# Transport analysis of different charge/mass impurities injected by laser blow-off in ECRH heated plasmas of TJ-II

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**INTRODUCTION.** The investigation of the confinement properties of impurity particles, with significantly different mass and charge, may help to elucidate the transport mechanisms operating in the core and at different plasma radii of fusion plasmas. In a previous work we reported on the global impurity confinement time behaviour of different impurities, LiF, BN and W, injected by laser blow-off [1], in electron cyclotron resonance (ECR) heated plasmas. Here we focus on its transport analysis in order to determine whether the small effect seen in the plasma core among the decay times of local global radiation can be translated in differences in transport coefficients when analysing the data using a full impurity transport code such as STRAHL [2].

In the field of impurity transport studies, several distinctive techniques are employed to inject impurities into magnetically confined plasmas and to study their transport dependence with charge and mass. For instance, in tokamaks the influence of ion charge, Z, on impurity transport was studied in ASDEX Upgrade [3] and in JET [4] by puffing of noble gases. In contrast, in the Large Helical Device stellarator the charge dependence on impurity confinement was investigated by injecting pellets containing different materials (C, Al or Ti) while monitoring the resultant perturbation by visible bremsstrahlung with temporal and spatial resolution [5]. The effort made in tokamaks to investigate the influence of impurity charge and mass has been summarized more recently in Ref. [6]. In the case of the TJ-II stellarator, a blow-off technique has been developed that permits impurity injection with a timing control that is significantly better than that achievable with gas puffing thereby making it a powerful tool for studying different aspects of impurity confinement relevant for fusion plasmas.

In order to compare the transport of light and heavy impurities injected by laser blow-off in the TJ-II stellarator, a transport analysis is performed using the impurity transport code STRAHL, from which fitted transport coefficients are obtained by matching the code results with the temporal behavior of the local emissivity deduced from bolometric array signals. This will show that a radial variation of transport coefficient is necessary to match experimental data. Additionally, it will be shown that the contribution of charge-exchange collisions of neutrals with impurity ions found to be crucial for matching local radiation data for low Z impurities, where atomic data on these processes are included in the code.

**EXPERIMENTAL.** This experiment was performed in the TJ-II, a four-period, low magnetic shear stellarator with major and average minor radii of 1.5 m and ≤ 0.22 m, respectively [7]. During the ECR heated phase, the density profiles (line-averaged, $n_e \leq 6x10^{19}$ $m^{-3}$) are rather flat whilst the electron temperature profiles are peaked with core values in the range 0.8 to 1 keV. In addition, the majority ion temperature radial profile is flat with a core value of around 80-100 eV.

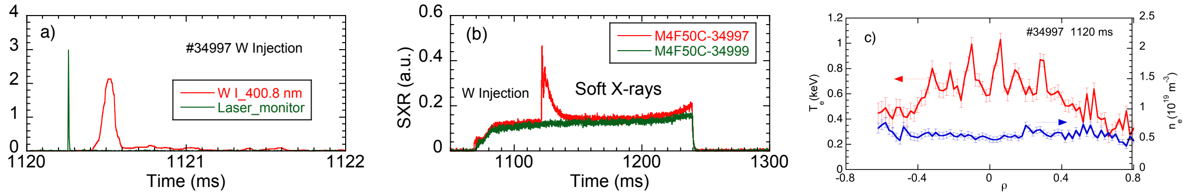

**Fig. 1.** Traces and profile of interest for the ECRH shot #34997 with W injection and reference #34999: (a) laser monitor and W I signal at the injection port; (a) soft X-ray (fast photodiode with a 50 μm Be filter) and (c) electron density and temperature profiles used in the simulation.

In Fig. 1 selected traces of shot #34997, where W was injected by laser blow-off, and the reference shot #34999, are shown along with the Thomson scattering profiles used to perform the impurity transport analysis.

**IMPURITY TRANSPORT RESULTS AND DISCUSSION.** In order to estimate the experimental impurity fluxes we have proceeded to match, using STRAHL, the temporal behavior of reconstructed global radiation signals measured by a bolometric array, with a similar, but improved, method reported previously [8]. The impurity radial flux is parameterized by two radially-dependent coefficients: a diffusion coefficient, D ($m^2/s$), and a pinch velocity, V (m/s). In a first step the iteration method consists in scaling, by factors flat profiles of D and V, in order to estimate approximate values which can account for the radiation emissivity evolutions obtained at different rho´s. The simulation involves an iterative process with the possibility of modifying the transport coefficients as well as several experimentally unknown parameters in the code, *e.g.* impurity radial deposition, impurity flux, *etc.*, in order to achieve a best fit between experimental data and simulation results.

