JOINT EUROPEAN TORUS

JET–P(93)87

V.V. Parail, J.G. Cordey, E. Springmann, A. Taroni

A Numerical Simulation of the L-H Transition in JET with Local and Global Models of Anomalous Transport

A Numerical Simulation of the L-H Transition in JET with Local and Global Models of Anomalous Transport

V.V. Parail[1], J.G. Cordey, E. Springmann, A. Taroni

JET-Joint Undertaking, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]*Permanent address: Russian Research Centre 'Kurchatov Institute', Russia*

Preprint of a paper to be submitted for publication in
Nuclear Fusion
October 1993

ABSTRACT

A numerical study of the dynamics of the L-H transition in JET was done using models of anomalous transport which depend either on local or on global plasma parameters. Comparison with experimental results [1] shows that the best agreement is reached when using a global model for reducing χ_e, χ_i and D in the region where shear becomes large (e.g. outside q=1 surface). Thus the L-H transition manifests itself as a sudden drop of transport coefficients everywhere outside the q=1 surface, not only in a narrow layer near plasma edge. The slow improvement of plasma confinement which follows such a fast transition could then be attributed to the inverse dependence on density of the transport coefficients near the plasma centre.

I. INTRODUCTION

It was shown experimentally [1] that L-H transitions in JET have some features which could not be described by conventional picture in which the L-H transition manifests initially itself as a sudden reduction of anomalous transport coefficients near plasma edge [2], followed by a slow improvement throughout the entire plasma on the energy confinement time scale. The most surprising one is the fact that L-H transition at JET is usually accompanied by instantaneous (within experimental accuracy $\Delta\tau \lesssim 3$ ms) reduction of at least the electron thermal diffusivity χ_e not only in a narrow (of the order of $\Delta r \sim \rho_{\theta i}$) region near plasma edge but in a quite broad region outside q=1 surface. The electron temperature (or electron thermal diffusivity χ_e) inside q=1 surface is practically unaffected by L-H transition but rather by change in plasma density. It is also worthwhile mentioning here some other features of plasma confinement in ELM-free JET H-modes, which were already observed [3] which are difficult to explain with the conventional picture of L-H transition. In particular it follows from experiment that the energy confinement time in ELM-free H-mode degrades with input power in accordance with gyro-Bohm scaling. On the contrary L-mode plasma is better described by Bohm-like scaling law. There is also a tendency for the energy confinement time in ELM-free H-modes to grow with the density so that in the VH mode it approaches its neo-Alcator value. The main goal of present work is to determine (on the basis of numerical simulation) which features the anomalous transport coefficients should contain in order to describe the above mentioned experimental results. Special attention will be given to comparative study of local and global models of anomalous transport.

In the first case transport is suddenly reduced at the L-H transition in the narrow region close to the plasma edge, in the second case it is reduced over the entire plasma cross section. The work is organised as follows. Local and global models are described in Section II. Section III is devoted to the analysis of the results of numerical study. The main conclusions have been formulated in the Summary IV.

II. LOCAL AND GLOBAL MODELS OF ANOMALOUS TRANSPORT

We will pay particular attention to the analysis of electron thermal conductivity because there are reliable experimental data on T_e profile evolution with good time resolution ($\Delta\tau \lesssim 3$ ms). But the numerical simulation was done using a complete transport model which consists of equations for the electron T_e and ion T_i temperatures, electrons density n_e and poloidal magnetic field B_p by using transport code JETTO [4]. JET shot #26021 with $B_T = 3T$, $I_p = 3$ MA was used as a reference discharge. The L-H transition in this discharge was triggered by NBI with input power $P_{NBI} \simeq 13$ MW. The main plasma parameters are shown in Fig. 1.

