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EVIDENCE OF AN EDGE IMPURITY TRANSPORT BARRIER IN JET L-MODE PLASMAS.

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Introduction

We have studied the transport of Fe and Ni, following laser blow-off injection, in JET L-mode plasmas. With the aim of trying to elucidate the radial profiles of the diffusion coefficient, D, and convective velocity, v, we have modelled the time evolution of the XUV/VUV line brightness for several ionization stages of the injected element, and the temporal evolution and spatial distribution of the accompanying soft X-ray emission, using the 1½-D impurity transport code SANCO.

Experiment

Small quantities of Fe or Ni were introduced into several L-mode, limiter plasmas, during the additional-heating phase (neutral-beam heating or ion-cyclotron resonance heating). The light emitted by the injected impurity was observed using a variety of spectroscopic diagnostics. A VUV broadband, survey spectrometer and a 2-m grazing-incidence spectrometer, both equipped with multichannel detectors, were used to observe $\Delta n = 0$ transitions belonging to Fe XV, XVIII-XXIV or Ni XIII, XVII, XVIII, XX-XXVI, respectively. In addition, the w-line of Ni XXVII was observed with a 24-m crystal spectrometer. A diode-array camera system was used to record soft X-ray emission through a 250 μm thick Be filter. The observed signal consists of the emission from the injected element superimposed on the slowly evolving background emission from the intrinsic impurities.

For the subsequent modelling, the lowest ionisation stages observed (*i.e.*, Fe XV and Ni XIII) were taken to represent the source function for the injected element. The magnitude and radial dependence of the transport parameters were then adjusted until an optimum fit to all the observed data could be achieved.

Results

To illustrate the results we will consider JET pulse 27342. This was a 3.5-MA, 2.8-T discharge with low ℓ_i and slow current penetration. Iron was injected 6 s after the start of the plasma, during the 7-MW neutral-beam heating phase. No sawteeth were present.

The previously observed /1/, central region of substantially reduced diffusion, and a transition to an outer region of highly anomalous diffusion are also deduced from the present experimental observations. For the pulse considered, the transition is smoother and has a wider radial extent than usually inferred for pulses which have similar plasma parameters, but are not of the mode-B type. A good fit to the soft X-ray data and the time evolution of the brightness of the Li-like (and for shots with Ni-injection also the He-like) ion line may be obtained. However, in order to reproduce successfully the time evolution of the line brightnesses for the Be-like and lower ionisation stages a transport barrier at the plasma edge has to be invoked. This transport barrier may be produced either by reducing the anomalous diffusion coefficient or by increasing the convective velocity, or both, within the last few cm of the last closed flux surface (LCFS). The effect on the time histories of including such a barrier is illustrated in Fig. 1. Here, data for Fe XXIV, XXIII, XXII and XIX are shown along with two code calculations, with (dashed line) and without (dash-dotted line) inclusion of an edge transport barrier. It is seen that, whereas the Fe XXIV time history may be well fitted by either model (within the noise on the data), the time evolution of Fe XXIII and lower stages cannot be adequately modelled without the assumption of an edge transport barrier. The discrepancy becomes greater the lower the ionisation stage.

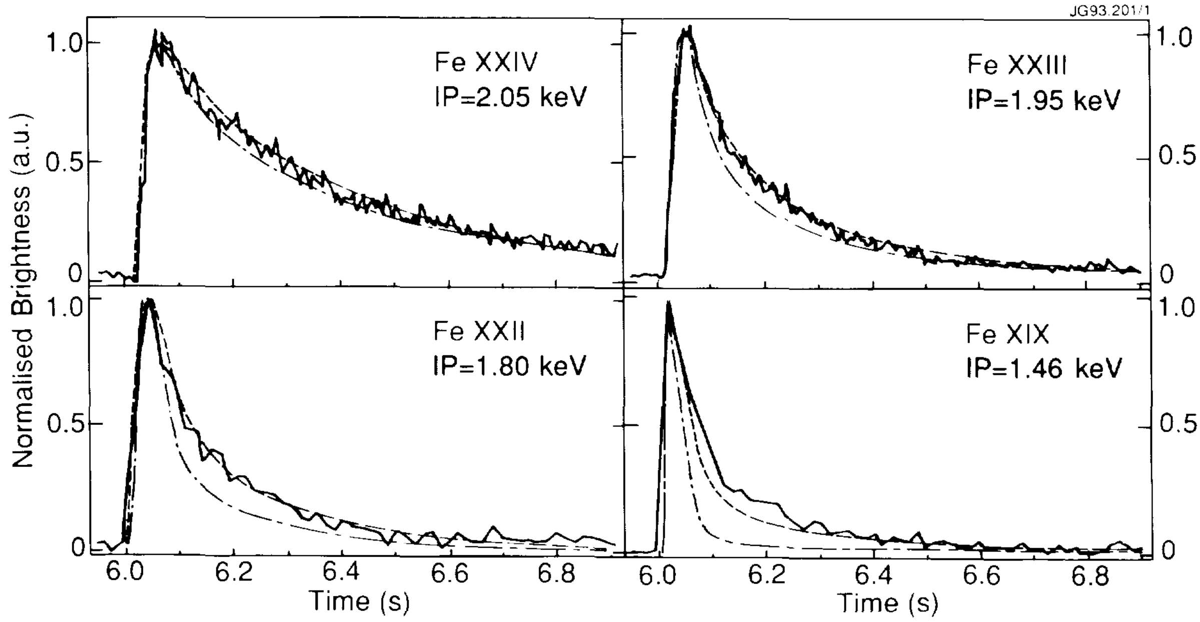
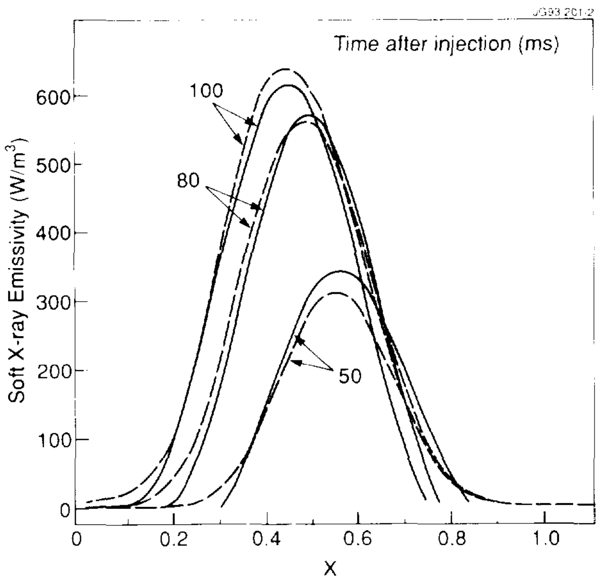


