# CARBON DENSITY IN THE WENDELSTEIN 7-AS STELLARATOR MEASURED WITH THE HIGH ENERGY LI-BEAM

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## INTRODUCTION

W7-AS has been in operation since the summer of 2000, now with divertor modules in place of the previous inner sector limiters. Two major goals of a divertor are to reduce impurity release from the target plates as well as to entrain impurities within the divertor region. The relation between impurity release from the divertor and the impurity concentration in the main plasma is not clear presently [1,2] . In DIII-D, for example, a drastic reduction of carbon influx from the traget plates due to wall conditioning has not led to any significant decrease in average carbon core contamination [3]. In W7-AS the target-tiles (carbon fibre composite) of the divertor represent the only carbon source - apart from a few protection shieldings for in-vessel diagnostics. This is in contrast to most tokamaks where a large fraction of the inner vessel is covered by graphite tiles. In the present study the carbon concentration in the main plasma is examined under various operating conditions and related to physical parameters characterizing impurity production. A new Li-beam based diagnostic system is employed to measure $C^{6+}$ densities in the edge region and core plasma to examine divertor impurity control.

## EXPERIMENTAL PROCEDURE

The $C^{6+}$ density is determined using a 50keV neutral Li-beam for Charge-Exchange-Spectroscopy [4]. The light emitted by the $C^{5+}$ (n=8 to n=7) transition is used, employing interference filters at 529nm (FWHM=1nm) in combination with photomultipliers. The density $n_{C6+}(z)$ at 14 radial positions on the beam line with z as a relative beam coordinate is calculated from the radial light profile using state-selective cross sections and the population of the Li 2s-4f levels. Presently, the setup allows radial profiles of $n_{C6+}$ to be resolved with 50ms time-averaging over a range of 12cm along the beam for electron densities $n_e(z)<1x10^{20}m^{-3}$. Calculations of the charge state distribution of carbon show that for electron temperatures larger than 200 eV carbon is more than 80% fully ionized. In this region the concentration $n_{C6+}/n_e$ was determined by using the electron density evaluation of the Li(2p) light profile and averaging $n_{C6+}/n_e(z_i)$ over typically 3 positions $z_i$. The fraction $n_{C6+}/n_e$, in the following for convenience refered to as carbon concentration, usually lies between 0.3 and 1.5% for the freshly boronized machine and is taken as the core carbon contamination. Error bars shown in the figures represent statistical errors inferred by time averaging and background substraction. The systematic error of $n_{C6+}/n_e$, which is mainly determined from uncertainties in cross section data, population of excited Li-levels and neutral beam strength, is estimated as +/-50%. In the present experimental campaign with frequent boronization, $n_{C6+}/n_e$ was found to be reduced by a factor of 2-3 compared to identical plasma discharges without boronization last year.

Carbon influx from one divertor module was monitored by observation of $C^{1+}$ radiation at 514.6nm. Neglecting variation of photon efficiencies with temperature and density in first approximation, the measured photon flux is proportional to carbon influx [1].

For the systematic investigation of carbon concentration, electron resonance heated discharges of 0.7s duration with 0.3, 0.6 and 0.9MW heating power were performed (shots #50510-50540) on the second shot day after boronization, keeping the line density constant and switching from low to higher heating power at about the middle of the discharge. The electron temperature at the strike points of the target plates is in the range 35-80eV for all discharges, hence physical sputtering should be the prominent mechanism for carbon release. Four different line-averaged densities $\bar{n}_e$= 1...6 x$10^{19}$$m^{-3}$ were studied in a typical island divertor configuration with a value of the external rotational transform $ι_a$ =0.566 and 2.5kA control-coil current, mean plasma radius of 11.6cm and x-point to target distance of 3.9cm. The same set of discharges was performed in a limiter configuration ($ι_a$ =0.54), where the last closed flux surface (LCFS) is determined by the intersection of closed magnetic field lines with the divertor as limiting element and mean plasma radius of 15.3cm.

## RESULTS

Fig.1 displays $C^{6+}$ density profiles for the four different $\bar{n}_e$ within the limiter configuration. $n_{C6+}$ increases with $\bar{n}_e$, hence one might expect carbon concentration to remain approximately constant. However, as Fig. 2 shows, no simple relationship between carbon concentration and $\bar{n}_e$ is exhibited. Additionally, a trend of increased carbon concentration with heating power is observed. In order to resolve a satisfying systematic dependence of carbon concentration, the influx of carbon has to be analysed: Fig.3 displays the $C^{1+}$ light signal of the upper divertor module, versus upstream density $n_e$(LCFS) derived from the Li-beam. In both configurations the $C^{1+}$ signal depends almost linearly on $n_e$(LCFS). In the divertor configuration the $C^{1+}$ signals show signs of saturation at higher $n_e$(LCFS), which is more pronounced at smaller heating power. This effect is also observed in the saturation current of target-mounted Langmuir probes [5]. Neglecting data points where $C^{1+}$ signals begin to flatten, carbon density rises with increasing $C^{1+}$ signal in both configurations (not shown), which suggests a simple relationship between carbon influx and carbon core density.

