*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-1.035 (2002)*

Particle Transport and Density Profile Analysis of Different JET Plasmas

L. Garzotti[1], G.Corrigan[2], X. Garbet[3], D. Heading[2], T. T. C. Jones[2], P. Lang[4], P. Mantica[5], H. Nordman[6], V. Parail[2], B. Pégourié[3], J. Spence[2], P. Strand[6], M. Valovič[2], J. Weiland[6]
and contributors to the EFDA-JET work programme*

[1]Consorzio RFX – Associazione EURATOM-ENEA sulla Fusione, I-35127 Padova, Italy
[2]EURATOM-UKAEA Fusion Association, Culham Science Centre, OX14-3DB Abingdon, United Kingdom
[3]Association EURATOM-CEA, CEA/DSM/DRFC, CEA-Cadarache, 13108 St. Paul-lez-Durance, France
[4]Max Planck Institut für Plasmaphysik, IPP-EURATOM Assoziation, D-85748 Garching, Germany
[5]Istituto di Fisica del Plasma EURATOM-ENEA-CNR association, Milan, Italy
[6]Association EURATOM-VR, Chalmers University of Technology, SE-41296 Göteborg, Sweden
**see annex of J. Pamela et al., "Overview of Recent JET Results and Future Persepectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento 2000), IAEA, Vienna (2001)*

Introduction

Several experiments, relevant for the study of particle transport and density profile evolution, have been performed on JET during the last experimental campaigns. A number of discharges have been simulated by means of the JETTO transport code and the results are presented in this paper. Two transport models have been employed: the semi-empirical mixed Bohm/gyro-Bohm transport model [1] and the first principle Weiland's model [2], based essentially on transport induced by ion temperature gradient and trapped electron modes. Particular attention was paid to the effect of an anomalous convective particle flux on the peaking of the density profile. This convective particle flux is introduced in the code either by the addition of an anomalous particle pinch velocity (mixed Bohm/gyro-Bohm model) or by the presence of off-diagonal elements in the transport matrix, containing terms depending on $\nabla n/n$, $\nabla T/T$ and $\nabla B/B$ (Weiland's model).

The experimental scenarios analysed can be characterised as follows: stationary, radio-frequency (RF) only heated discharges, without central particle source due to the beams, quasi-stationary or slowly evolving discharges with moderate gas puffing [3] and strongly perturbed, deep pellet fuelled discharges [4, 5].

Description of the shots analysed

The main parameters of the shots simulated are summarised in table I.

Pulse	B_T (T)	I (MA)	P_{NBI} (MW)	P_{ICRH} (MW)	$n_e(0)$ (10^{19} m^{-3})	$T_e(0)$ (keV)	Mode
49030	3.2	2.5	1	4.5	7	2	L
51034	2.6	2.3	-	4	1.5	6	L
52961	2	1.9	8	-	9	2	H
52979	2	1.9	10.4	-	9	2.5	H

Table I: main parameters of the shots simulated.

Shot 49030 is a deep pellet fuelled, high density, L-mode plasma. The pellet injection frequency was 5 Hz whereas the LIDAR Thomson scattering sampling frequency was 4 Hz. This allows a reconstruction of the post-pellet density profile evolution with 50 ms time resolution. Shot 51034 is a stationary, RF only heated, low density, L-mode plasma. Shot 52961 is a neutral beam heated, high density, sawtoothing, ELMy H-mode plasma. Moderate deuterium puffing ($2.5 \cdot 10^{22}$ atoms/second) was performed during the discharge. The density profile remains stationary until the sawteeth are lost because of the relatively low beam power. Then the density profile starts to peak due to the central beam particle source and finally the plasma disrupts. Shot 52979 is similar to shot 52961 but the beam power was high enough to maintain the sawteeth activity and to keep the density profile stationary.

