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Influence of the ^{4}He Concentration on H-Mode Confinement and Transport in ASDEX Upgrade

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Introduction

The transition from graphite to full tungsten plasma facing components (PFCs) in ASDEX Upgrade indicated that the storage and release of ^{4}He after He glow discharges is significantly different for W PFCs compared to graphite PFCs [1]. As a consequence, substantial He concentrations were found in plasma discharges after repeated inter-discharge He-glow. It turned out that these concentrations had a strong detrimental effect on the global energy confinement time [2]. A similar effect was already found in JET for discharges with He majority [3], but our data suggest that the confinement degradation sets in already at rather low He concentrations.

Experiments

The ^{4}He (further denoted by He) concentration $c_{He} = n_{He}/(n_{He} + n_D)$ is monitored routinely by passive spectroscopy in the divertor. It is evaluated from the HeI (588 nm), HeII(469 nm) and D_β (486 nm) using the inverse photon efficiencies $S/XB = 5$, 10 and 150 respectively, under the assumption that the influxes are a measure of the relative edge densities of deuterium and helium. However, it is known from experiments and code calculations [4] that for trace He amounts in the plasma, He is de-enriched in the divertor by a factor of 0.25-0.35. Therefore the actual He concentration in the main plasma can be larger by up to a factor of 4 compared to that measured in the divertor, consistent with indications from exploratory He main chamber measurements (visible, VUV and CXRS). The majority of the investigated discharges was at $I_P = 0.8$ MA, $B_t = 2.0 - 2.5$ T, $q = 4.5 - 5.7$ and $P_{NBI} = 5 - 7.5$ MW. Only discharges without

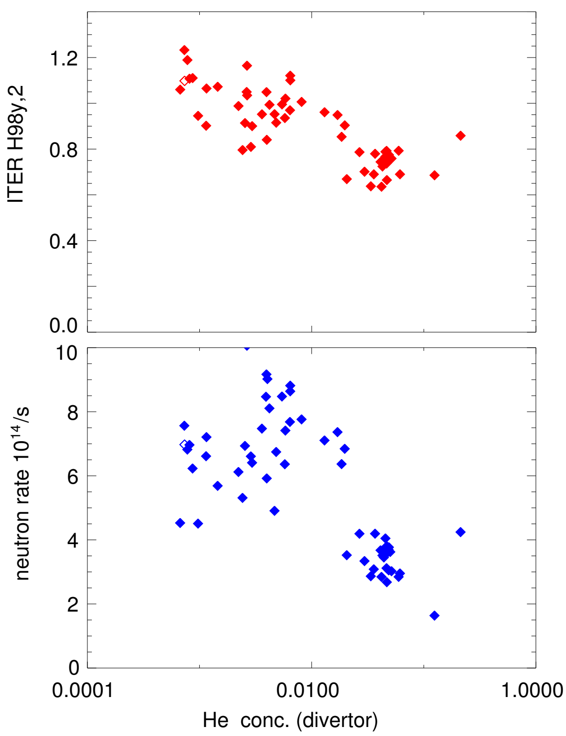

Figure 1: ITER H98y,2 factor and neutron rate versus He concentrations in the divertor.

