Neon transport simulation for highly peaked density FTU plasma

C.Mazzotta[1], M.E.Puiatti[2], L.Gabellieri[1], G.Apruzzese[1], V.Dolci[1,3], L.Carraro[2], F.Causa[1], A.Romano[1] and the FTU team*

[1] *Unità Tecnica Fusione, ENEA C.R. Frascati, via E.Fermi 45, 00044 Frascati (Roma), Italy*

[2] *Consorzio RFX, Corso Stati Uniti 4, I-35127 Padova, Italy*

[3] *Dip. di Fisica, "Sapienza" Università di Roma, P.le Aldo Moro 5, 00185 Roma, Italy*

**See the appendix of G.Pucella et al., Proceedings of the 25th IAEA Fusion Energy Conference, Saint Petersburg, Russia, 2014*

Introduction

It is well known that density profile peaking is mostly associated to better plasma performances. In particular, in the so called RI mode, which is an improved confinement regime obtained in Tokamaks by injecting controlled quantities of gaseous impurities (mainly noble gases such as Neon or Argon), it has been assessed that a stable radiative edge seeded with light impurities has beneficial effects on confinement and induces density peaking [1,2]. On the other hand, the risk associated with a too large an amount of impurities is to increase the plasma pollution, producing large values of the effective charge and of the radiated power from the plasma center, which can lead to plasma disruption. Indeed, general aim of impurity seeding experiments is a high radiation level from the edge avoiding impurity accumulation in the center. In this framework, impurities transport studies in reactor-grade plasmas are of outmost importance to deepen the understanding of their role in triggering such improved regimes. This paper addresses the issue of the behavior of Neon when used as a seeding impurity in FTU Tokamak experiments, where a significant increase of electron density peaking is observed [3].

FTU Neon injection experiments

Neon injection experiments have been recently performed in FTU. Similar to TEXTOR, the first device where RI-modes have been well described [2], FTU has a nearly circular cross-section, a poloidal limiter and operates in L-mode. The Neon injections recently described in FTU (current I=360 kA, field B=5.2 T, density before injection $n_e=5\cdot10^{19}$ m^{-3}) can cause a spontaneous increase of the line average density by a factor 2 and the peaking factor ($n_{e0}/\langle n_e\rangle_{vol}$) easily reaches 3.5 and over [3]. From the point of view of transport, in particular of microturbolence analysis, first results lead to identify the mechanism of density peaking with the ITG growth rate, as calculated by Gyro-Kinetic codes [3,4], which decreases in consequence of Neon injection, resulting in a decrease of the outward particle flux and in the peaking of the density profile.

The applicability of these results to a machine with the size of e.g. ITER has to be further investigated, in particular deepening the understanding of the impurity transport mechanisms, in order to describe their role in the on-axis density increase. At this purpose a set of new experiments have been recently performed on FTU to extend the set of explored parameters (scan in current, starting densities, amount of impurity injected etc.). All these discharges need to be carefully modelled in terms of microstability analysis, and this is a work in progress for which the calculation of the impurity profile is decisive. In addition, the characterization of the Neon behavior is necessary to identify its contribution to the observed density peaking, and to investigate the influence of light impurities on particle transport [4,5,6,7]; in fact the result will be an input for the gyro-kinetic codes.

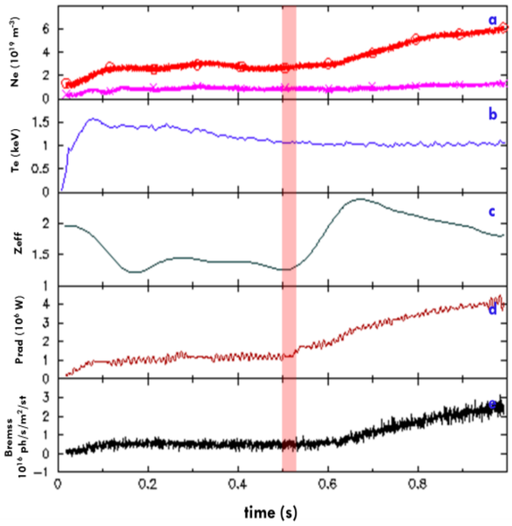

Figure 1. time traces for #35907 discharge; the light red vertical box marks the Neon injection. a) line averaged electron density red for the central chord, pink for the peripheral one. b) Central Electron Temperature by ECE. c) Zeff time trace. d) Radiation power by bolometry. e) Central Bremsstrahlung signal.

