Energy and particle balance studies under full boron and lithium-coated walls in TJ-II

F. L. Tabarés, M. Ochando, D. Tafalla, F. Medina, K. McCarthy, M. Liniers, J. Guasp, E. Ascasíbar, T. Estrada, I. Pastor and TJ-II team.
As. Euratom/Ciemat, Av. Complutense 22, 28040 Madrid Spain

1. - Introduction

In this work, the impact of wall coating on the global and radial energy balance of NBI heated plasmas in TJ-II is addressed. Comparison of the plasma performance under boron and lithium walls allows us to distinguish between particle balance (i.e. recycling) and energy balance-related effects concerning the specific characteristics that have been found under fully lithiated walls in TJ-II [1]. Example of these characteristics are the spontaneous development of peaked plasma profiles and their transition to broader, cleaner ones and the onset of plasma collapse as defining the operational density limit [2]. It is shown here that, by external gas injection, it is possible to get some control on plasma profile, and a possible mechanism is proposed in order to account for the observations made in perturbative fuel and impurity injection experiments.

On the other hand, ion energy balance under very low recycling conditions, such as those obtained under Li walls in TJ-II, could be strongly modified due to minimization of charge exchange losses and the concomitant flattening of edge Ti profiles [3]. The possible changes in Ti (a) values will be directly reflected on the sputtering characteristics of Li from the walls. This point has also been addressed in this work, and the absolute values and Te dependence of the effective Li sputtering have been computed under ECR and NBI heating conditions. No evidence of enhanced peripheral Ti under low recycling wall conditions has been found to date.

2. - 0-D Energy Balance

At the end of 2007, a campaign was initiated in TJ-II aimed at comparing the effects of wall coating on plasma parameters under the same heating and configuration conditions. Although, due to density control problems, a lower range of plasma parameters (electron density, energy content,) was accessed under boronized walls, for the overlapping region ($ne_{line} < 2.5x10^{19}$ m^{-3}) a high similarity in global plasma parameters was found. In figure 1, the resulting values for volume average electron temperature (defined as the ratio of total diamagnetic energy content to the line average electron density) and maximum Ti achieved are shown for both wall scenarios. As seen, no significant difference can be claimed for these parameters at densities in the range of ECRH and low-density NBI values. This is more evident if the possible energy loss channels, Prad and the energy-integrated charge exchange fluxes, are compared. These parameters, normalized to the average density, are shown in figure 2. Again, no systematic difference is seen in the overlapping range of densities respect to the type of conditioning, if allowance for the shot to shot dispersion is made for. However, a significant improvement in confinement can be deduced for lithiated walls at higher densities than those shown here [4]. This is precisely the range over which plasma profile undergoes the spontaneous transitions described in the next section.

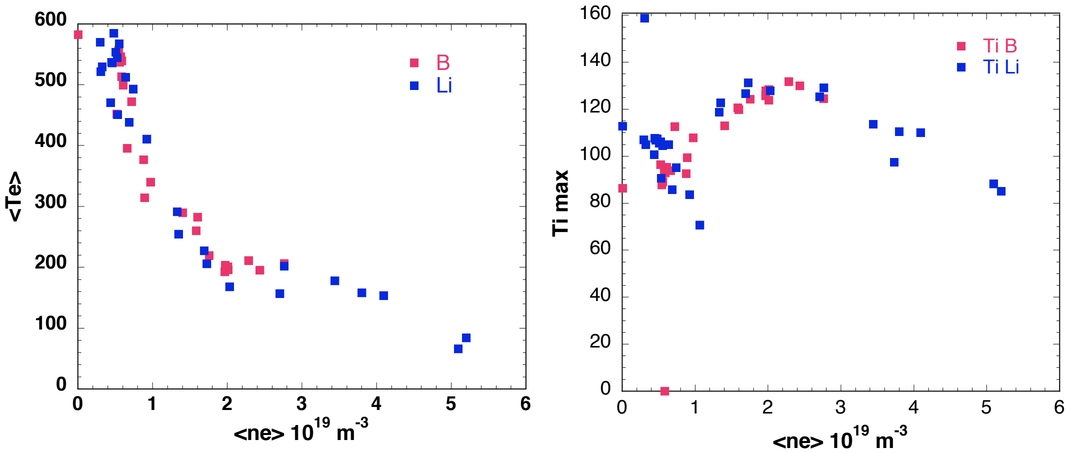

Figure 1. Evolution of average plasma electron (left) and ion (right) temperature with electron density for B and Li coatings.

