Characterization of the ELMy H-mode regime
with the ITER-like wall in JET

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1. Introduction

The installation of a full tungsten divertor and a beryllium first wall in JET, the so-called ITER-like Wall (ILW) [1], provides a unique opportunity to study the influence of the wall materials on the ELMy H-mode regime, the foreseen reference scenario for ITER.

With the new ILW, the H-mode regime has been readily achieved with low shape ($\delta\sim0.25$) and high shape ($\delta\sim0.4$) with a small amount of additional heating power [2], either from neutral beams or ICRH systems (less than 2MW). During the initial development phase, metallic impurity events have been observed but in the course of the further operation their frequency strongly decreased, hinting to a conditioning effect of the plasma wetted surfaces. An example of an ELMy H-mode discharge obtained in JET with the ILW is given in the Figure 1. 10.5 MW of NBI power was applied in a 2.0MA/2.1T plasma. The configuration is a low triangularity ($\delta\sim0.25$) with the inner strike point lying on the vertical target (coated tile) and the outer strike point on the horizontal target (bulk tungsten tile). A significant amount of deuterium was puffed ($\sim10^{22}$D/s) continuously in the divertor during the main heating phase, as this was found to prevent tungsten accumulation and central radiation as already shown in ASDEX Upgrade [3]. Regular type I ELMs are still observed on the BeII line emission and on the line integrated density at a frequency of about 12 Hz. The ELM signature in the radiated power and the D_α emission is strongly reduced compared to the carbon wall, suggesting a different deuterium and impurity release from the plasma facing components under the transient heat flux.

The central electron temperature and the line integrated density reach equilibrium at 51s while the Zeff is about 1.5. The confinement improvement factor achieved in this discharge is close to $H_{98y2} \sim 0.9$.

2. Compatibility with the tungsten divertor

One of the main objectives of the ILW project is to study the compatibility of the tungsten divertor with the plasma scenarios foreseen for ITER. The reduction of the operational domain was faced in the first H-mode experiments when the available power was close to the L-H threshold. Long ELM free phases are producing strong increase of the

Figure 1: typical ELMy H-mode discharge in JET with the ITER-like wall (#82122, 2MA/2.1T, δ~0.25)

bulk radiation and the impurity content (W and Ni), eventually leading to a back transition to L-mode as the power across the separatrix P_{sep} decreases as illustrated in the Figure 2. An ELM is observed at the back transition (pedestal collapse) and in the consecutive L-mode phase the bulk radiation decays rapidly indicating that the impurities are purged from the confined plasma. Once the P_{sep} re-increases above the L-H threshold value, the plasma goes back to H-mode. It has to be noted that if the additional power is maintained, no disruption occurs while switching off the NBI power in such a situation may lead to disruption. The increase of the NBI power combined with strong deuterium gas puffing rate (above 10^{22}D/s) opens up the operating space by increasing the ELM frequency, flushing out the tungsten. While the increase of NBI power enhances the tungsten source and the gas puffing tends to decrease it, it was found that the minimum gas puffing rate decreases with the injected power, as shown in the Figure 3. This points out the key role of the impurity transport, compared to that of tungsten particle source. In terms of minimum ELM frequency a lower limit of
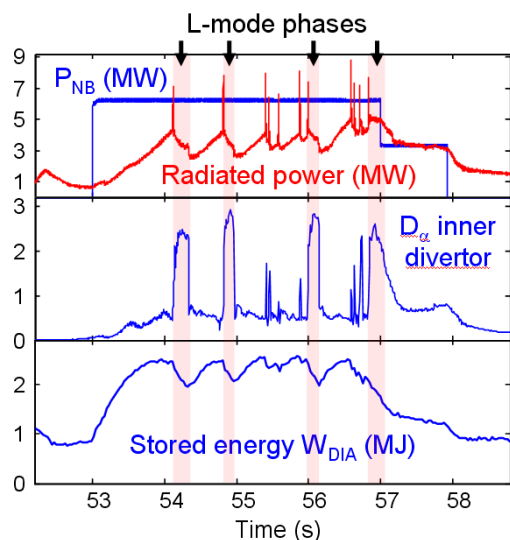
Figure 2: ELM free phases leading tungsten accumulation and H-L back transition (#81914)

