

## **Influence of the beam isotope and of the plasma composition on the performance of plasmas with a radiating mantle in TEXTOR-94.**

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### 1. Introduction

The RI-Mode on TEXTOR-94 [1] is a well-established and robust plasma regime, combining simultaneously high confinement (with a quality between ELMy and ELM-free H-Mode confinement), high density (close to or even above the Greenwald limit) and high radiation (up to  $P_{\text{rad}}/P_{\text{tot}}=95\%$ ) in a mantle around the plasma. Up to now, most RI-Mode experiments have been performed in deuterium plasmas heated at by least 25% of D<sup>0</sup> NBI-co injection in the total heating power. In this paper we investigate the influence on confinement resulting from changes in the beam isotope and main plasma isotopic composition in radiative mantle experiments on TEXTOR-94.

### 2. Experiment

#### a. Method

To investigate the influence of the heating channel on the performance of beam heated impurity seeded discharges, we have used two tools: changing the beam species and changing the plasma composition. Both influence in a different way the critical energy  $E_c$ , determining the fraction of the beam energy deposited to electrons and ions. The critical energy is defined as [2]:

$$E_c = 14.8 A_b T_e [n_e^{-1} \sum (n_i Z_i^2/A_i)]^{2/3}$$

where  $T_e$  and  $n_e$  are resp. the electron temperature and density,  $A_b$  the atomic mass of the injected beam particles and the sum runs over the different plasma ions with mass  $A_i$  density  $n_i$  and charge  $Z_i$ .

Change in plasma composition. For a hydrogen/deuterium plasma with light impurities, the factor  $[n_e^{-1} \sum (n_i Z_i^2/A_i)]^{2/3}$  can be simplified to  $[0.5(1 + c_H)]^{2/3}$  with  $c_H = n_H / n_e$  the hydrogen concentration of the plasma. Changing from H to D plasmas reduces the critical energy by 37%.

Change in beam species. Changing the beam species from hydrogen to deuterium will double the value of  $E_c$ . Note, however, that this will also change the shape of the beam power deposition profile.

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At a constant electron temperature, a factor of about 3 difference in  $E_c$  (with a corresponding change of a factor of two in the ratio of beam electron to ion heating for the discharges considered here) can thus simply be obtained by changing from  $D^0 \rightarrow H^+$  to  $H^0 \rightarrow D^+$  heating.

### b. Results

The results discussed in this paper have been obtained from  $H^0$  or  $D^0$  injection in  $H^+(D^+)$  Ne seeded plasmas with a hydrogen content ranging from 10 to 80%. The hydrogen content is measured at the edge from  $D/H$  intensity measurements. Assuming the same concentration in the centre is consistent with neutron production measurements. For all combinations we have tested we found an increase in confinement during neon seeding. The increase in the energy at the moment of the Ne seeding is the highest for  $D^0 \rightarrow D^+$  injected plasmas, resulting in RI-Mode plasmas with an enhancement factor  $f_{H93} = 1$  for the energy confinement with respect to the ITERH93-P scaling at high densities with  $n/n_{GW} = 0.95$ , with  $n_{GW}$  the Greenwald density. The increase in stored energy during impurity seeding is less with  $H^0$  injection. This is observed immediately at the start of the  $H^0$ -NBI-co injection, even under conditions where the plasma composition is nearly unchanged compared to discharges with  $D^0$ -NBI-co heating. In Fig.1, we show the diamagnetic energy obtained in a  $H^0$  NBI-co discharge, compared to a discharge with otherwise similar plasma parameters, but heated with  $D^0$  NBI-co. As the contribution of the fast particles to the diamagnetic energy is rather low at the high densities realised (less than 5% from TRANSP [3] simulations), this result indicates that some role has to be played by the mass of the injected fast particles in establishing the plasma stored energy.

In addition a gradual decrease in confinement is observed with increasing hydrogen content of the plasma. A statistical overview of the experimental values obtained for the energy confinement time as a function of the hydrogen content of the plasma is shown in Fig. 2. The decrease in confinement is stronger than given by the mass dependence in the ITERH93-P scaling law ( $\tau_E \propto A_i^{0.41}$ ), as indicated by the dashed line in the figure. Remarkably, this difference in confinement with plasma composition and heating method is obtained for nearly unchanged plasma temperature and density profiles. The peaking of the density and temperature profiles obtained during Ne seeding varies very little with the plasma composition or injected beam species. This is illustrated in Fig. 3, where we have plotted electron density and temperature profiles for the  $D^0$  NBI-co and  $H^0$  NBI-co heated discharges of Fig.1, before (full lines) and during Ne seeding (dashed lines).

