# IMPURITY RETAINMENT IN THE DIVERTOR OF ASDEX

G. Fussmann, K. Behringer, K. Bernhardi, G. Haas, W. Poschenrieder,
B. Richter, Z. Szymanski[+] and A. Eberhagen, O. Gehre, J. Gernhardt,
G. v. Gierke, E. Glock, F. Karger, M. Keilhacker, S. Kissel[++], O. Klüber,
M. Kornherr, G.G. Lister, G. Lisitano, H.-M. Mayer, K. McCormick, D. Meisel,
E.R. Müller, H. Murmann, H. Niedermeyer, H. Rapp, B. Scherzer, F. Schneider,
G. Siller, P. Smeulders, F. Söldner, E. Speth, A. Stäbler, P. Staib,
G. Staudenmaier, K. Steinmetz, K.-H. Steuer, E. Taglauer, O. Vollmer,
G. Venus, F. Wagner
Max-Planck-Institut für Plasmaphysik, EURATOM-Association, D-8046 Garching

Abstract. The retainment and exhaust capability of the ASDEX divertor for neon and argon is studied and compared with limiter discharges. No significant influence of the scrape-off plasma on the divertor impurity outfluxes is observed. The fluxes, however, show a strong top-bottom asymmetry reversing with the direction of the toroidal field.

Introduction. An important characteristic of a divertor is its efficiency for retaining impurities. In this respect, impurities with high probability for readsorption, e.g. metal vapour or highly active gases are to be distinguished from gases with low adsorption, e.g. rare gases. In case of the latter kind - on which we are concentrating in here - the divertor retainment efficiency is characterized by a divertor containment time $\tau_D$. In terms of this quantity the flux out of the divertor is given by $\phi_D = N_D/\tau_D$, where $N_D$ is the number of particles in the divertor. Under stationary conditions (without external pumping) this flux is balanced by a corresponding flux of ions $\phi_p = N_p/\tau_p$ leaving the plasma, with $\tau_p$ being the particle confinement time in the plasma. The exhaust efficiency of the divertor, defined as the ratio of number of particles in the divertor and the plasma, is thus given by $N_D/N_p = \tau_D/\tau_p$. Whereas $\tau_p$ is known to be of the order 5-20 ms for light and medium impurities in ASDEX /1/, no experimental information existed until recently on $\tau_D$. From Monte Carlo code calculations /2/ as well as 1D scrape-off modelling /3/ a very high retainment efficiency was expected (at least for the ohmic case where thermal forces are negligibly small) because of the high streaming velocity of the background plasma towards the neutralizer plates.

In case that impurities are not ionized in the divertor throat the divertor confinement is determined purely by geometry; the corresponding vacuum time constant $\tau_{D,vac}$ should impose a lower limit on $\tau_D$.

Retainment of gaseous impurities. The retainment of gaseous impurities is studied by injecting short puffs ($\Delta t \sim 6$ ms) of neon or argon either into the plasma chamber, or the upper or lower divertor chambers. In addition single and double null configurations are realized. The number of injected atoms is typically $5 \times 10^{17}$, i.e. approximately 1 % of the plasma particles. Most of the experiments were performed in ohmic discharges with narrow divertor slits ($d_s = 3.5$ cm) but in some cases neutral injection heating has been applied during and after the gas puff. The impurity density in the plasma is obtained

---

[+] On leave from Institute of Fundamental Technological Research, Warsaw, Poland

[++] On leave from Massachusetts Institute of Technology, Cambridge, USA from absolute spectroscopy measurements whereas the partial pressures in the divertor- and plasma-chambers are measured by means of mass spectrometers.

It is found that in any of the nine possible combinations of gas inlet and divertor configuration a quasi-stationary state is reached after a few 100ms. During this phase only 3 % of the injected particles (neon) are found in the plasma. Consistent with this approximately 100 % of the particles are detected initially in the divertor chambers. The volume outside of the plasma in the plasma chamber is observed to be effectively "pumped" by the plasma. In the single null configurations the concentration in the plasma is typically twice as large as in the double null case. An assessment of particle balance during and after the discharge shows a deficiency of about 20 % of the initially injected particles, which is obviously due to implantation of high energy ions ($T_i \gtrsim 20$ eV) in the neutralizer plates.