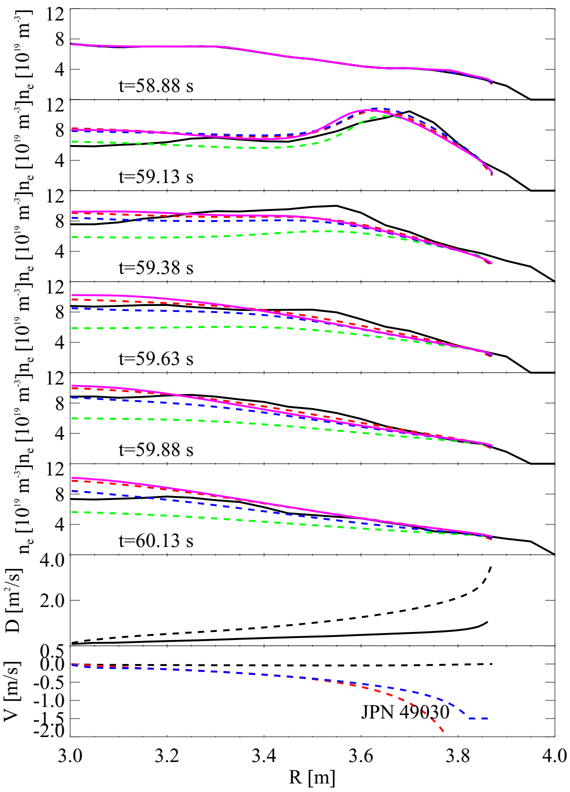


Figure 1a: simulation results for shot 49030. The first six frames show the density profile evolution. The solid black line is the experimental profile. The dashed lines are the simulations obtained with the mixed Bohm/gyro-Bohm transport model without pinch (green), with $V=-c_T D\nabla T/T$ and $c_T=0.125$ (red) and with $V=c_q D\nabla q/q$ and $c_q=0.25$ (blue). The solid magenta line is the Weiland's model. The seventh frame shows the particle diffusion coefficient given by the mixed Bohm/gyro-Bohm model (dashed line) and the effective particle diffusion coefficient given by the Weiland's (solid line) model. The last frame shows the Ware, $\nabla T/T$ and $\nabla q/q$ pinch velocities (black, red and blue dashed lines respectively).

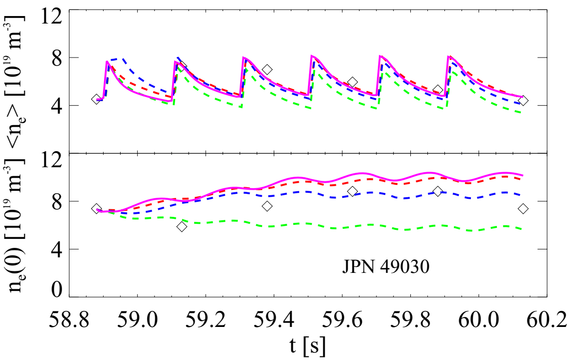


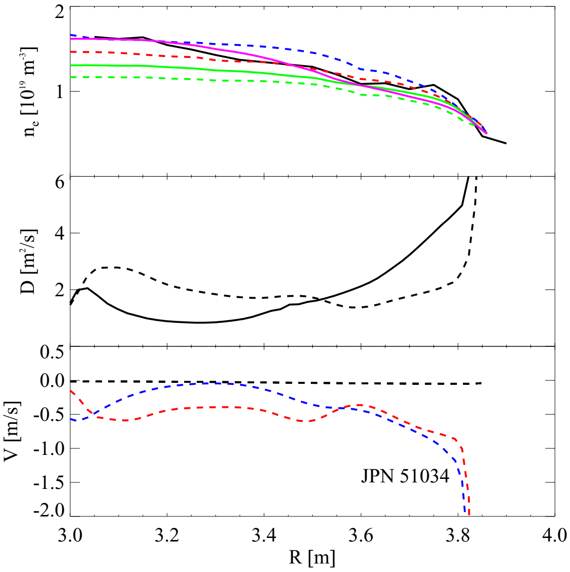
Figure 1b: density time traces for the simulations of shot 49030. The meaning of the colours and linestyles is the same as in figure 1a. The open diamonds are the experimental LIDAR measurements. The top frame shows the evolution of the volume average density whereas the bottom frame shows the evolution of the on axis density.

Simulation results

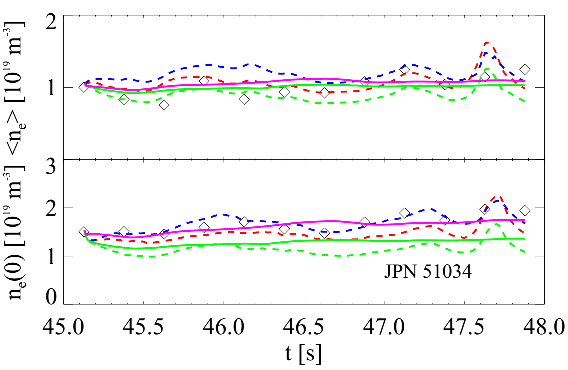
Figures 1a and 1b show the results of the simulations for shot 49030. It can be seen that both the mixed Bohm/gyro-Bohm and the Weiland's model reproduce the density profile evolution. In order to simulate the central density behaviour, it has been necessary to introduce in the mixed Bohm/gyro-Bohm model an anomalous pinch velocity, which can be up to an order of magnitude greater than the neo-classical Ware pinch. This velocity has been modelled by two theory based expressions $V=-c_T D\nabla T/T$ and $V=c_q D\nabla q/q$ [6, 7, 8] where D is the particle diffusion coefficient and the values of c_T and c_q used in the simulation were 0.125 and 0.25 respectively (the same values have been used for all the discharges simulated).

