Isotopic plasma wall changeover experiments during long discharges in Tore Supra

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I - Introduction

Particle control is a critical issue for ITER: particle injection and extraction systems must regulate the D-T fuel densities, exhaust helium ash and minimize the tritium (T) vessel inventory. A retention rate of 10% of the T injected in ITER ($200 Pam^3s^{-1}$) would lead to the in-vessel T-limit (~700g) in ~70 pulses. In today's tokamak dominated by carbon, retention rates by co-deposition in the order of ~20-30% are regularly obtained [1]. Although ITER will not operate with a D-T mixture whilst the divertor targets will be in carbon, co-deposition of D with Be will occur. In present fusion devices, a part of the long term hydrogen retention has been found to be accessible by He or isotope exchange with plasma [2]. In ITER, the end of the discharge could be used for reducing the amount of T trapped by switching to He or H_2 injection during the ~200s of plasma following the burning phase. Thanks to the long discharge (>6 min) capabilities of Tore Supra, experiments have been carried out to evaluate the effectiveness of such a scenario in reducing the T inventory during plasma operations. In Tore Supra, the retention rate during long discharge is in the range of ~ $2\text{-}3 \times 10^{20} Ds^{-1}$ (50-60% of the injection) resulting in a regular built up of the D in vessel inventory dominated by co-deposition [3]. The amount of particles accessible by changing the plasma composition from D to He and from D to H has been evaluated. The main processes of particle removal are discussed and the EIRENE code is used to assess the differences observed between He and H change over. Finally, the consequences for the next discharge are also reported.

II - D to He change over experiments

Starting with a device operated only in D_2 since months, the first series, D to He change over, of long discharges (~60 to 110s) has been performed with the following main parameters: I_p=0.7MA, B_T=3.8T, $n_l=3.5 \times 10^{19} m^{-2}$ and 3.8MW of LH. In pure D_2 injection, the retention observed during this discharge is in the range of $2\text{-}3 \times 10^{20} Ds^{-1}$ for a gas injection of

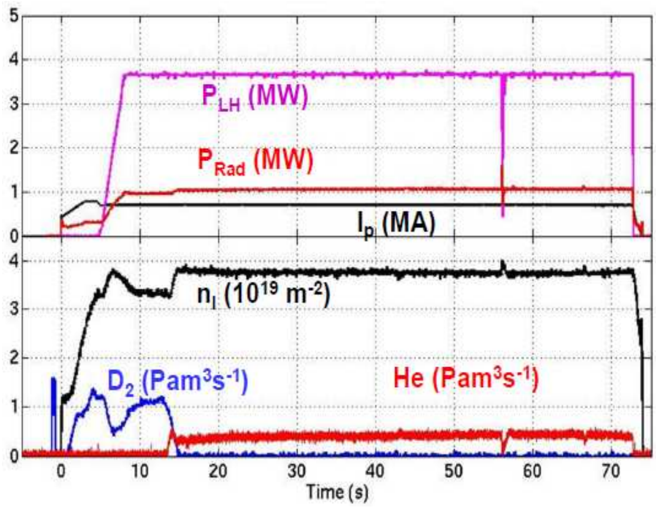

Figure 1: Time evolution of the first discharge (#46701) of the change over experiments series

$5.0x10^{20}Ds^{-1}$(~1.0 Pam^3s^{-1}). Figure 1 displays the general plasma parameters of the discharges run for these studies. For the first pulse of the series (Fig. 1), after 13s with D puffing only, the gas injection was changed to He. The plasma composition started from >90% D and 55s after the D to He transition, the plasma composition was dominated by He with a ratio $n_{He}/(n_{He}+n_D)$> 75%. Steady state conditions were reached after less than 30s as showed by the D_α signal (Fig. 2) emitted from the toroidal pump limiter (TPL) and exhibiting a dramatic drop to a low and steady state value after only 30s of He injection (characteristic time ~11s). The same proportion of D_2 and He is observed in the gas pumped and at the end of this first He discharge (Fig. 1) a net vessel depletion of $3.0x10^{21}$D is obtained. After 2mn10s, this value reaches ~0.8-1.0x10^{22}D. However, with the same plasma parameters, no more gain can be expected since the D proportion in the plasma and therefore in the pumped gas is only in the range of 10%.