From transport calculations as well as experiments under limiter conditions we get a particle confinement time of ~10 ms for neon. Multiplying this value with the measured ratio of $N_D/N_p$ a divertor confinement time of $\tau_D$ = 150-300 ms is obtained which is close to the vacuum time constant $\tau_{D,\ vac}(Ne)$ = 150 ms in contrast to expectations.

A more direct measurement of $\tau_D$ is possible in the double null configuration by puffing gas into the top chamber and measuring the pressure built up in the bottom chamber, or vice versa. Furthermore, a direct comparison with $\tau_{D,vac}$ is possible by shifting the plasma to the single null configuration and puffing into the non-activated divertor chamber. From such measurements the agreement between $\tau_D$ and $\tau_{D,vac}$ can be proved in case of neon for various plasma parameters ($I_p$ = 300 - 380 kA, $n_e = 1.8 - 4 \times 10^{13}$ cm$^{-3}$) during the ohmic phase. The same measurements are also performed for argon (the ionization energy of which is markedly reduced compared to neon; 21.6 eV and 15.8 eV), where in addition the influence of neutral injection is investigated. Results are presented in Fig. 1 where normalized partial pressure signals are plotted as a function of time after gas puffing (t = 0.8 s; time constant of mass-spectrometer 160 ms, curve 1). Also in this case the rise times do not differ by more than a factor of two. However, with neutral injection ($P_{NI}$ = 1.6 MW, $\Delta t$ = 0.4 s, curve 2) $\tau_D$ is found to be even smaller than $\tau_{D,vac}$ (curve 3).

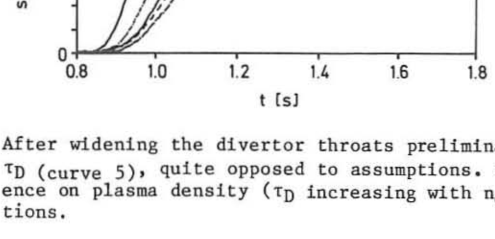

Fig. 1:
Normalized signals of Ar-pressure increase in bottom divertor in case of Ar-injection into plasma chamber (1) or top divertor (2-5) for various scenarios: single null (3), double null with N.I. (2), OH-phase (4), OH-phase with divertor slits enlarged (5)

After widening the divertor throats preliminary results show an increase in $\tau_D$ (curve 5), quite opposed to assumptions. Furthermore a significant dependence on plasma density ($\tau_D$ increasing with $n_e$) now requires more investigations.

The small influence of the plasma scrape-off on the impurity outflux of the divertor is difficult to explain. Thus, according to Langmuir probe measurements close to the neutralizer plates /4/, lower limits of the electron temperature and density within the divertor slits are estimated to $T_e \sim 20$ eV, yielding ionization lengths of 1.7 cm and 0.2 cm for neon and argon, respectively, so that in particular in case of Ar the divertor throats should be opaque for neutrals.

The exhaust efficiency of the divertor is also checked by comparison with limiter discharges. For this purpose equal amounts of neon are puffed into the plasma chamber using first a carbon mushroom limiter (without separatrix) and thereafter realising the double null configuration. The spectroscopic traces of NeX and Ne VIII-lines are shown in Fig. 2 for the two cases. Both signals yield an intensity ratio of ~4.5. Since the plasma parameters differ only slightly in the two discharges (divertor: $n_e = 1.9 \times 10^{13}$ cm$^{-3}$, $T_{eo} = 1.20$keV; limiter; $n_e = 2.1 \times 10^{13}$ cm$^{-3}$, $T_{eo} = 1.25$ keV) this ratio reflects directly the ratio of the impurities. Although this comparison demonstrates the divertor exhaust, the effect is much less than expected. Obviously, also in the limiter case only a fraction of ~15 % of the injected particles are found in the plasma. The majority is supposedly implanted into the limiter within a time interval ~10 ms (Fig. 2) since the recycling rate in a limiter discharge is much higher than in a divertor discharge; thereafter a recycling equilibrium is established. This assumption is supported by the observation of a successive increase of neon from shot to shot.

