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Screening of intrinsic carbon with a stochastic magnetic boundary on TEXTOR-DED

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1. Introduction

In tokamak research stochastic magnetic boundaries induced by resonant magnetic perturbations (RMP) are applied to improve particle and power exhaust characteristics. One objective pioneered at the US tokamak DIII-D [1] and investigated also at the JET tokamak [2] is the control of the harmful Type-I edge localized modes (ELMs) in H-mode plasmas by RMP fields. However, one common characteristic feature in these experiments is a reduction of the electron density in center and on pedestal top during RMP application. This so called *particle pump out (PO) effect* is assumed to be caused by a stochastic magnetic field region with enhanced radial particle transport [2, 3]. The mechanism for the PO and the exploration of possibly connected beneficial effects of this regime are objectives in actual research. In this contribution we will focus on the impurity screening facility of stochastic edge layers. It was shown with the ergodic divertor at Tore Supra [4] that a stochastic boundary is able to flush back impurities. Here we focus in particular on the relation of particle PO and screening of intrinsic carbon.

At TEXTOR an external RMP field with poloidal/toroidal base mode configurations m/n=3/1, 6/2 and 12/4 is applied with the Dynamic Ergodic Divertor (DED). In general [4], extended flux tubes of short field lines (L_c<L_K (20-30m), L_c is field lines' connection length from wall to wall, L_K is the Kolmogorov length) are existent adjacent to ergodic flux channels with long field lines (L_c> L_K). The laminar flux tubes act as SOL of the multipolar divertor structure while the ergodic domains show stochastic transport characteristic, due to high field line diffusion ($D_{fl} \sim 10^{-5}$ m). Earlier experiments at TEXTOR showed a dominating effect of the laminar field lines and a modest level of stochastic transport. No global particle pump out was observed but poloidally localized ergodic and SOL-like transport characteristics [4]. In order to enhance the stochastic features of the edge layer, we adapted plasma position and edge safety factor in experiment such that magnetic modeling with the GOURDON code showed a broadened stochastic layer and SOL flux tubes of negligible extend. Then particle PO was achieved in experiments in m/n=3/1 base mode configuration above a certain DED current threshold. Fig.1 shows the time traces of the central line integrated density [n_e l.a.] for two discharges #103900 and #103902. The experimental settings are: plasma current I_P=360 kA, toroidal magnetic field B_t=2.25 T, edge safety factor q_a=5.0, P_H=1.2 MW (counter current NBI heating), central plasma position R_0=1.755m. The DED current was decreased from

I_{DED}=2.8 kA in #103900 to I_{DED}=1.4 kA in #103902. Both currents stay below the m/n=2/1 locked mode (LM) threshold and gas fuelling was switched off. Accordingly, the observed density rise in both shots is determined by wall recycling and beam fuelling. In these experiments a correlated decrease in [n_e l.a.] of 22% is observed, averaged for 2.5s < t < 3.0 s, during high current DED application while in the discharge with lower current [n_e l.a.] is not affected. In the following the reaction of the carbon content after transition to this particle PO regime is discussed.

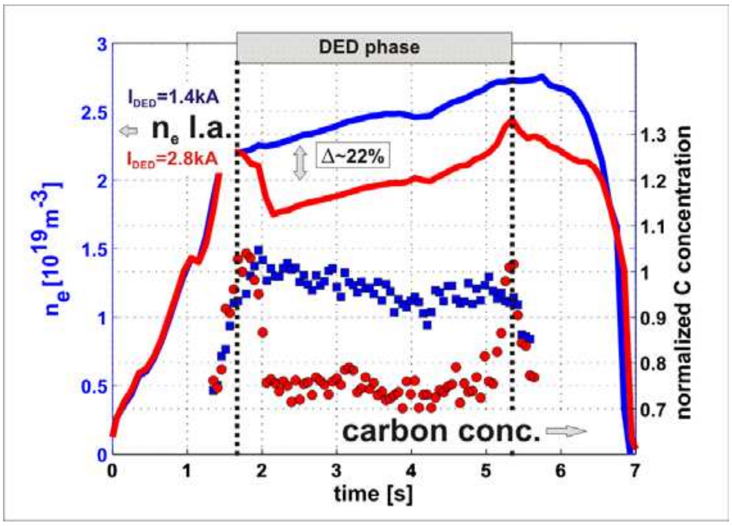

Figure 1: Electron density and normalized carbon concentration at center for discharge with low (blue) and high I_{DED} (red)

