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PARTICLE TRANSPORT ANALYSIS OF PELLET FUELED JET PLASMAS

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1. INTRODUCTION

An understanding of the mechanism controlling particle transport in tokamaks is of crucial importance in projecting the fueling requirements and performance of such devices. Multiple pellet injection experiments have been carried out on JET to determine heating and confinement characteristics of pellet fueled plasmas [1,2,3]. We report in this paper on the analysis of electron particle transport in these multi-pellet fueled JET plasmas under ohmic heating, ICRF heating, and NBI heating conditions in primarily limiter configurations. The study of particle transport in JET plasmas is based on measurements by a 6-channel far-infrared interferometer for density profile evolution and H_α detectors for edge source magnitude.

Fluctuation induced transport is frequently suggested as the mechanism responsible for the anomalous particle and heat fluxes observed in tokamaks. As part of our analysis, we compare the determined electron particle and heat fluxes with fluctuation induced transport calculations using electron and ion drift wave mechanisms as the dominant fluctuation spectrum. The Onsager symmetry found in the neoclassical transport theory of fluctuations [4] can be used to determine a connection between the anomalous electron particle and heat flux.

2. ANALYSIS

An interpretive particle transport analysis code (PTRANS) has been written at JET to analyze particle transport in pellet fueled plasmas. This transport code is used to compare the measured density evolution with calculations using a number of different transport models to determine which ones may apply. We also analyze the data using a version of the QFLUX [5] interpretive code to integrate the continuity equation directly using the experimentally determined time-dependent density profiles. This analysis gives a particle balance determination of the diffusion for a given convective flux model.

2.1 PTRANS Particle Transport Code

PTRANS is a 1-1/2 D (non-circular geometry) radial transport code that calculates the evolution of density by solving the continuity equation for up to 32 different particle flux models $(D(\rho), v(\rho))$ independently and in parallel [6]. The calculations are initialized with the experimental profile shortly after the pellet deposition. A finite differencing method is used to solve the continuity equation with both implicit and explicit terms (Crank-Nicholson scheme).

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The flux-surfaced-average continuity equation is

$$\frac{\partial n_a(\rho,t)}{\partial t} + \frac{1}{V'(\rho,t)}\frac{\partial}{\partial \rho}\left[V'(\rho,t)\langle \Gamma_a(\rho,t)\cdot\nabla\rho\rangle\right] - s_a(\rho,t) = 0, \tag{1}$$

where the radial particle flux Γ is defined by

$$\Gamma = -D(\rho,t)\frac{\partial n(\rho,t)}{\partial \rho}\langle|\nabla\rho|\rangle + n(\rho,t)v(\rho,t). \tag{2}$$

Transport coefficients used in the models may have neoclassical [7] and anomalous parts. The neoclassical electron particle flux is given by

$$\Gamma_e^{NC} = -D_n^{NC}\frac{\partial n_e}{\partial \rho} - D_T^{NC}\frac{\partial T_e}{\partial \rho} - v_p^{NC} n_e, \tag{3}$$

where the last term is the Ware pinch whose velocity is given by

$$v_p^{NC} = K\epsilon^{1/2}\frac{E_\parallel}{B_p}, \quad K \sim \frac{2.30}{[1+\nu_e^{*1/2}+\nu_e^*][1+\nu_e^*\epsilon^{3/2}]}. \tag{4}$$

The radial shape of the edge source $s(\rho,t)$ is obtained from external neutral deposition calculation (QFLUX) using H_α edge measurement to determine the magnitude. There is optional source feedback built into the code which can adjust the magnitude of the source profile for each model to keep the number of particles in the plasma the same as that determined from the experimental density profiles. This is used in ICRF heated plasmas when the RF is initially turned on since the H_α detectors used to measure the source magnitude are located away from the antennae and do not see the particle source from the antennae until a particle confinement time later.

