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Impurity transport simulation in Radiatively Improved and ITB plasmas in FTU

L. Carraro[1], M.Finkenthal[2,3], K.Fournier[4], L.Gabellieri[5], M.Leigheb[5], M.Mattioli[1,5], D. Pacella[5], M.E.Puiatti[1], P.Scarin[1], M.Valisa[1]

[1] Consorzio RFX, Associazione Euratom-ENEA sulla Fusione, Padova, Italy
[2] Plasma Spectroscopy Group, Johns Hopkins University, Baltimore, MD 21218
[3] Racah Institute of Physics, Hebrew University, Jerusalem, Israel
[4] Lawrence Livermore National Laboratory, P.O. Box 808, L-41, Livermore CA 94551
[5] Associazione Euratom-ENEA sulla Fusione, Centro Ricerche Frascati, CP 65, Frascati, Roma, Italy

Introduction

The behaviour of the impurity transport in the experiments aimed at accessing enhanced confinement regimes in FTU, in particular high electron temperature regimes associated with internal transport barriers (ITB) and Radiatively Improved (RI) regimes, has been investigated. In the neon seeded discharges the brightnesses from metals decreases, due to a decreased influx from the wall; the analysis of impurity transport indicates the same transport parameters as for shots without neon.

In the discharges featuring ITBs, where the electron temperatures are in the range of ~10keV, the analysis includes the high ionisation stages of molybdenum up to the Be-like Mo^{38+} ion with a line detected in the XUV spectrum at 50Å. An inward pinch velocity enhanced inside the barrier, and a "typical" diffusion coefficient (0.5 m^2/s, not dependent on plasma radius), are necessary to reproduce FTU plasma emissons (soft x-ray (SXR), radiated power, line, visible bremsstrahlung). Brightnesses from metals increase in time during ITB discharge, indicating an enhancement of metal influxes from the wall.

RI modes

Neon has been injected in FTU plasma to explore performances with an edge radiating layer in saturated ohmic confinement regimes (SOC) [1]. The chosen discharges had a line averaged density of 1-1.1 10^{20} m^{-3}, the density to enter the SOC regimes in FTU being 0.7-0.8 10^{20} m^{-3}. Injection of neon enhances the radiated power up to 90% of the input power, the electron density profiles peaks while the peak electron temperature does not change. The neutron yield increases by a factor 3-6, and the kinetic thermal energy and energy confinement time are larger than those w/o neon. The brightnesses of the intrinsic metallic impurities (Mo, Fe, Ni) decrease during the injection of neon: this behaviour may be interpreted as a change in the impurity transport parameters or a decreased influx of metals associated to a lower edge temperature. The results of a 1-dim impurity transport model show that the global behaviour of the impurities can be reproduced assuming the same transport coefficients in both discharges with and without seeding. In Figure 1 the time brightnesses of a Ne line, of a Mo line and of a O are shown as an example. Analyzing two successive very similar shots, with and without Ne seeding, it is found that both are well reproduced with the transport parameters of fig.2 (which are "standard" for FTU impurity transport in Ohmic plasmas, the diffusion coefficient being uniform and about an order of magnitude greater than neoclassical), assuming a metal influx from the wall decreasing in time (see fig.3). This result is consistent with a picture in which neon seeding does not change impurity transport characteristics, while the enhancement of radiated power at the edge and the simultaneous decrease of power flux trough the SOL onto the wall, reduce metal and oxygen influxes.

ITB discharges

Stationary electron ITB, lasting several confinement (5-10) times, where obtained in FTU (at high density up to $\overline{n}_e=10^{20}$ m^{-3}) combining LHCD and ECH [2]. The measured peaks of electron temperatures reach values of the order of 10 KeV [3].
Impurity line brightnesses in the range 40-330Å [4,5,6] have been followed as functions of time and a particular discharge (#20859) will be presented here. First, the high ionisation degree of Mo ions has been confirmed by the detection of the Δn=0 resonance line of Be-like Mo^{38+} ions at ~ 50Å. High Mo ionisation states have already been reported for other FTU ITB plasmas [7], but with smaller resolution and at shorter wavelengths (1.5-5.5Å); spectral features due to Δn=1 (n=3 to n=2) transitions of Mo up to Mo^{39+} had been interpreted as emitted by a 8KeV plasma near to ionisation equilibrium.
The simulations with a one dimensional impurity transport model have indicated that the 50Å line has a detectable level when $T_e(0)\geq7$ KeV, assuming a diffusion coefficient much lower than the typical $0.5m^2/s$ value. These simulations confirm also, as experimentally found, that the Li-like Mo^{39+} line at ~58Å is not above the detection limit when $T_e(0)\leq10$ KeV. The 50Å line has been observed with a frame read-out time of 0.1s, insufficient to study the line time behaviour; this has been possible for longer wavelenghts lines.
The simulated brightness of Mo Be-like line at 50 Å is greater than the experimental value; however the experimental value has been deduced assuming for the XUV spectrometer sensitivity a calibration [8] obtained before an exposure to air. The experimental time evolutions of emission lines from Mo and Fe have been satisfactorily reproduced [fig 4] considering an absolute calibration of the VUV SPRED spectrometer about 30% less than the sensitivity obtained by the branching ratio technique (quoted errors are ± 35% [5]); the signal from visible Bremsstrahlung results also to be well simulated [fig 5]. Experimental visible bremsstrahlung shows a bump in the phase 0.22 s-0.32 s, while the maximum heating power is applied, not reproduced by the simulation. The increased visible-bremsstrahlung phase does not find correspondences on experimental signals from line emissions and SXR (Figs 4 and 6) and probably is caused by light coming from the plasma edge, due to the high heating power, overlapping with the bremsstrahlung emission. The experimental SXR brightness has been reproduced by the simulation within a factor of 1.55 [fig.6]. The best simulations of experimental data have been obtained with a pinch velocity enhanced in the central region and without significative actions on the diffusion coefficient [see fig.7, in which the neoclassical D values are reported for comparison]. This is a little in contrast with results of analysis of the main gas transport behaviour which indicate a particle diffusivity very close to the neoclassical one (*1.5) [2]]. Regarding impurities, if the diffusion coefficient is reduced by a factor of 10 inside the barrier, to make it close to neoclassical, very peaked Zeff and Prad profiles, indicating impurity accumulation, are found in that region, not confirmed by the experimental results.
The same transport parameters allowed to satisfactorily simulate the FTU plasma emissions in the ITB shot 21548, with a measured electron temperature of about 8KeV.

