrals to penetrate the X-point before the low divertor temperatures required for recombination to occur can be reached, leading to leading to substantially modified detachment behaviour at high density in comparison with D discharges. Radiation otherwise originating from low charge states of carbon in D plasmas is presently thought to originate from HeII line emission during helium operation. Interestingly, at a given density and within a certain power range, periodic oscillations of the HeI light emission in the inner divertor have been observed in L-mode. This phenomena is probably associated with the radiation behaviour of He leading to T_e oscillations when a critical temperature and density is reached.

Power deposition on the divertor targets has been investigated by IR thermography, thermocouples and Langmuir probes. In general, the inner/outer target asymmetry in this deposition is similar in He to that in D (fig 4). Preliminary analysis shows that the deposition profiles are 30-80% larger than in deuterium. Investigation of the ELM behaviour is of particular interest for the validation of ELM models since collisionality in He is four times that in D (at the same T_e). The data indicate that the ELM rise time (~500-800μs) is larger than in comparable D discharges, although studies of ELMs in D show that the ELM rise time can vary significantly (4).

Summary. Helium plasmas in L- and H-mode (1-2 MA, 1-2 T) with He NBI up to 12 MW have been studied in JET. Type I and III ELMy H-modes have been routinely obtained. Energy confinement is observed to decrease by about 20% in He compared with similar D plasmas and the L-H transition power is about 50% higher in He. Achievement of H-mode in D plasmas is therefore easier than in He and this is an important conclusion for the non-active phase of ITER. Carbon impurity release at the inner divertor is significantly decreased in He, showing that chemical erosion in D plasmas determines more or less completely the carbon production there. At the outer target, physical sputtering is an important C source in helium, particularly during H-mode. Reduced CX fluxes in He lead to a strong decrease of carbon released from main chamber wall in diverted discharges. The He L-mode density limit is about twice that in D with the limit being determined by overall radiation collapse. In general, although relevant ELMy H-modes can be obtained in helium, helium operation would not provide an adequate test of critical divertor physics issues for ITER which must be a key objective for any low activation phase.

1. Nuclear Fusion, Vol. 39, No. 9 (1999) 1133
2. J. Rapp et al this conference
3. V.Riccardo, P.Andrew , K.H.Finken to be published
4. T.Eich et al , this conference

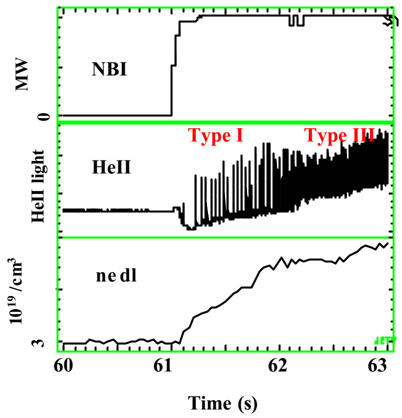

Fig 1 Typical behaviour of density and ELM behaviour in a He ELMy H-mode without active He pumping.

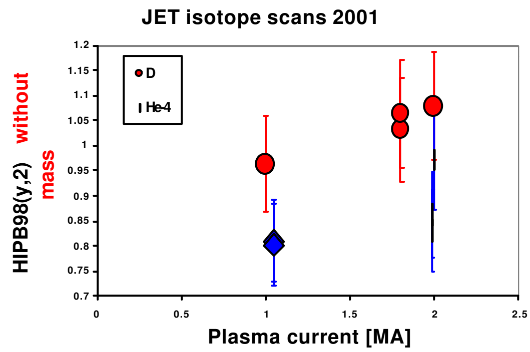

Fig 2 *Confinement based on H98(y,2) without mass dependence for D and He shots in the range of 1-2 MA.*