Both in the local and global models it was assumed that $\chi_e \cong D \cong (\chi_i - \chi_i^{neo})/3$, where χ_i^{neo} - ion neoclassical thermal diffusivity, D - plasma diffusion coefficient. Neoclassical resistivity was assumed for the current density evolution. The following expression for particle flow was used in the numerical simulations:

$$\Gamma_n = -D\left(\nabla n_e - \frac{n_e}{2T_e}\nabla T_e\right) \quad (1)$$

where second term in the right hand side describes particle pinch due to temperature inhomogeneity [5]. The simplest expression was used to describe both electron and ion heat flows:

$$Q_{e,i} = -n_{e,i}\chi_{e,i}\nabla T_{e,i} \quad (2)$$

In both local and global models of anomalous transport all transport coefficients depend on local plasma characteristics (such as T_e, n_e, ∇T_e etc.). We chose the following form for the transport coefficients:

$$\chi_e \cong \left(\chi_i - \chi_i^{neo}\right)/3 \cong \alpha_1 \frac{(T_e)^{1/2}}{n_e qR} + \alpha_2 \frac{\nabla(n_e T_e)}{n_e B_T} q^2 \tag{3}$$

where α_1 and α_2 are constants determined empirically from numerical simulations. It is worthwhile mentioning that the second term on the right hand side (3) with $\alpha_2 = 3.3 \times 10^{-4}$ (SI units with T_e in eV) was used in [6] to fit L-mode confinement on JET and corresponds to a model of the Bohm type. The first term in right hand side (3) with $\alpha_1 = 1.2 \times 10^{-19}$ describes ohmic confinement (neo alcator scaling) and is of the gyro Bohm type. It seems reasonable to use a linear combination of these two terms to fit ohmic, L and H modes.

The transport coefficients are equal for both local and global models in L-mode $\left(\alpha_1^L = \alpha_1^G \text{ and } \alpha_2^L = \alpha_2^G\right)$. The difference between local and global models is introduced only in H the regime. Namely we assume that the coefficient α_2 is decreased by a factor of 10 after L-H transition everywhere inside plasma volume in the global model. In the local model both α_1 and α_2 are decreased by a factor of 10 after the L-H transition but only in a narrow region near the plasma edge (say for $\rho \gtrsim 0.9$). The characteristic radial distributions of χ_e in L and H modes for local and global models just before and after transition are shown in Fig. 2. The local model corresponds to the conventional picture of the L-H tansition in which turbulent oscillations are suppressed initially in very narrow region near plasma edge. Whilst the global model corresponds to the idea of toroidally linked turbulence [7-9] with a characteristic radial extension of the order of plasma minor radius. Note also, that global model of L-H transition suggests that anomalous transport shifts from being of the Bohm type in L-mode to gyro-Bohm one in the H-mode.

III. NUMERICAL ANALYSIS OF L-H TRANSITION

The time evolution of electron temperature at different radii for JET shot #26021 during the L-H transition is shown in Fig. 3. As it was first noted in [1] the most striking feature is that after L-H transition (after H_α drop) electron temperature begins to increase everywhere outside the $q \cong 1$ surface. Inside the $q = 1$ surface the electron temperature is practically unaffected by the transition. It is seen that the temperature continuously grows in this region (together with a rising density) even before transition. This may be due to the fact that transport is already very small in this region even in L-mode in case where MHD activity (sawteeth or $m/n = 1/1$) is suppressed. The numerical simulation of the time evolution of electron temperature is shown in Fig. 4a, 4b for local and global model respectively. The density evolution was not computed in these calculations but taken from experiment. It can be clearly seen that local model leads to the usual picture of heat pulse propagation toward plasma centre triggered by sudden change of electron thermal diffusivity near the plasma edge. It is worthwhile to recall that the electron thermal diffusivity in both models contains a term which is proportional to $\nabla(n_e T_e)/n_e$. It means that we have already taken into account nonlinearity which is usually used to explain the experimentally observed factor of two increment in the thermal diffusivity during heat pulse propagation. The fact that such a nonlinearity fails to match the experimental results with computed ones allows us to conclude that any "reasonable" nonlinearity (like $\chi \sim T^n$ or $(\nabla T)^n$ with $n << 10$) could not explain experimental picture of L-H transition on JET.