Fig. 1: Time evolution of the normalised brightnesses of Fe XXIV, XXIII, XXII and XIX, following injection of Fe at 6.0 s. The solid line represents the data. Two sets of code calculations are shown, with (dashed line) and without (dash-dotted line) the edge transport barrier. The ionisation potentials (IP) are also given.

Figure 2 shows the soft X-ray emissivity profiles at three time slices after the injection: 50, 80 and 100 ms. Solid lines represent the data after backbround subtraction and dashed lines the simulation. The coordinate on the abscissa is the normalised minor radius $x = r/a$, where a is the radius of the LCFS or limiter. As can be seen, the agreement between the simulation and the data is excellent. At times later than 100 ms the background correction to the data becomes uncertain. Hence, no profiles are shown for later times. The simulated profiles shown were obtained with the edge barrier included. However, for the soft X-ray emissivity a simulation excluding the edge barrier will fit equally well, the effect of the barrier on the core being negligible.



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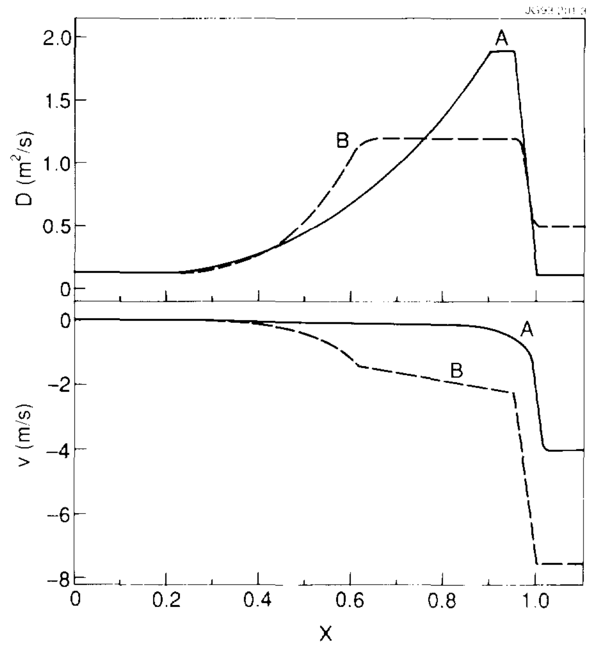

Fig. 3: Two sets of transport parameters (diffusion coefficient D and convective velocity v) that may be used to fit the data shown in Figs. 1 and 2.

Figure 3 shows two sets of transport parameters that will fit the temporal and spatial evolution of the data equally well within the error limits of the data. Set A was used to obtain the "best fit" in Fig. 1, as well as the emissivity profiles in Fig. 2.

Discussion

We find from the above results, that we may distinguish three different regions of transport in the plasma: a central zone of substantially reduced diffusion, an intermediate region with high, anomalous diffusion, and a narrow region near the edge with reduced D and/or enhanced convection. The edge barrier is typically located within 5-8 cm of the LCFS. The effect of the barrier is to retain the impurity during the outflow phase at a radial location (*i.e.*, temperature) where the pertinent ionisation stages have the opportunity to recombine.

As is evident from Fig. 3, various combinations of D and v can be found which will yield radial profiles of the impurity flux which are all compatible with the observed temporal evolutions and profile shapes. The absolute values of the brightnesses and emissivities can, however, be very different. Therefore, absolute measurements of all these quantities would be desirable in order to further constrain the range of acceptable transport parameters. To this end, absolute sensitivity calibration of the VUV and XUV spectrometers is in progress, as well as a review of the atomic data used in the transport code /2/.

In the absence of absolute VUV/XUV line measurements we can only determine a broader range of possible solutions. While in the H-mode case the edge transport barrier has clearly been demonstrated to be of a convective nature /3/, in the L-mode case the situation is less clear. Generally, the values of v found near the edge are much lower than those found in H-modes. Indeed, it was possible to fit the data by reducing the diffusion coefficient near the edge while, at the same time, keeping v very small everywhere.

Further insight into the relative influence of D and v could be gained by comparing the rise-time and decay-time of the line brightnesses. For the present data set the time resolution is insufficient to make such a test. In addition, the source function would need to be more accurately known. To this end, it would be necessary to monitor the emission from the neutral or the very lowest ionisation stages of the injected element with good time resolution.

References

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