Predictive Modeling of Impurity seeded Plasmas in JET

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1. Introduction.

The possibility to improve confinement in tokamaks by seeding of impurities has been successfully realized in several devices [1,2,3]. However earliest trials on JET [4] were not encouraging and sowed doubts that this mode of operation can be achieved in large machines. New series of experiments performed during the past year have shown that also in JET a positive effect of impurity seeding can be attained through an optimization of the puffing scenario. E.g., carefully dozed puffs of argon allowed to maintain good confinement in the H-mode discharges at an electron density close to the Greenwald limit.

In this contribution we present the results of theoretical analysis and numerical modelling of another scenario performed on JET with neon impurity seeded into L-mode discharges. This choice is explained by several reasons. First, the theoretical models applied for our study were developed to analyze the results from TEXTOR[2] and DIII-D[3] where the stage of improved confinement, the so called Radiative Improved (RI) mode, was achieved starting from the L-mode conditions. Up to now these models do not include the edge barrier and are limited in applications to the H-mode conditions. Second, although transiently the most characteristic features of the classical RI-mode such as peaking of density and pressure have been seen in JET namely under these conditions. As an example Fig.1 shows the radial profiles of plasma parameters measured in #50329 before and after Ne puff.

2. Gyro-Kinetic Stability Analysis

Characteristics of drift instabilities, which provide the main contribution to the anomalous transport in tokamaks, namely the ion temperature gradient (ITG) and dissipate trapped electron (DTE) modes, have been intensively analyzed by the code for Gyro-Kinetic Stability (GKS) for a wide range of wave numbers [3]. These simulations show that seeding of impurities results

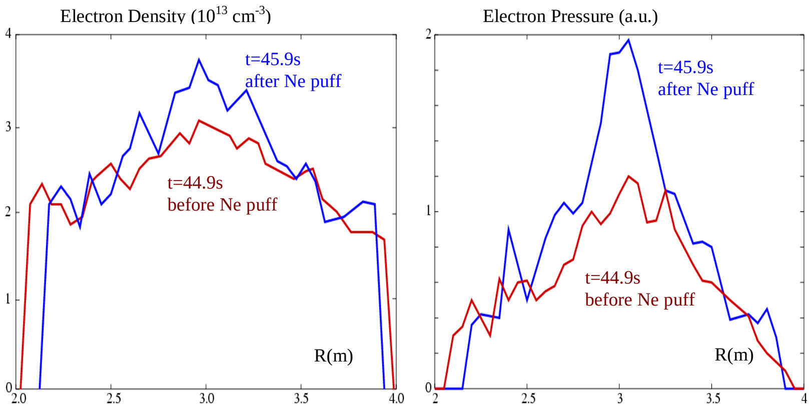

Fig.1. Modification of electron density and pressure profiles in JET #50329 caused by Puff of Neon

mostly in reduction of the growth rates for perturbations with small perpendicular wave numbers corresponding to ITG modes. For discharges with unbalanced neutral injection GKS computations predict an important role of ExB shearing leading to complete stabilization of these modes. However, even in this case the strong shearing of the toroidal rotation, which provides the main contribution to Ω_{ExB}, occurs at the discharge stage, when the ITG growth rate is already significantly reduced by the direct effect of impurities. Therefore in the predictive transport modelling only the latter has been taken into account. A firm consideration of the role of Ω_{ExB}, which requires a self-consistent description of the plasma rotation, will be done later.

3. Predictive transport modelling

Two approaches have been applied to perform a predictive transport modelling of the L-mode plasmas in JET seeded with impurities. The Chalmers advanced fluid model [5] for temperature gradient driven instabilities was used to determine all anomalous transport coefficients necessary for transport modeling. A code based on this model was successfully run before to simulate standard L and H-mode discharges in JET and ASDEX-U. In computations performed for L-mode discharges in JET seeded with impurities the radial profiles of the particle densities and temperatures are computed using the sources from interpretive calculations. The results of this study indicate, that the reduction in the transport occurs because of the increase in the plasma effective charge, Z_{eff}, and due to the reduction in the electron density at the plasma edge, which leads to reduction in the parameter $\eta_i=L_n/L_T$.

The conclusion above agrees principally with the results of modelling by the code RITM [6]. This code provides a self-consistent description of the transport of recycling neutrals (molecules, reflected, Franck-Condon and hot atoms), electrons and ions of the working gas and all charged states of He, C, O, Ne and Si impurities, the energy transfer in the electron and ion plasma components and diffusion of the plasma current. RITM operates with a half-empirical model for ITG and DTE induced anomalous transport, proposed initially to simulate the plasma evolution in the RI-mode in TEXTOR-94 [7]. This model has been amended by a proper description of the DTE transport at a low collisionality typical for JET. The particle fluxes contain both diffusive and convective part: $\Gamma_{\perp}^{e,Z} = -D_{\perp}^{e,Z} \frac{\partial n_{e,Z}}{\partial r} + V_{\perp}^{e,Z} n_{e,Z}$; the electron diffusivity includes contributions from ITG, DTE and edge turbulence: $D_{\perp}^{e} = D_{\perp}^{ITG} \cdot f_{tr} + D_{\perp}^{DTE} + D_{\perp}^{edge}$; here f_{tr} is the fraction of trapped electrons computed by taking into account both inhomogeneity of the magnetic field and detrapping by coulomb collisions and this factor reflects that ITG turbulence leads to particle transport mainly through stochastization of banana orbits [8]. The electron pinch-velocity is assumed to be governed by the magnetic shear [9]: $V_{\perp}^{e} = \left(D_{\perp}^{ITG} \cdot f_{tr} \frac{4r}{3R} + D_{\perp}^{DTE} \right) \frac{d \ln q}{dr}$; the diffusivity of impurities is adopted the same as for the main particles, however their pinch velocity is neoclassical: $D_{\perp}^{Z} = D_{\perp}^{e}, V_{\perp}^{Z} = V_{\perp}^{Z,neo}$; the anomalous transport at the plasma edge is due to turbulence caused by electric currents in the scrape-off layer (SOL) [10], which is assumed decaying from the separatrix inside the confined volume at a distance of the pressure decay length in the SOL, L_P: $D_{\perp}^{edge} = \frac{cT_e^{sep}}{eB} \frac{\rho_s^{sep}}{L_P^{sep}} \exp\left(-\frac{r_{sep} - r}{L_P} \right)$. The anomalous transport coefficients are computed in mixing length approximation, $D_{\perp}^{ITG,DTE} = \frac{\gamma_{\max}}{k_{\perp,\max}^2} \times q^2$, with the growth rates γ_{max} corresponding to the most unstable modes.

