STUDY OF IMPURITY ACCUMULATION IN THE ASDEX TOKAMAK

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Abstract: The internal disruptions are found to play an important role in preventing impurity accumulation. We describe several situations where strong peaking of metallic impurities in the plasma center is observed after suppression of the sawtooth activity.

I. Introduction

The possibility of high level impurity accumulation in tokamaks and stellarators was already recognized in the early days of these devices. From a theoretical point of view the principle mechanisms leading to accumulation became quite evident: The frictional forces between impurity (z) and background ions (i) should result in radial ambipolar interchange fluxes ($z\Gamma_z = -\Gamma_i$), such that the high Z impurities are rapidly driven towards the plasma center.

In the experiments, on the other hand, such a dramatic accumulation was generally not observed. During the last years, however, a number of observations showed clear evidence that, at least under certain conditions, strong impurity accumulation can occur /1, 2/, and in the following we will discuss the various observations made on ASDEX.

II. Impurity accumulation and counteracting mechanisms

Impurity accumulation was observed in ASDEX for the first time during the quiescent H-phase achieved by NI heating. As reported in /3/ these discharges collapse because of tremendous radiation losses in the plasma center. The quiescent H-mode differs from the normal one by the lack of bursts caused by edge localized modes (ELMs). It was originally assumed that accumulation can be prevented in the normal H-phase due to counterating mechanisms being correlated with the ELMs. A more detailed analysis, however, revealed that also in this case a quite similar accumulation of metallic impurities takes place /4/. The main difference between normal and quiescent H-phase is found in the Fe-impurity concentration (and hence the Fe influxes) during the preceding L-phase. This concentration is typically three times higher for the quiescent case.

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It is still unclear whether during the H-mode the ELMs effectively improve the screening efficiency of the plasma or if they are rather an indication of low metallic influxes.

Comparing ASDEX with other tokamaks /2/, we have to realize that in our experiments sawteeth do not occur during the H-phase. Therefore, the above accumulation is presumably more pronounced in ASDEX since the counteracting effect of the internal disruption is missing. The dispersing effect of sawteeth (st) has already been shown in a number of investigations /1, 5/. In ASDEX we have studied this effect by means of: a) current ramp-up to increasing plateaus, b) Kr gas puffing, c) pellet injection.

In addition, we have investigated sawtooth initiation during the early current build-up phase. Frequently, the first sawtooth is a very pronounced event (the so-called "Ereignis", further discussed in /6/). By comparison with discharges where the sawteeth grow continuously from noise level, some information on the transport induced by sawteeth can be obtained. Such a comparison is shown in Fig. 1. It is seen that the discharge exhibiting the "Ereignis" shows a substantial increase in the central soft X-ray (SX) intensities prior to the st-crash. After the crash, the SX-signal (dominated by Fe) approaches rapidly the trace of the reference shot. We also note that there is practically no effect to be seen on other spectroscopic signals (FeXVI, OVIII) emitted from outside half the minor radius. Taking further into account that central temperatures differ only by $\lesssim 1\%$ in the two cases, we conclude: Sawteeth expell in short pulses impurities out of the central region but do not lead to a net loss of particles from the plasma volume.

The effect of sawtooth suppression by current ramp-up has been described in /7/. Here it suffices to repeat the essential findings: Firstly, the procedure is not successful in any case. Depending on small changes of some unknown parameters, st may be suppressed or sustain with marked amplitude for the residual part (~2s) of the discharge. In case of suppression, only two changes are observed: 1) the n_e-profile is becoming more peaked, and 2) the central radiation losses are considerably increased (~ factor 10 for $q_a \leq 3$) and become comparable to the input power of ~0.2 W/cm^3, although the Z_{eff} determined by resistivity is as low as ≤ 1.5. Moreover, inspite of the high radiation losses, both the total energy content and the central energy density remain unchanged in comparison with the st case. Thus, a concomitant substantial reduction of the thermal conductivity is to be inferred.

Similar effects can be observed by applying Kr-puffing as demonstrated in Fig. 2. Shot #19691 is a discharge following a shot into which Kr had been blown. The SX-rays (as well as Kr-lines of highly ionized ions) are seen to increase monotonously. As to be seen from the st-amplitude $A=(\bar{n}_e - \langle\bar{n}_e\rangle)/\langle\bar{n}_e\rangle$ (with $\langle\bar{n}_e\rangle$ being the averaged line-density) plotted on top of Fig.2, there are no sawteeth developped in this discharge. The following shot had even less Kr and this time st occur after t=0.72 s. The reduction in the central soft X-rays is evident (whereas the non-central OVIII-radiation is nearly uneffected).

As mentioned above, another method for st-suppression is the injection of pellets with the centrifuge system. This has been done in ohmic discharges and also under carbonized conditions during counter-NI heating (see Ref. /8/ for more detail). The salient features to be observed during the post pellet phase, when the st activity is reduced or even quenched are as de-

