Plasma Transport Properties at the L–H Transition and High Performance Phase of JET Discharges

V V Parail[1], B Balet, J G Cordey, M Erba, T T C Jones, P J Lomas, P Smeulders, E M Springmann, P M Stubberfield, A Taroni, K Thomsen.

JET Joint Undertaking, Abingdon, Oxon, OX14 3EA.
[1] Permanent address: Russian Scientific Centre "Kurchatov Institute", Moscow, Russia.

INTRODUCTION

Recently [1] an analysis of a series of low density high power JET pulses has revealed that this type of discharge can not be correctly described by conventional picture of L-H transition in accordance with which the transition is caused by an abrupt reduction of transport coefficients only in a narrow region near the separatrix. In particular it has been deduced from the fast response of the electron temperature at the transition [2] that the electron transport must change over a very wide region extending from the edge to a position approximately half way in less that a few msecs time ($\Delta t \leq$ 4msec) after L-H transition. TRANSP analysis shows [3] that not only χ_e, but also the ion thermal diffusivity χ_i, the effective particle diffusivity and toroidal anomalous viscosity also drop abruptly at the transition over a wide radial region outside q = 1 surface (fig. 1). The analysis shows also (see fig. 2) that the global energy confinement time increases more than three times in comparison with L-mode phase in the best hot ion shots, and this change also occurs in less than a few msec after L-H transition. This figure shows that there is no separate H-VH transition in these low density hot ion JET pulses, however it appears that the extent of energy confinement time increase after L-H transition depends on the intensity of plasma wall interaction.

NUMERICAL ANALYSIS

All these facts support the idea that the plasma turbulence is linked in the radial direction by the toroidicity. If the plasma turbulence does form such an extended structure with the characteristic radial correlation length Δr of the order ~ a, then the suppression of plasma turbulence in one place (e.g. near the separatrix) should lead to the formation of a very wide transport barrier. We will refer to this model of the L-H transition as the global one. In the conventional local model of L-H transition the characteristic speed of the modification of plasma parameters (e.g. T_e) is determined by the velocity of heat pulse propagation, whilst in the global model this speed corresponds to the group velocity of plasma turbulence. It was shown in [2] by predictive modelling that global model can easily explain experimentally observed dynamics of fast electron temperature modification after L-H transition. On the contrary, conventional local model of L-H transition, in which χ_e is reduced near plasma edge only, fails to reproduce the experimental picture if we do not use strong nonlinear dependences of χ_e on ∇T_e or on T_e. In order to check what kind of nonlinearity is required to fit the experiment, we conducted a predictive modelling of T_e evolution after L-H transition assuming that χ_e depends on ∇T_e and T_e as follows:

$$\chi_e = \chi_o \frac{(\nabla T_e)^{m+1}}{T_e^{\ m}}. \qquad (1)$$

Analysis shows (fig. 3) that only the very extreme, unrealistically non-linear forms for χ_e (m>>10) can account for the fast response of the electron temperature in the plasma mid region. Therefore we can conclude that during L-H transition all of the plasma transport coefficients experience a very fast and large reduction over a wide radial region outside q = 1 surface. It is quite possible that such a strong modification of plasma turbulence can result not only in change of the value of the confinement time but also in modification of its dependence on plasma parameters (for example τ_E can change from Bohm to gyroBohm type). To investigate this problem we study the further evolution of plasma parameters beyond L-H transition. We chose hot ion H-modes (I_p = 3MA) pulses (#26087 and 26095) and a high β_θ H-mode pulse with $I_p \sim$ 1MA (#25264) as reference pulses and carry out a numerical analysis of these pulses with predictive transport code JETTO. The evolution of plasma density was taken from the experiment, equations for T_e and T_i were solved with the following boundary conditions:

$$-\left[\chi_{e,i}\ \ n\nabla T_{e,i} + \frac{3}{2} T_{e,i}\ \ D\nabla n_{e,i}\right]_{r=a} = \alpha_{e,i} T_{e,i} \Gamma_{\parallel r=a} \qquad (2)$$

where $\Gamma_\parallel$ is the parallel particle flow in the SOL. Numerical analysis shows that such boundary conditions allow us to reproduce the formation of a transport barriers after L-H transition when both χ_e and χ_i are significantly reduced as compared with the L-mode. We used the following expressions for χ_e and χ_i.