The global model however gives an electron temperature evolution which is very similar to the experimental picture. The direct comparison of numerical simulation with experimental data is shown in Fig. 5.

An interesting mechanism appears if we calculate the temperature and density evolution simultaneously, which, at first glance, might be expected to explain the observed features of the L-H transition using the local model. The result of such a self consistent modelling is given on Fig. 6, showing that the implementation of the density evolution into numerical simulation leads to simultaneous temperature rise after L-H transition in the whole plasma column (compare with Fig. 4). The physics of this mechanism can be clarified from the following consideration. The density evolution is described by continuity equation:

$$\frac{\partial n}{\partial t} e = \mathrm{div}\,\Gamma_n + S_e \qquad (4)$$

where S_e is a source of electrons due to neutrals ionisation. We assume in our model that total number of particles does not change during the L-H transition. Thus the amplitude of the source term has to depend on plasma diffusivity near the edge:

$$\int S_e dV = \Gamma_n|_{r=a} \qquad (5)$$

and decreases at the moment of L-H transition (notice that the neutral atoms propagate across plasma very rapidly, with $\tau \sim a/c_s$, $\tau << 1$ ms). The source of particle influences the evolution of the electron temperature in accordance with the energy conservation law:

$$n_e \Delta \frac{\partial T_e}{\partial t} \sim -T_e \Delta \frac{\partial n_e}{\partial t} \sim T_e (S_L - S_H) \qquad (6)$$

Where $S_{L,H}$ - source of particle just before and after L-H transition correspondingly, $\Delta(\partial T_e/\partial t) = \partial T_e/\partial t_L - \partial T_e/\partial t_H$ - change in the rate of T_e rise during L-H transition. As the source of particle changes almost instantaneous in the whole plasma volume, the electron temperature will react to this variation also almost instantaneously everywhere.

Detailed analysis shows nevertheless that this mechanism, very interesting in its nature, is not sufficient to explain the experimental picture of the T_e evolution. Our numerical analysis, using the code FRANTIC to evaluate the profile of neutrals shows that the source of neutrals has a very hollow profile for JET conditions, decreasing exponentially toward plasma centre (see Fig. 7). Thus (see eq. (6)) $\Delta\partial T_e/\partial t$ is also a very hollow function of minor radius, which does not correspond to experimental observation. It is worthwhile to mention that self consistent modelling of density and temperature evolution during L-H transition with global model leads to results which practically coincide with those of the prescribed density evolution.

It should be also mentioned that the global model gives better conformity with experimental picture also in the way it describes the slow temperature rise with the density growth. Detailed comparison of transport coefficients with experimental ones and its dependence on plasma parameters in particular is outside the scope of this work, which main aim is to point out the possible different nature of transport in L and H regimes.

IV. SUMMARY

A numerical analysis of the dynamics of the L-H transition was done by using a local and a global model of anomalous transport. The results of this study lead us to conclude that at least in JET the L-H transition can not be explained as a sudden reduction in transport coefficients (formation of transport barrier) limited to the plasma edge only. Much better agreement with the experimental observations is reached by using the global model, in the frame of which the L-H transition is followed by a sudden reduction of transport coefficients everywhere outside the $q \cong 1$ surface. This result supports recent theoretical ideas [7-9] in which the plasma turbulence in a tokamak forms large linked convective cells with a characteristic correlation length of the order of plasma minor radius. The results indicate also that confinement in L and H modes could be of a different nature and that in the usually used expression $\tau^{H}{}_{E} \cong H \times \tau^{L}_{H}$ the enhancement factor H should be not a number but rather function of the plasma parameters.

ACKNOWLEDGEMENTS

The authors wish to acknowledge D.J. Campbell, A. Colton, A.E. Costley N.C. Hawkes, D.G. Muir, S.V. Neudatchin, J.J. O'Rourke, A.C.C. Sips, K. Thomsen and G. Vayakis for numerous fruitful discussion.

REFERENCES

[1] Neudatchin, S.V., Cordey, J.G. and Muir, D.G., 20th EPS Conference on Controlled Fusion and Plasma Physics, Lisboa, 1993 p.2. p.83.

