Core transport and pedestal characteristics of nitrogen seeded H-mode discharges in ASDEX Upgrade

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1 Introduction

Nitrogen seeding is established as a divertor cooling tool in the tungsten coated device ASDEX Upgrade [1] . It is now the routine actuator in the real time control of the divertor temperature. In particular, it is necessary in discharges with high P/R, such as the improved H-modes. While N_2 radiates around the separatrix and in particular close to the divertor [2] , it does not accumulate in the core, provided Electron Cyclotron Resonance Heating is applied centrally. The energy confinement turns out to be improved with respect to discharges without N_2, with the same engineereing parameters and similar plasma conditions.

2 Nitrogen seeding and confinement

The beneficial effect of N_2 seeding on the stored energy has been observed in the tungsten coated ASDEX Upgrade [3] . In the 2009 campaign, improved edge diagnostics coverage has enabled to resolve the kinetic profiles in the pedestal region. The efficient divertor cooling and the confinement improvement have been reliably reproduced, both after a fresh boronisation and with the unboronised machine. The time traces of a typical pair of discharges with and without N_2 seeding are plotted in Fig. 1.

The increase in $H_{H98(y,2)}$ is more pronounced at high P_{NBI}, because N_2 is input as a feedback actuator for the divertor temperature, so more N_2 is puffed at higher auxiliary power.

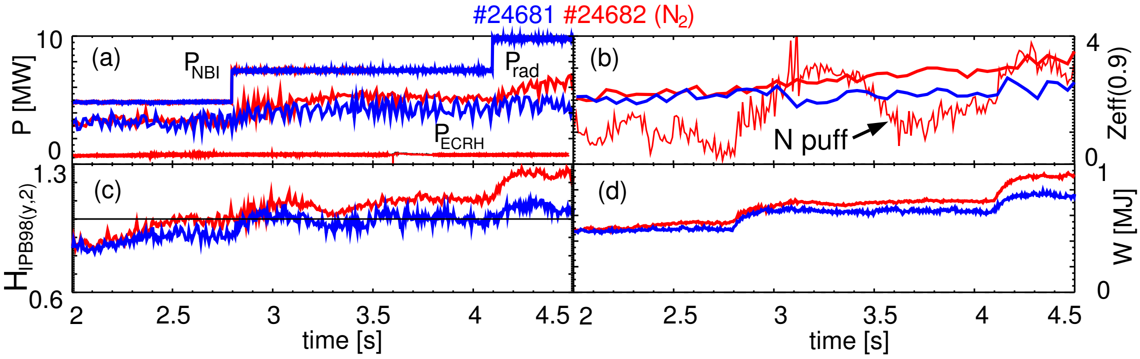

Figure 1. Time traces of two discharges with (red) and without (blue) N_2 seeding. (a) Heating power (b) Z_{eff} and N_2 puff rate (c) $H_{H98(y,2)}$ (d) Stored energy

The kinetic profiles (Fig 2) exhibit an improvement mainly in the temperature channels displayed in (a) and (b). Given the high collisionality, the T_e and T_i profiles are close to each other. In some cases the density profile is more peaked in presence of N_2, as in Fig.2(d), but not enough to explain the observed confinement improvement. In most cases, however, adding N_2 seeding does not modify the density profile at all [3] . The effective charge Z_{eff} is plotted as well, in Fig. 2(c).

Gyrokinetic calculations identify the Ion Temperature Gradient driven mode as dominant

