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Influence of isotopic composition on the performance of plasmas with a radiating mantle in TEXTOR

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Introduction

The Radiative Improved (RI) Mode on TEXTOR is a well-documented and robust plasma regime, combining high confinement, high density (close to or even above the Greenwald limit) and high radiation in a mantle around the plasma. Most RI-Mode experiments have been carried out in D plasmas with D fuelling and a strong correlation is found between the enhancement factor of the confinement with respect to the RI-Mode scaling (τ_{RI}=K$\overline{n}_e P^{-2/3}$) and the peaking of the density profile γ_n, the edge neutral pressure p_n and the recycling flux Φ_R.[1-3] In this paper we present the comparison between the confinement properties of the RI mode obtained in pure D plasmas and in pure H or mixed H/D plasmas.

Comparison of energy confinement properties of discharges in Deuterium and Hydrogen

The discharges in Hydrogen and in Deuterium for which we study the isotopic dependence are discharges heated with 1.3 MW Neutral beam of Hydrogen or Deuterium in the Co direction and with seeding of Ne to produce the transition to the RI mode.

In L mode discharges, the energy confinement time depends on $\sqrt{A_i}$ and in the H mode, the ITER- H 93p law predicts an almost similar dependence in $\overline{A_i}^{0.41}$. Assuming this dependence on the atomic mass, we will adopt the following relationship for the energy confinement time and we will test it with respect to our experimental measurements:

$$\tau_{RI} = \sqrt{\overline{A_i}}\,\mathrm{K}nP^{-2/3} \text{ with } \overline{A_i} = \sum_{i=1,2} \frac{A_i n_i}{n_e}. \qquad (1)$$

To highlight the deviations of the measured energy confinement time τ_E with respect to this law, we will divide the measured confinement time by τ_{RI} as given by (1). We present in figure 1 the normalized $\tau_{norm} = \tau_E / \tau_{RI}$ as a function of $\overline{n_{e0}} / n_{GR}$.

It is observed:

- that in Hydrogen plasmas, it is more difficult to obtain a high plasma density without a degradation of the confinement time.
- that the confinement time follows more or less the law (1), but there is a relatively large dispersion of the results around this law. The large dispersion in the dependence

of $\tau_{norm} = \tau_E / \tau_{RI}$ as a function of $\overline{n_{e0}} / n_{GR}$ is at least partly linked with the correlation between the quality of the energy confinement time and the level of recycling flux. In Deuterium plasmas, the degradation of the quality of the confinement when the recycling flux is increased was already reported [3]. A similar correlation is observed here in Hydrogen discharges (fig. 2) but the recycling flux is on the average larger in Hydrogen plasmas for a given value of $\overline{n_{e0}} / n_{GR}$. The difference in confinement time between H and D at high densities is correlated with the fact that these high-density discharges are obtained with larger recycling fluxes.

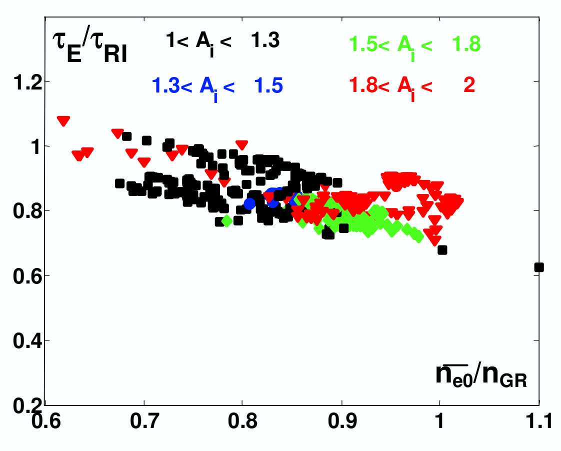

Fig. 1 Evolution of τ_E / τ_{RI} as a function of $\overline{n_{e0}} / n_{GR}$ for different isotopic compositions of the plasma.

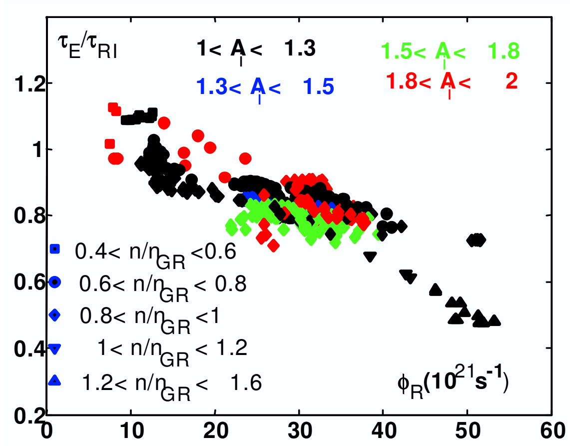

Fig. 2 Evolution of τ_E / τ_{RI} as function of recycling flux for different isotopic compositions of the plasma.

