EFDA–JET–R(12)02

M. Beurskens, C. Giroud, J. Hughes, A. Kallenbach, P. Lomas, G. Maddison,
R. Neu, I. Nunes, M. Reinke, F. Ryter and J. Schweinzer

Quality of H-mode Plasmas (A report on the experience from JET, AUG and C-Mod)

Quality of H-mode Plasmas (A report on the experience from JET, AUG and C-Mod)

M. Beurskens, C. Giroud, J. Hughes, A. Kallenbach, P. Lomas, G. Maddison,
R. Neu, I. Nunes, M. Reinke, F. Ryter and J. Schweinzer

4. Quality of H-mode plasmas. (a report on the experience from JET, AUG and C-Mod)

Marc Beurskens, Carine Giroud, Jerry Hughes, Arne Kallenbach, Peter Lomas, Geoff Maddison, Rudolf Neu, Isabel Nunes, Matthew Reinke, Francois Ryter, Josef Schweinzer.

The change over from a full carbon to a full metal wall has reduced the accessible operational space in both AUG and JET tokamaks. The AUG carbon wall (AUG-C) was replaced in a step wise manner from 1999 to 2007 by a DEMO-relevant full W-wall and divertor (AUG-W) [1], whereas in JET the carbon wall (JET-C) was fully replaced in 2009-2010 by an ITER-like Be main chamber first wall and W divertor (JET-ILW) [2]. We have found a common pattern in these full metal devices that the global and pedestal confinement are affected by a requirement for increased gas fuelling (to screen high-Z impurities influxes). Figures 1 a&b show a comparison of Type I ELMy H-mode plasmas in AUG (I_p=1MA, B_T=2-3T, δ=0.2, P_{In} = 3-6 MW, 1.3 < β_N < 1.6 – to be updated) [3]. The figures show that when the same density is obtained and the same fuelling level is applied the normalised confinement in terms of $H_{98y,2}$ is similar between AUG-C and AUG-W. In comparison, Figure 2 shows the confinement for JET Type I ELMy H-mode plasmas (I_P =2.4-2.6 MA, B_T = 2.3-2.7 T, δ_{av}=0.2 and 0.4, P_{NBI} = 12-16 MW, 1.3 < β_N < 1.8). For low triangularity (δ) plasmas, the downward trend of $H_{98y,2}$ with density follows a similar trend as was reported for JET-C in [4] and is in agreement with the AUG observations. However, for the high-δ plasmas a further degradation is observed; whereas in JET-C high δ plasmas could sustain good confinement $H_{98y,2}$~1 up to the Greenwald density limit, the benefit of δ seems to have disappeared in JET-ILW [5,6].

In AUG a strong correlation is found between the divertor neutral background pressure and normalised confinement in both AUG-C and AUG-W as can be seen in Figure 3. It is so-far unknown in which way the divertor neutral pressure can affect the confinement. Nevertheless, in AUG-W this effect can be mitigated by means of impurity seeding as is demonstrated in Figure 4. At t=2.5s nitrogen is seeded and the normalised confinement increases from $H_{98y,2}$=0.8 to 1.2 whereas the divertor neutral pressure remains unchanged or even increases. A similar observation holds for JET. Here no divertor neutral pressure measurements are available and the divertor recycling level is used instead. Figure 5 shows $H_{98y,2}$ as a function of the inter-ELM outer-divertor D_α level (averaged over 20-80% of the ELM cycle). At increasing recycling level the normalised confinement steadily decreases for plasmas without nitrogen seeding. However, like the AUG observations, when N_2 seeding is applied, $H_{98y,2}$ increases by up to 15%, approaching the enhancement factor obtained in JET-C – albeit only for high δ plasmas. This beneficial effect of impurity seeding on plasmas confinement has also been observed in Alcator C-Mod [7], Figure 6, and is a general observation in tokamaks with a metal first wall. Moreover, in JET-C nitrogen seeding did not lead to an increase in confinement, which suggests that the low-Z impurities N_2 and C play a similar role in enhancing the plasmas confinement [8,9].

