CONFINEMENT AND TRANSPORT STUDIES AT HIGH POWER IN ASDEX UPGRADE

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1. Introduction

At ASDEX Upgrade the NBI heating power has been doubled to 14 MW H or 20 MW D. Additionally the new cryo pump (100 l/s)[1] started operation increasing the pumping capacity by a factor of ≈ 7. This allows to analyse a substantially wider part of the parameter space in terms of transport and confinement. Since the higher H^0 power now allows to obtain type I ELMy H-modes in hydrogen as well, the first part of this paper treats the isotope effect of type I ELMy H-mode confinement which is investigated by global and local analysis. The second part compares type I and type III ELMy H-mode global and local confinement data to investigate the effect of pedestal height and profile stiffness. Finally, we analyse the effect of the saturation of the stored kinetic energy with increasing power in H and D. The analysis is limited to plasmas without neoclassical tearing modes which have been observed with deuterium for powers above 5 MW to 15 MW depending mainly on β_N and $\nu^\star$ [2].

2. Isotope effect in type I ELMy H-modes

An influence of the isotope mass on confinement in ASDEX Upgrade plasmas has already been reported for L-mode and H-mode [3] with the restriction, that only type III ELMy H-modes could be included for hydrogen. The new results are shown in Figure 1, which compares total energy confinement times τ_E^{tot} of type I ELMy H-modes in H and D (i.e. NBI losses except shine through and energy content due to fast particles are not subtracted). As abscissa the ITER-92P(y,tot) [4] ELMy H-mode scaling has been used with the modification that it was calculated setting $A_i = 2$ also for hydrogen. Thus the isotope dependence ($A_i^{0.38}$) of the scaling is eliminated and only the deuterium results should scatter around the solid line. The long dashed line gives the prediction of the scaling for the hydrogen H-modes, the short dashed line is the result of a linear fit to the data. At a first glance it indicates that for large values of τ the confinement is higher than predicted. Since this is only founded on three points which lie even closer to the prediction than most of the deuterium values, the DIII-D data in the ITER H-mode database [5] have been investigated for comparison. These hydrogen data which are in number and achieved τ comparable to the hydrogen points in Fig. 1 do not show the deviation from the scaling, so this point can only be clarified with additional experimental data. Figure 2 shows density and temperature profiles of an H and a D fueled type I ELMy H-mode with nearly the same NBI heating power (10.3 MW), I_p (1 MA) and B_t (2.5 T, ion-$\vec{\nabla} B \rightarrow$ X). The ELM frequencies are 290 Hz (H) and 240 Hz (D) The time intervals are chosen such that the density profiles are nearly identical. For the deuterium shot T_i data are not available, but in the hydrogen case T_i is very close to T_e. Assuming $T_e = T_i$ reduces the difference in confinement to the difference in the T_e profiles. The logarithmic plot shows well, that the profiles are self similar as reported

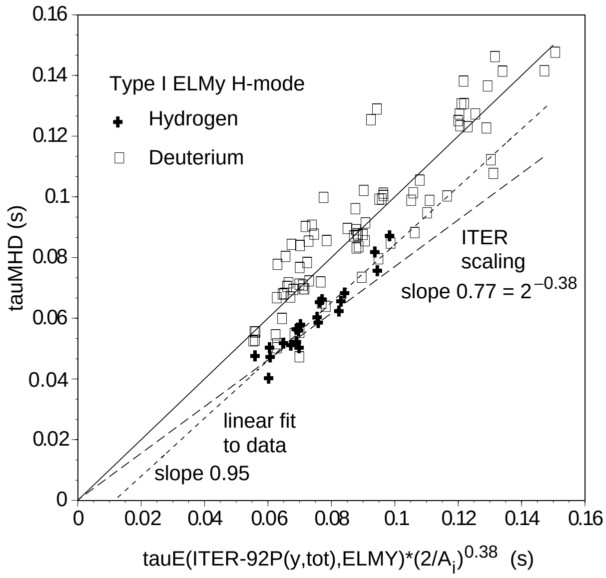

Figure 1. Isotope effect in global scaling.