2.2 Anomalous Transport Calculations

An enhanced version of the time slice interpretive transport code QFLUX [5] has been developed at JET to perform calculations of anomalous fluctuation driven transport using the neoclassical transport theory of fluctuations [4]. This code is run for a number of time slices through the discharge and calculates the coefficients of the Onsager transport matrix and the thermodynamic forces that drive the transport. Assumptions are made that there is no plasma rotation for non beam heated discharges and that the ion temperature profile is the same shape as the electron profile (but scaled from central measurements). Initial calculations have been done using electron and ion drift waves as the fluctuation mechanisms. In analyzing discharges with this code, we calculate the fluctuation amplitude needed to explain the anomalous particle flux as determined from a particle balance calculation. This amplitude is then used to calculate the resultant anomalous electron heat flux from the transport matrix. This fluctuation driven heat flux is then compared to the anomalous electron heat flux as determined by power balance calculation.

3. RESULTS

Peaked electron density profiles are generated in JET discharges from pellet injection with central penetration. These density profiles are frequently found to slowly decay to a peaked profile on a broad pedestal. The decay of the peaked profile is sometimes accelerated by the application of ICRF on axis and NBI. In the cases where accelerated profile decay is seen, a broad flat density profile quickly appears that is characteristic of auxilliary heated limiter discharges. It is found that the neoclassical pinch velocity is reduced when the auxilliary heating is applied due to the change in electric field and collisionality. This reduced pinch appears to play a role in the peaked profile decay.

The period of the peaked density profile in sawtooth free limiter discharges has been analyzed and the electron profile evolution modeled by the use of a neoclassical pinch velocity and a time independent diffusion coefficient with a strong increase at the radial position of the density pedestal formation as shown in Fig.1. The diffusion model used is more than an order of magnitude larger than the neoclassical value. This same transport model is found to be applicable in both ohmic and ICRF heated discharges although the heated case shows slightly higher diffusion. Calculations of the density evolution using the $(r/a)^2$ dependent diffusion coeffient suggested by Hulse [6] for TFTR ohmic cases does not yield the observed density pedestal on the outer half of the minor radius.

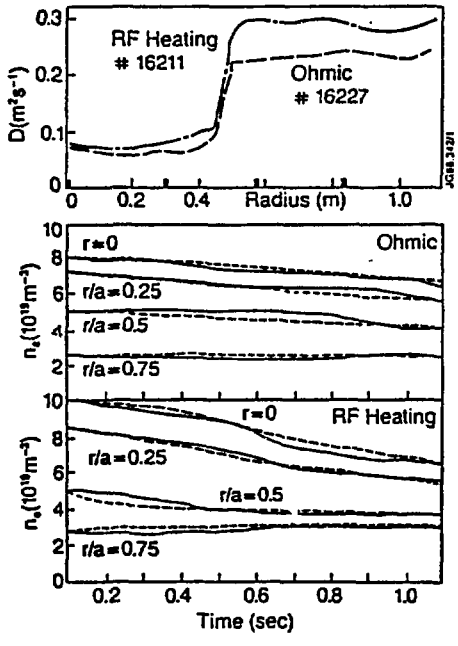
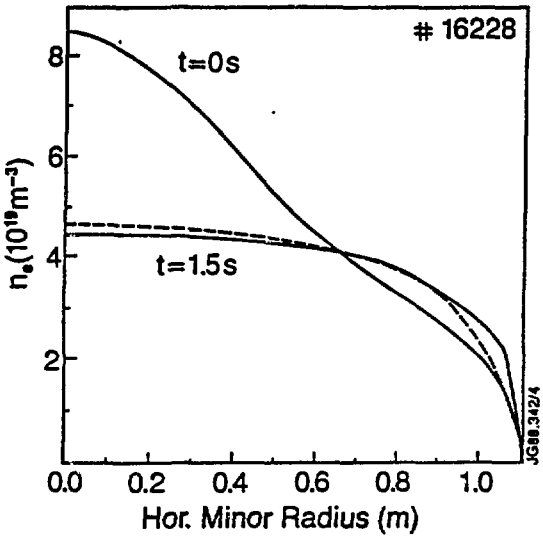