The global confinement improvement with N_2 seeding in JET-ILW is due to an enhancement of the pedestal pressure through an increase of the pedestal temperature [5,6], Figure 7a. The ratio of core and pedestal confinement remains unchanged for all the JET-C and JET-ILW pulses, as seen in Figure 7b, and hence the confinement is set by the achievable pedestal pressure and profile stiffness. This has also been observed in AUG where N_2 leads to an increase in pedestal temperature and the core pressure profile peaking remains unchanged [10,11]. In contrast, for Alcator C-Mod the confinement improvement is observed to be through an increase in pedestal density, although here also the core profiles are stiff.

In view of our recommendations for ITER, the clearest difference seen between full Carbon and full metal devices is the loss of the well performing zero gas flux, low recycling scenario going from C to W or Be/W. However, we believe that this is of little consequence for the choice in divertor material as ITER will require high gas rates for heat load mitigation and for operation close to the density limit in any case. (Therefore the use of confinement data from low recycling regimes in extrapolations to expected ITER confinement performance may be misleading, and may lead to over-optimistic predictions). The use of low-Z impurity seeding may aid the baseline H-mode scenario in ITER with a full metal wall, especially for the high-δ plasmas. This is in good synergy with the need for divertor heat load mitigation (not discussed here).

We interpret the results presented here in favour of a start-up in ITER with an all-W divertor, since it is uncertain that an ITER scenario developed with low power in a C divertor can be transferred to an all-W ITER divertor. The uncertainty is obvious from the unexplained empirical behaviour shown here, and a clear recommendation is to work on the physics behind these observations. But with the present understanding, and the fact that C is not allowed in a nuclear phase, starting with W has lower risk regarding H-mode quality for the nuclear phase (the increased risk items like W melting and W transport are dealt with in other subgroups).

[1] R Neu et al 2009 Phys. Scr. 2009 014038 doi:10.1088/0031-8949/2009/T138/014038
[2] [Matthews-PSI-2012] International Conference of Plasma Surface Interaction, Aachen, 2012
[3] F Ryter – Private communication
[4] G. Saibene et al, 2002 Plasma Phys. Control. Fusion 44 1769
[5] C Giroud et al, IAEA, 2012
[6] M Beurskens et al, IAEA, 2012
[7] A. Loarte et al, , Physics Review Letters, 2010
[8] G Madison et al, Physics Review Letters, 2011 &
[9] C Giroud et al, Nuclear fusion, 2012
[10] "Overview on plasma operation with a full tungsten wall in ASDEX Upgrade" Journal of Nuclear Materials In press, corrected proof, 0 (2013), doi:10.1016/j.jnucmat.2013.01.006
[11] G Tardini et al 2013 Plasma Phys. Control. Fusion 55 015010 doi:10.1088/0741-3335/55/1/015010