$$\chi_i = \chi_i^{\ neo} + \alpha_2^i \frac{c\ \nabla n T_e}{eB\ \ n} a\ \ q^2, \quad \chi_e = \alpha_1 \frac{c^2}{\omega_{pe}^2} \frac{V_{Te}}{qR} \frac{r}{R} + \alpha_2^e \frac{c\ \nabla n T_e}{eB\ \ n} a\ \ q^2 \qquad (3)$$

Where $\chi_i^{\ neo}$ is the neoclassical ion thermal diffusivity, α_1, $\alpha_2^{l,i}$ numerical coefficients. The first term in right hand side of (2) leads to Alcator scaling, second term in (2) and (3) gives Bohm-type transport. Model (2-3) was used to simulate L-mode JET discharges with $\alpha_2^i = 3\alpha_2^e = 10^{-3}$ and $\alpha_1 = 0.71$.

The calculated temporal evolution of the electron and ion energy content for the H-mode phase of shot II 26095 is shown in fig. 4 together with experimental behaviour. The radial profiles of T_e and T_i are shown in Fig. 5 at t = 53.3s. Analysis of the reference discharges show that the best agreement can be achieved if one assumes that $\alpha_2^i = 3\alpha_2^e = 10^{-4}$ in ELM free H-mode discharges. It corresponds to more than one order of magnitude reduction in ion thermal diffusivity near plasma edge. This reduction is so big that ion transport becomes of the order of neoclassical in the inner half of plasma column. This is most easily seen for the 1MA discharge, where when $\chi_i^{neo} \sim q^2$ becomes so large that even the very moderate assumption $\chi_i \simeq 3\chi_i^{neo}$ leads to underestimation of ion temperature and energy content.

CONCLUSIONS

Both electron and ion thermal diffusivities are reduced by one order of magnitude everywhere, not only in a narrow region near separatrix during the L-H transition.
There is no separate H-VH transition on JET, this "transition" corresponds to (coincides with) the cessation of ELMs. In the ELM free phase ion transport in the core is close to its neoclassical value, but probably rises towards plasma edge (however still remaining much less that it was in L-mode). The best agreement with experiment is obtained with the model which simultaneously takes into account both the global reduction of Bohm type anomalous transport in plasma core (which probably changes confinement from Bohm to gyroBohm) and formation of temperature pedestal near plasma edge.

REFERENCES

[1]. Neudatchin, S.V., Cordey, J.G., and Muir, D.G. 20th EPS Conf. on Contr. Fus. and Plasma Phys., Lisboa, 1993 part II, p. 83.

[2]. Parail, V.V., Cordey, J.G. Springmann, E. and Taroni, A., JET-P(93)87, submitted to Nuclear Fusion.

[3]. Cordey, J.G. Muir, D.G., Neudatchin, S.V. Parail, V.V. et al., Workshop on H-mode Confinement, Japan 1993, will be published in Plasma Physics and Contr. Fusion, 1994.

[4] Conner, J.W., Hastie, R.J., and Taylor, J.B., Proc. Roy. Soc. London Ser. A 365, 1 (1979).

[5] Romanelli, F., and Zonca, F., 20 EPS Conf. on Contr. Fusion and Plasma Phys. Lisboa, 1993, part IV, p. 1383.

[6] Le Brum, M.J. et al., Phys. Fluids B, 5 (1993) 752.

