PREDICTIVE MODELLING OF ENERGY TRANSPORT IN JET DISCHARGES

M.Erba, A. Cherubini, V. Parail, E. Springmann, A. Taroni.
JET Joint Undertaking Abingdon Oxon OX14 3EA U K

1) INTRODUCTION

Energy transport in the different regimes of confinement observed at JET can be studied using a Bohm-like model for L-mode electron transport [1] as a starting point:

$$\chi_e = \alpha_e \frac{c|\nabla(n_e T_e)|}{eBn_e} aq^2 \quad , \quad \chi_i = \chi_i^{neocl} + \alpha_i \chi_e \tag{1}$$

where q is the safety factor, χ^{neocl} is the neoclassical ion diffusivity while α_i,α_e are numerical coefficients to be determined empirically. Using model (1) it is possible to simulate a variety of L-mode and ohmic JET discharges with fixed numerical coefficients (sections 2 and 3).

Since at the L-H transition a global sudden reduction of the electron heat diffusivity is observed [2], we have been able to set up a model for the H-mode regime reducing the diffusivities by a constant factor over all the plasma (see section 4). It has not been possible to study the Bohm versus gyro-Bohm aspects of the scaling of heat transport in H-mode due to the restricted variation of plasma parameters in our selected discharges; a gyro-Bohm-like model with a radially increasing shape [3] can be equally successful.

To simulate predictively the formation of the temperature pedestal we assume the existence of a neoclassical transport barrier on a thin layer ($\sim\rho_{pi}$) inside the separatrix, and the H-mode numerical simulations have been repeated using these boundary conditions successfully reproducing the experimental trends (section 5).

2) SIMULATION OF JET L-MODE DISCHARGES

In our approach we start from the observation that the results of TRANSP analysis of ordinary L-mode JET discharges indicate that $\chi_i > \chi_e$ all over the plasma column, so that we use eq. (1) for χ_i with α_i>1. We consider a set of L-mode discharges chosen in the JET data-base where the experimental ion temperature profiles are available with parameters in the range: $0.11 \le \langle n_e \rangle (10^{20} m^{-3}) \le 0.55$, I_p (MA) ≈ 3 , B_t (T) ≈ 3 , $4 \le P_{in}$ (MW) ≤ 18.

The simulations have been carried out in a semi-predictive way using the JETTO transport code: only heat diffusion has been modelled, while experimental density and Z_{eff} profiles have been imposed throughout the time evolution. It is found that a model with $\alpha_e = 2.0 \cdot 10^{-4}, \alpha_i = 3$ gives good results also in cases with predominant electron heating.

3) SIMULATION OF JET OHMIC DISCHARGES

Analysis of ohmic discharges [4] has shown that when the density is too high the confinement time does not rise linearly with density as prescribed by the so-called Neo-Alcator scaling law and saturates. Recent results from ALCATOR C-MOD [5] suggest that this regime might be described using an L-mode-like model. We choose for simulation a set of 5 JET ohmic discharges with parameters in the range: $0.10 \leq \langle n_e \rangle (10^{20} m^{-3}) \leq 0.37$, $1 \leq I_p$ (MA) ≤ 7 , $1.7 \leq B_t$ (T) ≤ 3.3.

In fig. 1 the profiles obtained with a neoalcator-like model [6], with the Bohm model (with the same value of the coefficients given above) and the experimental profiles are shown. Analysis of the corresponding values of thermal energy shows that the linear scaling with density and weak scaling with current, typical of the neoalcator-like model, are not in agreement with experimental results, which are much closer to the L-mode scaling.

4) SIMULATION OF H-MODE ELM-FREE, MHD-FREE DISCHARGES

Following the results presented in [2], we derive a model for H-mode by reducing the numerical coefficient α_e by ~10 times with respect to L-mode down to $0.2 \cdot 10^{-4}$. Due to the non-linearity in the parametric dependencies of χ this results in a reduction of the numerical value of χ by a factor ~ 3. We point out that due to this reduction the neoclassical ion transport becomes important in the central part of the plasma column.

In this way we model the entire ELM-free H-mode phase for shots which have no large scale MHD activity (like roll-over), and we succeed in simulating both the evolution of the thermal energy and the temperature profiles at different times. Some of the selected discharges fall into the category of VH-mode with enhancement factor H>3, while others have 2<H<3.

We can simulate discharges with different values of the H-factor using the same transport model because an important role is played by effects not directly related to heat diffusion, like the shape of the power deposition profile and the temperature pedestal. Edge temperatures of at least 3 keV are in fact characteristic of high performance shots in JET, and roughly half of the total thermal energy is stored in this pedestal.

5) A MODEL FOR BOUNDARY CONDITIONS IN H-MODE DISCHARGES

Assuming that perpendicular transport inside a transport barrier located at the plasma edge is of the order of the neoclassical one in the banana regime we obtain the following condition:

$$\chi_i n_i \nabla T_i + \frac{3}{2} T_i D \nabla n_i \approx -n_i T_i \frac{\rho_{pi}}{\sqrt{\varepsilon \tau_{ii}}} F_T \qquad (2)$$

