Investigations of tungsten in the central plasma of ASDEX Upgrade

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The tungsten concentration c_W in the main plasma of ASDEX Upgrade was determined by observation of the quasicontinuum structure of W in the 5 nm region. The calibrated intensity of this structure was used to monitor the tungsten inventory in the main plasma. Tungsten concentrations as low as 10^{-6} were detected by means of spectroscopic observations in the VUV-region. In 85% of all investigated discharges c_W were found to be below $2 \cdot 10^{-5}$. Correlation studies were performed to investigate the dependence of c_W on plasma parameters.

Identification of tungsten and determination of c_W

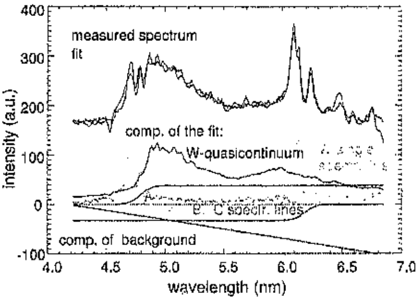

Fig. 1: Determination of the tungsten inventory in the main plasma by a fit of the VUV spectrum at about 5 nm. The calibration of the intensity ($I_{qc} \rightarrow c_W$) was done by comparision with the total tungsten radiation after W laser ablation.

The tungsten divertor experiment at ASDEX Upgrade [1] offered the possibility to test tungsten as a plasma facing component under fusion relevant divertor conditions. Of major interest was the resulting concentration c_W in the main plasma and the dependence of c_W on other plasma parameters. In preliminary studies tungsten was injected into the plasma by means of laser ablation. The temporal development of the total radiation measured by a bolometer camera system allowed to subtract the background radiation and to obtain the total tungsten radiation. A comparison of the measured radiation $P_{W,meas}$ with calculated radiation losses $p_{W,calc}$ [2] yields $c_W = P_{W,meas}/(p_{W,calc} \cdot n_e^2)$. In a fusion experiment with a continuous source of tungsten like the W divertor at ASDEX Upgrade it is not possible to subtract the background radiation of the plasma to get the weak tungsten radiation. Therefore a spectroscopic method was used to detect tungsten and to determine its concentration in the main plasma. The observation of the plasma was performed by means of a grazing incidence spectrometer with a time resolution of up to 5 ms and a spectral range 4 nm – 30 nm. Additionally a Bragg-crystal-spectrometer was used to investigate the x-ray-region at about 0.7 nm. In these wavelength regions single lines of Br- to Ni-like ions could be observed[3], which occur only in additionally heated plasmas because of the high ionization energies. The usually dominating spectral structure in both ohmic, L- and H-mode discharges, however, was the tungsten quasicontinuum at about 5 nm, which is emitted by W-ions in the neighborhood of Ag-like tungsten (W^{27+})[4]. Therefore this structure was used to monitor W and to determine c_W. In order to get a quantitative information a regression with several sample spectra was done to simulate the measured grazing incidence spectra. The method is demonstrated in fig. 1, which shows in the upper half the input spectrum together with the fit result and in the lower half the sample spectra (background, B-, C-, O-lines, W quasic., and W single lines). The intensity I_{qc} of the quasicontinuum was calibrated by means of c_W determined from the total radiation losses in W laser ablation discharges. The obtained concentration is valid for the plasma shell with $T_e \approx 1$ keV. The thickness of the emitting shell decreases in discharges with high central T_e, because it is shifted to the plasma edge. Therefore a correction factor has to be applied, which is in the range of 0.5–2. The concentration determined by this spectroscopic method in W laser ablation discharges agrees within 50% with the concentration determined with the help of the bolometer camera system for discharges with W-LBO.

Correlation studies

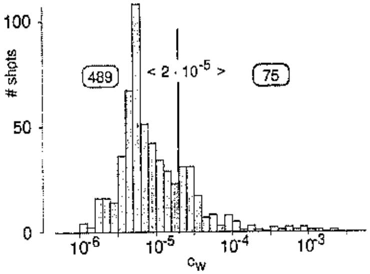

Fig. 2: About 85% of the observed discharges show c_w *below* $2 \cdot 10^{-5}$.

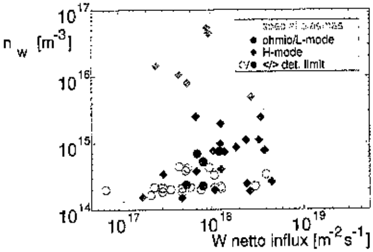

Fig. 3: Weak dependence of the central W density on the W influx from the divertor plates (special plasmas are shaded grey)

Fig.2 shows the distribution of discharges as a function of maximum c_W of the discharge. About 85% of all investigated plasmas show tungsten concentrations below $2 \cdot 10^{-5}$ (75% below $1 \cdot 10^{-5}$). c_W almost never reached values which influenced the chosen discharge program. Only in a very few discharges with special parameters (co-injection, low voltage of the neutral beam heating, improved confinement regimes after switch off of NBI beams) c_W was higher and the radiation was sometimes strong enough to cause hollow T_e-profiles. Several plasma parameters, e.g. plasma current, toroidal field, n_e, etc., were investigated with respect to their influence on c_W. The lack of clear dependences indicates that the transport of tungsten is influenced by parameters which were not considered in the global analysis (cf. [5]). Especially the dependence of the W density $n_W = c_W \cdot n_e$ on the tungsten influx caused by erosion of the divertor plates is obscured by the transport history which the tungsten ions have already experienced on their way into the main plasma. This is elucidated in fig. 3, where n_W is shown as a function of the net tungsten influx from the divertor plates $\Gamma_{W,div}$, which is calculated from the intensity of the dominating WI line at 400.9 nm (the redeposition of the sputtered W is considered)[6]. Although there is an increase of n_W with increasing $\Gamma_{W,div}$ the spread of the data points is rather broad.