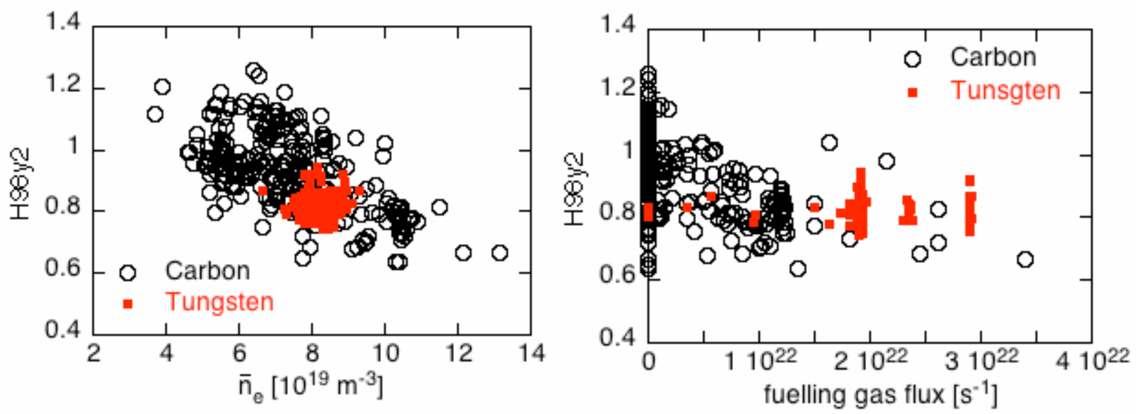

Figure 1: AUG Database comparison of normalised confinement in 'standard H-modes' for operation with carbon (black) and Tungsten (red) wall.a) $H_{98y,2}$ vs line averaged density and b) $H_{98y,2}$ vs deuterium fuelling.

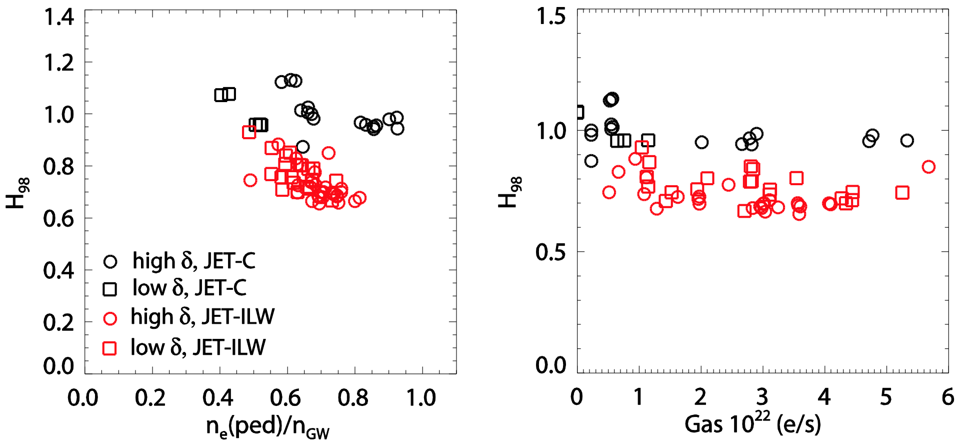

Figure 2: JET database comparison of H_{98} for baseline Type I ELMy H-mode plasmas at low (δ=0.2) and high (δ=0.4) triangularity. (I_P =2.4-2.6 MA, B_T = 2.3-2.7 T, P_{NBI} = 12-16 MW)

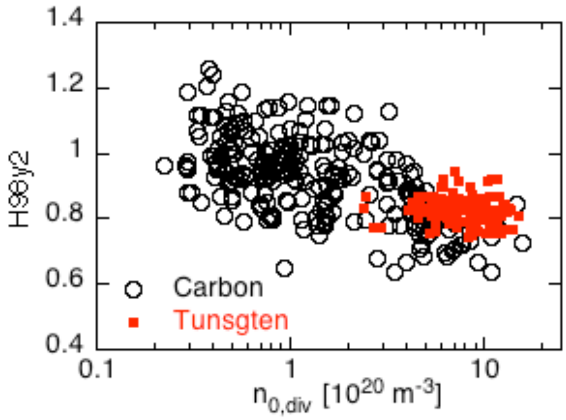

Figure 3: AUG normalised confinement versus divertor neutral pressure.

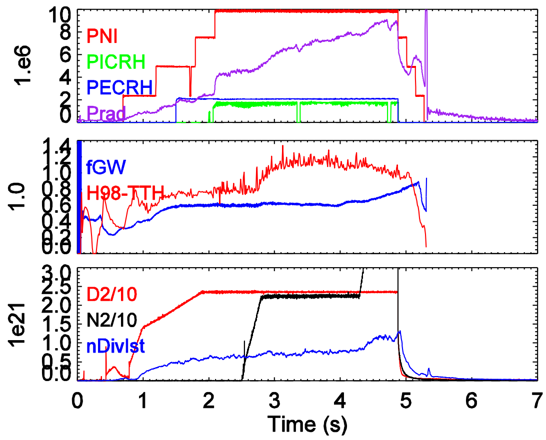

Figure 4: Nitrogen seeding in AUG pulse #29254. I_p=1MA, B_T=2.5T P_{NBI}=10MW. At t=2.5 s N_2 is seeded.