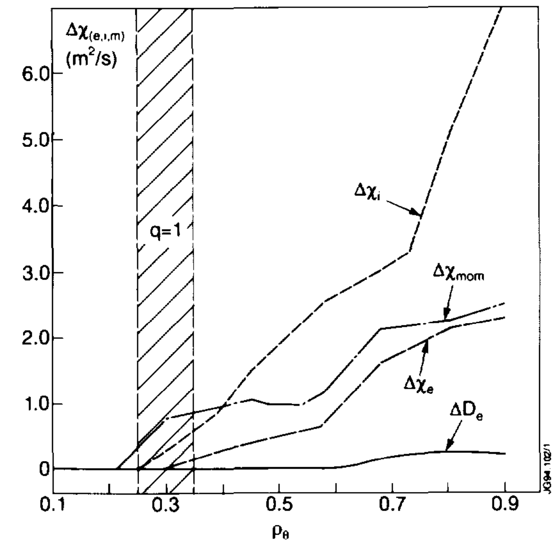

Fig. 1 . Modification of plasmas transport coefficients after L-H transition

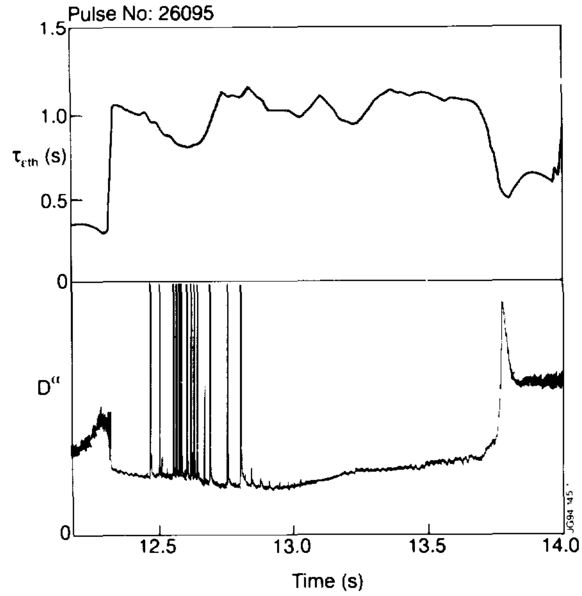

Fig. 2. Temporal evolution of t_E and D_α signal in hot-ion shot

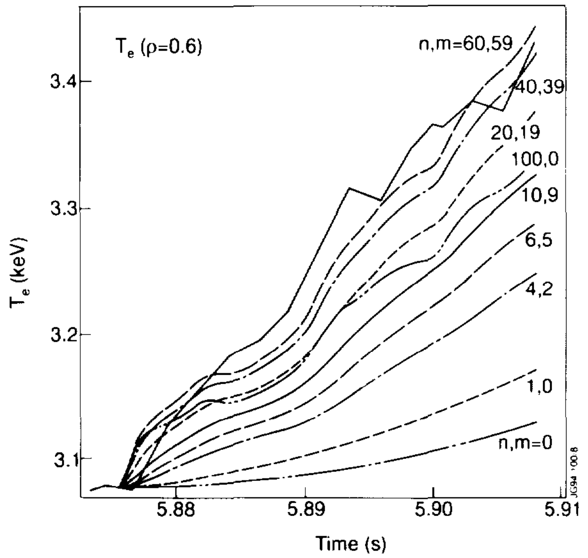

Fig. 3. Evolution of calculated T_e (ρ = 0.6) for different values of m,n.

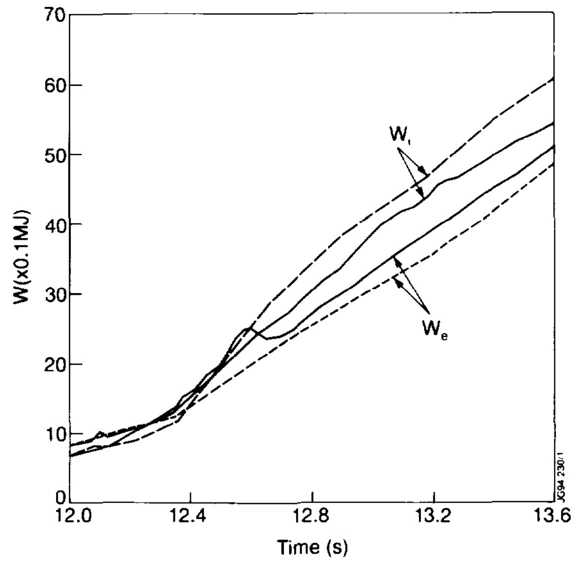

Fig. 4. Experimental (solid) and calculated (dashed) temporal evolution of electron and ion energy content for hot-ion H-mode

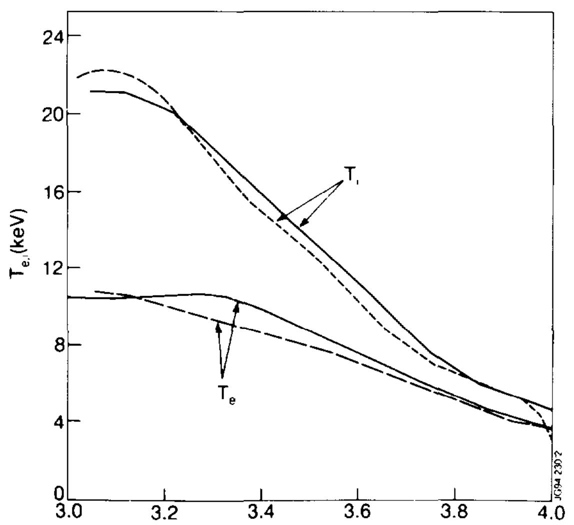

Fig. 5. Experimental (solid) and calculated (dashed) radial distribution of T_e and T_i in hot-ion H-mode.