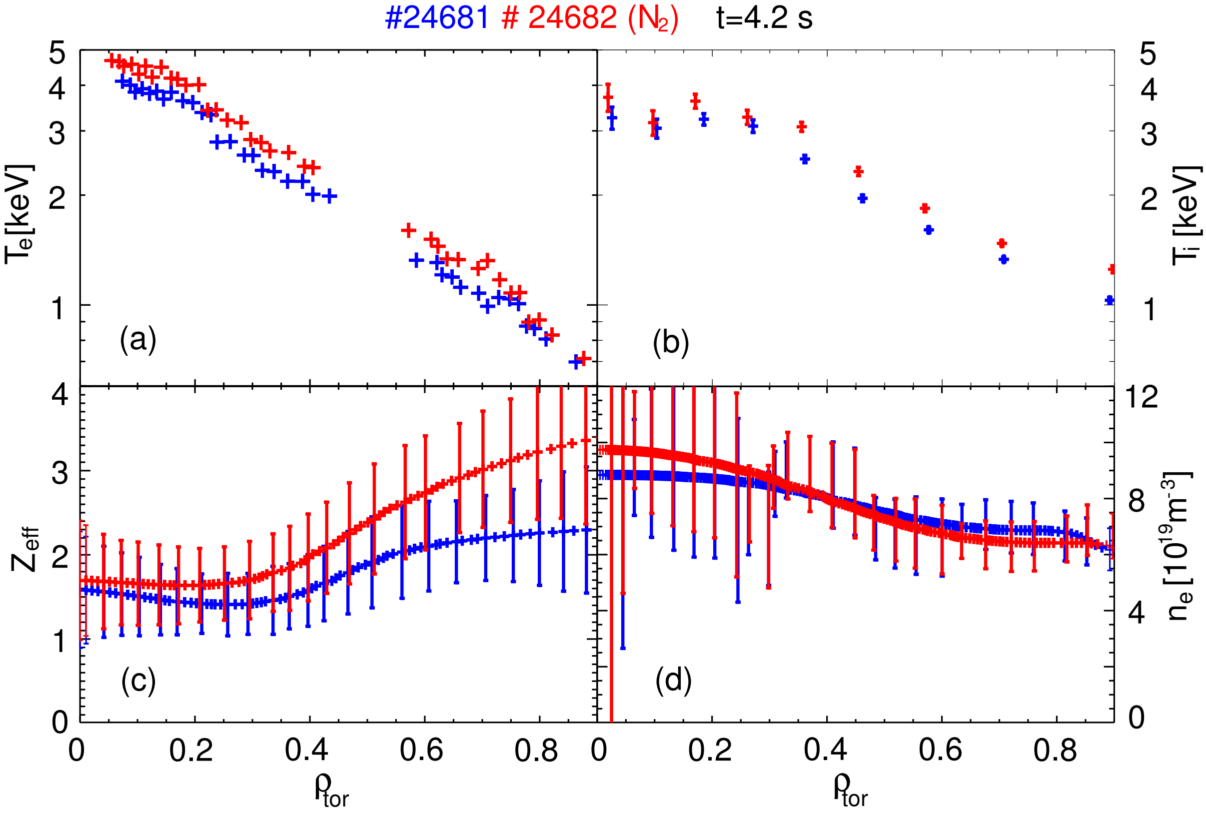

Figure 2. Comparison of discharges with (red) and without (blue) N_2 seeding. (a) T_e and (b) T_i profiles on a semilogaritmic scale (c) Z_{eff} profiles (d) n_e profiles.

instability in the core plasma. Under these circumstances, profile stiffness is expected, so that the inverse gradient length $R/L_{T_j} := R * |\nabla T_j|/T_j$ (j labelling electrons or ions) is constrained near its critical value [4] . Moving from the pedestal top inwards, R/L_{T_j} is the same in the discharges with and without N_2, within the experimental uncertainties, as the logarithmic scale of Fig. 2highlights. The core confinement improvement is therefore mainly due to the higher pedestal pressure, extending to the core via profile stiffness. The pedestal kinetic profiles are plotted in Fig. 3.

3 Transport analysis with and without nitrogen seeding

The experimental uncertainties for n_e, ∇T_i, ∇T_e are too large for a power balance anal-