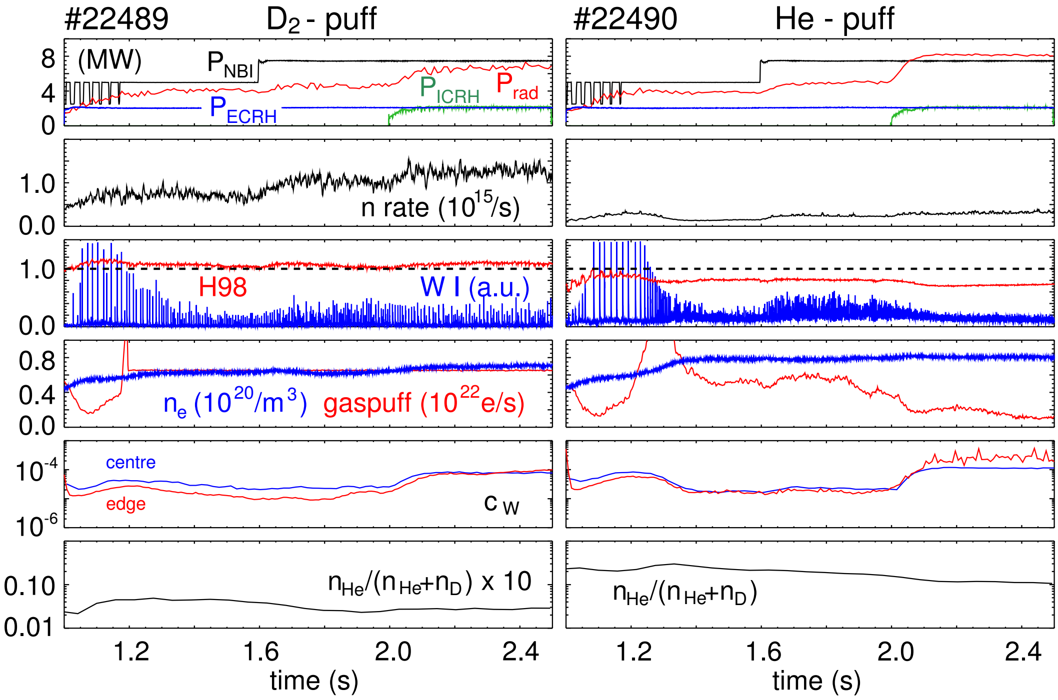

Figure 2: Comparison of discharges with D_2 (#22489, left-hand side) and He puffs (#22490, right-hand side) and otherwise similar technical parameters. The parameters from top to bottom are: Auxiliary heating power (NBI, ECRH, ICRH) and radiated power; neutron rate; ITER98 H-factor and W I divertor radiation; line averaged density and gas puff rate (electrons/s); central and edge W concentration; He concentration.

strong NTM activity, as well as with tungsten concentrations below 10^{-4} were taken into account in order to exclude an detrimental effect on confinement. In the investigated density range ($\bar{n}_e = 6-8\cdot 10^{19}$ m^{-3}) a L-H threshold power of 2.4-3.2 MW is expected in pure deuterium. Therefore the applied heating power is far above the threshold power and an influence of the proximity to this threshold can most likely be excluded even if P_{thr} in He is higher as found in [3]. The confinement decreases from $H98y,2 \approx 0.8-1.2$ at $c_{He}^{div} < 1\%$ down to $\approx 0.7-0.8$ for $c_{He}^{div} > 3\%$ (see Fig. 1), which means that a strong degradation of confinement is already found for He concentrations in the main chamber of about 10%. The degraded confinement gets also obvious from the neutron rate which decreases faster as expected from the dilution by He alone (lower part of Fig. 1).

Detailed Comparison

In order to rule out long term effects due to machine conditioning, dedicated consecutive discharges were performed in a close sequence using either a D_2 or a He puff for building up the plasma density. By repeats of the specific discharges the central as well as the edge plasma parameters could be measured with a good accuracy and in addition outliers in confinement can be ruled out. Fig. 2 shows the comparison of two subsequent discharges having identical technical parameters, except that discharge #22489 was fuelled with D_2 and #22490 was fuelled with He (the densities were not completely matched due to the different recycling behaviour). The 'D' discharge, which had a residual He concentration far below 1% (note the He concentrations is multiplied by 10 in case of the 'D' discharge) yields an H factor above 1 for all heating phases, whereas the confinement of the 'He' discharge ($c_{He} \approx 20\%$), is degraded to $H98y,2 = 0.8$ during the phase without ICRH. In this first phase with ECRH and 5 - 7.5 MW of NBI, no significant difference in the ELM behaviour is observed. As ELM indicator, the brightness of the W I line in the divertor is used in order to get rid of the influence of the reduced D radiation. Additionally, the W sputtering, which is governed by low-Z impurities [5], is strongly temperature dependent and therefore a strong change in the SOL parameters would immediately show up in the emissivity of the W I line. During the phase with additional ICRH a change to ELM type III seems to appear in the He-discharge, leading consequently to an even lower confinement. Even stronger as the H-factor, the neutron rate decreases at least by a factor of 4, documenting the combined effect of dilution (which would result in a factor less than 2) and lower central ion temperature. The W concentration is similar in both discharges before the phase with ICRH, excluding a dominant influence of W radiation on the observed behaviour. An investigation of the edge profiles reveals, that the width of the ion temperature (T_i) gradient zone deduced from fast measurements using charge exchange spectroscopy (CXRS) on C^{6+} [6] is larger in the deuterium case, leading to a higher pedestal value ($T_i \approx 1$ keV instead of 0.6 keV). Since the densities where not matched exactly in both cases the ion and electron pressure profiles are compared during the time period 1.7-1.95 s in Fig. 3. Here the dilution of the ion density by He is taken into account. The scatter in the data is not due to noise but results from individual ELM crashes seen in the temperature profiles. Whereas the electron pedestal pressures are similar in both