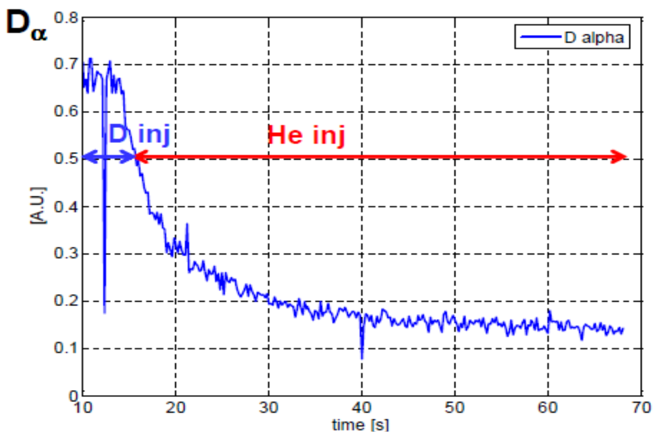

Figure 2: Time evolution of the D_α signal during the change over from D to He (#46701)

III - D to H change over experiments

The device being back to D_2 operation (after 7mn 46s of D_2 injection), the same experiments have been reproduced with a change over from D to H. The results exhibit a different behaviour compared to He since with H gas injection, the D plasma content does not drop significantly. Indeed, after 6 discharges cumulating 4mn 30s of H_2 injection, the plasma isotopic ratio, $n_H/(n_H+n_D)$ is only of ~60% and does not exhibit any sign of significant further increase as illustrated on figure 3 where $n_H/(n_H+n_D)$ is plotted for 6 consecutive discharges. Under these conditions, the D removed from the device is larger than for the He experiments and the D recovered after 130s is ~$9.0x10^{21}$D. After 380s (4mn 30s) the total D recovered is

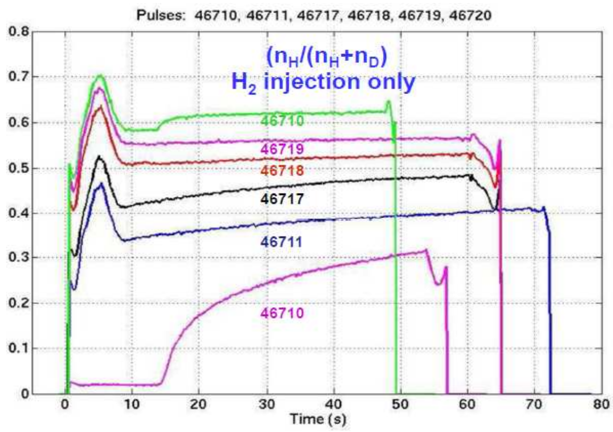

Figure 3: Time evolution of the plasma isotopic ratio $n_H/(n_H+n_D)$ for 6 consecutive plasma discharge with H_2 injection only and cumulating 4mn30 of plasma.

~4.2x10^{22}D whilst $n_H/(n_H+n_D)$ remains in the range of60% suggesting that some more D could be still pumped. It is worth noting that this amount of particle is in the range of the wall inventory supposed to be accessible with plasma operations [4] with the TPL (~8x10^{22}D). For He change over this is only ~10-15% of this reservoir that has been shown to be accessible.

IV - Discussion

From these experiments, compared to He, H plasmas exhibit more potential for minimising T inventory. This higher efficiency is attributed to charge exchange (CX) process which is typically 3 to 6 times larger for hydrogenic species compared to He. It results a stronger interaction with areas away from the "direct" contact area (areas exposed to ion only) with the plasma such as deposition areas. This has been confirmed by preliminary simulations using the EIRENE code (Monte Carlo code for neutral transport in the edge plasma). Figure 4 shows the interaction area of CX flux on a sector of 30° of the TPL for H plasma. This pattern is very similar to the one obtained for the ion flux (He and/or H plasma). The D particles removed from the device come mainly from the areas in interaction with the ion flux; the H and He ions acting as the desorption process onto the D implanted in the material (CFC for the TPL of Tore Supra). However, the CX flux is 5 times larger for H plasma compared to He and stronger plasma wall interaction occurs through CX process with codeposition areas enhancing the amount of D that can be recovered from these areas.