### 3. Evaluation of the influence of plasma composition and injected beam species on confinement.

We start from the energy balance equations for ions and electrons integrated over the plasma volume:

$$dE_e/dt + E_e/\tau_e = P_{OH} + P_{add,e} - P_{e,i}$$

$$dE_i/dt + E_i/\tau_i = P_{add,i} + P_{e,i}$$

with  $\tau_e$  and  $\tau_i$  resp. the electron and ion energy confinement time,  $P_{OH}$  the ohmic heating power,  $P_{add,e}$  and  $P_{add,i}$  resp. the additional heating power to electrons and ions, (note that losses due to convection, conduction and radiation are taken into account in the definition

of  $n_e$  and  $T_i$ ) and  $P_{e,i}$  the equipartition power transfer from electrons to ions. This last term can be written as  $P_{e,i} = \int n_e(T_e - T_i) dV / \tau_{equ}$ , where  $\tau_{equ}$  is an averaged equipartition time over the plasma volume, defined as

$$\tau_{equ} = 0.99 \times 10^8 \int n_e(T_e - T_i) dV / \int n_e(T_e - T_i) / [T_e^{1.5} n_e^{-1} / (n_i Z_i^2 / n_e A_i) \ln \Lambda] dV$$

with  $n_e$  in units  $m^{-3}$  and keV and  $\ln \Lambda$  is the Coulomb logarithm. Note that  $\tau_{equ}$  is not only determined by the electron density and temperature, but also by the plasma composition, leading to shorter equipartition times with increasing hydrogen content. To investigate the role of the heating mechanism and equipartition, we express the global confinement time  $\tau_{exp}$  under stationary conditions as a function of the equipartition time and the electron confinement time. We obtain:

$$\tau_{exp} = 2 \tau_e [1 / (1 + \beta)] + 2 \tau_{equ} [1 / (1 + \beta) (1/2 + (1 - \beta) / (2 \beta) - 1 / (1 + \beta))]$$

where  $\beta = P_i / P_{tot}$  (with  $P_i$  total heating of the ions and  $P_{tot}$  the total plasma heating), and the ratio between ion and electron energy confinement times. The influence on  $\tau_{exp}$  of the equipartition time becomes maximum for very large  $\beta$ , and then the global confinement time  $\tau_{exp} = 2 \tau_e + \tau_{equ}$ , which then becomes independent of  $\beta$ . From TRANSP simulations of the different discharges we have compiled the table below, summarizing the data obtained for the different cases.

Shot	Beam Species	$n_H / (n_H + n_D)$	$\beta = P_i / P_{tot}$	$\tau_{exp}$ [ms]	$\tau_{equ}$ [ms]	$\tau_e$ [ms]
82436	D <sup>0</sup>	0.12	0.34	65	12	4.0
82439	H <sup>0</sup>	0.21	0.25	54	9.5	2.4
82462	H <sup>0</sup>	0.80	0.28	39	7	2.0
82476	D <sup>0</sup>	0.60	0.36	46	7	2.5

From this table follows that the observed change in the experimental energy confinement time  $\tau_{exp}$  due to changes in the equipartition time and in the repartition of the heating between ions and electrons is maximum about 4 ms, and thus the changes have to be attributed to  $\tau_i$  and/or  $\tau_e$ .

#### 4. Discussion

From the values obtained for  $\tau_{equ}$  in the previous section, it is clear that changes in the heating channel or in the equipartition time due to a change in the injected beam species or plasma composition cannot explain the differences in energy confinement obtained. An additional argument showing that the heating channel cannot explain the difference in confinement observed is that changes in  $\beta = P_i / P_{tot}$  are not correlated with the changes in the global confinement time observed. It is also difficult to believe that differences in the shape of the energy and particle deposition profiles could cause the confinement effects observed, as this does not depend, for given density and temperature profiles, on the composition of the target plasma. Moreover, from TRANSP simulations a decrease in  $\tau_e$  for the outer part of the plasma radius has been found when going from H<sup>0</sup> D<sup>+</sup> to D<sup>0</sup> D<sup>+</sup> discharges with rather similar basic plasma parameters as illustrated in Fig. 4, evidence for a fundamental change in confinement. Therefore, another mechanism has to be invoked, as e.g. stabilization or destabilization of different plasma turbulences by the injected fast neutrals. With respect to this last point, it is interesting to note that (within the error bars) the same plasma profiles can be obtained for rather different energy confinement times and obtained with totally different heating mechanisms. As the main

reason for establishing the RI-Mode is now thought to be the stabilization of turbulence due to ITG modes [4] and this stabilization effect is determined (among other effects) by the peaking of the density profile, this result gives additional arguments for the fact that other factors than ITG mode stabilization appear to play a role in establishing the value of the stored plasma energy in Ne seeded discharges on TEXTOR-94.