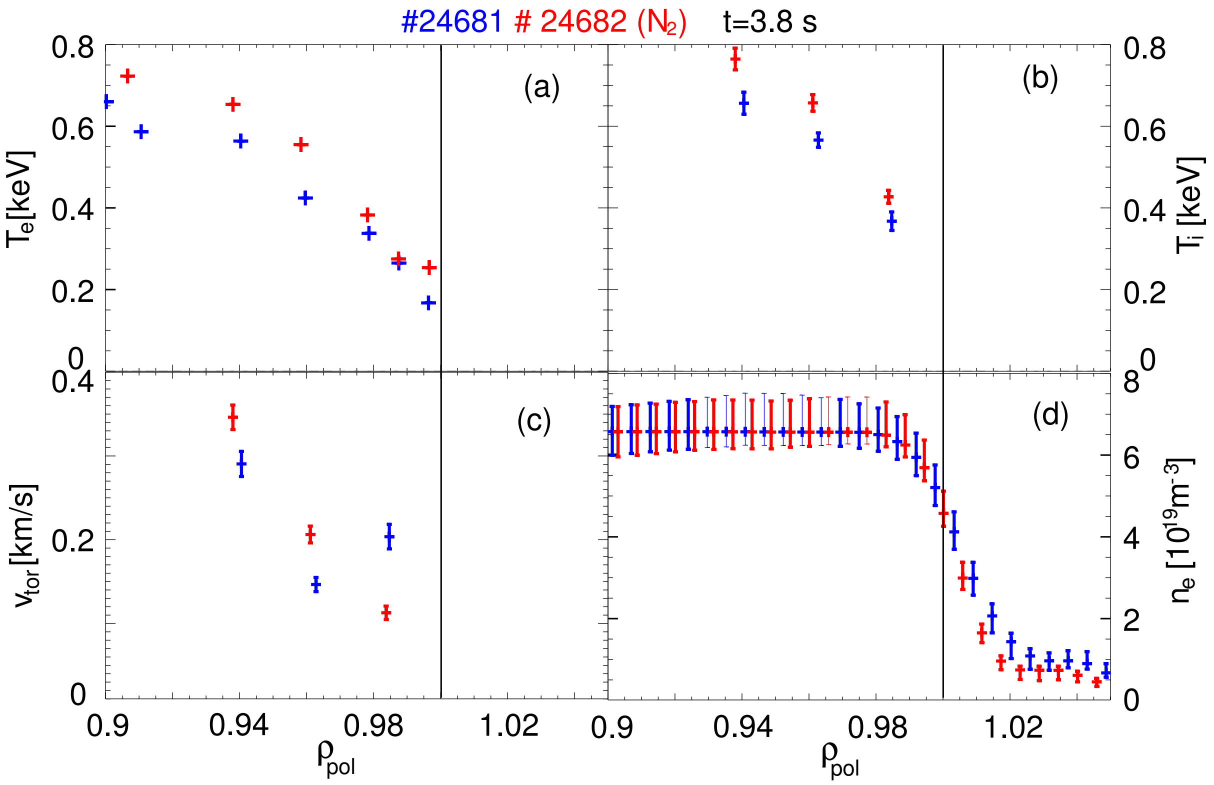

Figure 3. Pedestal profiles (a) T_e (b) T_i (c) v_{tor} (d) n_e

ysis to resolve a possible difference in the effective heat diffusivities between discharges with and without N_2 seeding. However, the TRANSP code [5] is used to calculate of the ion and electron heat fluxes and to provide a reference heat flux to the gyrokinetic simulations. A scan of the nitrogen concentration in linear gyrokinetic simulations had highlighted a mitigation of the ITG mode due to deuterium dilution, so that a transport reduction was predicted, mainly via a shift of the ITG critical R/L_{T_i} [3] , R being the major radius. However, only non-linear calculations at a given heat flux can assess the quantitative impact of N_2 seeding on the temperature gradients. The gyrokinetic code GENE [6] is used for a scan of ∇T_i, taking the experimental values for the input parameters T_e, T_i, n_e, ∇n_e, $\hat{s}$ and q. It is found that the predicted modification of R/L_{T_i} and R/L_{T_e} is negligible in the case considered, as illustrated in Fig. 4.

The stronger profile stiffness associated with a higher T_e compensates the shift in the critical L_{T_i} due to deuterium dilution, since the heat flux growth above criticality scales as $T_e^{\frac{5}{2}}$. As a consequence, at the relevant heat fluxes R/L_{T_i} at $\rho_{tor} = 0.5$ is the same, at $\rho_{tor} = 0.8$ it is predicted to be even slightly smaller in the case with N_2 seeding. This is consistent with the experimental result of Fig. 3.