In a series of similar discharges we observed also that the seeding of Neon leads to a decrease of the recycling flux that varies linearly with the quantity of Neon injected. The absolute value of the decrease in recycling flux for a given quantity of Ne is almost the same for both Hydrogen and Deuterium plasmas. Because the recycling flux in Hydrogen plasmas is larger than in Deuterium plasmas in the absence of Ne seeding, Ne injection does not reduce the recycling flux in Hydrogen plasmas to the levels measured in Deuterium plasmas.

Impact of gas puffing

To study the impact of the blowing gas on recycling flux, a series of similar Deuterium discharges were carried out with Neon seeding followed by a puff of H or D. Because of the limited quantity of H or D blown in the discharge, the mean isotopic composition of the plasma is only slightly modified by this gas puff. In fig 3 we present the time evolution of the main plasma parameters. We observe that

- Seeding of Neon produces immediately a reduction of the recycling flux and the peaking of the density profile even if the energy confinement time is not yet proportional to the density (fig 4-6).
- Increase of τ_E occurs when H or D gas is injected in the plasma and higher densities are reached. Evolution of the energy confinement time as function of n_e / n_{GR} for the cases of D or H puffing is presented in fig 4.

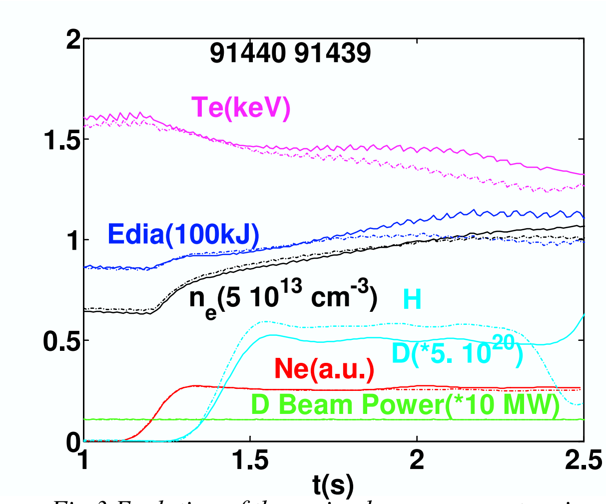

Fig 3 Evolution of the main plasma parameters in similar discharges with puff of D or H.

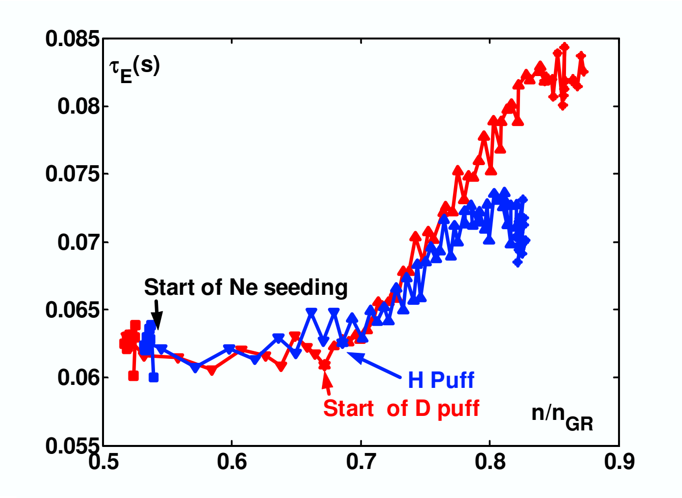

Fig. 4 Evolution of energy confinement time with n_e/n_{GR} *showing difference between H and D puff.*

-With the same amount of injected gas, the increase in density is lower when Hydrogen is puffed.

- Peaking of density profile due to Neon injection is maintained during Deuterium puff, which is not the case when Hydrogen is puffed at the same rate. (Fig. 5b)