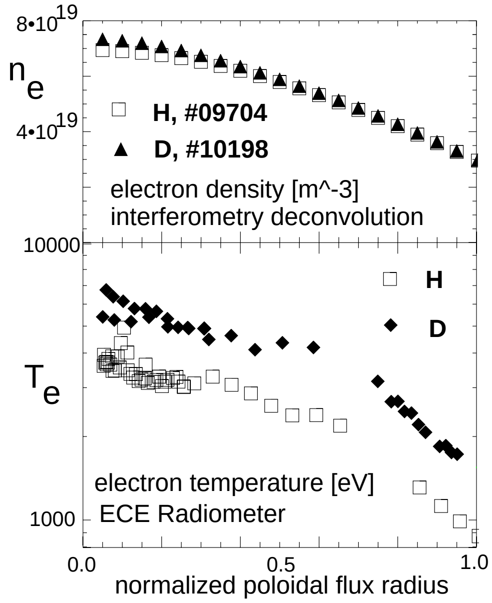

Figure 2. Profiles of H and D plasmas

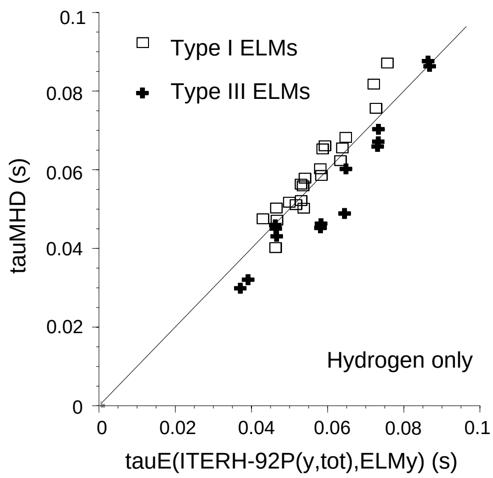

Figure 3. ELM type and global scaling

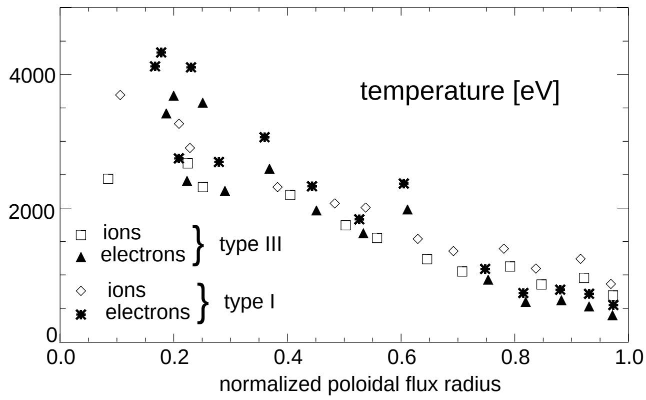

Figure 4. Influence of ELM type on T_e profiles

for various D fueled type I ELMy H-mode discharges [6]. The scaling factor between the two profiles is in agreement with the ratio of the measured plasma energies (W_{mhd}) which is 1.66. This is significantly more than the factor of $(A_{i,D}/A_{i,H})^{0.38}$ = 1.3 expected from the scaling. It should be noted that all global parameters which are needed for the scaling are identical for these shots except A_i.

3. Type I and type III ELMs in hydrogen

Hydrogen allows to compare type I and type III ELMy H-modes over a wide power range. Figure 3 shows the result of the global analysis for both types of H-mode plasmas from the hydrogen campaign with moderate densities up to 60 % of the Greenwald limit ($\bar{n}_{GW}$). The confinement of the different shots is compared by plotting the total energy confinement time τ_E^{tot} against the ITERH-92P(y,tot) scaling. It can be seen that type I ELMy H-modes perform about 20 % better than type III ones. For larger values of τ the H-factors increase for both types. Figure 4 shows as an example temperature profiles of a discharge which reached the