Conclusions

Impurity transport during Neon injection and discharges with ITB have been studied with a one dimensional time dependent diffusion model to reproduce plasma line and continuum emissions. The obtained results indicate that the observed decrease in time of metal brightnesses during Ne injection is due to a decreased influx from the wall and that the same transport parameters may be assumed with and w/o Ne.

The presence in the XUV spectrun of a Mo Be-like emission line confirms the high values of electron temperature reached during LHCD and ECH sinergetic injection. The experimental ITB scenario has been well reconstructed assuming an inward pinch enhanced inside the barrier.

References

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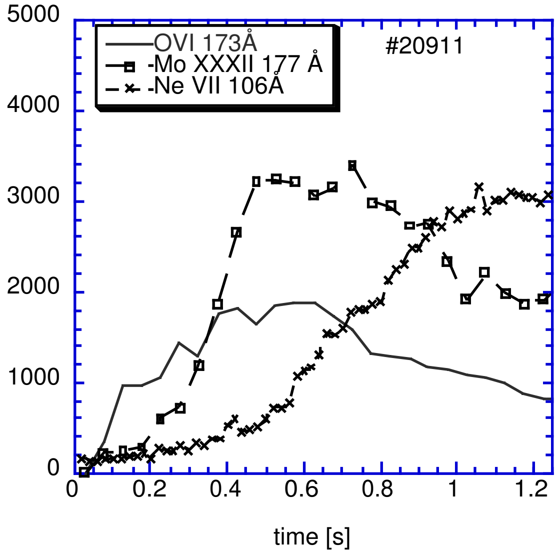

Fig.1 Time evolutions of Ne, Mo, O brightnesses in a discharge with Ne-injection

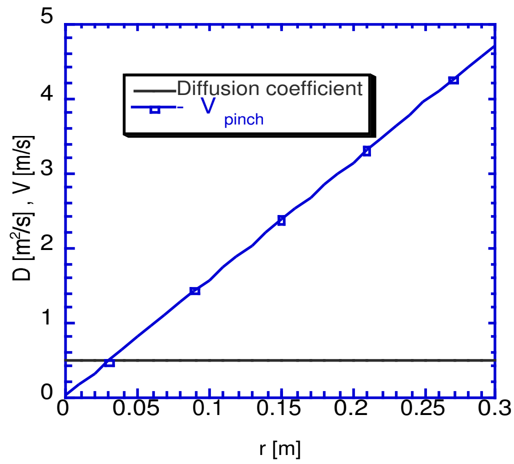

Fig.2 Profiles of diffusion coefficient and pinch velocity (inward) used to well simulate Ne seeded and unseeded discharges

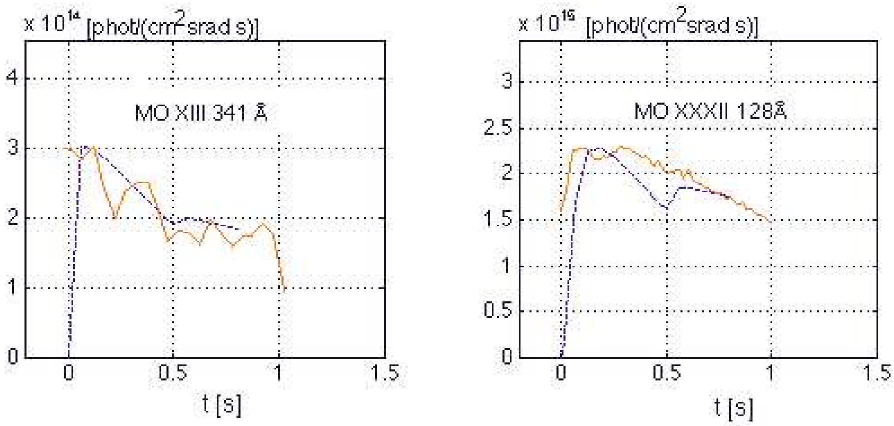

Fig.3 The metal influx decreasing in time during Ne injection explains the decrease of the highly charged ions (experimental in red, simulated in blue)