The results of computations with RITM presented in Fig.2 reproduce the peaking of the density and pressure profiles. This is caused by reduction in $D_{\perp}^{ITG}$ with Z_{eff} increasing during impurity seeding, which is also demonstrated in Fig.2. As a result the ratio $V_{\perp}^{e} / D_{\perp}^{e}$ increases and the electron density peaks. These results allow to interpret the necessity of a significantly higher plasma effective charge in JET than in DIII-D and TEXTOR in order to get a RI-mode effect: 5-7 res. 2-3. The ratio $V_{\perp}^{e} / D_{\perp}^{e}$, which controls the density peaking, is governed by the value $D_{\perp}^{DTE} / D_{\perp}^{ITG}$ and for a transition to the RI-mode the latter should exceed a critical level [7].

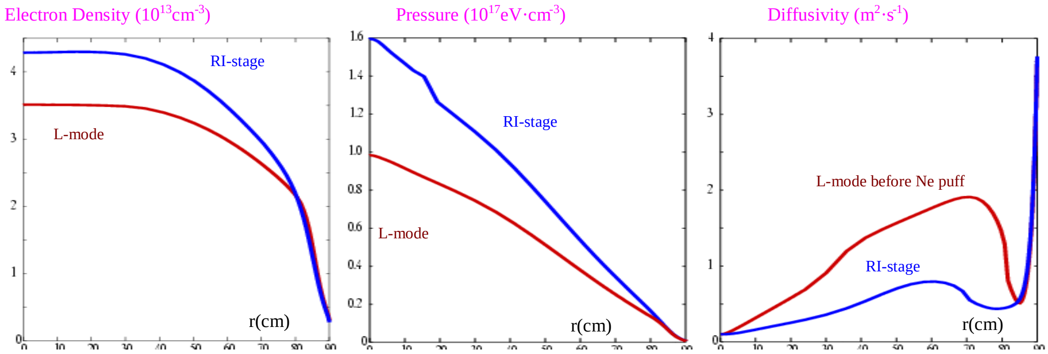

Fig.2. Computed profiles of the electron density and pressure and diffusivity for # 50329

On the one hand for plasmas of low collisionality as in JET, where the electron drift frequency exceeds the effective collision frequency of trapped particles, $D_{\perp}^{DTE} \propto n_e$ [11]. On the other hand $D_{\perp}^{ITG}$ decreases with increasing Z_{eff} and ITG transport is suppressed completely when the plasma effective charge exceeds a certain critical level [7]. Thus the lower the plasma density the higher Z_{eff} , at which $D_{\perp}^{DTE} / D_{\perp}^{ITG}$ approaches its critical level. Since the plasma density in JET L-mode is significantly less than in DIII-D and TEXTOR the required Z_{eff} is larger in JET.

4. Conclusion

The Gyro Kinetic Stability modelling predicts importance of direct impurity effect on turbulence. In particular this is necessary to get a strongly sheared toroidal rotation, which activates the “suppressive” role of the radial electric field. Predictive modeling with theoretical transport models, which take into account only this direct effect of impurities, reproduces peaking of profiles by seeding of neon into JET L-mode discharges. Low plasma density in JET requires a higher than in DIII-D and TEXTOR Z_{eff} to trigger the L-RI transition.

References

[1] Lazarus E.A. *et a*l 1984 J. Nucl. Mater. **121** 61
[2] Weynants R.R. *et al* 1999 Nucl. Fusion **39** 1637; Ongena J. *et al* 2001 Phys. Plasmas **8** 2188
[3] McKee G.R. . *et a*l 2000 Phys. Plasmas **7** 1870
[4] Matthews G.F. *et al* 1999 Nucl. Fusion **39** 19
[5] Nordman H. *et al* 1990 Nucl. Fusion **33** 983
[6] Tokar M.Z. 1994 Plasma Phys. and Control. Fusion **36** 1819
[7] Tokar M.Z. *et al* 2000 Phys. Rev. Lett. **84** 895
[8] Horton W *et al* 1985 Plasma Phys. Controll. Fusion **27** 937
[9] Baker D.R and Rosenbluth M.N. 1998 Phys. Plasmas **5** 2936
[10] Endler M. *et al* 1995 J. Nucl. Mater. **220-222** 293
[11] Kadomtsev B.B. and Pogutse O.P 1971 Nucl. Fusion **11** 67