### 5. Conclusions

By varying beam species and main plasma composition in beam heated impurity seeded discharges, we find differences in confinement which cannot be explained by differences in the heating mechanism, equipartition time or beam energy deposition profile.

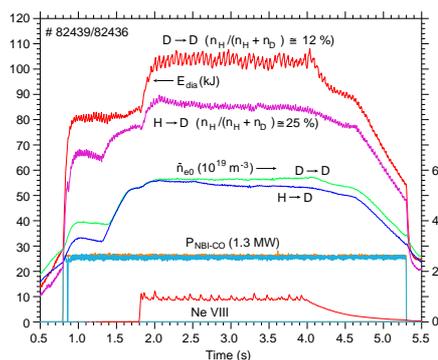


Fig.1: Comparison of the stored energy for a  $D^0 D^+$  and  $H^0 D^+$  heated discharge with Ne seeding, with similar basic plasma parameters.

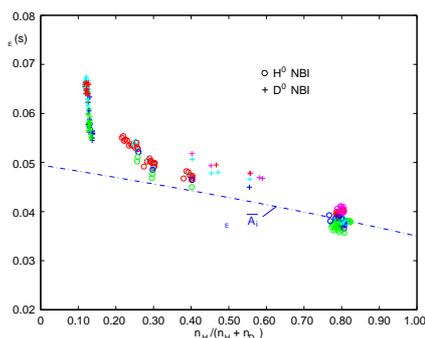


Fig.2: Statistical overview of the energy confinement time in H/D discharges with Ne seeding as a function of the hydrogen concentration. Red (green) symbols represent highest (lowest) Ne concentration.

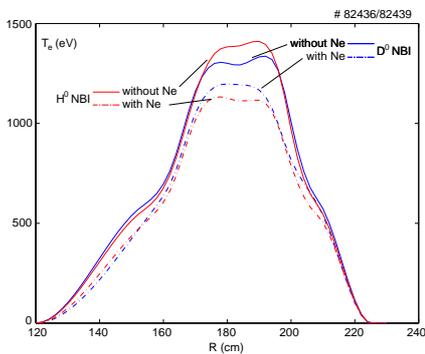
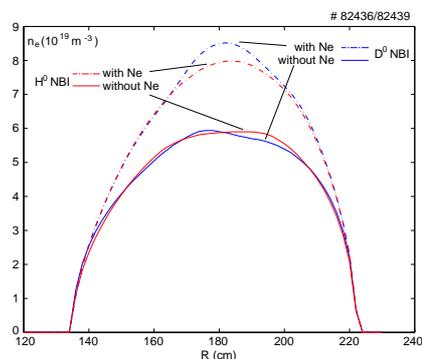


Fig.3 : Profiles of electron density (a) and temperature (b) for the discharges of Fig.1 before ( $t=1.5s$ ) and during ( $t=3.0s$ ) Ne seeding.

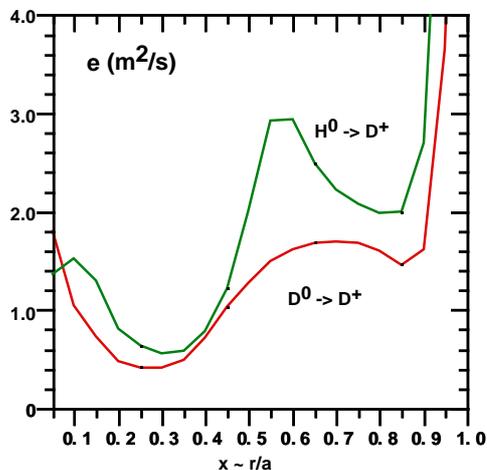


Fig.4: Radial profiles for  $\chi_e$  for the discharges of Fig.1 at  $t=2.4s$

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