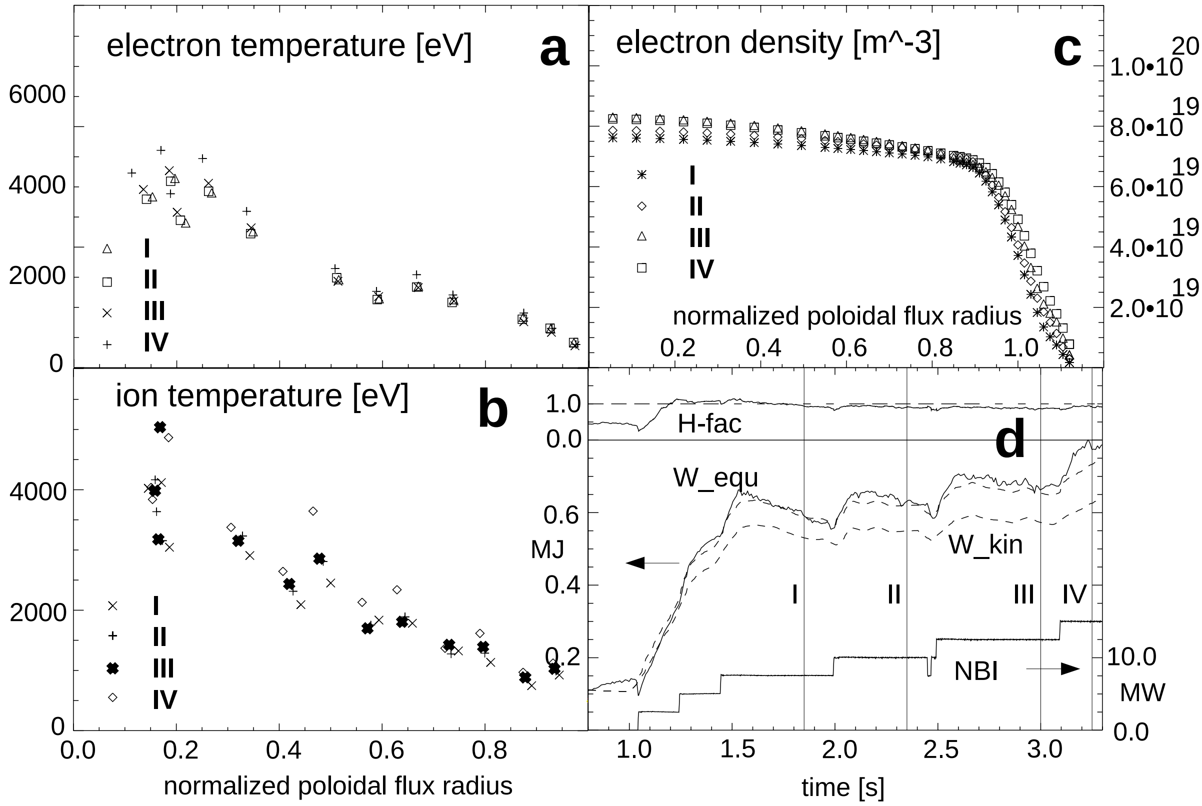

Figure 5. High power medium density discharge in deuterium (#10397, 1 MA, 2.0 T)

type I phase already with 5.75 MW NBI. In the beginning of the NBI phase type III ELMs occur (f_{ELM} = 230 Hz). After closing the gas valves the density decreases due to pumping with the cryo pump so that type I ELMs (f_{ELM} = 140 Hz) occur leading to an increase of the density (gas valves stay closed). The density profiles at the time points chosen for Fig. 4 are almost identical. The variation of the confinement ($\approx$ 1.2) is therefore only due to differences in the temperature profiles. Especially for the electrons, the temperature difference in the core is significantly larger than at the top of the pedestal, indicating that the change in the stored energy due to the pedestal ($1.5 * V * \langle n_e \rangle * k * \Delta T_{ped}$) is not the only reason for the change in confinement. On the other hand a logarithmic plot (not shown) reveals, that the relative temperature change at the top of the pedestal is about twice as large as for ρ_{pol} < 0.8. This breaks the self similarity observed for type I ELMy H-modes. The ELM type seems to modify the profile shape for ρ_{pol} > 0.8 which coincides with the region where a significant modulation of the pressure profile is observed during type I ELMs [7]. It should be noted that there is an hysteresis effect between both types of H-mode, since input power and density profiles are equal. As for the L-H transition this is easily explained by the better confinement at the edge, which keeps the pedestal temperature above the critical level separating type I and type III ELMs even when the density is raised again to a value where type III ELMs have been observed before.