[2] Kurki-Suonio, Burrell, T.K., et al., Nucl. Fusion 33, 301 (1993).

[3] H-mode Database Working Group, 20th EPS Conference on Controlled Fusion and Plasma Physics, Lisboa, 1993. p1. p.103.

[4] Cenacchi, G., and Taroni, A., in 8th Europhysics Conference on Computational Physics, Eibsee, 1986.

[5] Walt, R.E., Phys. Fluids, 25, 1269, (1982).

[6] Taroni, A., Erba, M., Springmann, E., and Tibone F., 20th EPS Conference on Controlled Fusion and Plasma Physics, Lisboa, 1993.

[7] Kadomtsev, B.B., Plasma Physics and Controlled Fusion, 34, (1992), 1931.

[8] LeBrun, M.J., et al, Phys. Fluids B, 5 (1993), 752.

[9] Connor, J.W., Taylor, J.B., and Wilson, H.R., Phys. Rev. Letters 70, (1993), 1803.

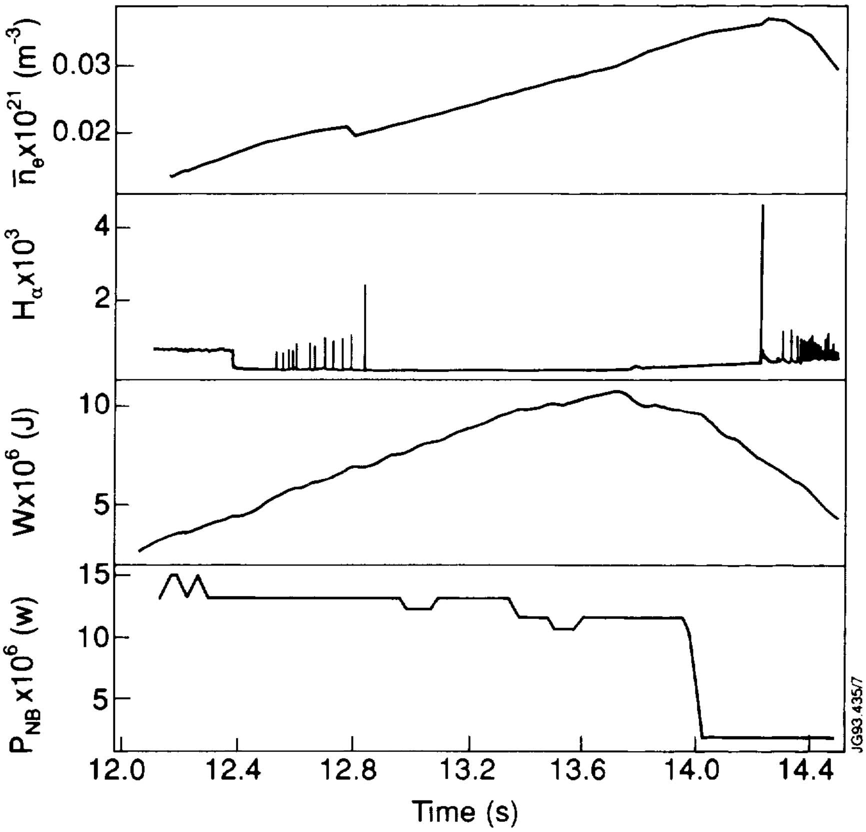

Fig. 1. The main plasma parameters for JET shot #26021: a) - average election density, b) - H_α signal, c) stored plasma energy and d) - NBI power.