10 Hz was found in all scenarios performed so far in the ILW with an H-mode edge. JET with the ILW and ASDEX Upgrade with the its tungsten wall showed a very similar behaviour, however in AUG the main tungsten source has been identified to be the main chamber while in JET, a priori, the tungsten source comes from the divertor. Another significant difference is the routine use of central heating by ECRH in AUG which extends significantly its
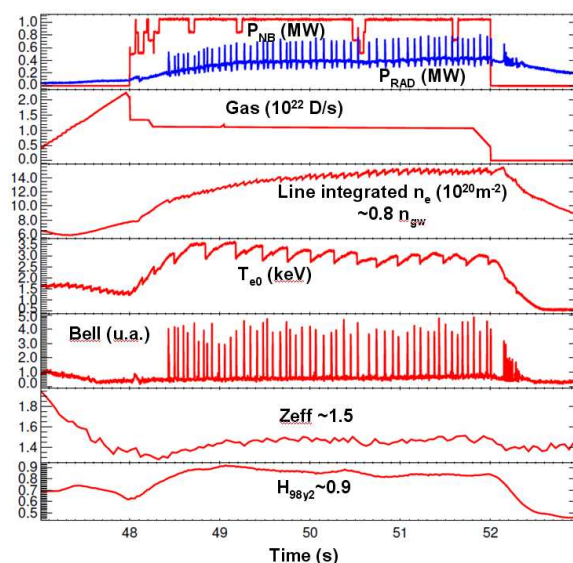
operational domain [3].

3. Comparison with the carbon wall

The comparison of well-matched pairs of discharges with carbon wall and ILW shows a degradation of the stored energy in the ILW, in particular for the high triangularity cases. This lower confinement is attributed to a cooler pedestal temperature. By comparing two high δ pulses at 2.5MA with the same conducted power across the separatrix and the same density at the top of the pedestal (C-59354, ILW-82537), the ILW showed

Figure 3: ILW operating space in the P_{NB} vs deuterium gas puffing rate at 2.0MA/2.1-2.2T

a reduction of the pedestal electron temperature by 30% (from ~1keV down to ~700 eV) while the profiles in the gradient region show the same stiffness. This is an extreme example but a trend emerges and is illustrated in the Figure 4 [4], where the temperature at the pedestal
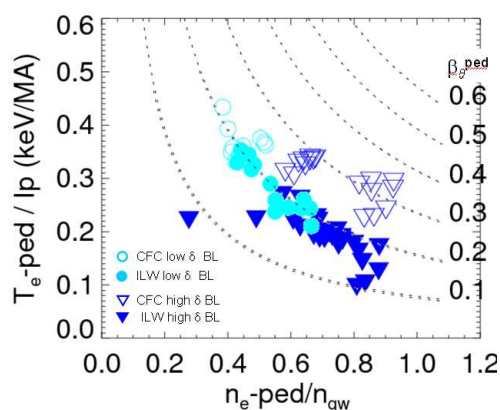

Figure 4: {T_e-ped/I_p, n_e-ped/n_{gw}} diagram comparing C wall and ILW at 2.5MA/2.7T

top (T_e-ped) normalised to the plasma current (I_p) is plotted versus the density at the pedestal top (n_e-ped) normalised to the Greenwald density (n_{gw}). The change in the wall composition is most likely at the origin of this difference. A change in the radiation pattern is obvious as showed in the Figure 5 with a strong reduction of the radiated power in the divertor region with the ILW (from 6 MW to 2 MW in the given example) leading to higher conducted parallel power and thus different boundary conditions for the pedestal. On the other hand, the bulk radiated power is comparable in the pairs of discharges (~3 MW in the given example).
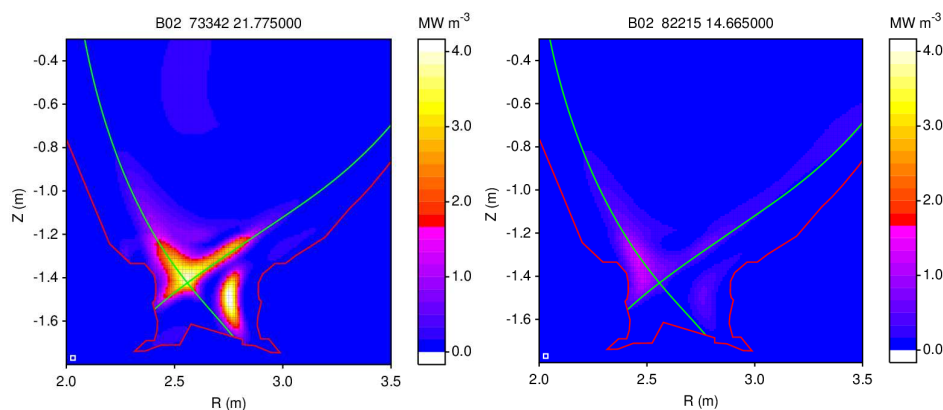