Comparisons between experimental results, *i.e.*, the temporal behavior of reconstructed local global radiation from bolometer arrays, and STRAHL simulations are shown in Fig. 2 for three selected radii and for three injected impurities. These correspond to best fits achieved by scanning the different parameters involved in the impurity transport code. The resulting D and V profiles are shown later as well as the sensitivity of the method to modifying the D and V profiles around the best predictions. Within the transport model employed in STRAHL and the method followed herein, i.e., using ~~the~~ local bolometric emissivities only [9], we can fit reasonable well the observed decay for rho's between 0 and 0.6. However, in general the fitting deteriorates outside these rho values, see Fig. 2.

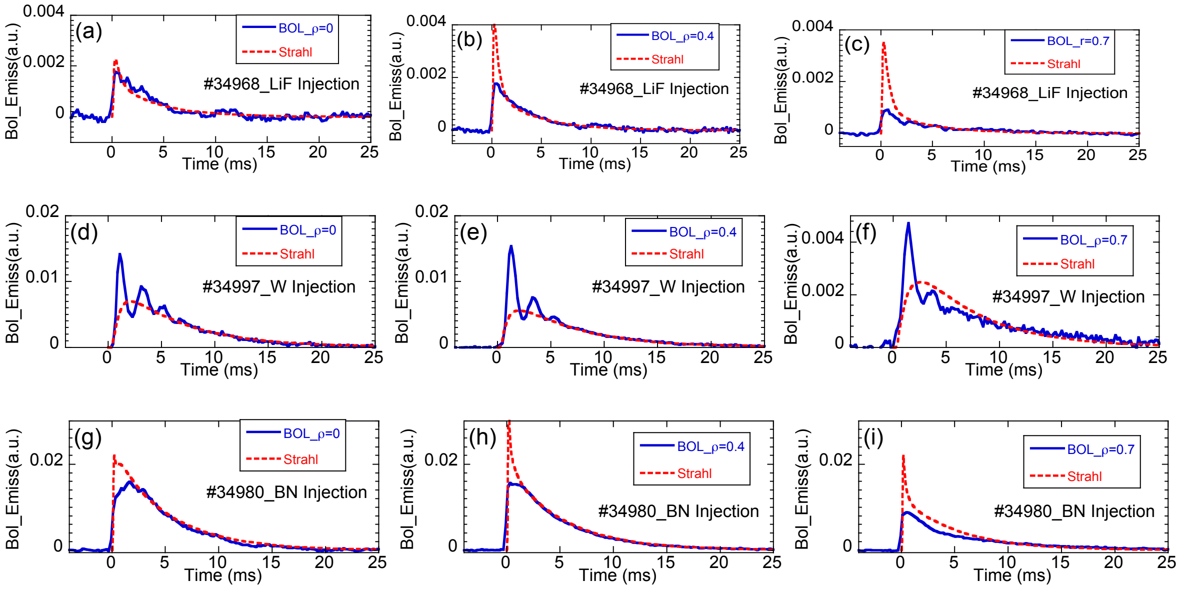

**Fig. 2**. Comparison of experimental deduced data (blue) with STRAHL simulations (red) that attempt to fit the decay phase of the perturbation of three different injected impurities for 3 plasma radii. Note: the fitting is poor at the peripheral plasma (ρ = 0.7). Here Time (ms) is time after impurity injection.

To illustrate quantitatively the sensitivity of fits to a change of the main transport parameters D and V, the plots included in Fig. 3 show how small changes in the D and V profiles affect the fitting of the experimental data.