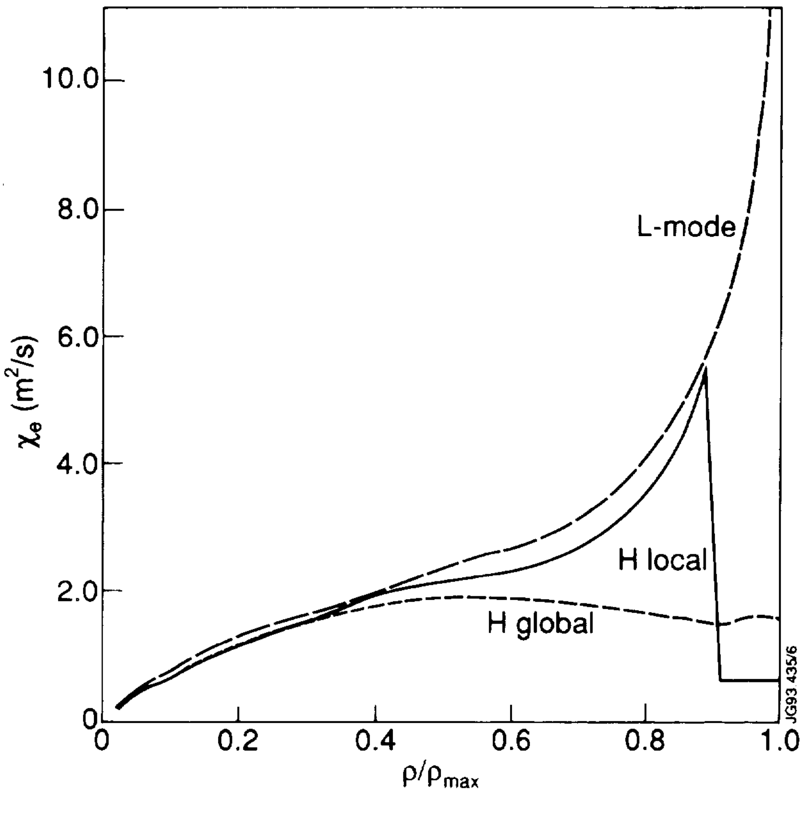

Fig. 2. Radial distribution of electron thermal diffusivity for L-mode (L), local model of H-mode (Lo) and global model of H-mode (G).

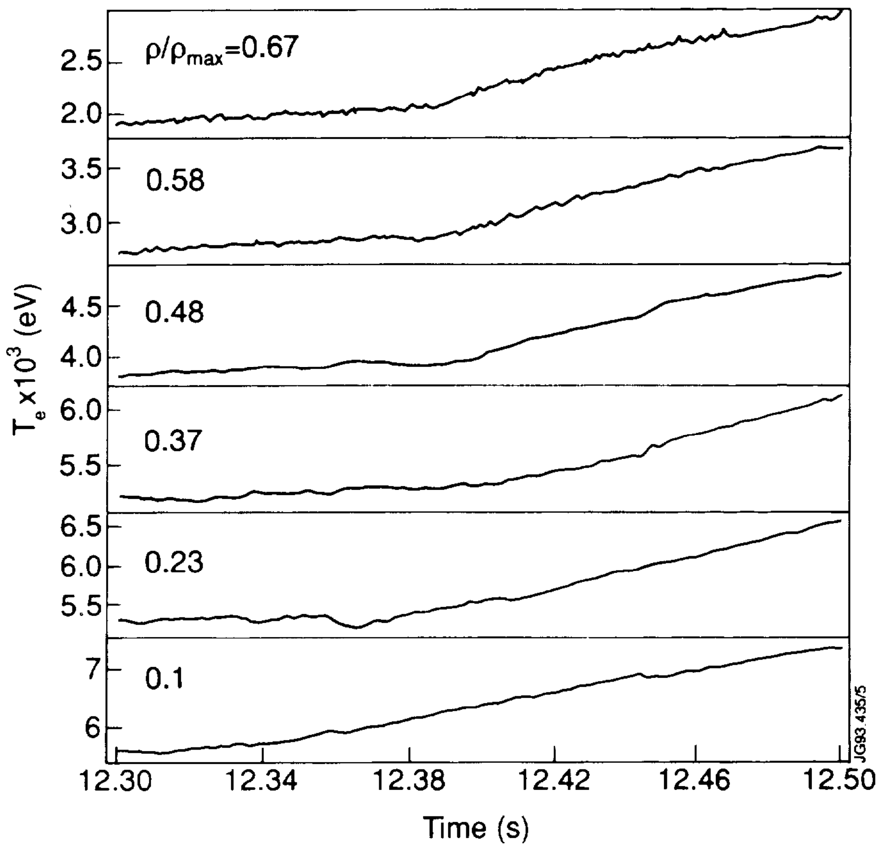

Fig. 3. Temporal evolution of ECE signals (electron temperature) at different radii ρ/ρ_{max} during L-H transition for shot #26021.