2. Experimental observation of carbon transport during particle pump out

To analyze the experimental findings on particle PO the magnetic topology of both discharges was modeled with the GOURDON code. Figure 2 (which includes also the lines of sight of the carbon diagnostic in the UV range) demonstrates that in the discharge with PO the laminar domains are limited to the very edge while the stochastic volume extends deeply in the plasma. This topological fact is suggested as driving force for an enhanced radial transport leading for the observed particle PO and for the effects discussed here. However, as these calculations were performed by a linear superposition of the perturbation field and the unperturbed magnetic equilibrium, screening of the external field might have to be considered and a weakening of the islands' sizes and of the level of stochastization is possible. CIII (229.6 nm) and CV (227.1 nm) line intensities are measured simultaneously along the nine lines of sight shown in Fig 2. Additionally, CIII is

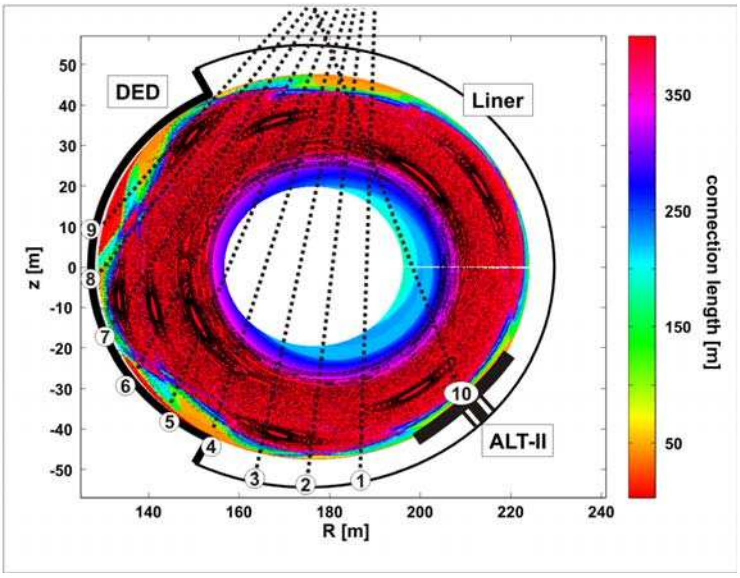

Figure 2: Magnetic field topology for #103900 (I_{DED}=2.8kA) with particle PO; superimposed are the lines of sight of the carbon spectroscopy system

measured on one chord pointing at the ALT-II limiter. First, we compare in Fig 3 the carbon line signals for two discharges, one without DED (blue) the other with a DED current of 1.4 kA and, accordingly, without PO (black, discharge #103902 in Fig.1). Here the application of DED leads to a periodical change in poloidal and toroidal direction in the CIII intensity – seen also on the bolometric signals- which reflects the magnetic topology of 3/1 mode on TEXTOR. Indeed, along chords 7-8, which point at the strike points, see Fig 2, CIII increases while it decreases on the chords pointing at the SOL.

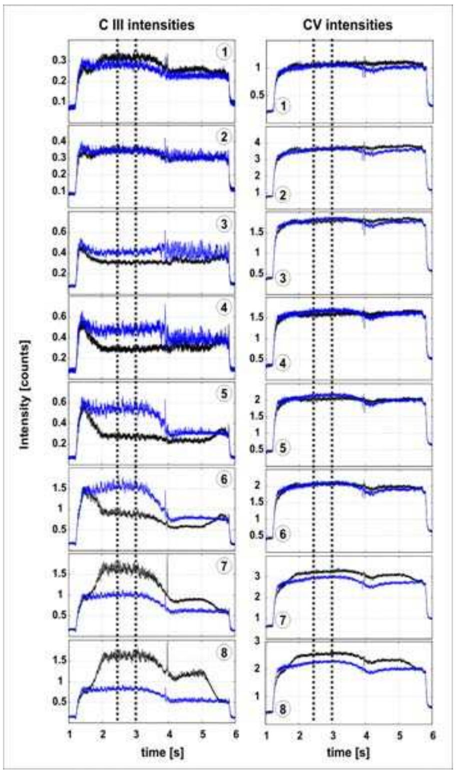

Figure 3: Time traces of CIII and CV line intensities for discharge w/o DED (blue) and with low DED

