Impurity screening in RFX-mod RFP plasmas

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Introduction

Impurity transport and particle confinement are important issues in plasma physics. In many experiments it has been observed that in high confinement regimes the radial profiles of impurity density tend to be more peaked than those of the main ion density. This phenomenon, 'impurity accumulation', has the immediate consequence of increased radiative losses and radiative instabilities which, in an ignited plasma, would result in a lower fusion power. The experimental evidence in RFX-mod RFP is that impurity core penetration is prevented. Such finding has been documented for intrinsic (C, O) and injected (Li, Ne, Ni) impurities in various experimental conditions [1] in Hydrogen plasmas. W LBO experiments performed last year confirmed that W doesn't progress into the plasma core.

Recent Ne puffing and Ni LBO injection in Deuterium plasmas confirm the impurity transport features found in Hydrogen.

1-dim collisional-radiative impurity transport simulations reproduce the experimental emission pattern with positive impurity flux convective term (outward) over the whole plasma radius, with a large velocity barrier at the plasma edge. This outward convection acts to prevent the impurity access to the core. Impurity accumulation is avoided even in the improved confinement self-organized helical regimes (SH) occurring at high plasma current (I>1. MA). Such a strong outward convection has not been found for the main gas [2-4], meaning that a favorable situation with peaked or flat density profiles and hollow impurity profiles is produced in RFX-mod.

A coherent impurity transport theoretical frame is still missing: with the present knowledge of the RFX-mod ion temperature profile, the found impurity outward convection cannot be ascribed to a classical 'temperature screening' effect. Gyrokinetic calculations (GS2 code) of turbulent transport, to evaluate the effect of electrostatic and electromagnetic turbulences on impurity fluxes, are compared with the 'experimental' impurity convection.

Results and Discussions

The impurity screening discussed in this contribution represents an appealing feature in the perspective of a metal wall. W LBO experiments have been performed in preparation for a change of the first wall from carbon to tungsten, proposed to reduce wall retention and desorption, preserving at the same time the present carbon wall capability of sustaining power loads as high as tens of MWm^{-2}. W transport code is not currently available at RFX-mod, however experimental findings confirm the C, O, Ne and Ni outward convections W does not penetrate into the plasma core and edge peaked Prad (Fig 1) and SXR (Fig 2) emissions are indeed measured during W LBO experiments in SH conditions

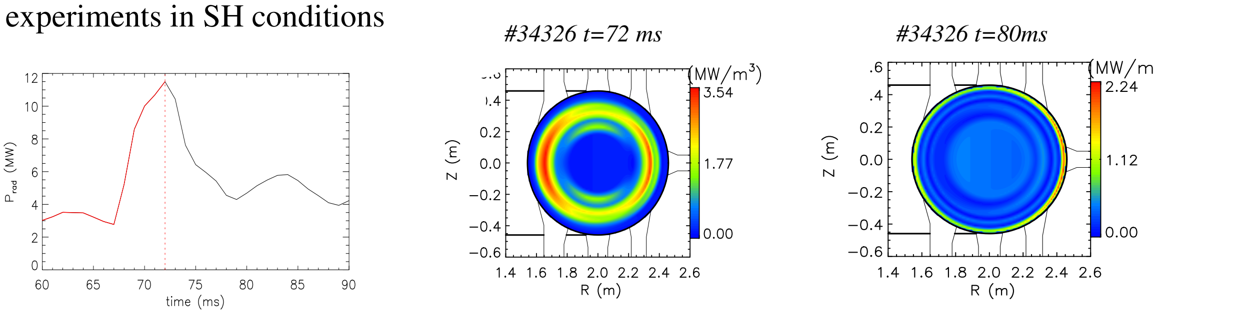

Fig 1.From left to right: Total P_{rad} signal during W LBO, inverted emissions at the peak of emission (72 ms) and at the end of the decay phase (80 ms.)