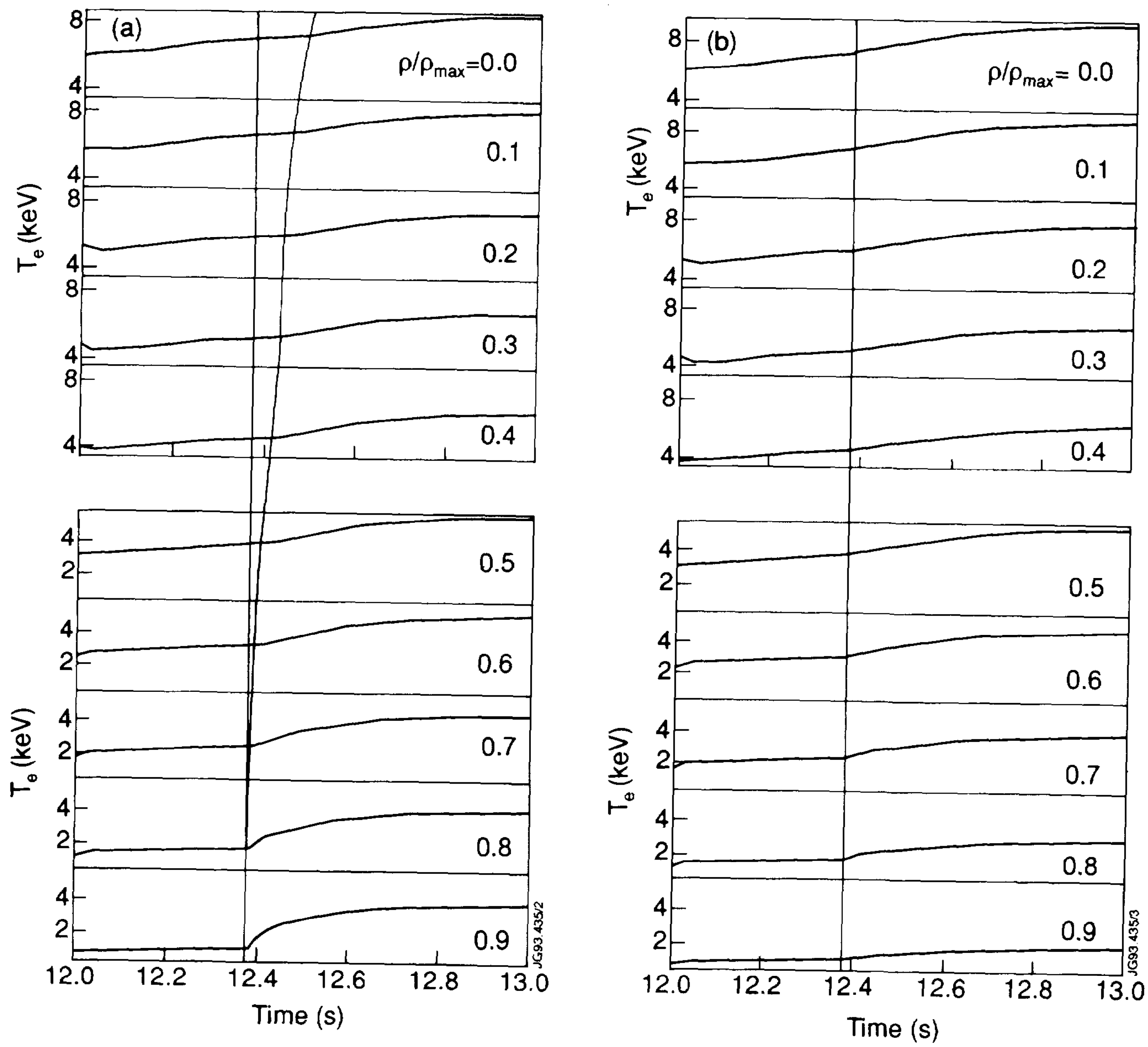

Fig. 4. Temporal evolution of computed electron temperature at different radii for local (a) and global (b) models.