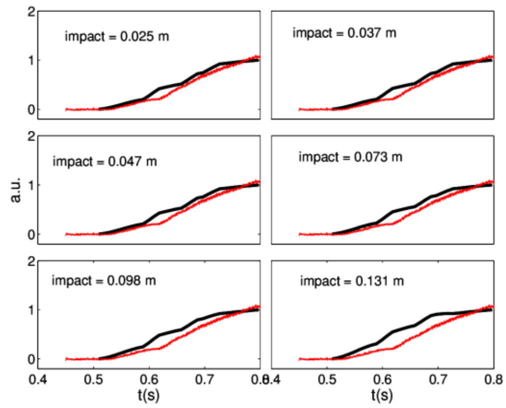

Fig.2: experimental (red) and simulated (black) time evolution of SXR brightnesses corresponding to line of sights at different impact parameter.

Neon transport analysis

In order to characterize Neon impurity ionization and transport subsequent to gas puff, a 1-dim collisional-radiative impurity transport code is used [8], which for each ion of charge Z solves the transport equation: $\frac{\partial n_Z}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(\Gamma_Z) = S$ (1) where S is a source term including the ionization and recombination balance and the neutral source. The flux of an ion of charge Z is: $\Gamma_Z = -D(r)\frac{\partial n_Z(r)}{\partial r} + v(r)n_Z(r)$ with D(r) diffusion coefficient and v(r) radial pinch velocity. D(r) and v(r) are assumed to be the same for all ions. Profiles from high resolution interferometer for the electron density and from ECE for the temperature are used as input to the code, taking into account their temporal evolution.

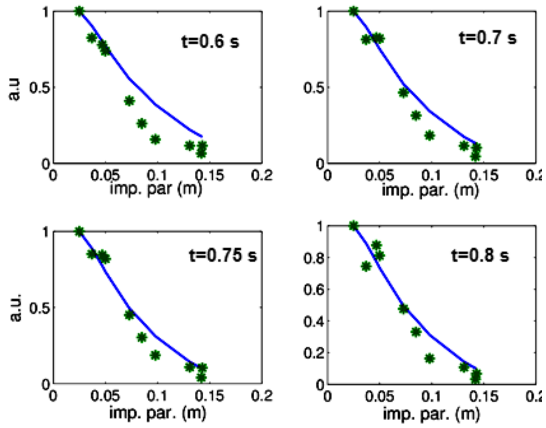

Fig.3: comparison of simulated profiles SXR brightness profiles (blue) with experimental points (green) at different times.

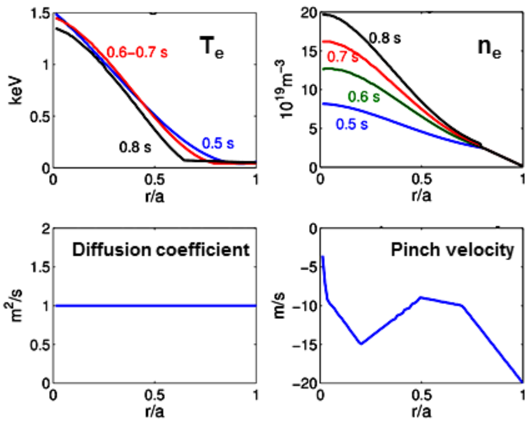

Fig4: Temperature and density profiles used in the calculation (top); diffusion coefficient and pinch velocity resulting from the simulation.