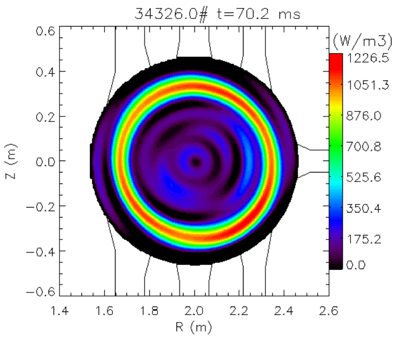

Fig.2 Experimental tomographic inversion of SXR emissivity at the maximum of the W LBO emission

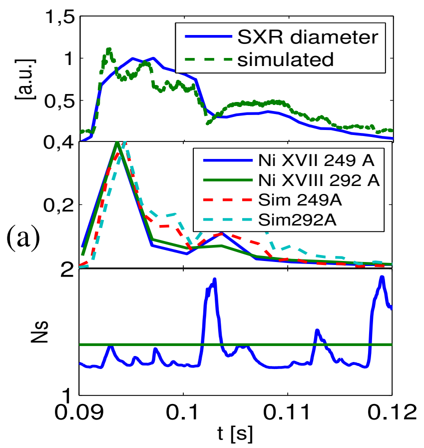

Fig.3 (a) Time evolutions of experimental and simulated central SXR emission, Ni XVII Ni XVIII line (most populated ions), spectral index $Ns=1/\sum_{n=-7}^{n=-15}\left(b_{1,n}^2 / \sum_{n=-7}^{n=-15} b_{1,n}^2\right)$ *,Ns≤2 indicates the presence of a SH regime.*

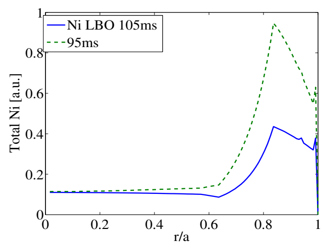

Fig.4 Total Ni density radial profiles

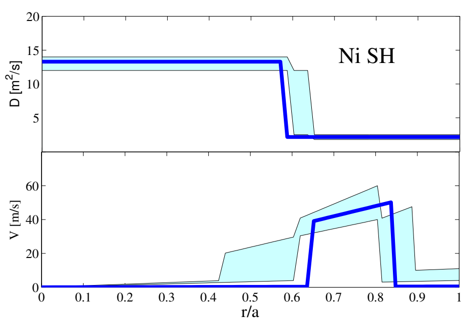

Fig5 Ni D and V profiles in SH scenario and correspondent ranges found in Hydrogen

First RFX-mod experiments with deuterium have been performed in the last quarter of 2013. A first survey scan of the main plasma parameters (current, density, edge field reversal) has been carried out with deuterium as the filling gas. First results are encouraging: the pureness and duration of the improved helical states increases. Though deuterium discharges have not been optimized yet (for example, the wall was not conditioned by boronisation), the electron energy confinement time increases by about 25%. To check the possible main gas induced effects on impurity transport Ni LBO experiments have been performed and analyzed in comparison with results found in H plasmas. The impurity transport coefficients, have been deduced in SH and MH scenarios by comparing the results of a 1D simulation with a large set of spectroscopic data [1]. Experimental and simulated signals are shown in Fig 3 (a) and (b).

As shown in Figs. 3, the experimental time evolution of the

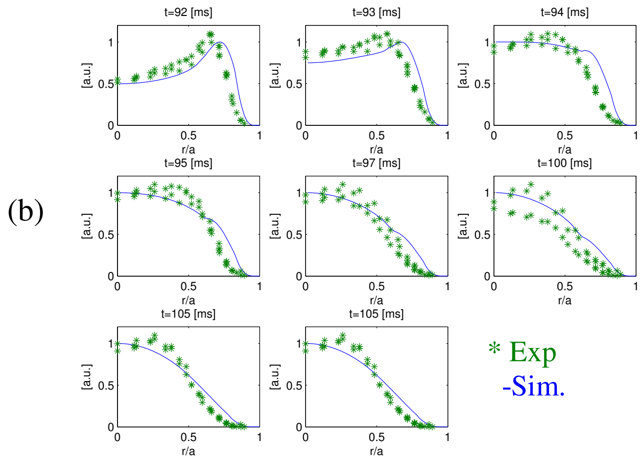

Fig3(b):Experimental and simulated SXR brightness normalized profiles during the Ni LBO pulse.

line brightness and of the SXR profiles following the LBO pulse has been well reconstructed by the model. In Fig 4 the total Ni radial profile is plotted at the peak of the emission and after the decay phase showing that Ni remains at the edge.