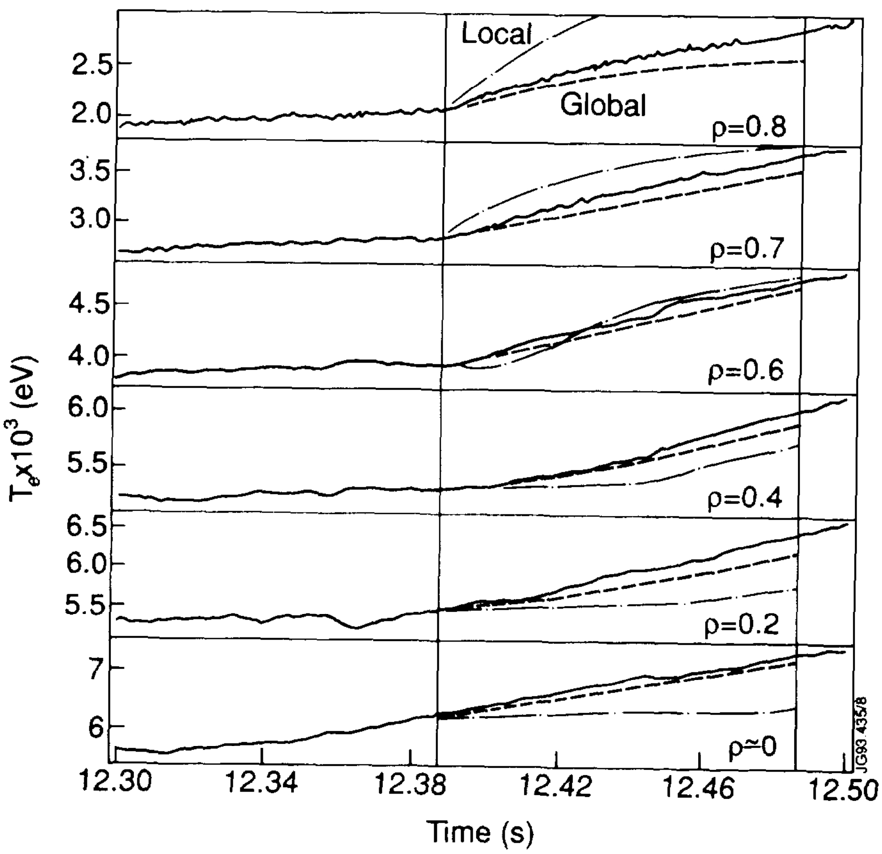

Fig. 5. Temporal evolution of electron temperature at different radii for shot #26021: solid line - experimental data, dashed line - local model, dotted line - global model.