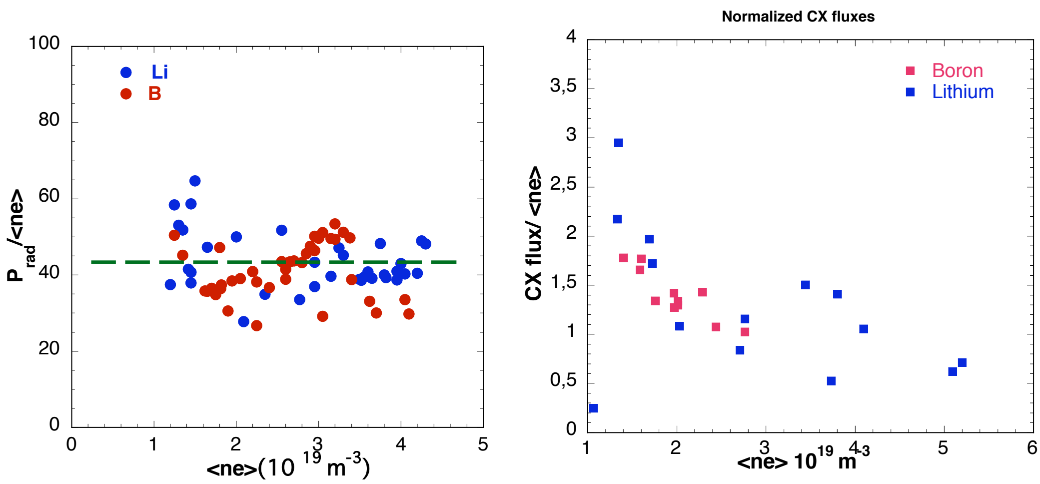

Figure 2. Normalized radiation (left) and CX (right) losses for B and Li coatings

3. Radial profiles of plasma parameters.

One of the most interesting phenomena observed under the lithium wall scenario is the development of plasma profiles with strong pressure gradients and enhanced central confinement, concomitant to central impurity accumulation. Alternatively, a broader, lower-central Zeff profile can develop under given circumstances. These profiles, whose shapes have been tagged as "bell" and dome" type, respectively, and the transition between them during a shot, are regularly classified and followed from bolometric data. The larger ratio of edge to core emissivity found in the dome profile makes them prone to radiative collapse [5] and therefore they are thought responsible for the density limit achieved under pure NBI heating, at central densities of $\sim 0.8.10^{20}$ m^{-3}. In order to get some insight into the driving mechanism of the transition, perturbative experiments have been carried out in neutral beam heated TJ-II plasmas (two injectors co and counter, 400 kW each). Namely, short pulses of hydrogen were injected into the bell-type plasmas at densities below the critical and the transition to the broader profiles was achieved. Alternatively, hydrogen-diluted neon pulses were used to force the transition and the changes in the so-induced emissivity profiles were recorded. Particle fluxes, Q_{in}, $< 7x10^{20}$ e/s were used for pure H_2 injection, and mixtures having a 5% and a 15% on Ne were injected when required. Besides the standard monitors of TJ-II, the set of diagnostics directly used in this work are a supersonic Helium beam to obtain peripheral profiles of electron density and temperature [6] and bolometer arrays to determine the time evolution of plasma emissivity profiles [7].

4. Results and discussion.

Series of discharges with different target densities (before launching the heating beams) were produced in order to explore the time evolution of electron density from the density-limited collapsing pulses to the stable low-density discharges. With the counter-injected neutral beam, less bell-shaped (little higher edge radiation and electron density) plasmas, as compared with co-injected case, have been obtained so far. Nevertheless, the transitions shown here, from rather peaked to fully dome profiles are also observed when average electron density exceeds $2.10^{19}m^{-3}$.

Detailed perturbative experiments were performed in series of more easily controlled density discharges (under co-NBI) to get some insight into the profile evolution and control. Figure 3 shows the time evolution of the radiation peaking factor, ($Prad_{center}/Prad_{edge}$), during a series of shots with variable level of injection of pure H_2.