4 Conclusions

The confinement improvement in N_2 seeded discharges is a robust observation, as it occurs at different heating power levels, with and without boronisation and different plasma den-

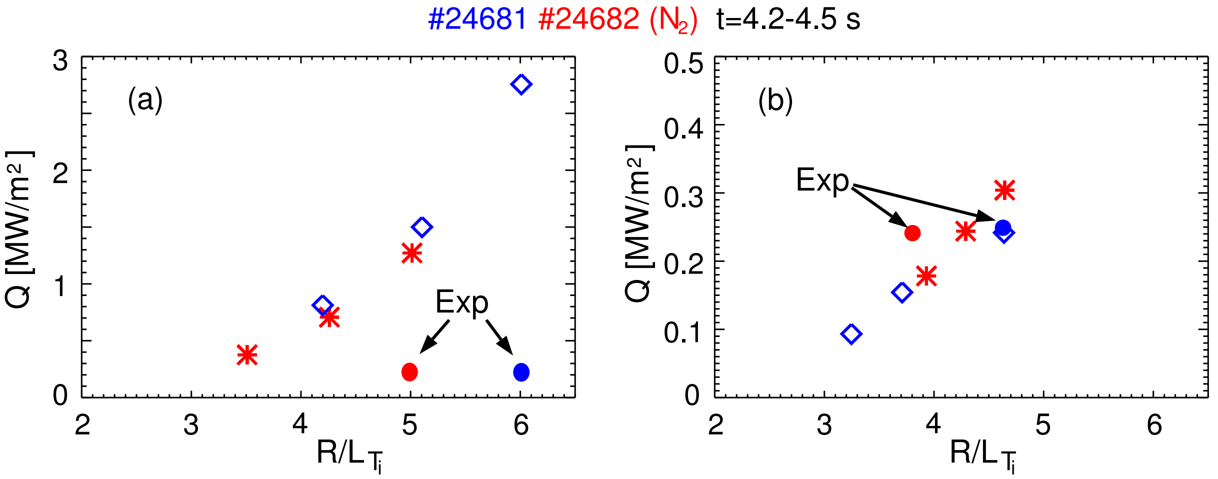

Figure 4. R/L_{T_i} scan with the non-linear gyrokinetic GENE. (a) At ρ_{tor}=0.5 (b) At ρ_{tor}=0.8. The full circles represent the heat flux reconstructed with TRANSP and the measured R/L_{T_i}.

sity. The gain in energy confinement increases with the auxiliary heating power, because N_2 is puff is higher in presence of higher auxiliary heating, since it is input as a feedback actuator for the divertor temperature. The improved edge diagnostics coverage in ASDEX Upgrade allows to resolve the kinetic profiles in the pedestal region; the measurements show that the confinement improvement in N_2 seeded discharges is largely an edge effect, as the pedestal pressure increases by up to 20 %. In the core, no significant enhancement in R/L_{T_i} is observed in general. Gyrokinetic non-linear simulations predict a shift in the critical gradient length in presence of nitrogen, but this is compensated by higher profile stiffness due to higher T_e, yielding only a negligible change in the core gradient length. Depending on the radial position, the gradient length can even slightly decrease, consistently with the experimental observations. The density peaking can slightly increase in presence of N_2 seeding, while in most cases it remains unchanged. Its effect on the energy confinement at medium-high density is negligible.

References

[1] O. Gruber *et al*, Nuclear Fusion **49** (2009) 115014

[2] J. C. Fuchs *et al*, Proc. of the 36th EPS Conference on Plasma Physics, Sofia, Bulgaria, Vol. 33E (2009), P-1.147

[3] G. Tardini *et al*, Proc. of the 36th EPS Conference on Plasma Physics, Sofia, Bulgaria, Vol. 33E (2009), O-2.004

[4] G. Tardini *et al*, Nuclear Fusion **42** (2002) 258

[5] A. Pankin, D. McCune, R. Andre *et al*, Comp. Phys. Comm. **159**, No. 3 (2004) 157

[6] F. Jenko *et al*, Physics of Plasmas **7** (2000) 1904