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Impurity Particle Transport with Radial Electric Field and Plasma Rotation in JET Optimised Shear Plasmas

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1. INTRODUCTION

JET Optimised Shear (OS) experiments have produced internal thermal transport barriers (ITB)[1] which clearly show up in the plasma density and temperature profiles. This paper studies the influence of an ITB on impurity transport in JET OS plasmas. Two species are studied: intrinsic carbon and injected nickel as a trace impurity. The possible relation of particle transport to pressure gradient ∇P_i, radial electric field E_r, and toroidal and poloidal rotation velocities V_ϕ and v_θ is investigated. We take two plasmas as examples which represent two groups of discharges with strong and weak transport barriers. Figure 1 shows the gradients in ion temperature and toroidal rotation profiles in these two OS discharges with different strength of ITB.

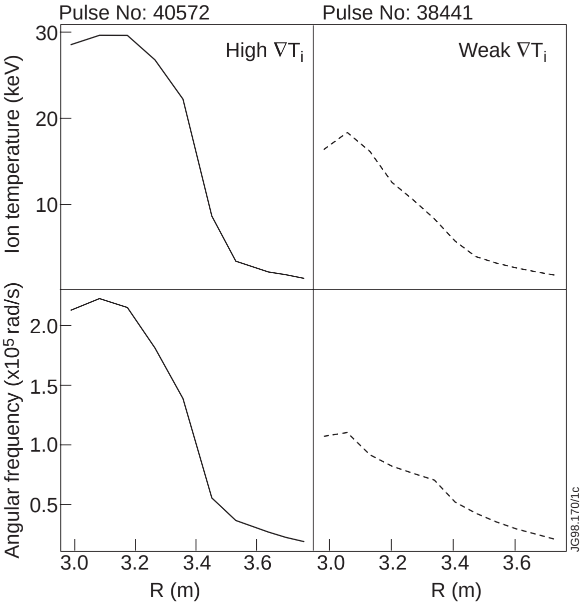

Figure 1. Plasma parameter in two cases of OS plasmas. There is a steep temperature gradient in plasma ion temperature, which indicates a decrease of radial thermal transport.

2. EXPERIMENTAL OBSERVATIONS

Trace Ni was injected into JET OS plasmas with a laser ablation system and its evolution in the plasma[2] was followed by the soft X-ray camera system, together with VUV and XUV spectrometers. The fully stripped C ion density and rotation frequency profiles were measured with the multi-chord charge-exchange spectrometer. The observations of the experiments show the following three features: A) The time evolution of Ni emission is strongly dependent on the strength of ITB. Evidence is seen in line intensities from VUV and x-ray spectrometers (Fig.2) and tomographic reconstruction of Ni ion emission (Fig.3) measured with SXR cameras. B) There are significant differences in C and Ni behaviour in strong ITB plasmas. Inside a strong ITB both the density and the concentration profiles of C^{6+} show a continuous increase with time, whereas the Ni density does not evolve in the region. This significant difference in C and Ni transport, indicates a charge and/or mass dependent transport. C) A poloidal asymmetry of the Ni density is seen inside the ITB as an effect of toroidal plasma rotation, and the radial location of the Ni density peak is closer to the plasma axis than is observed in hot-ion ELM-free H mode plasmas[2].

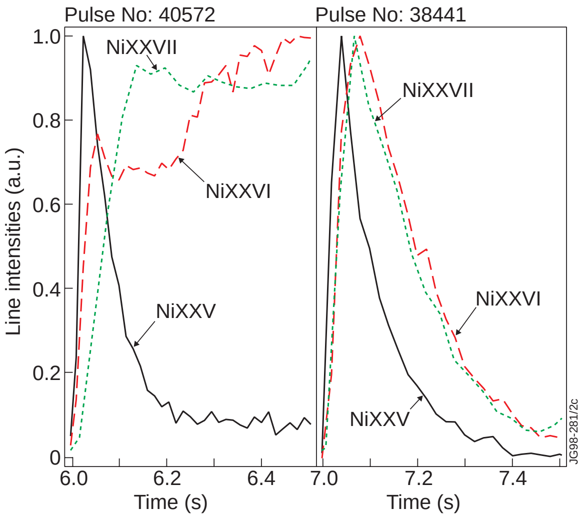

Figure 2. Line spectra from VUV show that in strong ITB case (40572) radiation from Li and He-like Ni ions does not decay, while in the weak ITB case (38441), they decay quickly.