Figure 5: tomographic reconstruction (inter-ELM Δt = 30 ms) of the divertor radiation for the C wall (left, #73342) and ILW wall (right, #82215) for a matched pair of pulses with similar magnetic configuration (2.5MA/2.7T), NBI power (14 MW) and deuterium gas fuelling rate (2×10^{22} D/s)

The neutral recycling is also substantially altered with the ILW as Be and C have not the same affinity with deuterium. A higher inter-ELM recycling is observed with the ILW, typically
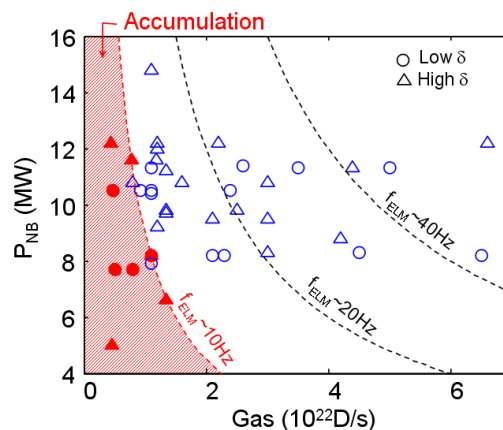
increased by a factor 2 for similar deuterium puffing rate and NBI power conditions while the intra-ELM is strongly reduced. It has to be noted that the deuterium gas puffing rate is still an order of magnitude below the recycling neutral flux but its impact on the confinement seems much stronger. Finally, the Zeff is substantially lower with the ILW and a reduction from typically ~ 2 to ~1.4 is observed. This could play a role in the edge transport barrier and pedestal stability, which would be consistent with first nitrogen seeding experiments with the ILW [1] and AUG results [3].

4. Conclusions

Although the constraint on the operational domain with the tungsten divertor was foreseen, the impact of the ITER-Like Wall on the confinement and on the pedestal was not expected. The confinement factor achieved in these discharges, as shown in the Figure 6, is in the range H_{98y2}~0.7-0.9, globally lower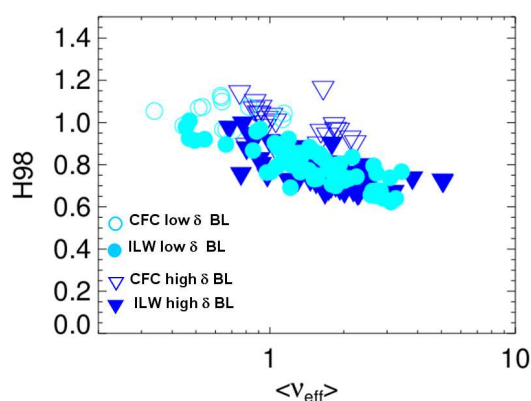 than what was achieved with the CFC walls in the same range of external settings (H_{98y2}~0.9-1.1). The access to high confinement at low puffing rate is not accessible any more because of the need of gas puffing for the control of tungsten accumulation. In addition, the high triangularity scenario at 2.5 MA exhibits confinement degradation with gas puffing which was not observed with the carbon wall in JET [5], although N-seeding experiment tend to recover the carbon wall behaviour [1]. These first set of discharges provide new insights on the H-mode and pedestal physics pointing out the possible effect of plasma composition (lower

Figure 6: Summary of the achieved H-modes in JET with the ILW so far with 1.0<Ip<2.5MA and P$_{NB}$<24MW, showing the H-factor (H$_{98y2}$) and the effective collisionality <ν$_{eff}$>.

Zeff and different divertor radiation pattern with the ILW) and deuterium recycling (Be vs C first wall). Nevertheless, some good confinement discharges (H$_{98y2}$ close to 1) have been obtained for the baseline 2.5 MA H-mode plasmas at high power and optimised gas fuelling in both high and low triangularity configurations (see Figure 6). These results constitute a first step in the demonstration of the compatibility of the foreseen ITER scenarios at higher heating power and larger plasma currents with the ILW.

Acknowledgment

References

[1]　　G. Matthews et al, review talk 20th Conf. on PSI, Aachen, May, 21-25, 2012, sub to J. Nucl. Mater.
[2]　　C. Maggi et al, this Conference
[3]　　R. Neu et al, invited talk 20th Conf. on PSI, Aachen, May, 21-25, 2012, sub to J. Nucl. Mater.
[4]　　L. Frassineti et al, this Conference
[5]　　G. Saibene et al, Nucl. Fusion 45 (2005) 297–317