Transport Analysis of Impurities Injected by Laser Ablation in the TJ-II Stellarator


Laboratorio Nacional de Fusión, Asociación Euratom-CIEMAT, Madrid, Spain.
*Max Planck Institut für Plasmaphysik, Garching (Germany).

Introduction
Transport studies of impurities injected into plasmas using laser ablation, or as pellets, have been made in various stellarator devices with the aim of obtaining localized information on transport coefficients in such magnetic confinement devices [1-4]. In a previous report on results of impurity confinement in the TJ-II [5], the decay of perturbations created by laser ablation were analysed using a stretched exponential. Here, the problem of determining local transport properties is now addressed using a selected set of discharges and applying a unique and original approach to deducing spatially resolved transport coefficients. It involves obtaining fits, by means of 1-D impurity transport code, to the localised temporal evolution of perturbed radiation signatures in tomographically reconstructed [6] soft x-ray profiles and global radiation signals. It should also be highlighted that the detailed temporal shape of such localized information is very sensitive to the transport coefficients assumed and that the use of bolometric data allows the analysis to be extended out to \( \rho \leq 0.8 \), whereas the soft x-ray data are limited to the plasma core.

The paper is organized as follows. First, the experimental technique and data analysis procedure are outlined. Second, discharges from a density scan and from an electron cyclotron heating power scan are analysed. Third, the results are discussed in the context of similar experiments performed in other stellarator devices.

Experimental and analysis method
Iron and silicon tracer ions were injected into almost stationary phases of ECRH plasmas in the TJ-II using the laser ablation technique. For this, a thin film of the material (1 \( \mu \)m (Fe) and 2 \( \mu \)m (Si)) was deposited onto the surface of a glass substrate and material was ablated by a short pulse of a focused Q-switched Nd-YAG laser beam (800 mJ, 10 ns). A more detailed description of this system is given in reference [5].

Here, we present the first attempt to simulate, using the 1-D impurity transport code STRAHL [7], the transient behaviour of the localized response of global radiation monitors...
to impurity injection. The perturbation resulting from injection is extracted from the absolute diagnostic monitor signal by subtracting the background. The results can then be compared with simulation code predictions. For this a simple transport model is used, \textit{i.e.} diffusion coefficient $D(\rho) = \text{const}$ and convective velocity $v(\rho) = \rho \times v$ ($\rho = 1$), to make an initial guess of the radial dependence. The code begins by taking the electron temperature and density profiles obtained by Thomson scattering and an initial guess of the transport coefficients based on the simple model outlined above. The code is then entered into a loop where it is repetitively called, each time scanning a single parameter in order to look for the best fit between the estimated and the experimentally deduced local evolution.

For experimental data one can choose either chord integrated signals or tomographically reconstructed emissions of total radiation and soft x-ray emission, or a mix of both (locally and chord integrated information). In this way, discharges can be analysed even if the signal information is incomplete. An example of the data analysis is shown in Fig. 1, where the local reconstructed signal of total radiated power is plotted for $\rho = 0.41$. Note that this data was reconstructed from a 20 channel bolometer array. The continuous traces are the results of a simulation scan of convective velocity. This kind of analysis is repeated for a range of effective radii in order to obtain a first guess for the radial dependence of the transport coefficients (this procedure will be optimised in a second improvement). Also, in the same figure, the signal traces of several monitors, used to follow a discharge into which Si was injected, are expanded to highlight the resultant perturbation.

![Fig. 1. a) An example of the analysis procedure showing the fitting of a locally reconstructed radiation signal and its modelling by the code for a scan of the convective velocity; b) the temporal evolution of various discharge monitors during Si injection.](image-url)
Results
For the first analysis of local impurity transport in TJ-II, two discharges from a density scan, into which Fe was injected by laser ablation during the plasma plateau, and two discharges from an ECRH power scan, into which Si was injected, were selected. In Fig. 2 the resultant diffusion coefficients ($D$) and convective velocities ($v$) are plotted for discharges 8746 and 8751. These are from the density scan performed in the standard TJ-II magnetic configuration (100_44_64). The line-averaged density of discharge 8746 ($0.61 \times 10^{19} \text{ m}^{-3}$) is close to the limit where the TJ-II plasma passes to an enhanced particle confinement regime that results in a sudden density rise and during which impurity decay measurements cannot be made. In contrast, the line-averaged density of discharge 8751 is much lower ($0.3 \times 10^{19} \text{ m}^{-3}$). The analysis was performed by searching for the diffusion coefficients and convective velocities, at each particular effective radius $\rho$, that best fit the detailed temporal evolution of the local reconstructed bolometric signals. It was found that, while the diffusion coefficient exhibits a radial dependence that is similar for both discharges, it is almost 10 times lower in the higher density discharge. Finally, the behaviour of the convective velocity profiles differs both in magnitude and shape, being opposite in sign at the core.

Next, Fig. 3 shows the results of a transport analysis carried out on discharges belonging to an ECRH power scan where impurity transport was probed by injecting Si into the plasma. In the figure, the spatial dependence of the diffusion coefficient is compared for three different levels of injected ECR power (it is observed that diffusion increases with power, most notably at the plasma core). In the same figure, for two of these discharges it is shown how the convective velocity is typically (this is true except at high densities) directed inward for radii less than $\rho \approx 0.5$ and outward for larger radii. Similar behaviour can be seen

![](image)

Fig. 2. The spatial dependence of the diffusion convective velocity for two discharges from a density scan: a) a discharge with $n_e = 0.61 \times 10^{19} \text{ m}^{-3}$; b) a discharge with $n_e = 0.3 \times 10^{19} \text{ m}^{-3}$.
in some transport analysis cases made by the Wendelstein 7-AS team [3] where they note that their analysis is more reliable for the plasma core than for the periphery, where it is based on extrapolation.

![Graphs showing spatial dependence of diffusion coefficient and convective velocity](image)

**Fig. 3.** Spatial dependence of: a) diffusion coefficient, and b) convective velocity for discharges with different injected power.

In conclusion, the determination of the radial dependence of transport coefficients from laser ablation experiments in TJ-II seems to be feasible for the data obtained, although improvements in the model and a more extensive analysis are needed to complete this work. In comparison with the conclusions from some earlier work [2], we have deduced a diffusion coefficient that increases towards the plasma centre, where most of the injected power is deposited. However, in contrast to the same work, we need a convective velocity to explain the detailed evolution of the perturbation seen in our experimentally deduced local information. Finally, our results coincide well with the sophisticated impurity transport analysis performed in the Wendelstein 7-AS [3].

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**References**