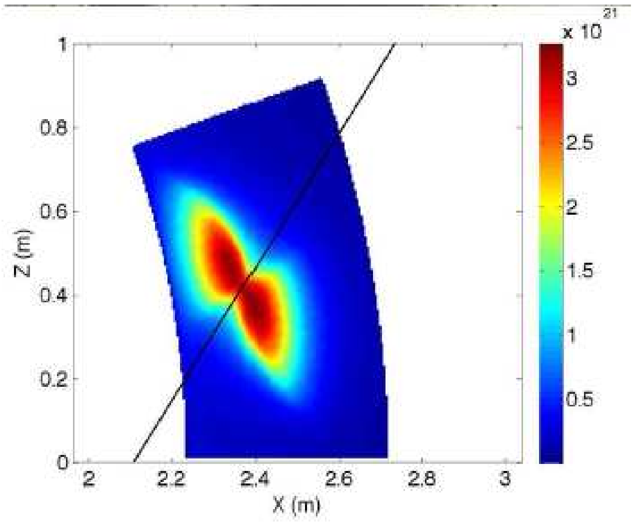

Figure 4: Atomic particle flux (Ds^{-1}) on a sector of the TPL of Tore Supra for an H plasma.

Since D has been removed from the wall, extra D injection has to be performed at the beginning of the next discharge to recover the same plasma conditions as before the change over. After He experiment, the extra amount injected has been evaluated of 2.0x10^{22}D, compared to the $1.0x10^{22}D$ removed. This is the consequence of the desorption process. Indeed, the D atoms removed from the TPL by He atoms are ionised in the SOL and a part of these particles is pumped whilst the rest experience co-deposition. For these discharges, in D, the retention rate is ~ 50% suggesting that a total of ~$2.0x10^{22}D$ has been removed from limiter divided in $1.0x10^{22}D$ exhausted by the pumping system and $1.0x10^{22}D$ co-deposited in shadowed areas. For the D to H change over, the results exhibit a very poor efficiency for changing the plasma (wall) isotopic ratio; indeed, after 50 s of pure D_2 injection the isotopic ratio is still in the range of 30% compared to the 3% of the initial pulse. As a consequence, and although a significant amount of D (T) can be removed from the vessel using H plasmas, the beginning of the next discharge will have to be used for adjusting the isotopic ratio by strong gas injection and corresponding total amount at least of the amount removed.

V - Conclusions

A series of experiments have been carried out in Tore Supra for evaluating the effectiveness for reducing the amount of tritium trapped in the device by switching to He or H_2 injection during the ~200s of plasmas following the burning phase (power and plasma current ramp down). From the results obtained during long discharges in Tore Supra, it appears clearly that He injection will not contribute to the drop of the tritium inventory in the vessel. Indeed, from the reported experiments “only” the areas exposed to the ion flux can be depleted from the D implanted; the He CX flux being not strong enough for contributing to the D removal from deposition areas. In contrast, H_2 injection will contribute to the reduction of the tritium inventory since the plasma facing components are exposed to both the H ion flux and the exchange flux (up to 6 times larger than the He CX flux). As a consequence, D (T) can also be removed from co-deposited areas.

Finally, the consequences for the next discharges exhibit unfavourable consequences for the He removal method, since twice the amount removed from the wall has to be re-injected whilst for H_2, the low efficiency of the gas injection for the isotopic plasma control inhibits a fast recovery of the target isotopic plasma ratio over time scale in the mn range.

References

[1] T Loarer et al., Nuc. Fusion 47 (2007) 1112-1120.

[2] T Loarer et al. J of Nucl. Materials, http://dx.doi.org/10.1016/j.jnucmat.2010.11.073

[3] E Tsitrone et al., Nucl. Fusion **49** (2009) 075011 (9pp)

[4] B Pégourié et al., Fusion Science and Technology, Vol 56, Oct 2009.