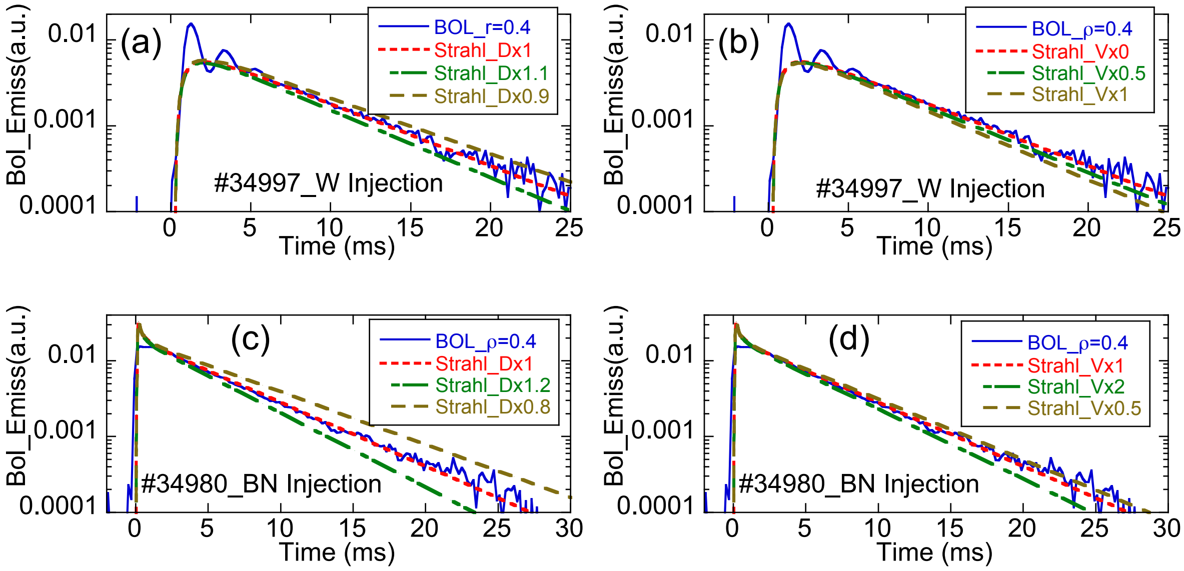

**Fig. 3**. Plots showing the sensitivity of the fitting procedure to changes in D & V at plasma radius ρ = 0.4: a) and b) for the case of W injection, c) and d) for the BN case.

In Fig. 3, the ρ = 0.4 case is chosen because it is a representative example for inner radius. We chose the cases of W and BN injection only in order to highlight two important points: 1) the greater sensitivity of changing the diffusion coefficient by a small percentage (10% in the case of W and 20 % in the case of BN) and 2) the lower sensitivity of the simulation results to larger changes in V. Notice that the W injection can be simulated with solely diffusion, that is compatible with V close to cero. In all cases the red line correspond to the best overall fit.

Finally, the transport analysis results for the three discharges and impurities analyzed are shown in Fig. 4. The D and V profiles corresponding to the best fits are plotted in red, whereas the dashed curves correspond to the sensitivity exercise represented in Fig. 3. The results obtained clearly agree with the results for LiF reported in [1] for the decay time analysis in comparison with the other two impurities, whose D and V are closer between them. In conclusion, the decay time analysis is more robust and sensitive to detect small differences in transport, but less adequate for comparison with theoretical estimates of impurity transport.

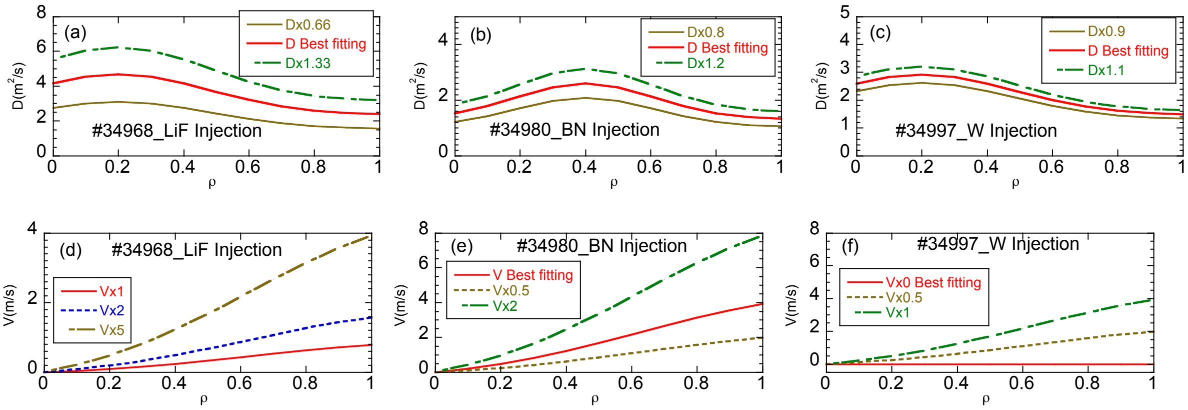

**Fig. 4.** Transport coefficients deduced from experimental data, using the STRAHL code, for the three injected impurities.

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