In eq. (1) D(r) and v(r) are assumed as free parameters within a procedure of minimization of the difference between the model output and the experimental data in terms of SXR emissivity (SXR being the radiation diagnostic characterized by the best time and space resolution). The result of the minimization procedure is then compared with other measurements, including effective charge, radiated power, spectral line time evolution. The analyzed discharge #35907 has a Neon injection starting at 0.5s (fig. 1, time traces of principal signals), which is viewed by SXR detectors and spectrometers 50ms later (fig. 2) due to the 1m distance of the gas valve from the plasma. The presence of heavy impurities is negligible in this discharge, so that most of the SXR brightness can be attributed to Neon. However, in the simulation the SXR brightness at t=0.5s (just before the Neon injection) are enhanced by a time-dependent factor proportional to the on-axis density increase and subtracted to the experimental signals, in order to isolate the Neon contribution. In figure 2 the comparison of SXR brightness time traces between simulation (black line) and measurement (red trace) at different impact parameters is shown. In figure 3 the experimental and simulated normalized profiles are reported at 4 times. At about 0.6s when the Neon enters the plasma, the density starts to grow up and peaks; at 0.8s the discharge reaches an electron density peaking of 3.2. Contrary to the electron density, the temperature does not change significantly in the central region (fig. 1 b), a modest cooling effect as density increases is observed at r/a > 0.5. Accordingly, the density and the temperature profile evolutions shown in fig.4

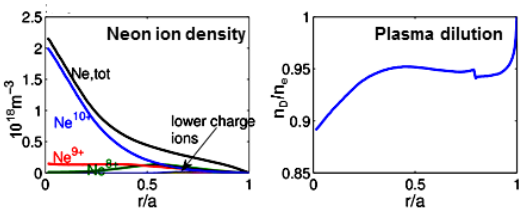

Fig. 5: Neon ion densities (left) and plasma dilution (right).

have been used in the simulation. The fig. 4 also shows the diffusion coefficient and pinch velocity resulting from the simulation, note that for D(r) an uniform profile was pre-assigned, and that the pinch velocity results being inward throughout the radius. As consequence the impurity presents a peaked density profile: the fig. 5 reports the profiles at different Neon ionization state. The SXR signals as shown in figs. 2-3 are compared in normalized units. To determine the absolute Neon density, the effective charge and total radiated power (fig. 1 c, d) have been compared between simulation and experiment, leading to the Neon ion densities and the total Neon density at t=0.8s as drawn in fig. 5. The Neon profile is peaked, but not much more than the same electron density. Indeed the plasma dilution due to Neon, defined as the ratio between deuterium ions and the total density, remains > 0.9 throughout the radius (fig. 5 at right), corresponding to a Neon contribution to the on-axis electron density of the order of $10^{19}m^{-3}$, much lower than the experimental increase > $10^{20}m^{-3}$. This is shown in fig.6: the black curve is the total density, the red is the total density with the Neon contribution subtracted, and the blue one is the difference between the electron density after and before the Neon injection. The increase of the effective charge integrated along the diameter is 0.6, consistent with the experimental findings.

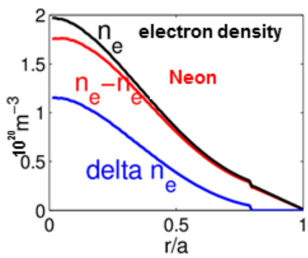

Fig.6: black: total density; red: total density with subtracted Neon contribution; blue: total density increase after Neon injection.

Conclusions

The simulation of a Neon seeded FTU discharge, featuring strong peaking of the electron density, has shown that, though due to an inward pinch the Neon has a peaked profile, such peaking is not significantly greater than the density one. Indeed Neon is responsible only of a modest increase of the central density, since the dilution remains > 0.9, while in the time range considered, the on-axis electron density increases by a factor 2.5 in the simulation with an observed peaking factor that reaches 3.2.

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