D and V found for Ni in SH phase are very similar to those found with H: they are plotted together with the ranges found in H plasmas in Fig 5.

To evaluate the impurity transport parameters in MH scenarios, Ip=600kA, $n/n_G > 0.4$ with Ne puffing experiments have been considered. In this D and V have been evaluated by best reproduction of experimental time evolutions of central SXR, P_{rad} and n_e radial profile (Fig.6). In Fig 7 the total Neon radial profile, showing that it doesn't penetrate the plasma core is shown, and in Fig.8 D and V obtained for Ne in MH Deuterium are shown with respect to the D and V ranges found in H plasmas.

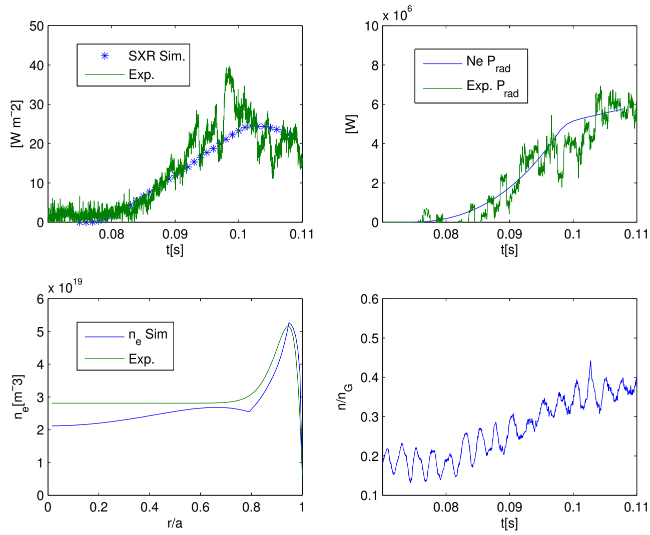

Fig.6 Top: experimental and simulated time evolutions of central Neon SXR brightness and total radiated power. Bottom: experimental and simulated n_e profile after Ne injection and time evolution of n/n_G

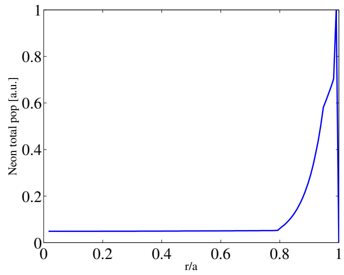

Fig 7 Total Neon density radial profile calculated at 110ms

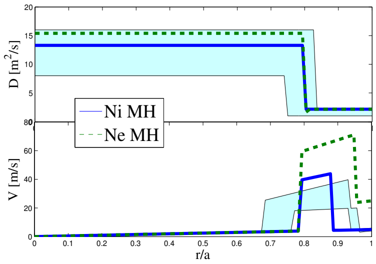

Fig.8 Ne (Ni) D and V profiles found in MH scenario and correspondent ranges in Hydrogen plasmas.

In the same figure D and V found for Ni in the previous case during the MH phase are also plotted. D and V close to those in Hydrogen are found for both Ne and Ni species.