Figures 2a and 2b illustrate the results of the simulations for shot 51034. In this case, since the density profile was stationary over the simulated time interval, the average density profiles are shown rather than their time evolution. Also in this case it can be seen that the Weiland's model reproduces reasonably well the experimental density profile, whereas an anomalous pinch velocity is necessary to simulate both the experimental density central value and profile peaking. The pinch velocity has been modelled in the same way as for shot 49030 and can be 5-15 times larger than the neo-classical Ware pinch. Finally, in order to assess the weight of the off-diagonal elements in the Weiland's model, a simulation was performed after dropping them from the transport matrix. In this case the agreement with the experimental measurements was poorer and a result similar to that obtained with mixed Bohm/gyro-Bohm model without anomalous pinch was obtained.

Simulation results for shot 52961 are presented in figures 3a and 3b. Since the discharge is slowly evolving in time the time evolution of the profiles is shown. It can be seen that, for this kind of plasmas, the Weiland's model gives good agreement with the experimental profiles, particularly in the gradient zone (0.5<r/a<0.9), whereas the mixed Bohm/gyro-Bohm model tends to produce a more box-shaped profile. The anomalous pinch velocity has been introduced in the mixed Bohm/gyro-Bohm model in the same way as in the two L-mode discharges previously analysed. However, in this case, the pinch velocity is one order of magnitude smaller than in the L-mode plasma and is comparable with the Ware pinch. Therefore the results of the simulations do not depend dramatically on whether an anomalous pinch is taken into account or not. This is a consequence of the fact that V is proportional to D and that, in H-mode, the particle diffusion coefficient is almost an order of magnitude smaller than in L-mode. A final comment can be made on the balance between the flattening of the density profile due to the sawteeth activity and the particle source due to the beams. It can be seen that the sawteeth are responsible for the flattening of the density profile in the plasma centre and that, when they are switched off in the simulation to reproduce the experimental behaviour, the beam source alone can account for the central density increase.

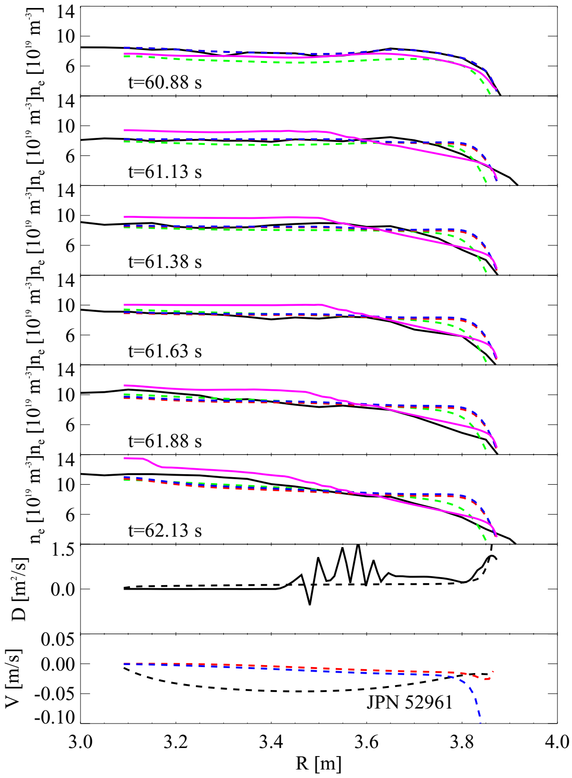


<u>Figure 2a:</u> simulation results for shot 51034. In the first frame are plotted the time averaged density profiles, in the second frame the particle diffusion coefficients and in the third the anomalous pinch velocities. The meaning of the colours and linestyles is the same as in figure 1a. The solid green line in the first frame is the result of the Weiland's model without off-diagonal elements.

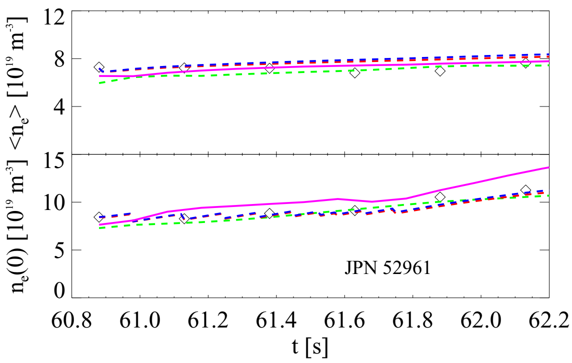


<u>Figure 2b:</u> same as figure 1b for shot 51034. As in figure 2a the solid green line is the result of the Weiland's model without off-diagonal elements.

