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Particle balance in TJ-II plasmas under boronized wall conditions

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Introduction

The retention of fuel particles on the plasma facing materials of fusion reactors is nowadays a major concern in fusion research in close relation to tritium built-up in reactors [1]. To date, no systematic accountability of the injected deuterium has yet been achieved in carbon-based PFM´s, and some of the trapping mechanisms are not fully understood [2][3]. On the other hand, and from a practical point of view, a good density control in TJ-II is mandatory in order to improve its performance. Only low Z materials are exposed to the plasma: the walls of TJ-II were previously boronized (Orto-carborane, ~50 nm, [4]). In addition, the two movable, poloidal limiters are made of graphite and carbon tiles are installed for protecting the vessel from NBI. In this work, some studies on the global particle balance in ECRH and NBI heated plasmas are presented. These findings are discussed under the light of the present knowledge on fuel retention in fusion devices.

Experimental

A calibrated, fast capacitance manometer was used to record the injected particle flux, and the released particles (H_2) were evaluated by a differentially pumped mass spectrometer. Helium glow discharges were eventually used for recovering the wall status. Other diagnostics, including ionization gauges (vessel pressure) and H alpha monitors have also been used. Operation of TJ-II is always performed at room temperature.

Results and Discussion

The wall content of particles was monitored during last campaigns in TJ-II. Under most conditions, a limit was observed that corresponds to wall saturation at $4.5 \cdot 10^{20}$ particles for the standard configuration (100_44_54). However, this limit can be avoided sometimes by careful spacing of non-fuelled shots, and further analysis of this effect is still necessary. When the saturation value is achieved the density control is very problematic, and transitions to plasma densities above the cut-off limit are often produced. This is aggravated by the presence of the transition to the EPC mode at line density values ~ $6\text{-}10^{12}$ cm^{-3} [6]. Taking a saturation value of the B/C layer of ~ 8.10^{16} cm^{-2} [1] and the plasma-wall geometry of TJ-II, an effective belt of interaction of <10 cm (poloidal) along the 10 m toroidal limiter can be estimated. This corresponds to a fraction the indented part of the vessel protecting the central coils. Figure 1 shows an example where this limit is reached. Helium glow discharge was applied during 30' after shot 12300 to deplete the wall, but as seen, density control is again lost as wall saturation is reached again.

In these analyses it was found that the NBI injector behaves as an important source of particles. This source is much higher than the expected contribution to the density built-up by the energetic neutrals, and it appears as a result of the migration of gas from the NBI's neutralizer to the vacuum vessel of TJ-II through the connecting duct. Typical values for this extra source are $3{\cdot}10^{19}$, reaching values up to $7{\cdot}10^{19}$ H atoms. Figure 2 shows that the relative strength of this contribution is always significant when compared to the plasma fuelling by gas puffing, and this flux must be taken into account on the particle balance. Also shown in the figure are amount of particles released between pulses, as measured with the mass spectrometer. It was found that the released gas after shots is almost insensitive to the amount of injected particles. This behavior has been observed also in other devices [2].

A relationship between the fraction of injected particles/shot that are trapped into the wall and the instantaneous inventory of the vessel was found to exist. Figure 3 shows how this ratio falls through a day of operation. Also shown are examples of pulses in which the cut-off density limit is overcome. In these shots, an increase of around a 20% in the particle inventory was found. To this point, the reason for that it is not clear, and both, the higher densities and lower plasma temperature of collapsing shots, leading to a shallower implantation could account for it.

The instantaneous flux of particles to the wall can be written as:

$$\Gamma \approx \frac{n_e \cdot V}{\tau_p}$$

With n_e electron density, V plasma volume and τ_p particles confinement time (~5-10 ms [5]). If the area density of trapped particles is known, it is possible make an estimation of a "effective" trapping efficiency, t, during a shot. This is defined as the ratio between the total trapped particles to the total fluency during a shot. Then, a "mean" recycling factor R=1-t is estimated. In Figure 4 values of R for an experimental session are shown. It can be seen that this factor rises with time, corresponding to increasing wall content. On the other hand, the wall evolution can also be followed from the Hα emission normalized to the electron density for constant plasma parameters. As shown in Figure 5, the normalized Hα and the "mean" recycling factor show a very similar behavior.

Post pulse outgassing of hydrogen molecules exhibit a time evolution characterized by a single power dependence of the type t^{-n}, with n≈0.7 independent of experimental conditions. This is consistent with a recombination limited diffusion mechanism [6]. Figure 6 shows this point with data obtained from the mass spectrometer analyzer, although the same behavior is observed from the machine's manometer readings.

Conclusions

Characterization of wall inventory in TJ-II has been possible by using a few diagnostics. A saturation limit corresponding to ~ $5 \cdot 10^{20}$ particles for the standard configuration was found. This value implies a highly localized plasma-wall interaction area. Density control above this limit can only be achieved by He Glow Discharge conditioning, restoring the initial state of the wall.