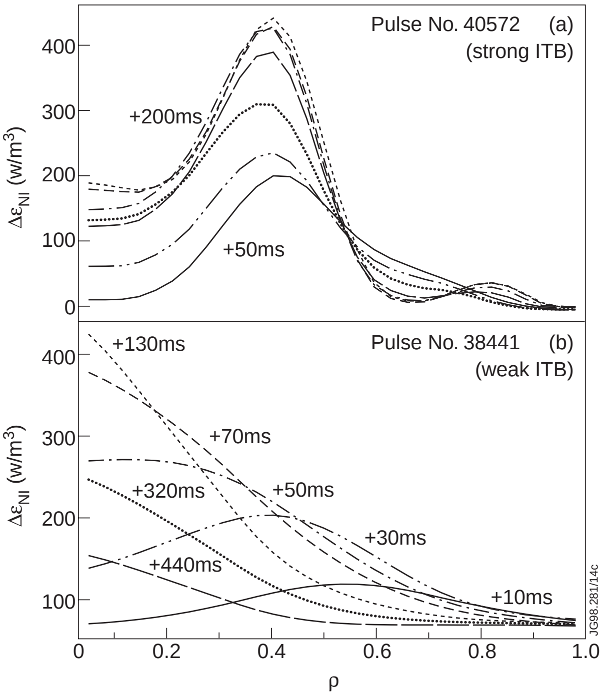

Figure 3. Background subtracted flux surface averaged tomographic reconstruction show that with strong ITB (a), Ni ions are retained in the middle radius (r/a~0.4) of the plasma; while in the weak (b), Ni ions reach the centre of the plasma and decay very quickly.

3. TRANSPORT ANALYSIS

The impurity transport is simulated with a numerical code SANCO. In the strong ITB plasmas, in the plasma core region, a diffusion coefficient which is equal to the neoclassical prediction, within the errors, is needed to simulate the Ni emission feature in the strong barrier cases in Fig 3. The pinch velocity is 0 inside the barrier, but has a value of about 10~15m/s outside r/a~0.6. This is required in order to simulate the time behaviour of the Ni emission which reaches r/a=0.5 within 60ms. Also the difference of the Li-like and Be-like (NiXXVI and NiXXV) line intensities can be reasonably fitted with a strong pinch.

It is difficult to calculate a neoclassical pinch value accurately because of its sensitivity to the derivative of the measurements. Therefore we cannot make a comparison with neoclassical predictions.

In weak ITB case, the Ni transport derived from the soft x-ray measurement[2] is far larger than that in the strong ITB case. The comparison of transport coefficients of the two cases is shown in Fig.4. Inside the ITB, diffusion coefficients are a factor of about 10 times lower in a strong ITB compared to that in a weak ITB plasma. Carbon transport is deduced by fitting the measured C^{6+} density profiles with the same code. As shown in Fig. 5, an inward convection around the ITB region is needed to match the experimental C^{6+} density data. The diffusion coefficient used in the simulation is $D = 0.6\ m^2/s$, constant across the plasma.