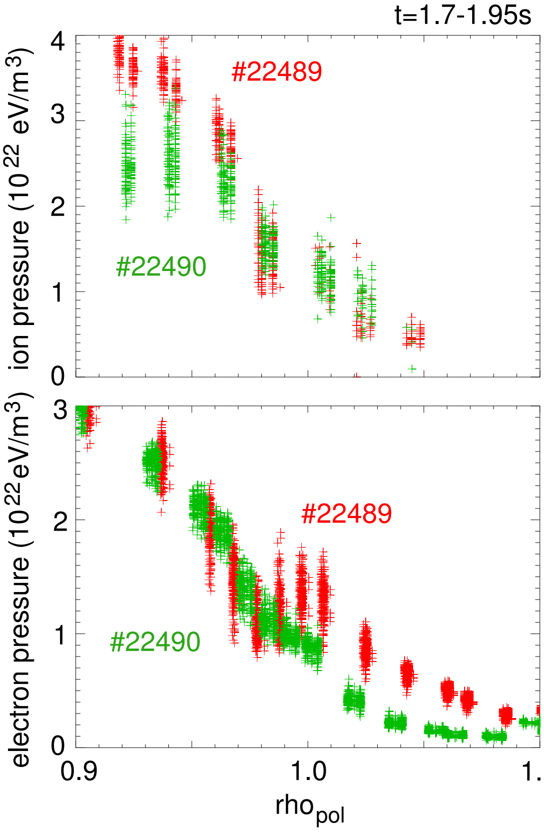

Figure 3: Edge ion and electron pressure profiles of the above shown discharges during $t = 1.7 - 1.95$ s.

cases a 20-30% larger pedestal ion pressure is found in the deuterium discharge. Integrating the pedestal pressure over the plasma volume yields pedestal energies of 160 kJ (#22490) compared to 200 kJ (#22489). This means that difference in the total stored energy (480 kJ instead of 600 kJ) can be explained by a degraded pedestal and its effect on the central confinement due to profile stiffness. Unfortunately, no CXRS measurements for the central T_i were possible in the discharge with He puffing due to too low carbon levels, but, the lower n-rates ($0.25 \cdot 10^{15}$ s^{-1} instead of 10^{15} s^{-1} see Fig. 2) are consistent with a 20% lower central ion temperature. The particle confinement seems not to be degraded, since the W concentration, which is very sensible to changes in transport, is almost identical.

Conclusions

An evaluation of discharges with similar technical parameters reveals that already He concentrations at the level of a few percent show a confinement degradation closely to values observed for He majorities in JET and ASDEX Upgrade. Dedicated experiments, which compare discharges where He or D is puffed, respectively, confirm this observation. Measurements of the edge plasma profile suggest that the degraded confinement in the discharges with He is due to an eroded ion pedestal and the effect of profile stiffness. The findings may be important for ITER, which is designed to achieve He concentrations of about 5% in the main plasma [7], since the He resulting from the fusion reaction itself may degrade the performance not only by dilution but also by lowering the confinement. However, as long as the physics reason for this behaviour is not identified, an extrapolation to ITER edge parameters are not straight forward. Further investigations will concentrate on a variation of the plasma parameters to consolidate the experimental evidence.

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