4. Profile saturation at high heating power

In ASDEX Upgrade, a saturation of the kinetic energy at high heating power can be seen from the density and temperature profiles for both isotopes For deuterium the power was ramped up in steps up to 15 MW (Fig. 5d), no neoclassical tearing modes occured in this case ($\bar{n}_e \approx 0.65\ \bar{n}_{GW}$).

T_e and n_e increase only marginally (Fig. 5a,5c), the change in T_i seems to be larger but only for the last time slice it is significantly above the scatter (Fig. 5b). To check the consistency with the further increasing W_{mhd} the ASTRA code [8] has been used to get a calculated W_{mhd}. The good agreement of experiment an calculation (Fig. 5d) indicates the reliability of the profile data. Describing the saturation by $W_{kin} = P^{\alpha}_{NBI}$, we find α = 0.35. This is in agreement with the thermal ITERH-92P(y,th) scaling. The corresponding H-factor is also close to one (Fig. 5d). A similar discharge in hydrogen has been analysed (not shown). For hydrogen we do not yet know the NBI losses and we only calculate the kinetic energy from the profiles and check the power dependence. A cross check is again the simulation of the equilibrium energy. Here the unknown NBI losses (between 0 % and 20 %) play a less important role, since the contribution of the fast particles is in the range of 15 % of the kinetic energy (Fig. 5d). The agreement of the kinetic and magnetic analysis is comparably good as for deuterium. Assuming $W_{kin} \propto P^{\alpha}$ delivers $\alpha \approx$ 0.19 when increasing the power from 8.8 MW to 12.3 MW, which is significantly lower than predicted by the scaling. In [4] it has been noted, that the exponent derived for P depends on A_i. Fitted separately, the H data show a stronger saturation than the D data. The difference of the exponents of P between D→D and H→H for ELMy H-mode is 0.10±0.04, close to our experimental result. They show the importance of including such an interaction in the commonly used scalings.

5. Conclusion

For both isotopes a profile saturation with increasing heating power is observed in ASDEX Upgrade. The high power deuterium data well below $\bar{n}_{GW}$ fit the ITER ELMy H-mode scalings. The hydrogen data show an even stronger confinement decay with increasing power which is only compatible with the scaling if a (log-linear) interaction term is included [4]. For a pair of discharges with identical global parameters except A_i the variation of the confinement was a factor of two larger than expected from the scaling.

The T_e profiles of the type-I ELMy H-modes now obtained for hydrogen have the same shape as those in the deuterium. In contrast to this, type III ELMy H-modes break this shape similarity at the edge, where T_e is lower, leading to a reduction of confinement. Nevertheless, the absolute temperature decrease is larger in the core than at the pedestal. These results are in favor of a separate treatment for the two ELM types and suggest a careful analysis of the isotope dependencies in the ITER database.

References

[1] Bosch H.-S. et al.: *this conference*

[2] Staebler A. et al.: *this conference*

[3] Ryter F. et al.: *Europhys. Conf. Abstr.* **19C IV**, 89 (1995)

[4] H-Mode Database Working Group, presented by Kardaun O.: *Plasma Phys. and Control. Nucl. Fus. Res., Proc. 14th Int. Conf. Würzburg*, 1992, IAEA, Vienna, **3**, 251 (1993)

[5] ITERH.DB3 confinement database (1998), released by the ITER H-mode Database Working Group, ITER Physics Basis Doc Ch. 2.6, *subm. to* Nucl. Fusion

[6] Suttrop W. et al.: Plasma Phys. Control. Fusion **39**, 2051 (1997)

[7] Suttrop W. et al.: *Europhys. Conf. Abstr.* **19C III**, 237 (1995)

[8] Pereverzev G.V. et al.: IPP Report **5/42**, MPI f. Plasmaphysik, Garching (1991)