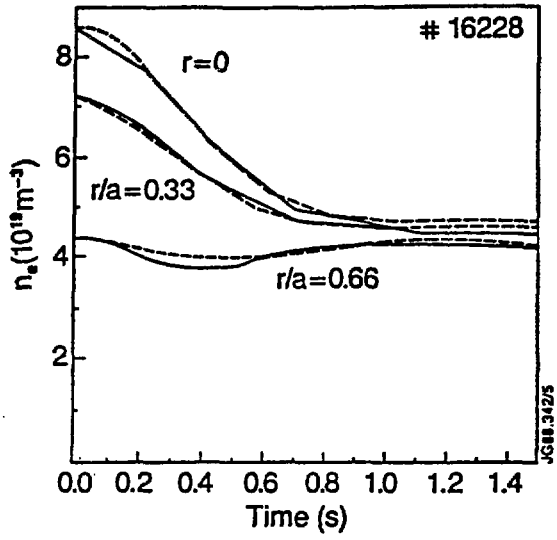
Fig. 1.

Electron diffusion coefficient for ohmic and ICRF heated cases. Measured (solid) and calculated (dashed) density at four radii for ohmic and ICRF heated cases.

In cases where the peaked density profile rapidy redistributes to a flat one, the diffusion coefficient can be modeled as a function of local electron temperature [8] such that the central diffusion rapidly evolves from the ohmic post pellet case to a diffusion coefficient profile which is more nearly flat as shown in Fig.2. This rapid change in diffusion suggests that another mechanism is present in these discharges that further

accelerates the central electron density decay. In a discharge where a clear transition from the ohmic like transport to one in which central MHD activity is seen from Soft X-rays, the profile evolution can be modeled by a transition from the ohmic like diffusion to the temperature dependent diffusion. The diffusion coefficient determined from particle balance calculations of the electron flux agree well with the best case diffusive models used in the discharges that have been modeled.





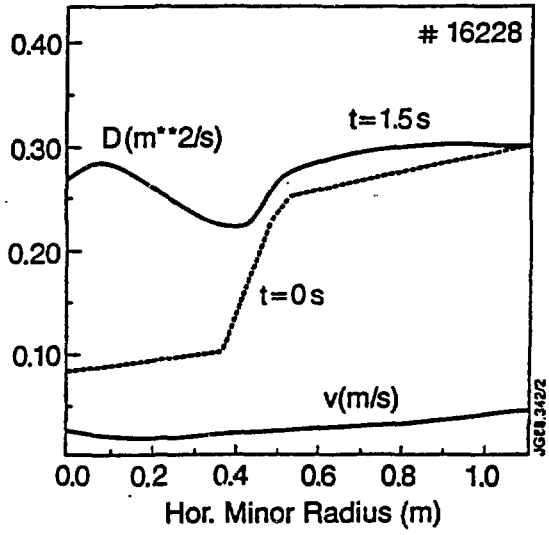


Fig. 2.
Measured (solid) and calculated (dashed) density profiles and evolution for an ICRF heated discharge using a temperature dependent diffusion coefficient. D is given by $D = D(\text{Ohmic case})\{1 + T_e(eV)^{1.3}/40000\}$

A large number of particle transport models have been used to analyze a variety of JET pellet fueled discharges including a model that has been used to predict CIT performance [9]. This model uses $D = (n_e(m^{-3})/10^{19})^{-1}$ and $v = -2Dr/a^2$. The results from this model as shown in Fig.3 typically yield peaked density profiles when

the measured profile is seen to remain flat in the center. If these JET results scale down to smaller ignition machines such as CIT, the currently predicted preformance may be over estimated.

