Modeling of plasma fuelling and nitrogen seeding of JET discharges with the COREDIV code

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1. Introduction.

In view of possible realistic predictions for ITER-relevant scenarios with impurity seeding, JET discharges with nitrogen injection have been numerically simulated in recent years using the self-consistent transport code COREDIV [1, 2]. The coupled core-edge code COREDIV [1] (1-D radial transport in the core, 2-D poloidal and radial transport in the SOL, self- consistent with respect both to the interaction core-SOL and main plasma-impurities) has been developed and benchmarked against JET discharges [2], proving its capability of reproducing - with the diagnostic and modeling uncertainties - the main features of JET seeded plasmas, as the electron temperature and density profiles, the total radiated power, P_{rad}, and the ionic effective charge, In the core, the electron and ion energy fluxes are defined by a local transport model which, for a given profile of the transport coefficients (usually parabolic), reproduces a prescribed energy confinement law (enhancement factor, $H_{98P(y,2)}$). A simple slab geometry (poloidal and radial directions) with classical parallel and anomalous radial transport (order of 0.5 $m^2 s^{-1}$) is used for the SOL. Chemical and physical sputtering together with sputtering by seeded nitrogen account for the fluxes of the intrinsic carbon and recycling is a free parameter. Z_{eff}. It should be noted that COREDIV, although intrinsically time dependent, has been used so far to analyze only steady state plasmas (average values for ELMy discharges).

2. Experiments and simulations.

We have considered a set of nitrogen seeded JET discharges in ELMy H-mode (I_p=2.5 MA, B_T = 2.7 T, q_{95} = 3.5, P_{in} ~ 15 MW) in which both the fuelling and seeding rates have

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see the Appendix of F. Romanelli et al., Proceedings of the 22nd IAEA Fusion Energy Conference 2008, Geneva, Switzerland.

been systematically changed, on a shot to shot basis [3, 4]. Keeping the N puffing at Φ_N = 4.8 x 10^{22} el/s, the D puffing changes in the range 1.2 - 2.8 x 10^{22} el/s and keeping Φ_D = 2.8 x 10^{22} el/s, Φ_N changes in the range 0 - 2.8 x 10^{22} el/s. Increasing the D puffing, the volume average electron density $\langle n_e \rangle$ is seen to increase from 5.7 to 7.6 x 10^{19} m^{-3} (with related decrease in Z_{eff}) and the confinement enhancement factor $H_{98P(y,2)}$ decreases from 0.95 to 0.82. Increasing the N puffing, $\langle n_e \rangle$decreases from 10 to 7.6 x 10^{19} m^{-3} and $H_{98P(y,2)}$ decreases from 1 to 0.82.

a) Prad and Zeff

Considering the D puffing scan, we have first examined with COREDIV the effect on Z_{eff} of a change in recycling coefficient (higher the puffing, higher the recycling) in the range 0.975 - 0.983. The effect both in Z_{eff} and in P_{rad} is negligible, although a significant effect is seen on the edge temperature and D flux leaving, however, their product nearly constant. A numerical test on the influence of a change in the position of the nitrogen inlet valve led to minor effects on Z_{eff} and P_{rad}, as well. Considering the value relatively high of $H_{98P(y,2)}$ - and its spread - in these discharges, we have modeled impurity transport to account for a linear dependence of the inward impurity pinch on the confinement level. The simple analytical expression we have adopted reads:

$$\Gamma_z = D_\perp (dn_z/dr + S\, r/a^2 \text{ x } n_z)$$

where Γ_z is the flux of impurities of charge z, $D_\perp$ is the anomalous perpendicular main ion diffusivity and S~ τ_E^2. With this choice, the resulting inward impurity pinch is proportional to τ_E (v_{pinc} ~ τ_E r/a^2) since in our transport model (see Introduction) $D_\perp$~1/ τ_E. In Figs.1,2 the experimental and simulated P_{rad} and Z_{eff} are shown for the D puffing scan. While P_{rad} remains nearly constant with increasing D puffing, Z_{eff} decreases as a consequence of the increase in the electron density and of the decrease in confinement (in impurity inward pinch). For these pulses, the resulting simulated impurity peaking (-v_{pinch}/D) is modest, in the range 0.3 – 0.6 m^{-1}, consistently with previous analysis of impurity transport with radiofrequency heating in JET [5]. Please, note that for these discharges the highest discrepancy between the experimental and simulated P_{rad} is about .0.3-0.4 MW. The discrepancy is much higher for the discharges of the N seeding scan, Fig.3. In fact, it reaches 0.8-0.9 MW, which is above the modeling and experimental uncertainties. However, the assumption of a small amount of N in the discharge Φ_N = 0 (consistent with nitrogen legacy, observed to occur on JET during these experiments.[3])

would lead only to a marginal change in the calculated Z_{eff} (Fig.4), while it would increase the level of the calculated P_{rad}, mainly due to the high electron density of this discharge and to the rather good radiation properties of nitrogen in the considered range of temperatures. Numerical decomposition of Z_{eff} in the carbon and nitrogen concentration shows the linear increase of N and the decrease of C with increasing Φ_N, thus confirming the replacement of C by the seeded N, previously observed on TEXTOR [6].

b) Deuterium and carbon fluxes.

