

## Investigation of Impurity Transport in TCV

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### 1. Summary

The effect of plasma parameters on impurity transport has been systematically investigated by laser ablation of Si trace impurities into a wide range of TCV discharges. The presence of these impurities leads to a strong increase of soft X-ray emission, whose intensity shows a characteristic pulse-like shape following ablation, with rise times in the range of 6-8ms, reflecting the penetration time, followed by a longer, exponential decay phase, which is taken as a measure of the impurity lifetime in the plasma.

The experimental study of the lifetime of the impurities in ohmic L-mode plasmas has been carried out with scans of the triangularity, elongation, plasma current, line averaged electron density and toroidal magnetic field.

The parameters  $\delta$ ,  $I_p$  and  $n_e$  have little effect on the impurity lifetime, while  $B_T$  and  $\kappa$  show a marked and surprising effect as higher values lead to shorter lifetimes.

The 1-D code STRAHL[1-2] has been used to simulate the X-ray emission from the impurities. The simulations show that the impurity edge diffusivity is strongly influenced by discharge conditions, correlating inversely with residence time, while the central transport is dominated by sawtooth activity rather than diffusive transport. The pinch velocity is found to be positive, (towards the plasma edge), and fairly independent of the plasma conditions.

### 2. Signals from X-ray diagnostics

The array of 200 soft X-ray photodiodes[3] is used as the main diagnostics in order to track the impurity concentration and emissivity inside the plasma. Following ablation, a fast increase of the emissivity from the plasma is recorded, showing a characteristic pulse-like shape adding to the background. As the photodiodes are masked by thin Beryllium filters, the spectral sensitivity is negligible below 1keV, thus obliterating the UV emission from many low ionisation states of the impurity. In the case of Silicon, the photodiodes record only the soft X-ray line emissions from H-like and He-like ions, in addition to part of the bremsstrahlung and recombination radiation. The results of a simulation with STRAHL are

shown in Fig. 1. The total detected X-ray power as well as its components are plotted in the case of a steady state flat profile of impurities, assuming corona equilibrium.

### 3. Experimental results

The experimental study of the impurity behaviour and of their confinement time has been carried on with scans of the triangularity ( $\delta = -0.16$  to  $+0.65$ ), elongation ( $\kappa = 1.6$  to 2.3, with constant profile of  $q_{eng}$  and hence same sawtooth radii [4]), line averaged electron density ( $n_e = 1.9 \cdot 10^{19} m^{-3}$  to  $6.5 \cdot 10^{19} m^{-3}$ ), plasma current ( $I_p = 160kA$  to  $520kA$ ), and toroidal magnetic field ( $B_T = 0.9T$  to  $1.5T$ ). Targets were limited, ohmically heated plasmas in L-mode.

The different line-integrated signals along the soft X-ray system viewchords show many common features like the exponential decay time, which is taken as the confinement time -or “lifetime”- of the impurities, and a residual asymptotic signal due to a low level of recycling the TCV walls. For a wide range of many parameters, the impurity lifetime is found to be almost constant at a value of around 25ms. In particular, this is observed in the electron density scan (at least for limiter plasmas, Fig. 2a), in the plasma current scan for  $I_p > 250kA$  (Fig. 2b) and in the triangularity scan for  $\delta > 0.16$  (Fig. 2c). For  $I_p$  or delta below the values indicated, the impurity lifetimes show a marked increase.

All these discharges were performed at the nominal toroidal magnetic field  $B_T = 1.5T$  and at  $\kappa = 1.6$ . A reduction of the magnetic field intensity produces an increase of the lifetime to almost the double, around 48ms, being all other parameters constant. This surprising effect, which seems to contradict the role of the magnetic field in the confinement of charged particles, is evident in Fig. 3a.