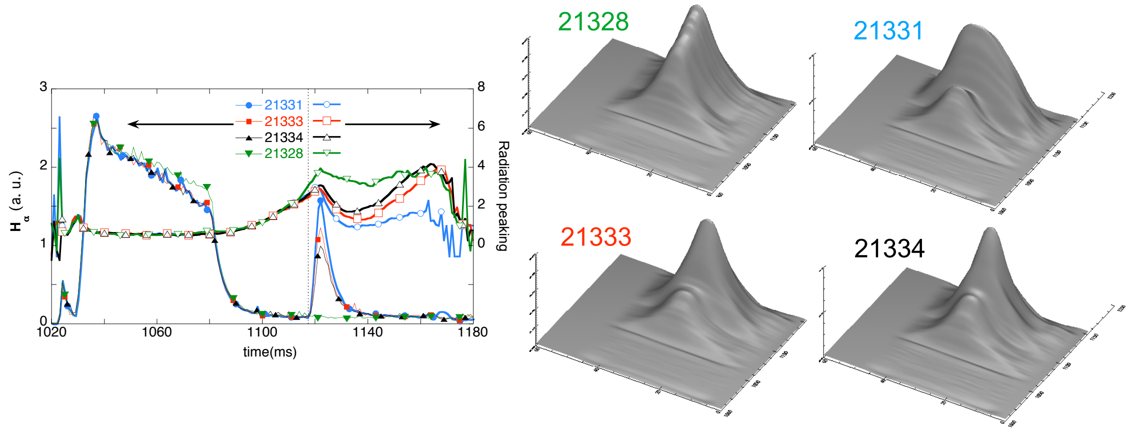

Figure 3. Induction of profile transition by a short gas puff at different amplitudes. For very low levels (21333 and 34) a reversible transition back to the bell type profile is seen. Full emissivity profiles are shown at the right for each discharge.

In a plasma discharge whose radiation profile is strongly peaked, like shot # 21328, the injection of a hydrogen flow can trigger the transition to a broad radiation profile (as occurs in shot #21331). Decreasing the level of the injected flow, the transition may be “softer” and even reversible, i.e., the bell profile can be recovered (shots # 21333 and # 21334), so that a good external control of the plasma radial profile can be achieved by this method. It is worthy to mention that, since the point of view electron density and radiation profiles evolution, the forced transition to the dome profile right after the injection is quite similar to the observed in spontaneous transitions (see Fig. 4).

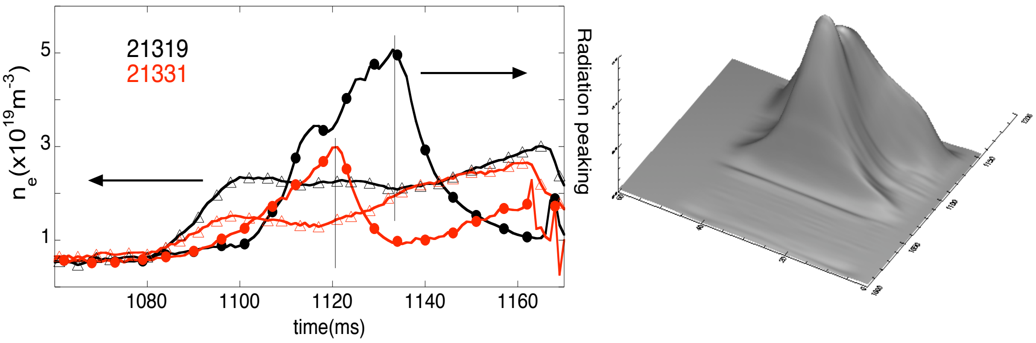

Figure 4. Left) Time stories of electron density and radiation peaking factor for two shots with forced (#21331) and spontaneous (#21319) bell-dome transition. Right) time evolution of emissivity profiles showing the changes from peaked to dome profiles (shot #21319).

Next, mixtures of H_2+ Ne (in volume concentrations of 5 and 15%) were also tried to trigger the transition in discharges with moderate (far from the "spontaneous" transition conditions) electron densities. Preliminary analyses show that the profile-change dynamics is "the same" as in hydrogen-pulse perturbed discharges, namely an almost simultaneous edge increase and core decrease (even sharply observed in central soft x-ray signals) of radiation. Complementary information is achieved by following the edge profiles associated to the different conditions. In figure 5 the radial profiles of electron density and temperature determined with the supersonic He beam diagnostic and recorded right before and after gas-pulse injections of different intensities, are shown. A marked decrease of Te by about 20 eV can be seen under the highest puffing conditions leading to the profile transition. The measured electron temperature reduction was essentially the same under Ne-seeded H_2 injection, even when a much higher effect was expected according to the corresponding cooling rates. Decreasing the gas inflow, the temperature perturbation is lowered until no effect is detected, although the most external radiation detectors still showed a slight and transient signal increase. It must be mentioned that, although the electron density does not appear to be perturbed in this plasma region, the Thomson scattering profiles in the gradient region (0.3 - 0.7 r_{eff}) show changes quite similar to the observed in the radiation profiles shown in Fig. 3.

