IMPURITY ACCUMULATION AND Z_{eff} PROFILES IN ASDEX HIGH CONFINEMENT REGIMES

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1. INTRODUCTION.

During the past years a large effort has been undertaken to overcome the degradation of energy confinement in auxiliary heated plasmas. Considerable improvement of confinement times is found in H-mode plasmas, in pellet refuelled discharges, in counter NI heated plasmas and more recently in the IOC-regime.

In the following we show that regimes of high energy confinement are accompanied by an improvement of particle confinement leading in some cases to strong impurity accumulation in the plama centre. The improved confinement of the background plasma makes the density control more difficult and can become a severe problem under high recycling conditions (carbonized walls, large areas of graphite).

The improvement of the impurity confinement is, of course, even more critical: high-Z impurities lead to large central radiation losses and can cause radiation collapse. Low-Z impurities as carbon and oxygen in the range of several per cent lead to high Z_{eff} values on axis which can result in unacceptable fuel dilution. Information on the important question whether impurities accumulate can be obtained from Z_{eff} profile measurements. Results for high confinement regimes in ASDEX will be presented.

2. Z_{eff} DIAGNOSTICS.

Z_{eff} profiles are determined across the entire minor radius of ASDEX from the intensity of plasma bremsstrahlung in the near infrared, where both recombination and impurity line radiation are in general negligible. We use the detection system of the Nd-YAG laser scattering equipment to measure the absolute value of bremsstrahlung along 16 chords simultaneously in 3 different wavelength bands between 750 and 1000 nm /1/.

The results are compared with those obtained from VUV spectroscopic measurements. The absolutely measured line radiation of relevant impurity species like Cu, Fe, C, O is used in a transport code to calculate impurity density profiles which are taken to derive a spectroscopic Z_{eff}. The agreement between the spectroscopic Z_{eff} and the bremsstrahlung Z_{eff} is within 20% /2/. In addition, carbon and oxygen density profiles are absolutely measured by charge exchange recombination spectroscopy during beam injection. This method delivers an independent crosscheck for the low Z impurity densities derived from the VUV.

3. EXPERIMENTAL RESULTS AND DISCUSSION.

3.1 Pellet Injection

Repetitive injection of pellets has been successfully applied in ASDEX to improve substantially energy confinement in ohmically and NI-heated plasmas /3/. A characteristic feature of the high confinement phase is a nearly complete disappearance of sawtooth activity and a pronounced peaking of the electron density profile. Maximum densities of up to $1.4 \times 10^{14} cm^{-3}$ are attained. Figure 1 shows a 3-dimensional plot of the time evolution of the radial Z_{eff} profiles within half the radius of a well analyzed pellet discharge /4/. After the last injected pellet (t = 1.18 s) Z_{eff} is about 1.3 and nearly constant over the radius. The Z_{eff} profile starts to peak at about 1.25 s. From spectroscopic and bolometric measurements we know that Z_{eff} is mainly determined by light impurities as oxygen and carbon. The resulting concentrations during the accumulation phase amount to 2 % carbon and 0.8 % oxygen, whereas the concentration of of metals like Cu which is the new divertor plate material, is only 0.08 %.

The measured time evolution of the Z_{eff} profiles in the main plasma region (s. Fig. 2) can fairly well be described by neoclassical transport calculations assuming a strong reduction of the anomalous diffusive term ($D_{an} = 0.05 m^2/s$) which is a consequence of the general improvement of confinement /5/.

In the outside region ($r > a/2$) the measured Z_{eff} values rise again to about 2.5 at the plasma edge indicating a weaker radial decrease of impurity density as compared to the electron density. This fact is supported by measurements of carbon and oxygen densities via CXRS. The increase of Z_{eff} towards the plasma boundary is observed in all discharge types.

3.2 IOC/Ccunterinjection

Peaked impurity profiles have also been found under the improved ohmic confinement conditions (IOC) and counter injection heating. In both regimes the improved particle confinement causes an accumulation of impurities in the plasma centre. Under carbonized wall conditions Z_{eff} is in both cases determined by low-Z impurities. The IOC regime, however, differs from the accumulation phase in ctr NI heated discharges and in pellet refuelled plasmas in one important aspect. While in those cases sawteeth are either absent or vanish during the accumulation process, they appear enhanced during the IOC phase. This leads to a less pronounced impurity accumulation and gives only a slight peaking of the Z_{eff} profile. $Z_{eff}(o) = 3$ and $Z_{eff}(a/2) = 2.7$ are found /6/.

3.3 H-Regime

In the H-mode the improvement of energy confinement results in the broadening of the density profiles. With the 16 channel Z_{eff} diagnostic we are able to analyze the impurity behaviour in a quiescent H discharge in the new ASDEX divertor configuration /7/. The global parameters are: I_p = 380 kA, B_T = 2.2 T, neutral beam heating (1.3 MW D^o in D^+) for $1.0 \leq t \leq 1.8$ s, slightly carbonized walls. The transition from L to H and back to L occurs at t = 1.18 s and 1.34 s, respectively.