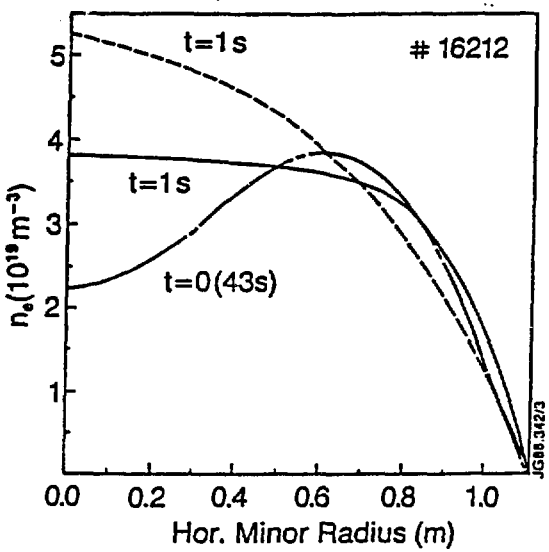


Fig. 3.
Experimental (solid) and calculated (dashed) density profiles for ICRF heated discharge with non central pellet penetration. The transport model used is $D = (n_e(m^{-3})/10^{19})^{-1}, v_p = -2Dr/a^2$.

Fluctuation induced transport calculations have been performed for over 10 pellet fueled discharges and have typically shown that electron drift wave driven electrostatic fluctuations in the quasilinear approximation show some correlation in the determined anomalous electron particle and heat transport. The power balance heat flux is typically a factor of 3-10 higher than the calculated fluctuation driven heat transport but shows a qualitatively similar profile shape.

4. CONCLUSIONS

The analysis done on JET sawtooth free discharges has shown that the density evolution following peaked profiles from pellet injection can be modeled with a neoclassical pinch velocity and a diffusion coefficient with a steep gradient at the radius of the density plateau which is near the q=2 surface. This type of transport model works in both ohmic and central ICRF heated discharges. Some of the auxiliary heated cases show rapid central density decay which may be due to MHD related turbulence. The profile evolution in these discharges can be modeled with a temperature dependent diffusion coefficient with the neoclassical pinch velocity. Discharges with non-central pellet penetration show no significant density peaking and cannot be modeled with the same transport coeffients as the peaked profile cases.

Transport calculations utilizing neoclassical fluctuation theory indicate that electrostatic fluctuations driven with an electron drift wave spectrum are not sufficient alone to fully explain the resulting anomalous particle and heat transport. Other mechanisms driving magnetic fluctuations presumably exist in parallel that may contribute more to the anomalous heat transport.

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] Milora, S.L., et al., "The JET Multiple Pellet Launcher and Fueling of JET Plasmas by Multi-Pellet Injection", 15th EPS Conference, Dubrovnik, 1988.

[2] Kupschus, P., et al., "Multi-Pellet Injection on JET", 15th European Conference on Controlled Fusion and Plasma Physics, Dubrovnik, 1988.

[3] Schmidt, G.L., et al., "Heating of Peaked Density Profiles Produced by Pellet Injection in JET", to be published in (Proc. 12th Int. Conf. Nice, 1988) IAEA.

[4] Shaing, K.C., "Neoclassical Quasilinear Transport Theory of Fluctuations in Toroidal Plasmas", Phys. Fluids 31 (1988) 2249.

[5] Keilhacker, M., et al., "H Mode Confinement in JET", Proc. 14th Eur. Conf. on Cont. Fusion and Plasma Physics, Madrid, 1987, 11D (III), EPS (1987) 1339.

[6] Hulse, R.A., et al., "Particle Transport in TFTR Ohmic Pellet Injection Experiments", Proc. 14th Eur. Conf. on Cont. Fusion and Plasma Physics, Madrid, 1987, 11D (I), EPS (1987) 318.

[7] Hinton, F.L., Hazeltine, R.D., "Theory of Plasma Transport in Toroidal Confinement Systems", Rev. Mod. Phys. 48, 239 (1976).

[8] Gondhalekar, A., et al., "Control of Density Profile and Particle Exhaust in JET", Bull. Am. Phys. Soc. 32(1987)9 paper 5V9.

[9] Stotler, D.P., Bateman, G., "Time-Dependent Simulations of a Compact Ignition Tokamak", Princeton Plasma Physics Laboratory Report 2510, 1988.

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