Screening and radiation efficiency of carbon with Dynamic Ergodic Divertor on TEXTOR

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1. Introduction

Understanding the change in impurity transport and radiation induced by the Dynamic Ergodic Divertor (DED) [1] is a major step to assess the viability of the concept of ergodic divertor to reactor grade plasmas. The idea is that the plasma-wall interaction can be mitigated and made tolerable in a future tokamak reactor using a perturbing magnetic field which destroys the closed magnetic surfaces at the plasma edge. The resulting stochastic layer is expected to lead to enhancement of particle transport, while keeping the plasma stored energy practically unchanged.

According to previous results from Tore Supra [2], edge stochastization causes the reduction of the edge temperature (accompanied by a higher level of edge radiation) and the increase of impurity particle screening.

Two modes of operation of DED have been tested so far on TEXTOR: m/n = 3/1 and m/n = 12/4. In the 12/4 mode the penetration of the perturbing field is limited to the very edge of the plasma, while in the 3/1 mode the perturbing field reaches the q=2 surface. The analysis of carbon transport, reported in reference [3], shows that decontamination of carbon [4] occurs at the onset of the 2/1 tearing mode, accompanied, however, by some decrease of the plasma stored energy. Preliminary observations of the effects on carbon transport of DED operating in 12/4 mode at reduced current, I_{DED} < 7 kA, indicate a very modest and occasional incremental screening of intrinsic carbon. In this paper, we consider DED experiments at full current, I_{DED} = 13 kA, with the aim of finding in the data of the screening efficiency some trends which may reflect – and clarify – the underlying physical mechanisms.

2. Diagnostics

In Fig.1 the experimental setup for the measurement of spectral line intensity and of bremsstrahlung emissivity is shown. The intensity of two carbon lines emitted in the UV range by C^{2+} ions (CIII line) and by C^{4+} ions (CV line) is measured along chords 1 to 9, five of them (chords 1-5) looking at the main source of carbon, the graphite divertor tiles. Bremsstrahlung in the visible range for the determination of Z_{eff} is detected along 22 chords distributed within the area bounded by red lines. For technical reasons, it was so far not possible to avoid reflections of light on all the chords, which prevents the possibility of Abel-inverting the signals. Therefore, considering the relatively high ratio of surface to volume of TEXTOR plasmas, the accuracy of the estimated Z_{eff} is rather low.

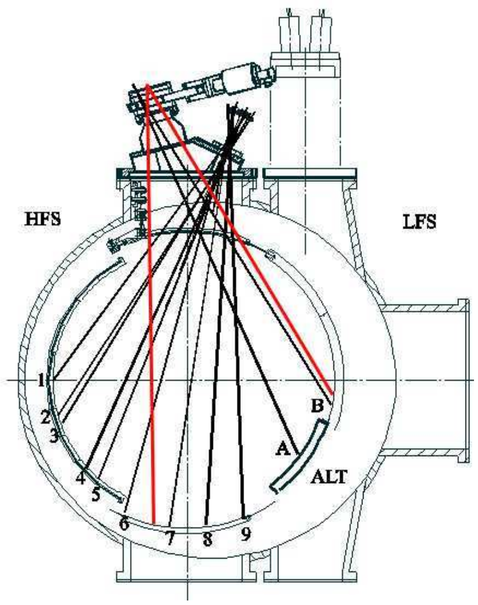

Figure 1: Experimental setup.

3. Experimental data and discussion

We take the ratio of the intensity of the CIII line to the intensity of the CV line (CIII/CV) as a measure for the screening efficiency. In fact, the flux of C^{3+} ions can be taken to be proportional to the intensity of the CIII line as the flux of C^{5+} ions proportional to the CV intensity, as explained in reference [3]. Since the C^{3+} ions are located at the very edge of TEXTOR plasmas, while the C^{5+} ions are located well inside the confined plasma, the incremental screening due to the action of DED can be defined as the ratio of (CIII/CV) with and without DED, i.e. $(\text{CIII/CV})_{\text{with}}$ / $(\text{CIII/CV})_{\text{w/o}}$. In our evaluations, the "CIII intensity" is the average value of the intensity of chords 1-5 (we do not take into account the CIII signals from C^{2+} ions originating mainly from charge exchange processes), while the "CV intensity" is the average value of the intensity of the signals emitted by chords 1-9.

Additionally, together with Z_{eff}, the total radiated power (P_{rad}) is used to determine the quality of cooling defined as P_{rad} / $[n_e^2(Z_{eff}\ -1)]$, which, being dependent on the edge temperature and strongly on impurity transport, can provide information on the effects of DED on the plasma edge.