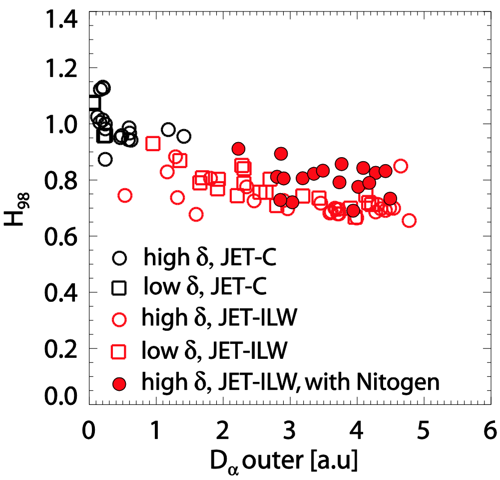

Figure 5: *JET normalised confinement versus inter-ELM D_α emission in the outer divertor averaged over 20-80% of the ELM cycle. Additional points are with N_2 seeding.*

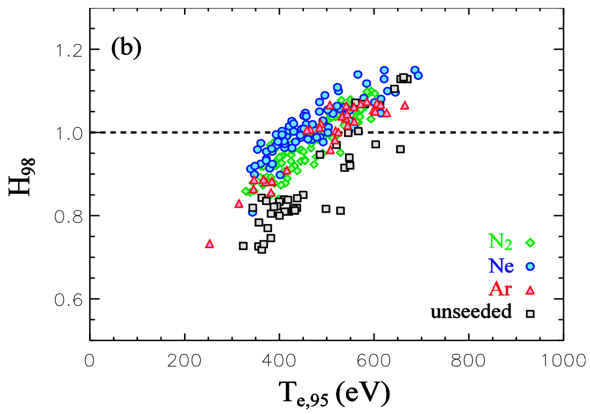

Figure 6: Improved confinement through impurity seeding in Alcator C-Mod with a Molybdenum wall

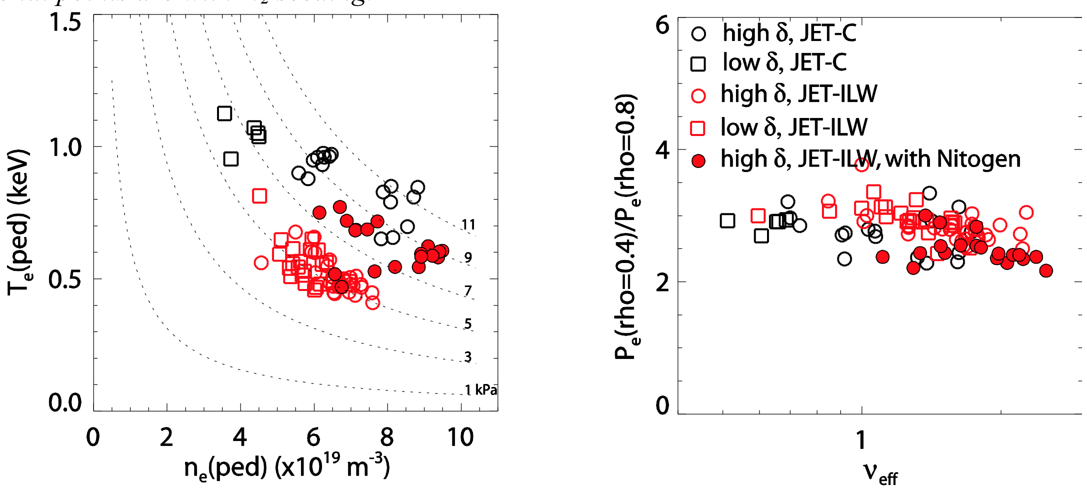

Figure 7 a) JET Pedestal T_e and n_e diagram and b) JET pressure profile peaking for pulse selection as Figures 2 and 5.