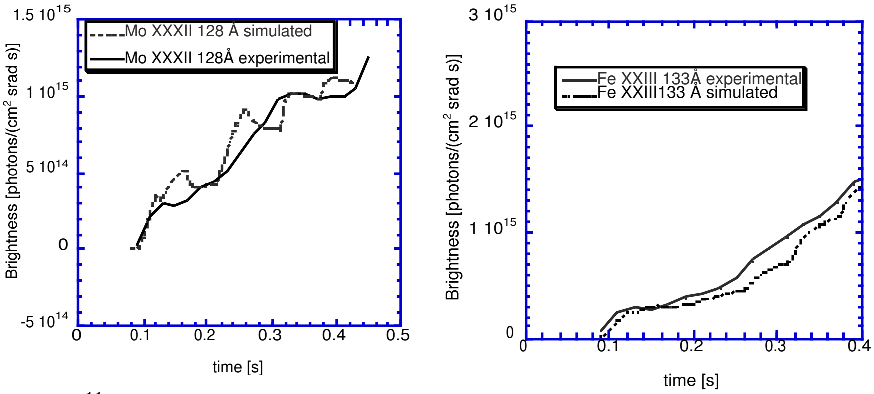

Fig.4 Temporal behaviours of experimetal and simulated Mo and Fe line brightnesses (#20859)

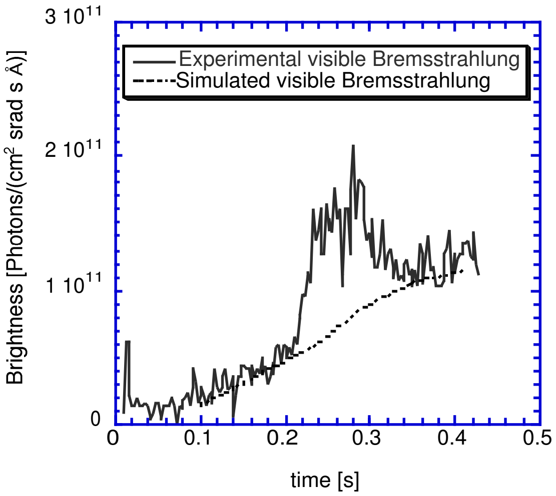

Fig5 Experimental and simulated Bremsstrahlung brightness in the visible range versus time (#20859)

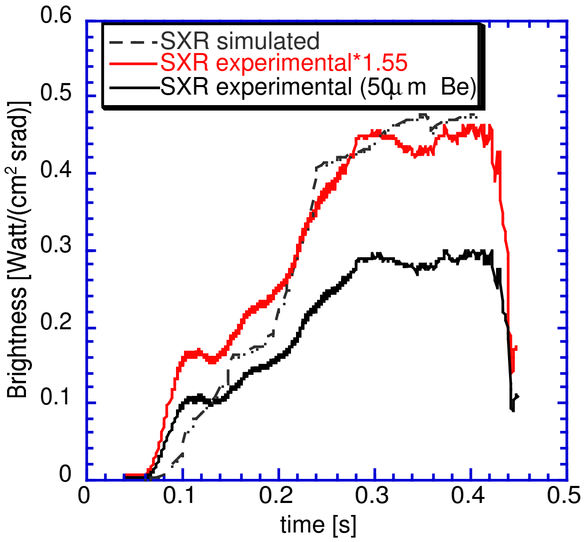

Fig.6 Time behaviour of experimental and simulated emission in the SXR range (#20859)

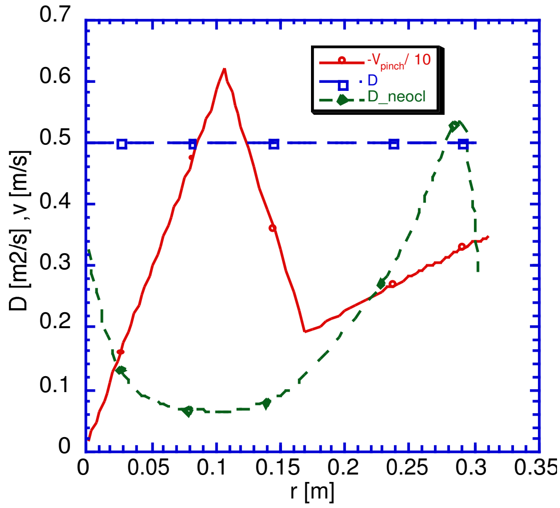

Fig.7 Transport parameters used to simulate ITB discharges and the neoclassical diffusion coefficient.