Summarizing, the results of the presented transport analysis done for Ne and Ni (very different species in mass and charge) in Deuterium plasmas confirm that in RFX-mod impurities show a strong outward convection: in both the MH and SH scenario the convective flux is outward directed, with a radial region where the velocity increases significantly; such region in the MH phase is more external and less extended than in SH (i.e. compare Ni transport coefficients in Figs 5 and 8). The analyses of main gas transport [4] show that the decreased core stochasticity leads the plasma in a reduced transport regime: in SH the diffusivity along the 90% of the radius is D~1m^2s^{-1}, in MH conditions D~30 m^2s^{-1}. Nevertheless the transport in SH is still anomalous, as highlighted by the comparison with the neoclassical D (~ 0.1-1 m^2s^{-1}). The main gas convection term is negligible in SH, it is outward of the order of 10 m/s in MH case. The strong outward convection characterizing impurity transport in SH conditions has not been found for the main gas, meaning that a improved confinement favorable situation with peaked or flat density profiles and hollow impurity profiles is produced.

RFX-mod impurity transport parameters compared to the theoretical predictions

The ‘experimental’ D and V in SH scenario have been compared with those calculated in Classical Collisional transport hypothesis [5] and those in MH conditions with transport coefficients predicted for transport in a stochastic magnetic field (following [6] with the measured magnetic amplitude fluctuations).

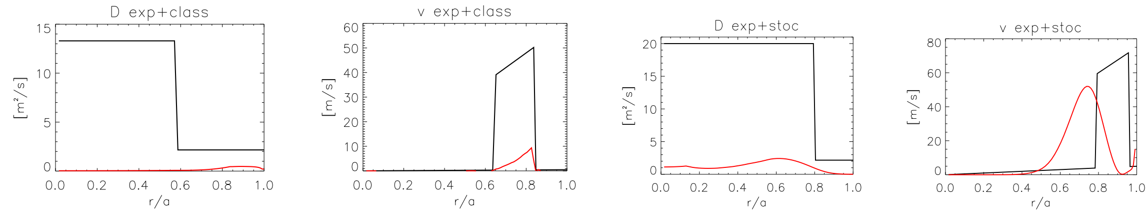

Fig.9 Left: experimental impurity coefficients SH conditions (black) in a helical state, compared with the classical ones (red).Right: experimental (black)) impurity diffusion coefficients in MH conditions compared with the stochastic ones (red) [4].

A coherent impurity transport theoretical frame is still missing: experimental outward V is consistent (not quantitatively) with classical collisions and 'experimental' D is larger than the predictions of particle transport through a stochastic magnetic field (Fig.9).

In SH conditions the RFP core plasmas is naturally endowed with almost conserved magnetic flux surfaces: in that scenarios microturbulence effects on impurity transport might be meaningful and the analysis for RFX-mod has started. The convection of impurities due to Ion Temperature Gradient instabilities/turbulence should occur toward the plasma core, and not toward the edge as experimentally found [7]. Other instabilities should then be active and further work is required to understand their existence and their role on impurity flux reversal. As an example Micro-tearing modes (MTM) are commonly unstable in RFX-mod during SH states [8], across the electron temperature barriers. Even though MTM mode are not expected to be main contributors to particle transport, the impurity flux driven by these turbulences has been evaluated with the GS2 code [9](Fig.9). In the same figure the peaking factor found deduced for C,O,Ni impurity transport simulations in SH conditions. The quasilinear calculations predict an outward velocity of (trace) impurities, strongly increasing with the charge, while experimentally the peaking factor does not depend on impurity charge.

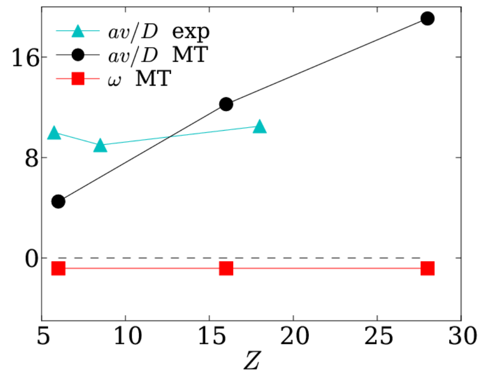

Fig.10 Peaking factor aV/D for fully stripped trace impurities for a shot in SH state at mid radius, calculated with GS2 compare with peaking factors deduced from the C,O,Ni impurity transport simulations

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