where ρ_{pi} is the ion poloidal Larmor radius, τ_{ii} is the ion-ion collisional frequency, ε is the inverse aspect ratio near the separatrix, F_T is a coefficient which depends on the geometry, collisionality and radial electric field and $0 \leq F_T \leq 1$[7]. The boundary condition for electron heat flow is similar to eq. (2) if we assume that the remaining magnetic turbulence near the separatrix keeps the electron particle flux at the level of the ion neoclassical flow. We find that using the above boundary conditions we can reproduce the experimentally observed ion and electron temperature evolution near the separatrix in the best Hot-Ion H-mode discharges, and that in case of relevant volume power losses the edge temperature is significantly decreased (see fig. 2a). An important property of boundary conditions (2) is that in the banana regime the heat flow does not depend on the temperature near the separatrix and $Q_{e-i} \propto n_i n_{e-i}$. This feature allows us to explain the experimentally observed fact that the global plasma energy confinement time in hot-ion VH-modes, formally defined as $\tau_E = W/(P - dW/dt)$, grows almost linearly with time together with the total energy content W (see fig. 2b). A saturation may occur in collisional regimes, where a temperature dependence is introduced by the plateau expression of the neoclassical diffusivity.

REFERENCES

[1] Taroni A., et al., Plasma Phys. Control. Fusion **36** (1994) 1629.

[2] Balet B., et al., "The Physics of L and H-mode Confinement in JET", 15th Int. Conf. on Plasma Physics and Contr. Nucl. Fus. Res., Seville, Spain (1994).

[3] Erba M., et al., "Simulation of L-mode Tokamak Discharges and ITER Performance with Energy Transport Coefficients of Bohm and gyro-Bohm Type", Proc. Workshop on Local Transport Studies in Fusion Plasmas, Varenna (1993) 39.

[4] Garbet X. , Payan J. , Laviron C. , et al. , Nucl. Fus. **32** (1992) 2147

[5] Porkolab M. , et al. , 'Overview of recent results from Alcator C-MOD', 15th Int. Conf. on Plasma Phys. and Contr. Nucl. Fus. Res. , Seville (1994).

[6] Merezhkin V.G. and Mukhovatov V.S., JETP Lett, **33** (1981) 446.

[7] S.-I. Itoh and K. Itoh, Phys. Rev. Lett. **60** (1988) 2276.

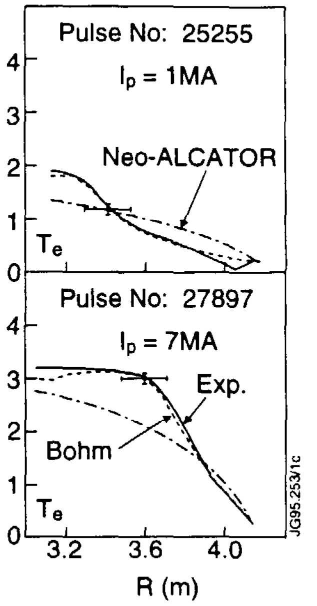
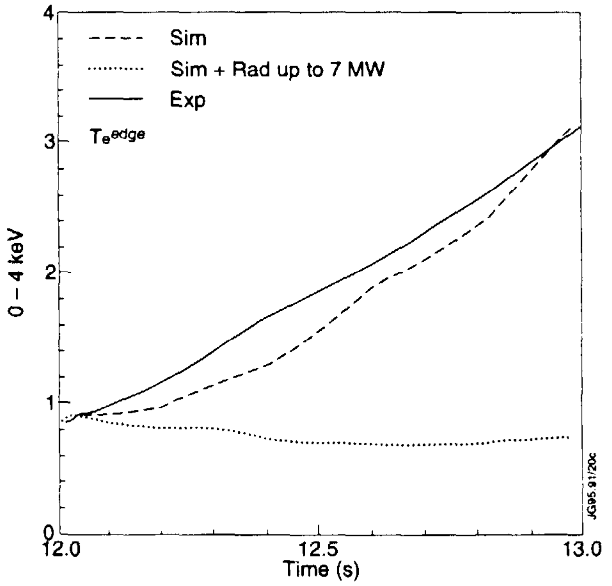


Fig. 1: Experimental temperature profiles (solid lines) and computed temperature profiles with the Neo-alcator-like and Bohm models (dotted lines) for a 1 MA and a 7 MA ohmic JET discharge.



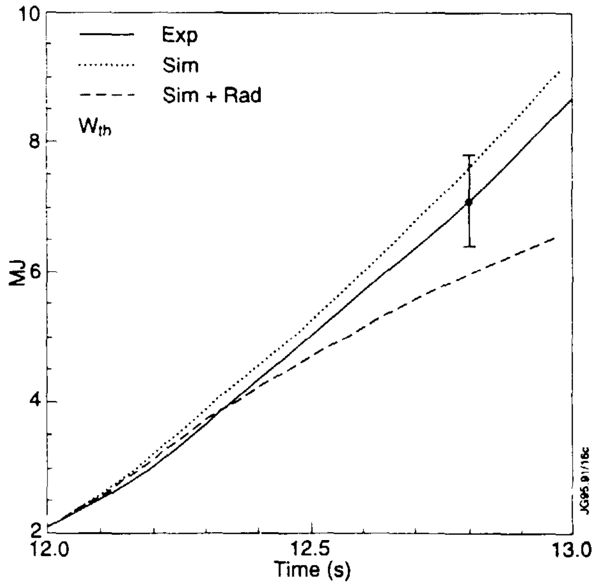


Fig. 2a : Time evolution of the edge electron temperature from experimental measurements (solid line) and from simulations carried out with and without the effect of 7 MW of radiated power (dotted lines).

Fig. 2b : Time evolution of the thermal energy from experimental measurements (solid line) and from simulations carried out with and without the effect of 7 MW of radiated power (dotted lines).