Considering that the carbon fluxes are proportional to the CIII emission since the core and edge plasma parameters are unchanged, we assume here that the total carbon flux does not change after application of DED. This assumption is supported by bolometric signals, which indicate an identical value for the total radiated power, P_{rad} for the two discharges (in these conditions, P_{rad} is nearly proportional to the emission of the Be-like C^{2+} ions). The intensity of CV signals is less sensitive to the change in the location of the carbon sources, due to the high ionization potential of the C^{4+} ions (about 400 eV). Earlier experiments [7] and model simulations [8] without DED show that for TEXTOR conditions the C^{4+} ions are nearly homogeneously distributed in poloidal angle at plasma minor radius of 38-40 cm, i.e. 6-8 cm inside the last closed flux surface. Indeed, only minor changes are observed on the CV signals in Fig. 3, in agreement with *charge exchange recombination spectroscopy* (CXRS) measurements, which also show a constant level of carbon content in these two discharges. This situation changes when the DED current is increased to a value at which the particle PO effect is induced. To quantify this change, the carbon line intensities for discharge #103900 and #103902 were averaged on each single chord in 2.5s < t < 3.0s and these values were then normalized to discharge #103896 without DED. The result is shown in Fig. 4. The ratio of CIII emission shows that with application of the DED the poloidal structure discussed before evolves, with stronger poloidal modulation for higher DED current. In contrast, for high DED current, inducing the particle PO, the CV emission is reduced by 25%, in average, on all channels not pointing directly into the strike points on the DED target (i.e. 7, 8). This reduction is marginally stronger than that of the electron density (15-20 %), implying that the C^{4+} ion density remains constant or slightly decreases with PO. On the other hand, measurements with a thermal Helium beam diagnostic show a reduction of the edge electron density by about 15 %. As the CIII signals do not decrease in average, we assume that the C^{2+} density as well as the carbon flux increase with high DED current. This assumption is again supported by the fact that P_{rad} is constant in both discharges, in spite of the described change in the plasma edge parameters. We can therefore conclude that a beneficial effect on carbon transport – increase of carbon flux by about 15 % and possibly a slight decrease in C^{4+} ion density - occurs in correlation to the particle PO. This beneficial effect might be expected to become more pronounced with increasing ionization stage of carbon, as Fig. 2 suggests a rather large radial extension of the stochastic volume. Indeed, CXRS measurements in the center of the plasma column show a decrease of C^{6+} ion density by about 30 %, leading to a decrease incarbon concentration comparable to that depicted in Fig1.

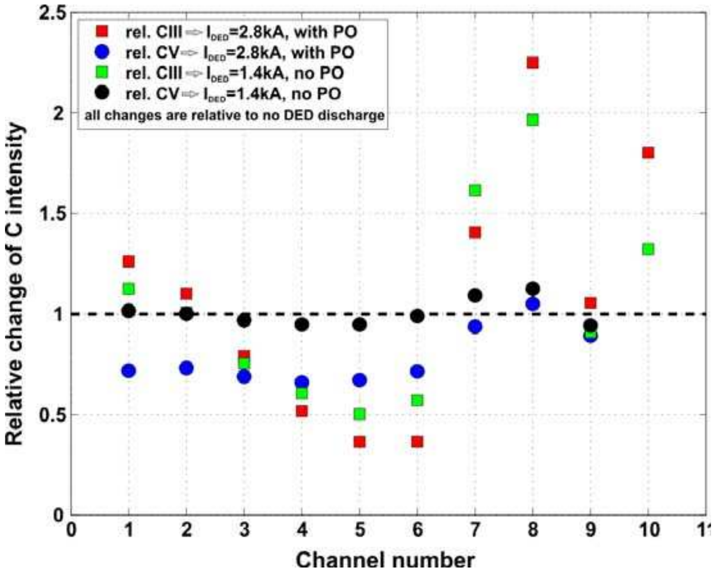

Figure 4: Change of CIII and CV intensities relative to no-DED discharge averaged for 2.5s < t < 3.0 s

3. Conclusion

This experimental investigations show evidence for a beneficial change of intrinsic carbon transport due to a stochastic magnetic boundary at TEXTOR-DED. Impurities penetrating from the SOL are flushed back leading to reduced carbon content in the plasma center. The deuterium neutrals are less affected by this mechanism as the neutral penetration depth is significantly shorter for carbon than for deuterium ($\lambda_D > 2\ \lambda_C$) where λ_D is in the order of a few centimeters for the typical TEXTOR conditions. A complementary mechanism to explain the experimental findings, refers to the enhanced radial transport of the main plasma ions which drag out selectively the highly ionized impurity ions by frictional forces [9]. The exact elaboration of the underlying mechanism is ongoing. Due to the complicated 3D structure induced by the DED on plasma and neutral gas, transport modeling is needed. At TEXTOR-DED the EMC3/EIRENE code, equipped with a collisional radiative model for impurity ionization and radiation, will be used to tackle this ambitious task.

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