Comparison simulation-experiment for the particle fluxes is a critical issue because, on top of the usual uncertainties related to the spectroscopic determination of the photon fluxes (absolute calibration, assumed symmetries), the evaluation of particle fluxes needs the ionization per photon (S/XB) to be assigned. This number, which depends strongly on the local temperature and density, can be determined only with some approximation and, in principle, should be different for each pulse. Following [7] we have assigned, both for the D_α and for CII line (λ = 515nm), S/XB = 30 for the outer divertor and S/XB = 15 for the inner divertor. In Figs. 5,6 the experimental and simulated D fluxes are shown for the D puffing and for the N seeding scans. For Fig.5, either the experimental point at the lower D puff is too low or those at higher puffing are too high. This is consistent with the fact that for the lower D puffing (low density) the calculated T_e(plate) is on the order of 30 eV while for the remaining two points (higher density) the calculated T_e(plate) is on the order of 10eV. Therefore the S/XB for the pulse at low puffing should be higher than that for the pulses at high puffing. Since for the N seeding scan the edge temperatures are rather similar to each other, the higher discrepancy simulation-experiment at the point Φ_N =0 is most likely related to the underestimation of the recycling coefficient (R=0.975) we have assumed for that pulse. Very similar results are seen for the comparison simulated-experimental carbon fluxes and very similar comments can be done.

3.Conclusion.

In spite of the limitations caused by the uncertainties in the measurements as well as in the model, including the oversimplified SOL model, the results presented in this paper show for the first time the capability of COREDIV of reproducing the main features of nitrogen seeded JET discharges at high confinement. To achieve this result, we had to modify the impurity transport model in COREDIV by introducing the anomalous pinch, linearly dependent on the level of confinement. Discrepancies between the experimental and simulated particle fluxes may partly be attributed to the oversimplification made in the evaluation of experimental data.

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References

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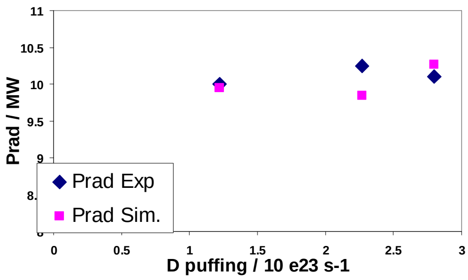

Fig. 1. Prad vs. D puffing

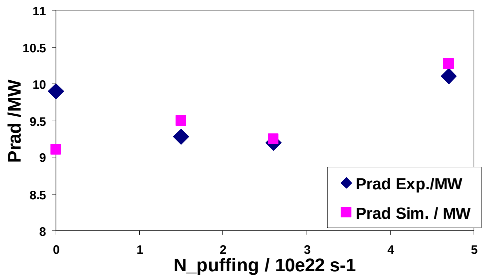

Fig. 3. Prad vs. N puffing

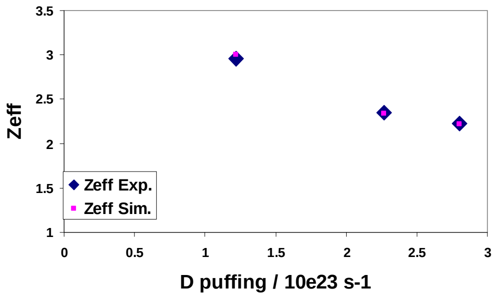

Fig. 2. Zeff vs. D puffing

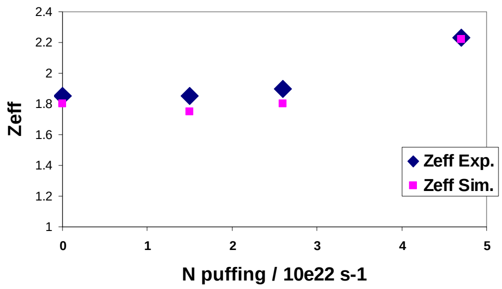

Fig. 4. Zeff vs. N puffing

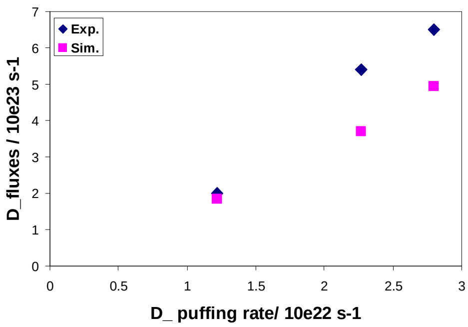

Fig. 5. D_flux vs. D_puffing

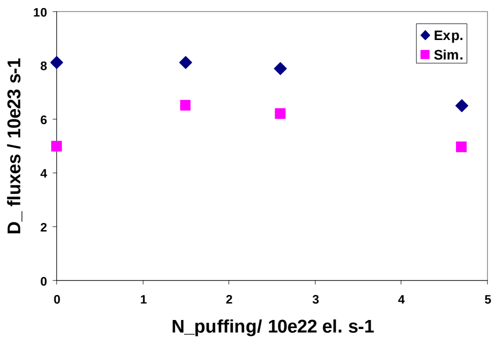

Fig. 6. D flux vs. N puffing