"Poloidal Asymmetric Impurity Radiation in Asdex in the Presence of Neutral Injection"

W.Feneberg,M.Kornherr,P.Smeulders,R.Bartimoro[1],G.Becker,H.Bosch, H.Brocken, A.Eberhagen,G.Fussmann,O.Gehre,J.Gernhardt,G.v.Gierke,A.Giuliana[1] E.Glock,O.Gruber, G.Haas,G.Janeschitz,F.Karger,M.Keilhacker,O.Klüber,P.Kotzé[2], K.Lackner, M.Lenoci[1],G.Lisitano,H.Mayer,K.McCormick,D.Meisel,V.Mertens,E.Müller, H.Murmann,H.Niedermeyer,W.Poschenrieder,H.Rapp,H.Röhr,F.Ryter[3], F.Schneider, G.Siller,F.Söldner,E.Speth,K.Steuer,G.Vlases[4],O.Vollmer,F.Wagner.
Max-Planck-Institut für Plasmaphysik,EURATOM Association, D8046-Garching.

During high power neutral beam injection (NI) in Asdex large poloidal asymmetries in the impurity radiation are observed. Dependent on the confinement regime [1]vertical asymmetries are found in energy and particle fluxes in top and bottom divertors and are also measured in the main chamber by VUV-spectroscopy, by bolometer and ultra-soft-X-ray (USX-) pinhole cameras. These measurements are all performed in the vertical plane. Fig. 1 shows the asymmetric line-integrated flux profiles as seen by the USX-camera for low confinement L-regime and for the normal high confinement H-regime close to the $L \rightarrow H$ transition. In the latter regime the up/down asymmetry becomes even more pronounced, while the bottom part of the profile appears to be similar to the one in single-null discharges [2]. The asymmetry starts to appear about 50 msec after the start of NI.

By means of a second USX-camera mounted nearly on top of the divertor tokamak also horizontal asymmetries are detected, which become especially pronounced in the H-regime during high power NI (3.4 MWatt)

The asymmetries are also dependent on the type of H-regime, that can be established. Two types have been found : the normal H- and the H^*-regime, which are characterised by the appearance or non- appearance of the edge-localised mode (ELM). The ELM's have a strong effect on both vertical and horizontal asymmetries and seem to prevent the impurity accumulation, that normally takes place in the quiescant H^* discharges without ELM-activity. As a matter of fact the accumulation of impurities seems to be closely correlated to a contraction of the radiation in the poloidal plane towards the outside of the torus, as can be seen in fig. 2.

Changes in the asymmetries are seen to be related to the plasma confinement properties. A possible candidate, that might explain the behaviour of the horizontal asymmetry of the impurity spatial distribution, is a stong toroidal rotation due to the nearly parallel NI. The rotation can be expected to depend on the confinement of particles and energy and has been measured spectroscopicly to be $2.10^7 cm/s$, during a normal H- discharge, in agreement with angular velocities of observed tearing modes.

The magnitude of this rotation is largely sufficient to make the centrifugal force the dominant term in the momentum balance along the magnetic surfaces, yielding a poloidal impurity distribution , that in first order of $\epsilon = r/R$, the inverse aspect ratio, can be written as :

$$n_Z(\theta) = n_Z(\frac{\pi}{2}) \cdot (1 - \epsilon (\frac{v_\phi}{v_{Zt}})^2 \cos\theta) \quad (1)$$

Here the poloidal angle θ increases clock-wise from torus inside to outside.v_{Zt} is the impurity thermal velocity and the remaining symbols are explained after eqno. 3.

If T_e and n_e are constant along the lines of force, then the measured emissivity would have a similar dependence on θ. The stuctures shown in fig 2. are obtained from the data of the two USX-cameras limiting the number of possible Fourier components in the poloidal plane. The spatial distribution of the emissivity $I(r,\theta)$ has then the general form of:

$$I(r,\theta) \;=\; I_0(r)\;.\;(\;1\;+\;h(r)\cos\theta\;+\;v(r)\sin\theta\;+\;e(r)\cos 2\theta\;) \qquad (2)$$

with $h(r), v(r), e(r)$ being the horizontal, vertical and resp. elliptic variation of the relative emissivity [3].

Recent more complete calculations show the connection between impurity spatial asymmetries and the impurity accumulation.

These calculations are based on momentum equations in the collisional regime for the main plasma ions and impurities as given by Braginski [4]with the friction term proportional to the relative velocities only. This means, that temperature effects [5]are neglected and impurities are treated as test particles. The neutral beam is assumed to produce a rotation of the main plasma in toroidal and poloidal direction. In contrast to present theories [5,6]the dependence of poloidal asymmetries and of the perpendicular transport of impurities from the poloidal rotation has been widely investigated. Using an expansion into the inverse aspect ratio for a geometry of concentric magnetic surfaces one gets in first order of ϵ for the average perpendicular impurity flow $< v_{Z,r} >$, defined as the ratio of the radial flux $\Gamma_{Z,r}$ to the mean density $< n_Z >$, the result :

$$< v_{Z,r} >= \frac{\Gamma_{Z,r}}{< n_Z >} = \frac{cT}{eBrZ}\epsilon a_1(1+\frac{m_Z v_\phi^2(r)}{2T}(1-\frac{Zm_i}{m_Z}+2(1-\delta)\frac{Rq}{a}\frac{cTL_i}{v_\phi(r)eBr})) \quad (3)$$