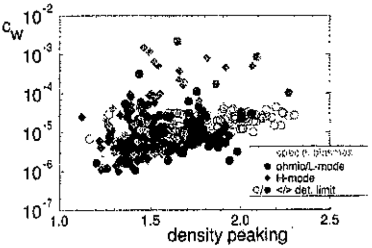

Fig. 4: Correlation between the density peaking and c_W.

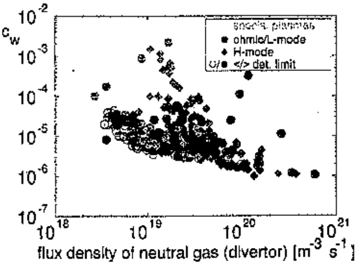

Fig. 5: c_W as a function of the influx of neutrals in the divertor region.

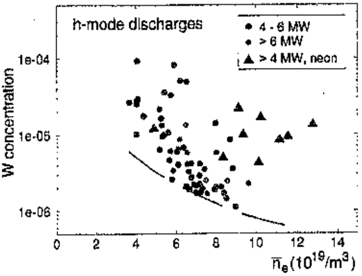

Fig. 6: Comparision of c_W as a function of n_e for different H-mode plasmas.

A somewhat clearer dependence was found on the density peaking and on the neutral flux density in the divertor region in case of H-mode discharges. Fig. 4 and fig. 5 show the correlation graphs for these two parameters. In the case of ohmic and L-mode discharges the weak dependence is caused by the detection limit of the spectroscopic observation. For H-mode discharges c_W increases with the density peaking (which could be a result of neoclassical effects) and decreases with increasing neutral flux density. The later effect is demonstrated in fig. 8 which shows the time traces for several plasma parameters for #7923. At about 3 s the flux density of the neutral increases and at the same time c_W decreases below the detection limit.

The influence of the density on c_W is demonstrated in fig. 6. The dashed line marks again the detection limit of the spectroscopic method. The decrease of c_W with density is more pronounced for plasmas with lower heating power (grey/black circles). In CDH-mode-discharges, however, there seems to be no decrease with the density. This effect can be explained by the density peaking of the n_e-profile, which is usually observed in those plasmas.

An example of a discharge with very good confinement is given in fig. 7. The H-factor (ITER89P) in this discharge was above two. After the start of the neutral beam heating (5 MW) the tungsten reaches very rapidly the $T_e = 1$ keV shell of the plasma, which is located at $\rho_{pol} \approx 0.8$ (W_{qc} -signal). The transport of tungsten to the plasma center, however, is very low. This can be seen from the temporal behaviour of the intensity of the isolated W lines (W_{sl} -signal, see fig. 1), which reaches its maximum 200 ms after the start of the NBI. Although energy confinement is good for these conditions, the maximum concentration remains below $2 \cdot 10^{-5}$ and no accumulation occurs.

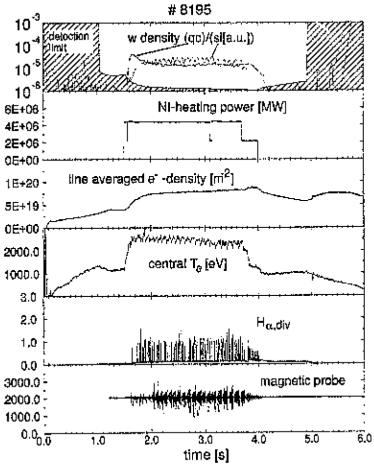

Fig. 7: Example of a discharge with high H-factor ($H_{ITER89P} > 2$) (# 8195).

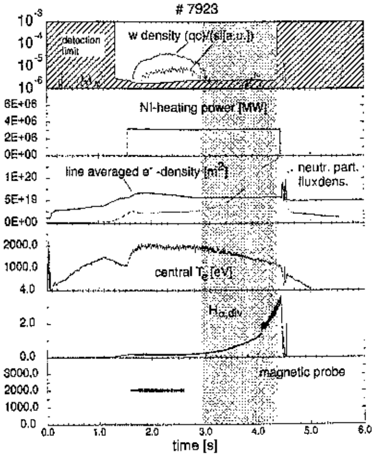

Fig. 8: Variation of c_W with the neutral flux density).

Summary and Outlook

The concentration c_W of tungsten in ASDEX Upgrade discharges in the plasma shell with $T_e \approx 1$ keV was determined from the intensity of the quasicontinuum structure of W at about 5 nm. The intensity I_{qc} of this structure was calibrated by comparison with the intensity I_{qc} during W laser injection experiments and theoretical radiation losses. In 85% of all discharges (ohmic, L- and H-mode) c_W was below $2 \cdot 10^{-5}$. The dependence of c_W on the W influx from the divertor plates was found to be very weak. This indicates a dominant role of the edge and main plasma transport. The remaining discharges with higher W concentrations could be identified as special scenarios (Co-injection, low NBI-voltage, high triangularity, improved confinement after reduction of NBI-power, and density peaking in H-mode plasmas). A reduction of c_W could be achieved with increasing plasma edge density.

The tungsten transport into and in the main plasma will be investigated by means of calculations with the transport code STRAHL [4]. Necessary W profiles will be obtained by means of the lines of the Br- to Ni-like tungsten ions in the plasma center and and the quasicontinuum at the plasma boundary. The influence of the divertor retention on the central W concentration will be investigated with a $W(CO)_6$-Probe, which is able to inject W both in the divertor region and in the boundary region (mid plane) of ASDEX Upgrade.

References

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