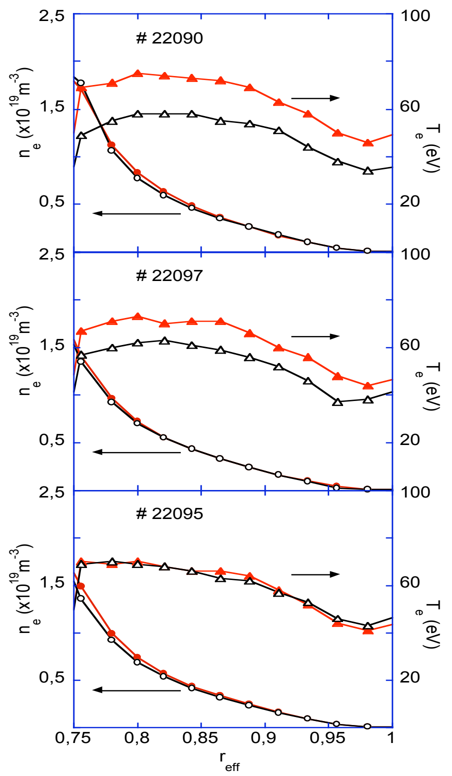

Fig.5 Edge profiles of electron density and temperature before (red lines) and after (black) Ne-seeded H_2 injections.

From the observations presented here, it can be suggested that profile shapes are indicative of how the fast, NBI neutrals couple with the plasma core. In this sense, enhanced peripheral charge exchange process could be a candidate to explain the profile dynamics.

5. In situ measurements of Li sputtering

One direct consequence of reduced ion energy losses under low recycling scenarios would be a higher value of the peripheral ion temperature. The sputtering yield of Li in H plasmas was evaluated by following the Li/Hα emission signals and using the corresponding S/XB factors [8]. Edge temperatures were again obtained with the He beam diagnostic and the ECE signal at the edge when available (ECRH phase). Radial profiles of Ti are obtained from the NPA diagnostic, although data at the LCFS are not as accurate as at the plasma core. Absolute sputtering yields lower by a factor of >10 with respect to those reported from laboratory experiments [8] were deduced form the measurements. However, it was found that a decay of this yield by a factor of two could be readily ascribed to the effect of He GD, performed at the beginning of the day for film conditioning. The dependence of the yield with edge temperature is displayed in figure 6. If one assumes that the energy of impinging ions on the wall is given by the usual expression (assuming Te=Ti): E ~5 kTe, then a slight decay of the yield at the highest Te values should be seen, and no threshold would be seen. The observed trend thus implies either a very low energy of impinging particles or a binding energy for the Li atoms in the film much higher than the one corresponding to pure lithium. The expected mixing by plasma erosion of the two film components (B and Li) appears as a possible candidate for this higher value, but an experimental effort aimed at the direct recording of the plasma ion energies at the film surface is presently being undertaken in order to clarify this point.

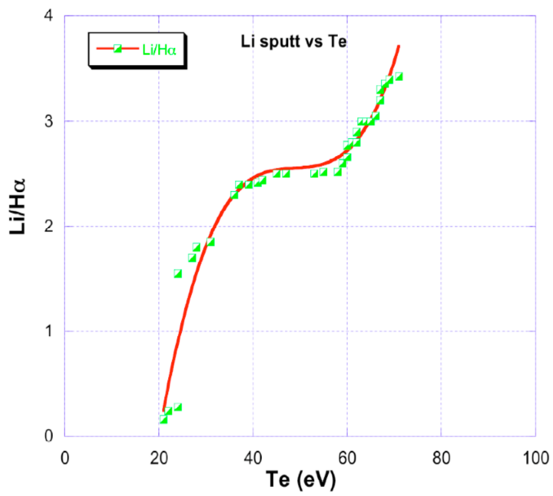

Figure 6.Li sputtering yield (a.u.) versus electron temperature at r=0.95

1] F.L. Tabarés et al. Plasma Phys. Control. Fusion **50,** (2008) 124051
2] L.E. Zakharov et al. J.Nucl. Mater. 363-365 (2007) 453
3] F.L. Tabarés, M.A. Ochando et al. 36th EPS 2009, Sophia, Ru.
[4] E. Ascasibar et al. These Proceedings
[5] M.A. Ochando, F. Castejón and A. P. Navarro Nucl. Fusion **37** 225 (1997)
[6] A. Hidalgo, et al. Rev. Sci. Instrum. **75** (2004) 3478
[7] M. A. Ochando et al., Fusion Sci. Technol. **50** (2006) 313
[8] J.P.Allain, D. G. Whyte and J. N. Brooks, Nucl. Fusion **44**(2004) 655.