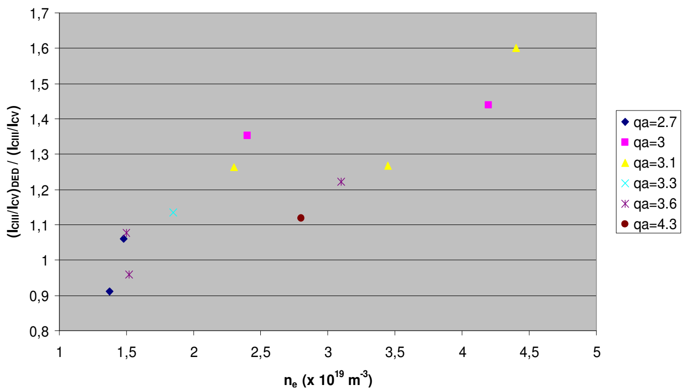

Figure 2: Incremental screening vs. density.

In Fig. 2 the incremental screening for I_{DED} = 13 kA is plotted as a function of the electron density, n_e, for a variety of non-consecutive discharges at different *q(a)*. Apart from a possible dependence of the incremental screening on *q(a)*, which may simply be due to differences among non-consecutive discharges, one sees a clear increase with density. Such an increase is however not clearly seen for the incremental quality of cooling. This may be due on the one hand to the uncertainties on Z_{eff} and on the other hand to the fact that bremsstrahlung and P_{rad} are measured in two different toroidal sectors, while we are essentially faced with a three-dimensional problem. The incremental screening plotted vs. *q(a)*, obtained from two discharges with plasma current ramp-down, does not show significant dependencies (Fig. 3). One might notice a small increase with *q(a)*, which, however, is of the same order as the error bar. Finally, the incremental screening is plotted in Fig. 4 as a function of n_e for two consecutive series of discharges, ohmic and NBI heated, both at a safety factor of around 3. One might distinguish a small increase of the incremental screening with increasing density, at least for the ohmic series, and one clearly sees that the data points of NBI discharges are systematically below the ohmic ones.

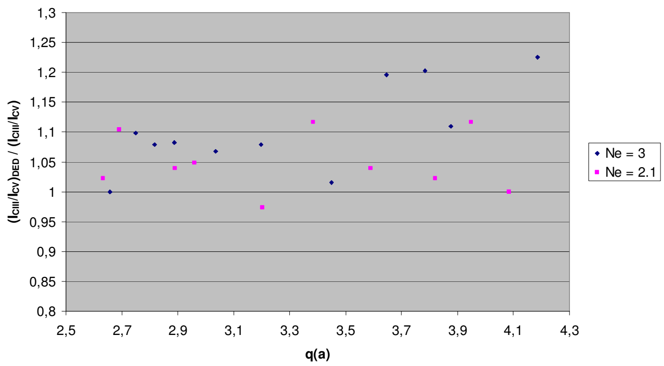

Figure 3: Incremental screening vs. *q(a)*.

A very common criterion used to describe the additional screening caused by DED, is the comparison of the carbon penetration depth λ_{ic} with the thickness of the stochastic zone Δ. The smaller their ratio (λ_{ic}/Δ), the better the incremental screening. Considering that λ_{ic} decreases with increasing n_e, this criterion might explain the observed increase of incremental screening with density (Figs. 2 and 4). It does however not explain the relative insensitivity of the

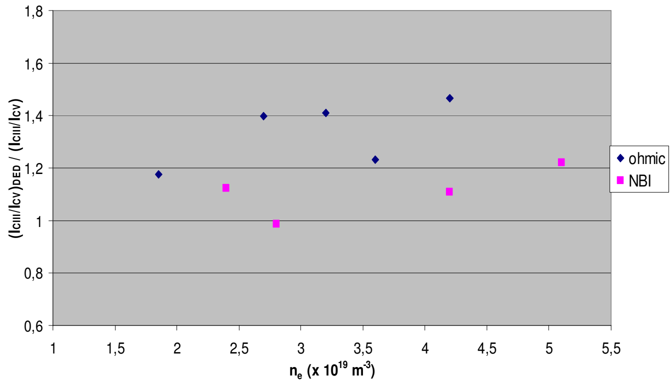

Figure 4: Incremental screening vs. density.

screening to a change in *q(a)*, if one considers the significant change in Δ when *q(a)* is changed [6]. In addition, the criterion does not appear to be adequate to explain the data of Fig. 4. Indeed, λ_{ic} is smaller for NBI (higher edge temperature) as compared to ohmic heating and so one would expect higher additional screening with NBI. An alternative approach rather considers the action of frictional forces on impurity ions, which leads to decontamination of highly ionized carbon ions, induced by enhanced transport of protons in a stochastic field [4]. Considering that those forces are proportional to the collision frequency between impurity ions and protons ($\sim Z^2\, T^{-3/2}\, n$), it seems that the data presented in this paper might be consistent with this mechanism. We are aware of the important limitation of this preliminary study due to the way the carbon fluxes are estimated. In the case of strong poloidal asymmetries in the carbon sources (which depend also on *q(a)*) – like in the presence of DED – the method we used is oversimplified and may lead to significant error. Work is in progress to improve the method by which the fluxes are estimated.

Acknowledgement

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