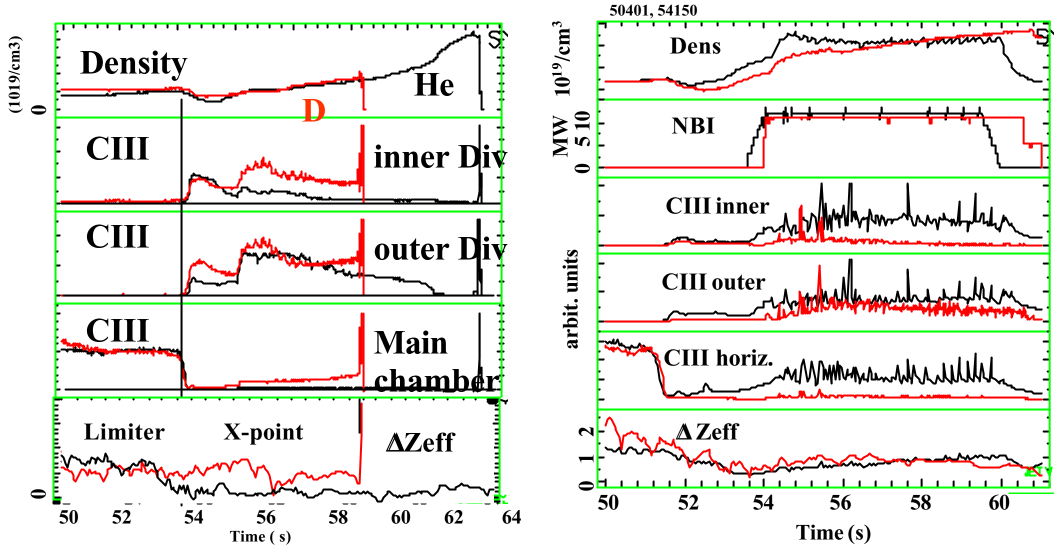

Fig 3a) *Evolution of the density, CIII light in the outer, inner divertor and midplane and Z_{eff} for L-mode density limit shots in He and D (low wall clearance).* ***b)*** *Evolution of the CIII light emission and Z_{eff} for two Elmy H-mode shots in He and D at 11 MW input power.*

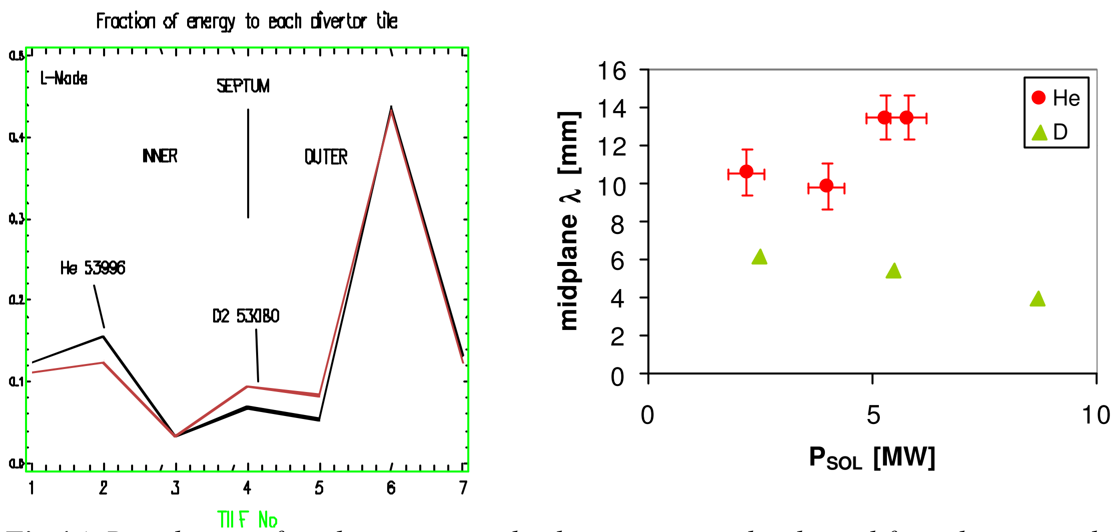

Fig 4a) *Distribution of total energy over the divertor target tiles derived from thermocouple data for two similar L-mode shots in He and D.* ***b)*** *Power decay lengths for the inner and outer divertor transformed to the horizontal midplane for L-mode shots in D and He and different power levels. Data are derived from thermocouple and Langmuir probe data.*