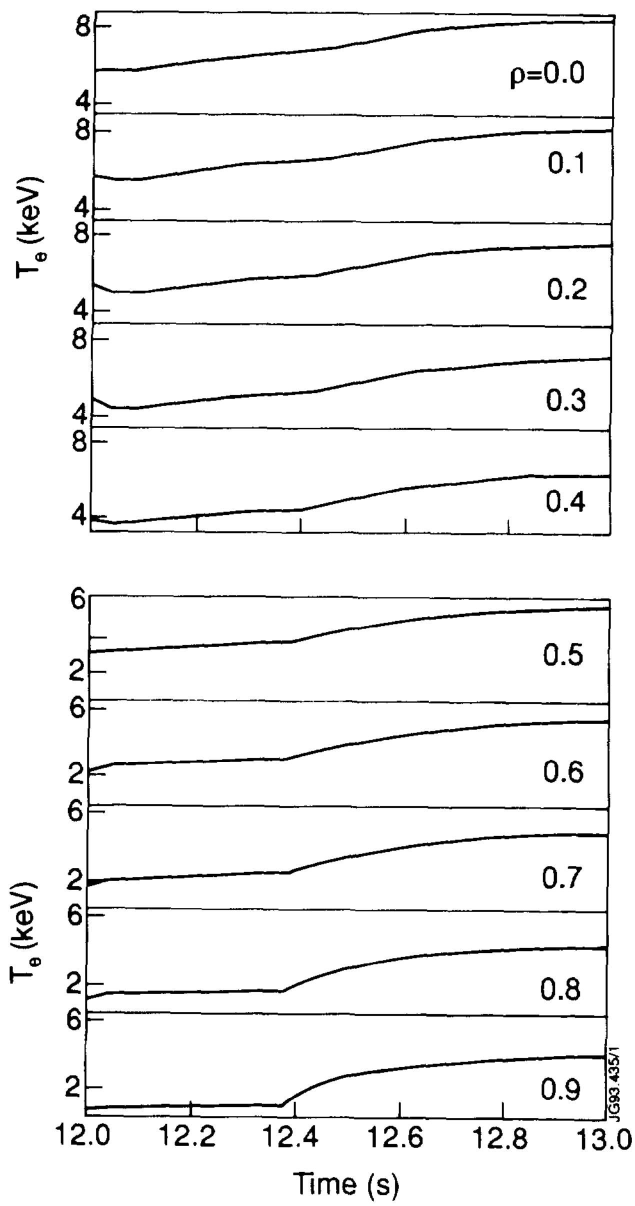

Fig. 6. Temporal evolution of electron temperature and density for local model (both T_e and n_e profiles are calculated).

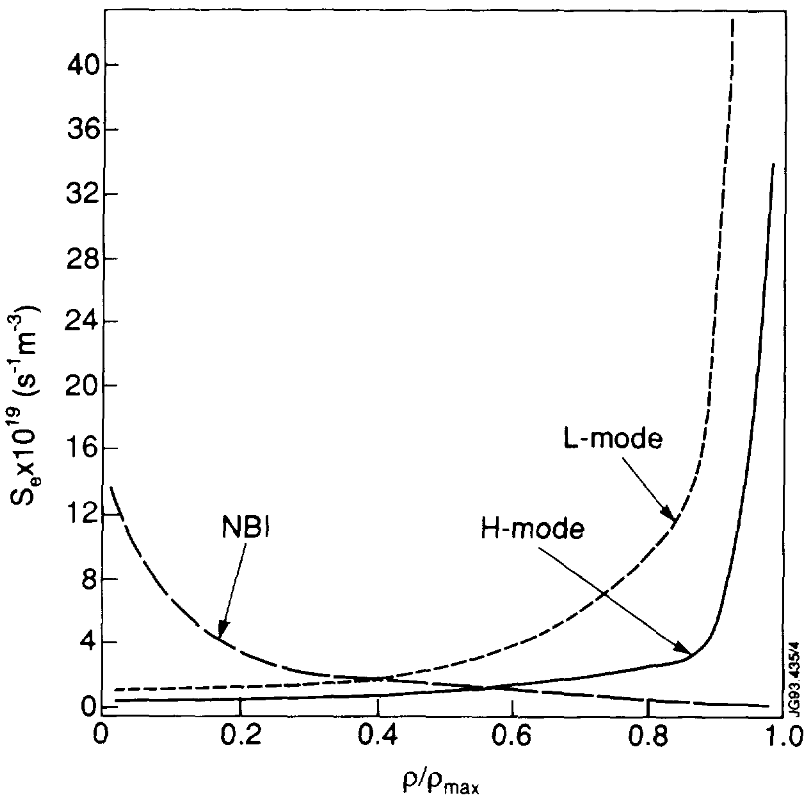

Fig. 7. Calculated radial distribution of electron's source Se for shot #26021.