An excellent agreement between recycling diagnostics (Hα vs Mass Spectrometer) has been found. It allows for the continuous monitoring of wall status in TJ-II.

Strong contribution of NBI-related gas sources have been found in neutral-heated plasmas. This contribution can even become the main source of particles under given conditions.

The hydrogen outgassing between shots shows a $t^{-0.7}$ behaviour, consistent with recombination limited diffusion.

Acknowledgments

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References

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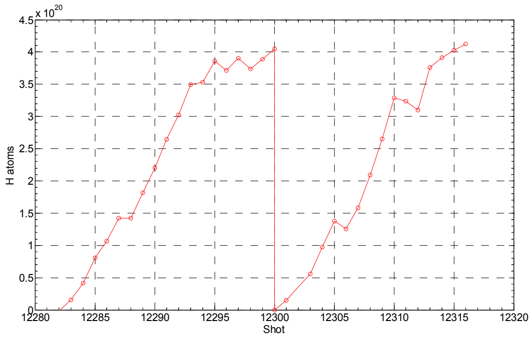

Figure 1. *Total particle inventory. At shot 12300 He Glow Discharge. Density cut-off in last pulses before and after glow.*

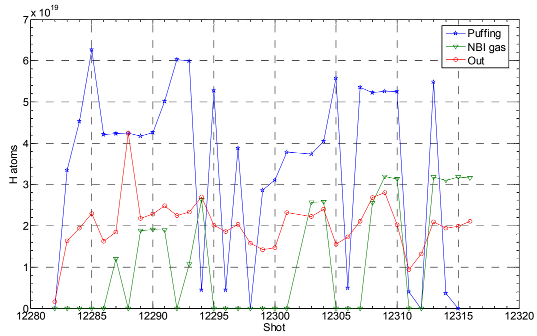

Figure 2. *Injected particles by the puffing valve (blue stars) and NBI (green triangles) and released ones, measured by the quadrupole analyzer (red circles).*

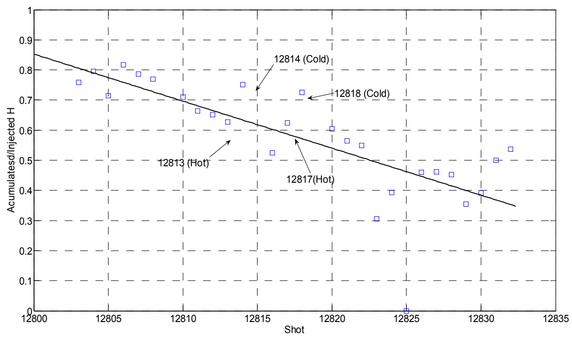

Figure 3. *Evolution of ratio between accumulated particles and incoming flux. The figure also shows how cold dense plasmas accumulate more hydrogen than that hot ones.*

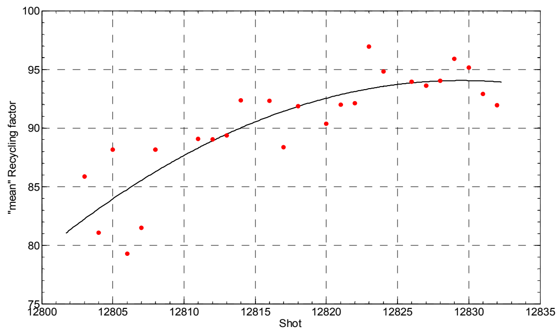

Figure 4. *Evolution of the "mean" recycling factor (see text)*

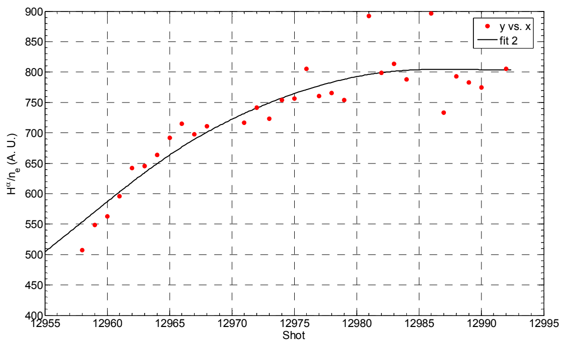

Figure 5. *Evolution of the normalized Hα*

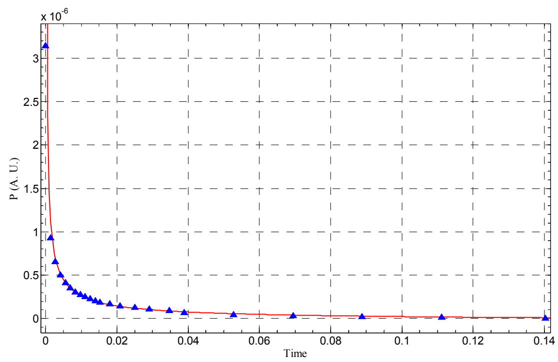

Figure 6. *Outgassing after a shot. Experimental points and fitting* ($t^{-0.7}$)