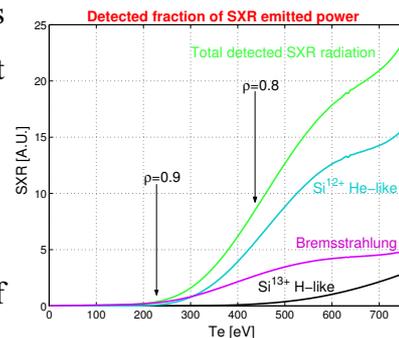


Fig.1. Detected soft X-ray emissivity vs electronic temperature in shot #19785. There is almost no contribution from plasma edge.

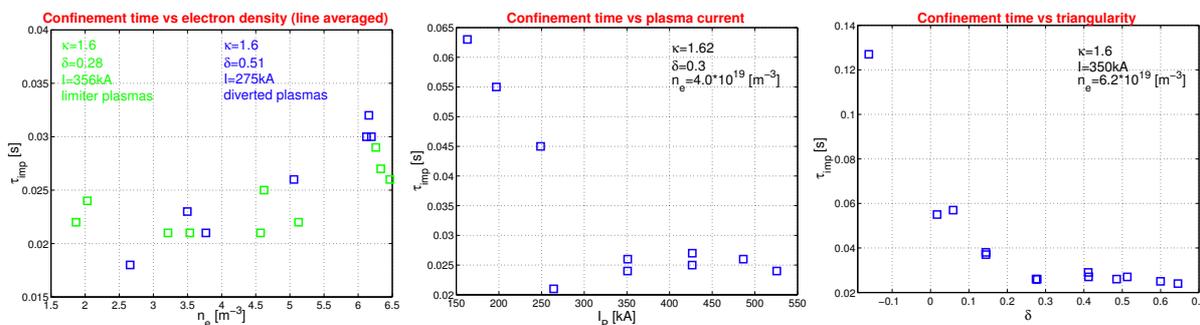


Fig. 2. (a) The electron density scan (line averaged) shows a slight difference in limiter and diverted plasmas. The lifetime is little sensitive to density, except for higher values ( $n_e > 6 \cdot 10^{19} m^{-3}$ ). (b,c) Values of the lifetime are flat up to marked thresholds in plasma current and triangularity.

The elongation scan was performed as well at  $B_T = 0.9T$  (Fig.3b). In agreement with the magnetic field scan, for low elongations the impurity lifetimes lie around 48ms, and are reduced to 20ms for increasing  $\kappa$  values at about 2.3. This behaviour is observed not only on the absolute value of the lifetime, but also in comparison with the electron energy confinement time, which in this scan is roughly constant. This factor-of-three decrease of the ratio  $\tau_{imp}/\tau_{Ee}$  is attractive for advanced, elongated tokamak reactor designs.

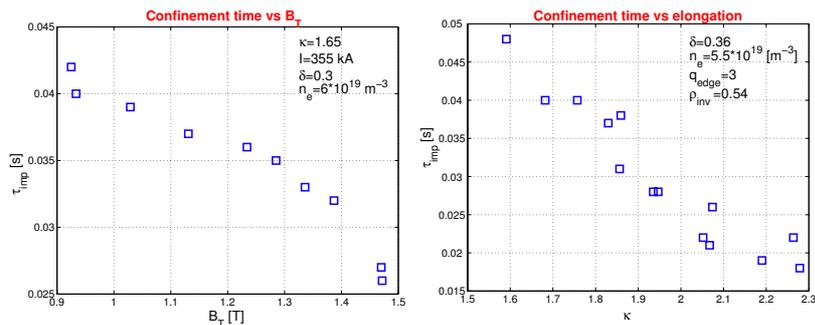


Fig. 3. (a) Non intuitive behaviour from the scan of the toroidal magnetic field. (b) The elongation scan has been performed at  $B_T = 0.9T$  and constant sawtooth inversion radius at  $\rho_{pol}=0.54$ .