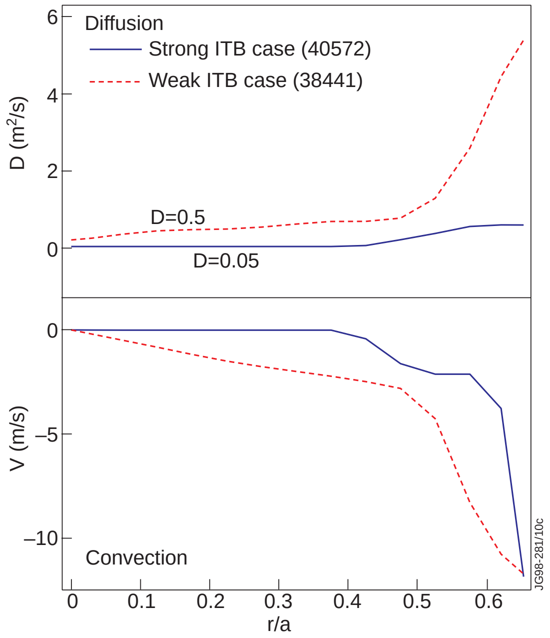

Figure 4. Comparison of transport coefficients in strong and weak ITB OS plasmas

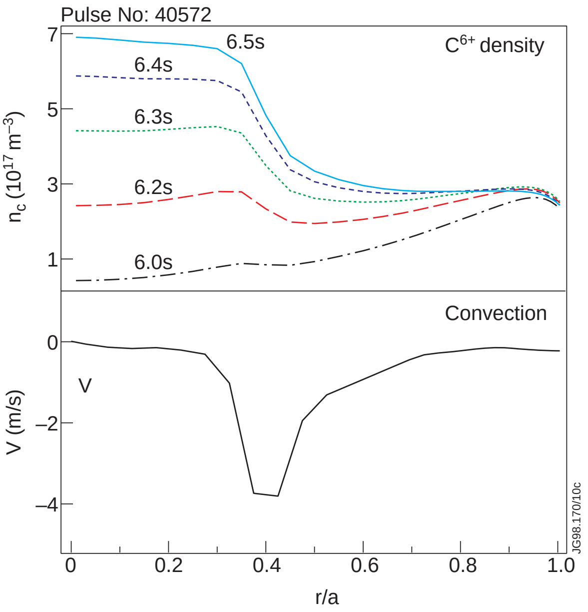

Figure 5. C^{6+} Density time evolution is simulated with a convection in the ITB region.

4. E_r AND $E \times B$ SHEARING RATE

A stronger ITB corresponds to higher E_r and $E \times B$ shearing rate, which is expected to reduce turbulent transport[3,4]. This is consistent with the measurement, as shown in Fig 6, the calculated shearing rate by Forcebal code[5]. Contributions to E_r come from the three terms in the radial force balance equation $E_r = (Zne)^{-1} \cdot \frac{\partial P}{\partial r} - V_\theta B_\phi + V_\phi B_\theta$, where V_θ (which is not measured in the centre of JET) has been given its neoclassical value. Calculations show that in a plasma with strong toroidal rotation, the main contributor to the E_r and hence the $E \times B$ shearing rate is from toroidal rotation. The centrifugal force resulting from plasma rotation could be an explanation of the difference of C and Ni transport in a strong ITB plasma[6].

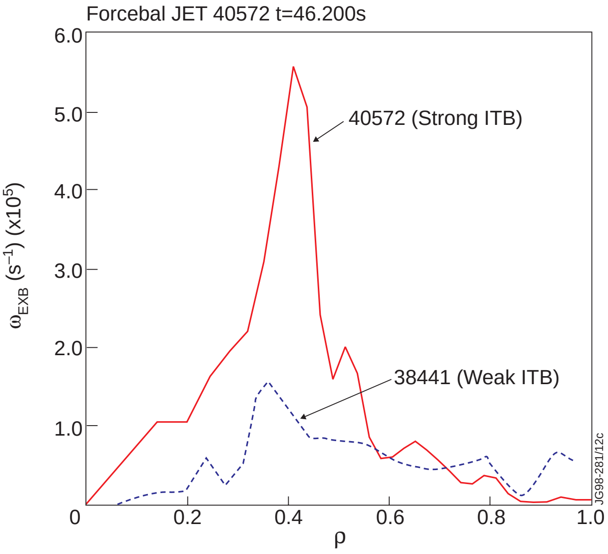

Figure 6. $E \times B$ Shearing rates in the strong (40572) and weak (38441) ITB plasmas, which shows clearly that a stronger ITB corresponds to higher $E \times B$ shearing rate.

5. CONCLUSIONS

In JET Optimised Shear plasmas, Ni injection experiments show that Ni transport is sensitive to the strength of internal thermal transport barrier. Tomographic reconstruction shows that the Ni emission is retained outside the ITB when there is a strong ITB. To simulate this feature, the Ni diffusion coefficient has to be reduced to $0.05\, m^2/s$, of the same order as the neoclassical predictions inside a strong ITB. An additional inward pinch around the ITB is required to reproduce measured carbon density profile. The $E \times B$ shearing rate in a strong ITB plasma is much larger than that in a weak ITB plasma, which is consistent with the theory of reduced turbulent transport by $E \times B$ shear. The toroidal rotation is the main contributor to the radial electric field and $E \times B$ shearing rate. Plasma poloidal rotation in a strong ITB region could be large enough to cause the differences of C and Ni transport.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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