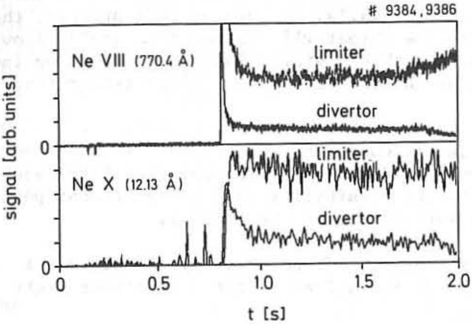

Fig.2:
Ne VIII- and Ne X-line intensities versus time for a limiter and a divertor discharge (equal neon puffs at t = 0.8 - 0.804 s into plasma chamber).

Up-down asymmetries in particle fluxes. When comparing the partial pressures in the upper and lower divertor chambers with a simple dynamic divertor model it becomes obvious that there is an asymmetry in the impurity fluxes leaving the plasma. The up-down ratios in the partial pressures are typically 1.5 in case of neon but rise up to ~5 for argon. Moreover, it is observed that the asymmetry changes sign when reversing the direction of the toroidal magnetic field. An example is shown in Fig. 3 where Ar is puffed into the plasma chamber. Neutral injection (N.I.) is applied in both cases, too, but seems to have no influence (Fig. 3). A vertical displacement of the plasma column, which could cause the asymmetry, can be excluded within an accuracy of $|\Delta Z| < 0.2$ cm from magnetic position measurements as well as $n_e$-interferometer measurements at $Z = \pm a/2$ (minor plasma radius a = 40 cm).

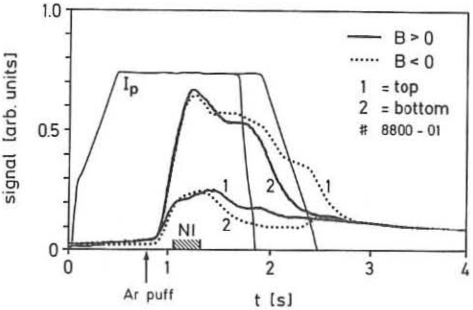

Fig. 3:
Ar-pressure signals from top and bottom divertor demonstrating inversion of top-bottom asymmetry when changing sign of toroidal magnetic field. Ar-puff at t=0.8s. The plasma currents (300 kA) are also shown as a function of time.

Summary. The retainment capability of the divertor is quantitatively associated with the molecular flow conductance of the narrow divertor throats. Accordingly, no pronounced reduction of impurity recycling by the counter-streaming plasma can be proved, though, ionization of neutrals within the divertor throats is most likely. With divertor throats widened up, however, preliminary results show a marked improvement in retainment with increasing electron density.

A possible explanation for such unexpected small influence of the scrape-off plasma may be due to cross diffusion of low Z-ions in the divertor throat and subsequent neutralization at the throat walls. Because of this process, the flow of particles penetrating into the throat will approach molecular flow conditions especially with decreasing throat width. This suggests an optimum width for divertor throats and also the use of aperture slits rather than long ducts.

The exhaust capability of the divertor could be demonstrated by injection of neon into similar limiter and divertor discharges. In comparing both cases, however, attention must be paid to the possibility that a significant portion of the injected particles may be implanted into the limiter.

A strong asymmetry, which changes sign with TF-polarity, is found in the impurity fluxes into the divertor. It is indicated that this effect might originate from high ionic charges.

## References

/1/ Behringer, K. et al., "Production and Transport of Impurities in the ASDEX Tokamak Plasma", this conference.
/2/ Schneider, W., Heifetz, D., Lackner, K., Neuhauser, J., Post, D. and K.G. Rauh, "Modelling of the ASDEX Scrape-off and Divertor", Symposium on Energy Removal and Particle Control in Toroidal Fusion Devices, July 1983, Princeton.
/3/ Neuhauser, J., Schneider, W., Wunderlich, R. and K. Lackner "Modelling of Impurity Flow in the Tokamak Scrape-off Layer, IPP 1/216 (April 1983).
/4/ Shimomura, Y., et al., Nucl. Fus. 23/7 (1983).