#### 4. Transport simulations

The 1-D simulation code STRAHL is used to calculate the time evolution of the impurity concentration after ablation and the corresponding X-ray signals as they would be measured by the photodiodes. Given the real plasma profiles of density and temperature as inputs, it is possible to evaluate the effects of different values of the transport parameters (diffusivity and pinch velocity profiles) as well as of the role of sawteeth in the transport of the impurities. It has been found that the lifetime, i.e. the exponential decay of the peaked signals, is determined mainly by the values of diffusivity and pinch velocity in the confinement region outside the inversion radius, while the central parameters and the sawteeth play negligible effects. The  $D$  and  $v$  profiles are marginally important provided the central and edge values are the same. In Fig. 4 some scans of  $D_0$ ,  $D_{edge}$  and  $v_{edge}$  are shown, referring to shot #19785 in the triangularity scan. In order to reproduce the correct values of  $\tau_{imp}$  and of the signal fwhm (the black rectangle in Fig.4, with an approximation of 2%), the bestfitting values -  $D_{edge}=0.3 \text{ m}^2/\text{s}$  and  $v_{edge}=+4.3\text{m/s}$  - are identified with an approximation of no more than 10%, beyond which it is not possible to find bestfitting  $(D,v)$  couples. The scan of  $D_0$  in Fig.4 shows that it is not possible to determine the central diffusivity this way. It is a remarkable fact that the value of the edge pinch ve-

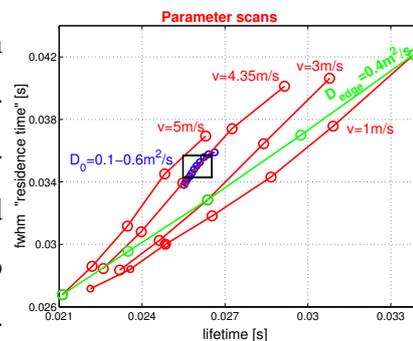


Fig. 4. Scans of the diffusivity and pinch velocity profiles in shot #19785.  $D_0$  varies between  $0.1\text{m}^2/\text{s}$  and  $0.6\text{m}^2/\text{s}$  marginally affecting  $\tau$ . The edge velocity is necessarily around  $4\text{m/s}$ .

locity is found to be positive, i.e. directed outward, and fairly independent of plasma conditions, at least in all situations in which  $\tau$  lies around the plateau at 25ms. Anyway the reproduction of shot #19782 ( $\delta=0.05$ ,  $\tau=57$ ms), which is almost identical in size to plasma #19785 ( $\delta=0.27$ ,  $\tau=26$ ms), shows similar values for  $D_{\text{edge}}$ , which is still around  $0.35\text{m}^2/\text{s}$ , while  $v_{\text{edge}}$  changes towards low negative (inward) values.

Fig. 5 shows how the removal and the change of sawteeth

frequency affect the simulated signals. The effect on the impurity lifetimes is less than 10%, while they influence significantly the influx phase. Sawteeth act as a rapid transport device towards the plasma centre in the first phase after the ablated impurities arrive at the plasma edge, as their radial profile is still hollow. As a consequence, sawteeth transiently increase the inward flux and the concentration of impurities in the centre of the plasma, with respect to plasmas without sawteeth.

The determination of the central diffusivity  $D_0$  can be attempted by reproducing the correct global risetime of the signal, for example from 20% to 80% of its peak value. Another possibility is the reproduction of the correct increase of the signal between two consecutive sawteeth during the influx phase. Both values are very sensitive to the duration of the source and to the delay of the first sawtooth following the start of the impurity influx. The spread of the particle source in time, which lasts about 4-5ms, makes the uncertainty on the central diffusivity quite important. Anyway, the correct risetime of the chord viewing the centre of the plasmas seems to be approached with fairly high values of the central diffusivity  $D_0$ .

## Acknowledgements

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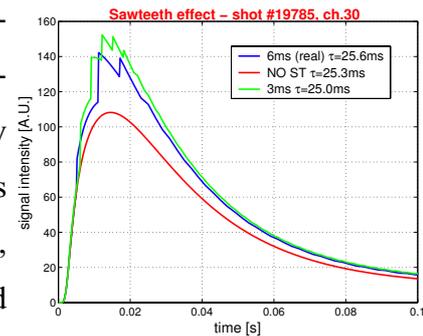


Fig. 5. Sawteeth frequency scan in simulation of shot #19785 affects the influx phase and the peak intensity of the signals.