$T = T_e = T_i = T_Z$ being the temperature, B the toroidal field, r the minor radius of the surface to be considered, Z the ionic charge, m_z, m_i the masses of impurities and main plasma ions, a the plasma radius, R the major radius, q the safety factor, $L_i = (r/p_i).(dp_i/dr)$ the dimensionless radial decay length of the ion pressure. The toroidal main plasma velocity is assumed to have a paraboloic profile : $v_\phi(r) = v_\phi^{(0)}(1-(r/a)^2)$. The parameter of the poloidal rotation of the plasma ions δ is defined as $\delta = v_{i,\theta}^{(0)}/(L_i cT/eBr)$, where the poloidal rotation follows the relation $v_{i,\theta} = v_{i,\theta}^{(0)}(1-\epsilon\cos\theta)^{-1}$. The last term in eqn. 3 shows the difference between co- $(v_\phi(r) > 0)$ and counter- $(v_\phi(r) < 0)$ injection, that originates from the difference in the toroidal rotation of impurities and the main plasma due to friction. The inertial term produces a large effect on the perpendicular transport of heavy impurities, the sign of which depends on the sine-Fourier component a_1 in the expansion $n_Z = n_Z^{(0)}(1+\sum_{m=1}^{\infty}(a_m \sin m\theta + b_m \cos m\theta))$. The impurity distribution has been obtained from the continuity equation $\nabla_\theta n_z v_{z,\theta} = 0$, assuming a quasi steady state equilibrium with poloidal flow velocities much larger than the perpendicular ones : $v_{Z,\theta} \gg v_{Z,r}$. A solution is readily obtained, when the impurity distribution is assumed to be far away from accumulation ($(1/n_z)(dp_Z/dr) \ll (1/n_i)(dp_i/dr)$). This is shown in fig. 3 and 4. As expected one finds the impurities concentrating to the outside due the centrifugal force. Fig. 4 shows that even for co-injection a poloidal rotation of the size of the diamagnetic drift causes a strong inward flux in the same order of magnitude as observed in Asdex during the H^* confinement regime. On the other hand a much larger poloidal rotation seems to produce a very effective outward drift. The latter could well be used to control the impurity level in divertor and limiter tokamaks.

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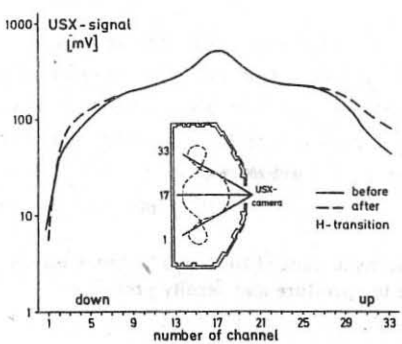

Fig.1 USX measurements in the vertical plane in mV versus diode number shortly before and after the $L \rightarrow H$ transition for a normal $\dot{H}$-discharge. Three lines of sight are shown in the inserted Asdex cross-section.

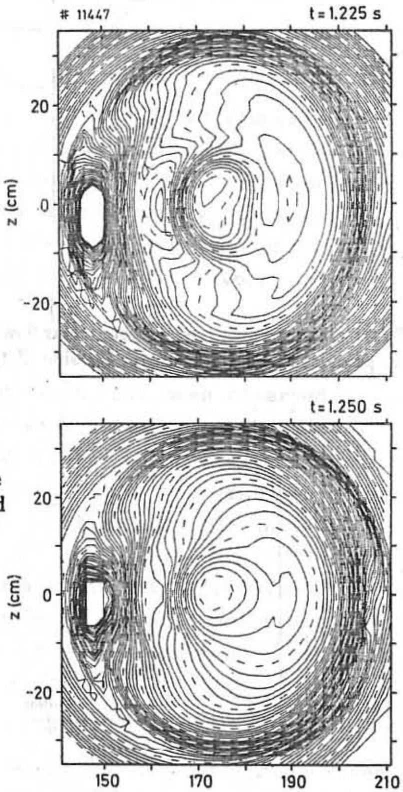

Fig:2 Iso-emissivity lines showing the plasma cross-section in USX light for maximum β (t=1.225 s) and later in time during the impurity accumulation phase (t=1.25 s) for a H^* discharge. $I(r=0)$ increases from 0.5 to 1.5 W/cm^3 during this time.

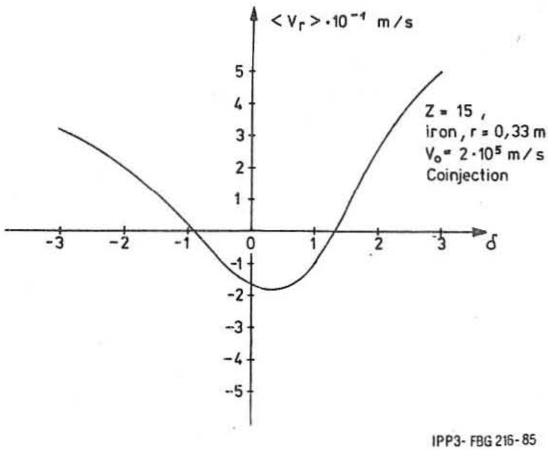

Fig.4 Calculated averaged perpendicular flow velocity in units of 10^{-1} m/s in Asdex versus the poloidal rotation parameter δ, using H-type temperature and density profiles.

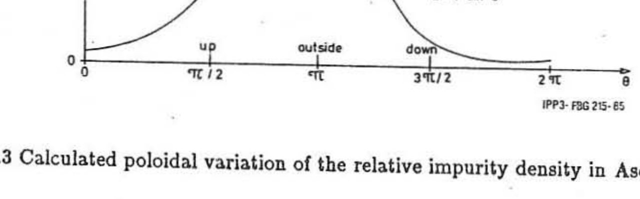

Fig.3 Calculated poloidal variation of the relative impurity density in Asdex.

[1] CNEN Frascati,Italy
[2] Nuclear Developement Corp. of South Africa, Pretoria
[3] CEN Grenoble, France
[4] University of Washington, Seattle