Finally the results of the simulations for shot 52979 are shown in figures 4a and 4b. Time averaged profiles are shown because,



<u>Figure 3a:</u> as figure 1a for shot 52961.



<u>Figure 3b:</u> as figure 1b for shot 52961.

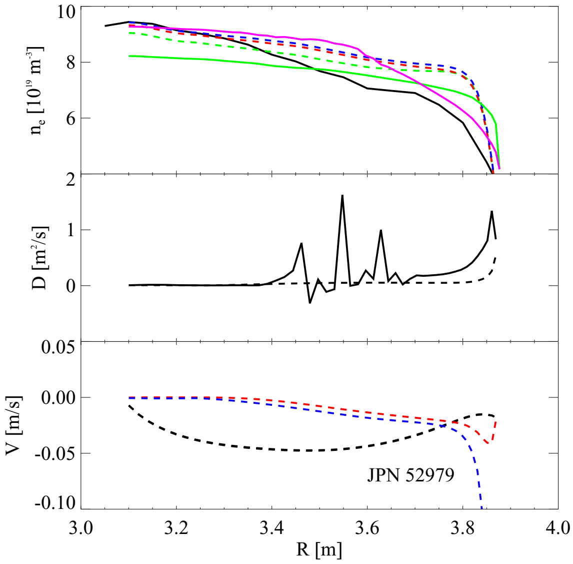


Figure 4a: as figure 2a for shot 52979.

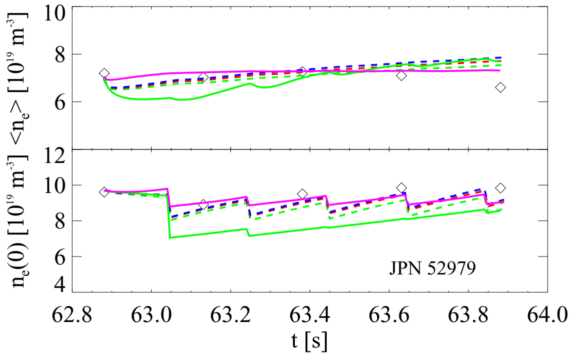


Figure 4b: as figure 2b for shot 52979.

as for shot 51034, the plasma was stationary over the simulated time interval. The same remarks done for shot 52961 apply: the Weiland's model better reproduces the experimental density than the mixed Bohm/gyro-Bohm model and the anomalous pinch velocity is reduced by one order of magnitude becoming comparable to the Ware pinch. Moreover it can be seen that, also in this case, the Weiland's model without off-diagonal elements fails in reproducing the experimental density behaviour. As for the sawteeth, they are present throughout the entire simulated time interval and their effect is to maintain a constant central density and prevent the profile peaking due to the beam particle source.

Conclusions

Particle transport and density profile behaviour have been simulated for different JET plasmas with the JETTO code using the mixed Bohm/gyro-Bohm and the Weiland's transport model. The main conclusions are that in the plasma centre ($r/a<0.5$) the sawteeth activity is the main particle diffusion mechanism. In the gradient region ($0.5<r/a<0.9$) the Weiland's model simulates the density profiles better than the mixed Bohm/gyro-Bohm model. Moreover, in this region, an anomalous pinch seems to be necessary to reproduce the experimental observations. This anomalous convective flux, being proportional to D, is evident in L-mode plasmas and reduces to the neo-classical level for H-mode plasmas. In all the shots considered, the off-diagonal elements of the transport matrix in the Weiland's model provide the convective flux adequate to reproduce the observed density profile peaking.

Acknowledgements

This work has been performed under the European Fusion Development Agreement.

References

[1] Erba M., *et al.*, Plasma Phys. Control. Fusion **39** (1997) 261.
[2] Weiland J., *Collective Modes in Inhomogeneous Plasma - Kinetic and Advanced Fluid Theory*, Institute of Physics Publishing, Bristol and Philadelphia (2000).
[3] Valovič M., *et al.*, in Proceedings of the 28th EPS Conference on Controlled Fusion and Plasma Physics, Madeira 2001, pg. 957.
[4] Jones T.T.C., *et al.,* in Proceedings of the 27th EPS Conference on Controlled Fusion and Plasma Physics, Budapest 2000, pg. 13.
[5] Garzotti L., *et al.*, in Proceedings of the 27th EPS Conference on Controlled Fusion and Plasma Physics, Budapest 2000, pg. 316.
[6] Dominguez R.R., Phys. Fluids B **5** (1993) 1782.
[7] Yankov V.V. and Nycander J., Phys. Plasmas **4** (1997) 2907.
[8] Baker D.R. and Rosenbluth M.N., Phys. Plasmas **5** (1998) 2936.