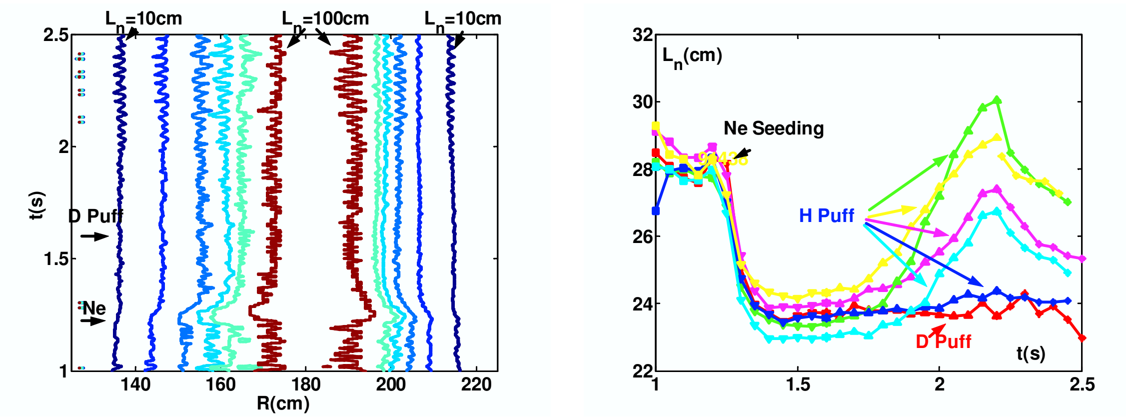

Fig 5. Evolution of characteristic lengths of the density $L_n = |n_e/(dn_e/dr)|$

Ne seeding is started at t=1.2 s. D is puffed from t=1.6 s to t=2.2 s.

a) Contour plot of L_n *as function of time and R at* L_n *= 10,20,30,40,50,100 cm.*

b)Time evolution of L_n *at radius R=150cm.(-- D, -- H(same rate as for D), -- H more Ne, -- H less Ne, -- H less gas,--H more gas) (red line: Deuterium, other lines: Hydrogen)*

The evolution of the characteristic length of the density $L_n = |n_e/(dn_e/dr)|$ shows that L_n is decreasing around a/2 (a=46 cm) at the beginning of Neon seeding. L_n is not modified by the puffing of D but, when Hydrogen is puffed, it increases around r=a/2 after some time. (Fig 5). Low L_n is slowly recovered at the end of the gas puff.

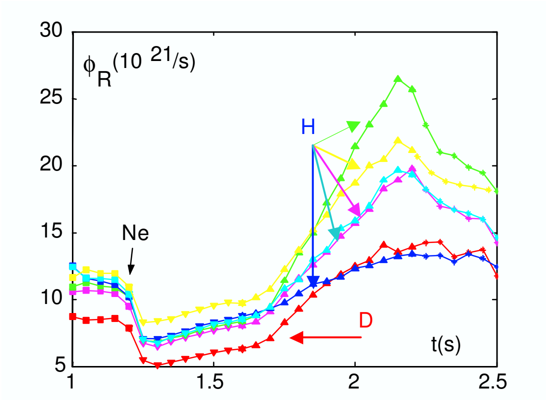

Fig 6. Time evolution of the recycling flux For various conditions of Ne seeding and H or D puffed from t=1.6 s to t=2.2 s. (idem fig 5b)

-Recycling flux Φ_R is increasing during the gas puff and is larger when Hydrogen is puffed in the discharge instead of Deuterium. The correlation between L_n and Φ_R is striking(fig. 5 and 6). To avoid the effect of gas puffing on L_n and on the recycling, the flux of Hydrogen puffed in the discharge must be significantly smaller than for Deuterium injection($\sim 2.10^{20}$/s). When more Neon is seeded in the discharge, more Hydrogen or Deuterium can be puffed in the plasma without loosing the peaking of the density profile and with lower recycling.

It has been reported in [2] that the energy confinement time is largely influenced by the shape of the plasma density profile and by the recycling flux in the discharge. The observation that both the peaking of the density and the recycling flux change when replacing Deuterium by Hydrogen gas puffing can thus explain partly the change in confinement time observed.

Conclusions

The RI mode energy confinement time scaling law possesses a dependence in atomic mass approximately equal to $A_i^{0.5}$ which is also the usual isotopic dependence in L and H modes. The correlations of the energy confinement time with the density peaking factor, and Φ_R in Hydrogen plasmas are similar to those observed in Deuterium plasmas. In Hydrogen plasma it appears more difficult to reach densities close to the Greenwald density without degradation of the confinement. A detailed study of this effect has been undertaken by first seeding Neon impurity in a medium density plasma to produce a radiating mantle followed by a D or H gas puff to rise the density. Different negative effects associated to Hydrogen fueling were observed: (i) a degradation of the confinement time is observed as compared to the case of Deuterium injection even if the plasma isotopic composition stays nearly unchanged; (ii) Peaking of the plasma generated by Neon fueling is counteracted by the injection of Hydrogen. A similar negative effect of fueling can occur in Deuterium injection but only at a much higher fueling rate. After the end of the H fueling, confinement and density peaking have a tendency to recover. The negative effect of H fueling can only be suppressed by going to very low fueling rates, much lower than usually necessary for D fueling. (iii) At a given density the recycling flux is on the average higher in the case of H injection with respect to D.
All these experimental facts prove that the gas puff flux, although being much smaller than the recycling flux, plays an important role in the control of the energy confinement time of the plasma.

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