Figure 3 shows the time dependence of the volume averaged $\langle Z_{eff} \rangle$ which determines the ratio of plasma current to loop voltage. $\langle Z_{eff} \rangle$ increases during the L phase and decreases in the H phase but starts to increase again at the end of the H-mode. In order to get more insight into the impurity behaviour Fig. 4 shows the radial development of Z_{eff} profiles at different times: OH (t = 0.9 s), L (t = 1.17 s) and H (t = 1.3 s). In OH and L the radial profiles are relatively flat, whereas in the H-phase strong accumulation occurs. The actual accumulation region is found to be within r $\leq$ 12 cm. From spectroscopic, bolometric and soft X-ray measurements we know that in the H-regime Z_{eff} is mainly determined by high Z impurities in contrast to the previous cases. The concentration of Cu and Fe amount to about 0.5 %.

Analogue to the other improved confinement regimes the observed accumulation process and the central Z_{eff} values can be explained by the neoclassical inward drift which becomes essential when the anomolous diffusion is suppressed. It should be noted that the high central Z_{eff} is of little importance for the volume averaged $\langle Z_{eff} \rangle$ which yields a relatively low value of about 3 for the H-phase, whereas the same quantity is as high as 4.5 during the preceeding L-phase.

4. CONCLUSIONS

Z_{eff} profile measurements show clearly that an improvement of energy confinement is accompanied by an improvement of particle confinement. In all four high confinement regimes more or less peaked Z_{eff} profiles are found demonstrating impurity accumulation. In high density cases low-Z impurities are responsible for the measured Z_{eff} profiles, whereas in the H-regime the strong peaking of Z_{eff} is mainly determined by metallic impurities which accumulate within less than 0.1 s to concentrations of up to 0.5 %. The present results can be explained by neoclassical inward drifts assuming that the anomalous diffusion is sufficiently suppressed which is a consequence of the improved confinement.

References

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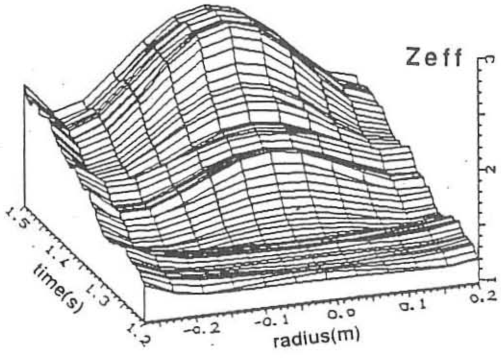

Fig 1 Time evolution of radial Zeff profiles in a pellet fuelled discharge. The accumulatior phase starts at about 0.1s after the last pellet.

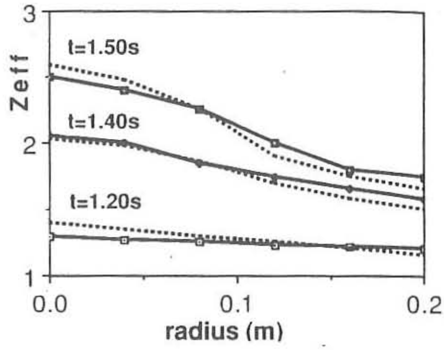

Fig 2 Comparison of measured and calculated(dotted line) at three different times during the accumulation phase.

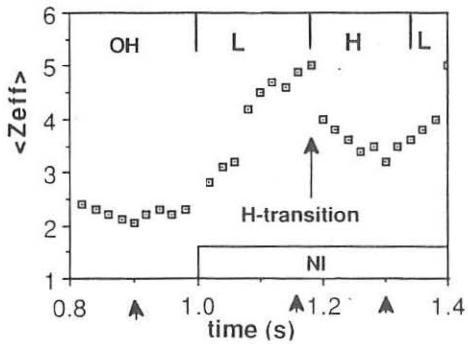

Fig 3 Time development of volume averaged <Zeff> of a neutral beam heated plasma in the sequence from OH to L to H to L.

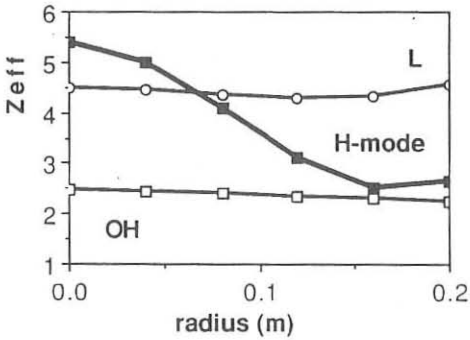

Fig 4 Radial Zeff profiles in OH, L and H phase at the times marked in Fig 3