Since $n_e$(LCFS) is approximately linear with carbon flux and is also related to core density, it is a convenient correlation parameter. Data at different densities can be compared if carbon concentration is related to the normalized upstream density $n_e$(LCFS)/ $\bar{n}_e$ as shown in Fig.4. This quantity generally decreases with increasing $\bar{n}_e$, in contrast to tokamaks, and increases with heating power [6]. In each configuration the data fit onto a common curve with positive slope (note the good correlation compared to Fig.2). This means that the carbon concentration is low if on the one hand carbon influx is low (small nominator of $n_e$(LCFS)/ $\bar{n}_e$ ) or on the other hand impurity dilution is high (large denominator of $n_e$(LCFS)/ $\bar{n}_e$). In the divertor configuration carbon concentration is much lower than in the limiter case. This difference can be attributed solely to configurational aspects: Due to the island geometry with open magnetic field lines at the target plate, a carbon atom released here has a smaller probability of entering the confinement region than for the limiter case. Moreover, the particle confinement time is about a factor of two smaller due to the reduced plasma radius.

## CONCLUSION

The carbon concentration in ECRH-discharges of different densities and heating power can be described in an adequate fashion using only the normalized upstream density $n_e$(LCFS)/ $\bar{n}_e$ as a scaling parameter- reflecting at least the balance of impurity sources and impurity dilution. This suggests that under these experimental conditions the influence of changes in impurity transport, expected to appear during variation of density and heating power [6], do not have an influence on carbon core concentration outside the error bars of present measurements.

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Fig.1: $C^{6+}$ density profiles in limiter configuration at 0.9MW ECRH power. The last closed flux surface and the averaging interval for carbon concentration are indicated.

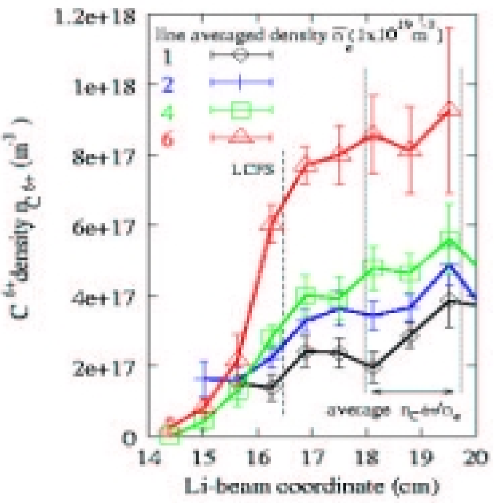


Fig.2: Carbon concentration at different average densities and heating power (0.3MW: circles, 0.6MW: squares, 0.9MW: diamonds) in divertor (red) and limiter (green) configuration.

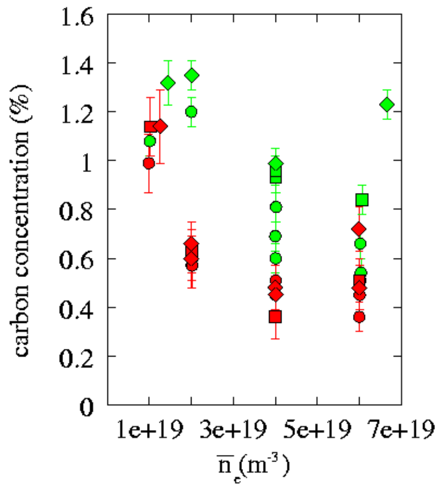


Fig.3: $C^{1+}$ light signal from divertor versus upstream density measured by the Li-beam (see legend of Fig.2).

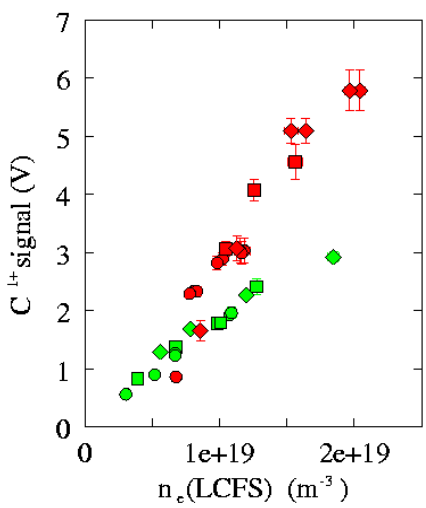


Fig.4: Carbon concentration as a function of normalized upstream density (see legend of Fig.2).