scribed before: Peaking of the n_e-profile, accumulation of metal impurities and improvement of energy confinement.
In the following, we concentrate on the accumulation aspects of two discharges with P_{NI}=0.45 MW (#20032) and 0.9 MW (#20033) counter NI (t=0.9 - 1.5s) into which 5 pellets have been injected (t=1.1 - 1.3s). In Fig. 3 we show the SX-signal of the second shot. The times of pellet injection are to be recognized from the $\bar{n}_e$ -trace depicted on top of Fig. 3. After the last pellet the sawteeth vanish (with one large exception) and the SX and TiXX intensities (λ=256 Å, peaking approximately at r=10 cm) are seen to rise exponentially. In Fig. 4 we compare the SX and TiXX radiation on log-scale for the two cited discharges. Each of the two signals is seen to rise very similar with a multiplier of ~2 for the shot with doubled NI power. This proportionality to P_{NI} is also found from bolometer array measurements yielding very peaked profiles with central radiation losses as high as 0.5 and 0.9 W/cm^3 for the two discharges. Despite these large losses the central T_e drop is only about 10 % ($T_{e,max}$≈1.4 keV). Assuming Ti being the most abundant metallic impurity in these discharges (Fe being strongly reduced by carbonization) we need a central density of $n_{Ti}(0)/n_e(0)$≈1 - 2%. Invoking the collision parameter $\alpha=Z^2n_z/n_i>4$, we conclude that the interaction of the impurity ions among themselves is much larger than with the background ions - a situation imposing greatest difficulties in theory. However, the parallel development of the signals shown in Fig. 4 demonstrates that nonlinear impurity transport processes, with the possibility of enhanced impurity accumulation on account of the high impurity density (as discussed in /2/), are probably unimportant.

III. Transport simulation

Our observations suggest the following ansatz for the impurity fluxes:

$$\Gamma_z(r,t) = \Gamma_s(r,t) + \Gamma_{an}(r) + \Gamma_{neo}(z,r)$$

with

$$\Gamma_s = \sum_k A_k P(t-t_k)\ V_s(r) n_z$$
$$\Gamma_{an} = -D_{an}(r)\ n'_z - v_{in}(r) n_z$$
$$\Gamma_{neo} = -D_i(r) n_z + Z(r) D(r) [n_i'/n_i - (o.5+1/Z) T_i'/T_i]$$

Γ_s represents the expelling effect of the sawteeth with P(t) being a pulse like-function Γ_{an} describes the underlying anomalous transport which is assumed equal for all particles, and finally Γ_{neo} is the neoclassical term /9/ (notation: $'=\partial/\partial r$).
We have simulated our experimental results using an impurity transport code applying measured $T_e(r,t)$ and $n_e(r,t)$. Particular emphasis has been devoted to the accumulation phase of #20033. In Fig. 3 we have included our results for the SX and TiXX chord integrals. All sawteeth were modelled in the same way: $\Gamma_{s,k}=V_{so}\exp\{-[(t-t_k)/\tau]^2\}(r/r_o)\exp(-r/r_o)^2$ with r_o=15 cm, τ=1ms, V_{so}= 1 000 cm/s. Most remarkably, these pulses control the peaking of the profiles very effectively at the beginning when the repetition time is still high. Assuming D_{an}=500 cm^2/s, V_{in}= 70 r/a cm/s, the peaking of the n_e-profiles could be roughly simulated by treating hydrogen in the code. Finally, in order to attain at least approximately the strong Ti peaking observed from the radiation profiles, we had to double the neoclassical drift term and dropping the outward T_i'/T_i term therein.

References
/1/ R.C. Isler, Nucl. Fusion, 24, 1599 (1984)
/2/ K. Ida, et al., Phys. Rev. Lett., 58, 2, 116-119 (1987)
/3/ M. Keilhacker et al., Proceedings of the 10th Int. Conf. on Plasma Physics and Contr. Nucl. Fus. Research, London 1984, Vol. I, p. 71
/4/ E.R. Müller, IPP III/112 (1986) to be published in Nucl. Fusion)
/5/ TFR Group, Nucl. Fus. Lett. 25, 8, 981-986 (1985)
/6/ O. Gehre, this conference
/7/ F. Wagner, to be published in Nuclear Fusion
/8a/ V. Mertens, and /8b/ F. Mast this conference
/9/ S.P. Hirshman, Phys. Fluids, 19, 1, 155-158 (1975)

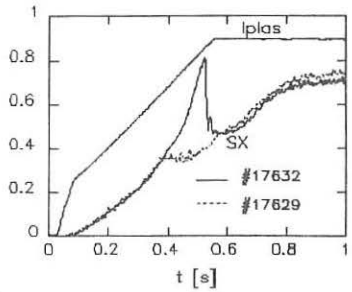

Fig.1: Soft X-ray emission in two discharges with different sawtooth initiation.

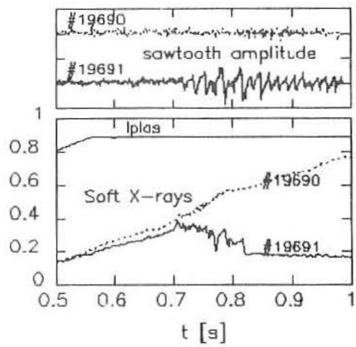

Fig.2: Increase of central SX radiation due to sawtooth suppression by means of Kr puffing.

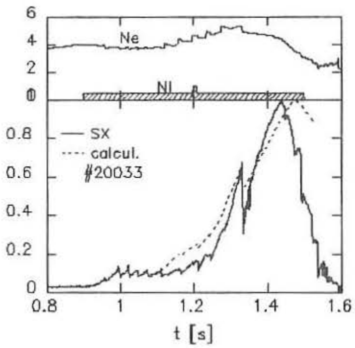

Fig.3: Impurity accumulation in case of pellet injection during the (counter) NI phase.
($\bar{n}_e$ in units of 10^{13} cm^{-3})

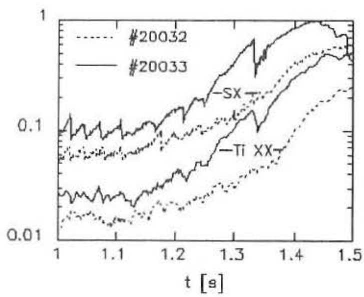

Fig.4: Development of SX and TiXX radiation, demonstrating the similarity of Ti accumulation in shots with different Ti influxes.