Topic: EX-C

Particle and Impurity Transport in Electron-Heated Discharges in TCV

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The behaviour of particle and impurity density profiles in ECH and ECCD L-modes, ITB's and H-modes is investigated in view of developing physics understanding for a predictive capability for α-heated, ignited reactor conditions. This work is motivated by the important implications, both positive and negative, that density profiles may have on fusion performance, including a potential boost in fusion power output if fuel density profiles are peaked and on the downside an increased proneness to impurity accumulation.

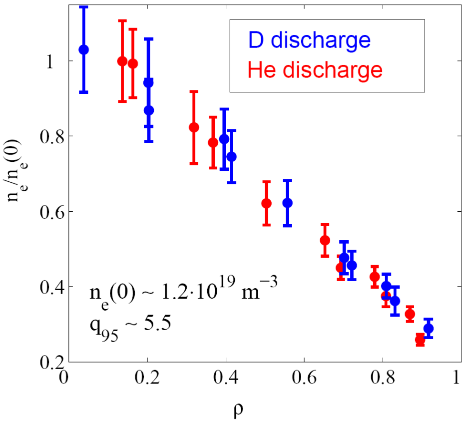

Fig.1. Comparison of density profiles in a deuterium and an otherwise identical He plasma

Fully ECCD sustained discharges in TCV have shown that peaked density profiles subsist in the absence of the Ware pinch. Similarly, discharges in helium plasmas, where neutral penetration by successive charge exchange reactions is quenched because of the low cross section for double charge exchange, show that peaked density profiles are still observed in the absence of a core particle source. The combination of these two observations provides experimental proof that peaked density profiles can only be explained by anomalous processes. Neutral penetration calculation using the KN1D and DOUBLE-TCV codes have confirmed that the experimental density profiles are too peaked, even in deuterium plasmas, to be explained by edge fuelling and diffusive particle transport alone.

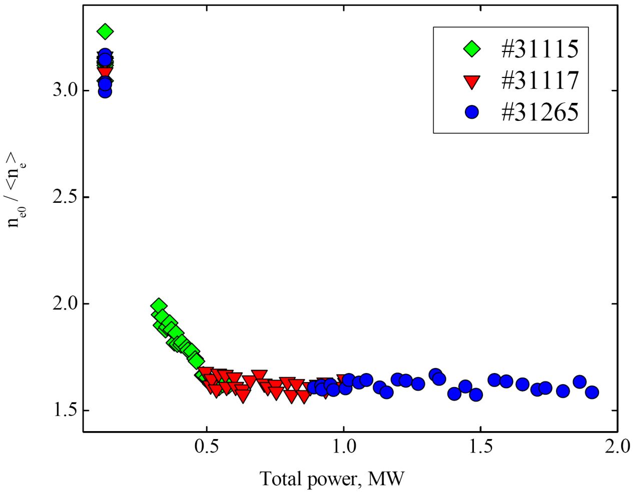

Fig. 2 Saturation of flattening at high power

The addition of core ECH to an Ohmic target discharge leads to partial flattening of the density profile (often dubbed 'pumpout'). This flattening effect saturates however for a total power exceeding the Ohmic power in the target discharge by a factor of 3 or more, leaving a moderately peaked density profile, both in L-mode and H-mode plasmas independently of the ECH power. Although the core flattening by ECH is in qualitative agreement with drift wave turbulence theory, the saturation is not predicted by theory. Stationary H-modes with $n_e(0)/<n_e>\sim1.5$ heated with 1.5MW of ECH to $\beta_N\approx2$

have been obtained both in type I ELMy and in stationary ELM-free regimes with low particle confinement. For a given operating β and average fuel density a peaking factor $n_{D,T}(0)/<n_{D,T}>\sim 1.5$, as observed in these discharges, is sufficient to increase the D-T fusion power in a reactor by 30% compared to a flat density profile. The observations on TCV suggest that even in the presence of strong alpha heating in a reactor, density profiles may remain peaked enough for significantly improving the fusion power output.

In L-modes, where a wide range of operating conditions are easily achieved, density peaking is found to scale with the peaking of the current profile and with the minor radius of ECH deposition for $P_{ECH}>0.5$MW. Steady-state electron ITB's are obtained in TCV by fully sustained off-axis ECCD, which leads to the creation of reversed shear q-profiles. Unlike L-modes, these plasmas do not experience flattening, even when central ECH is applied. The strongest barriers are characterized by $\nabla n_e T_e / (\nabla T_e n_e) \cong 0.45$, which is reminiscent of a neoclassical pinch (N.C. thermodiffusion).

Knowledge of the transport coefficients for plasma particles and their relation to heat transport coefficients is important for fusion performance and for comparison with theory. Measures of the residence time of hydrogen ion puffed into deuterium discharges have been used by a mass-discriminating compact neutral particle analyzer, yielding values for the ratio of particle residence time to energy confinement times in the range 1-2, consistently within errors, of expectations from drift wave turbulence theory. Similar ratios are found for the ratio of the residence times of laser ablated silicon impurities. Simulations of silicon transport using the impurity transport code STRAHL, constrained by measured X-ray signals from a 200 channel tomography system, show that impurity transport coefficients are well above the neoclassical values.

The presence of convective transport is clearly identified for intrinsic and extrinsic impurities and can differ significantly from convective electron transport. The radial profiles of fully ionized carbon released from TCV wall tiles were measured using an absolutely calibrated CXRS diagnostic. Experimental profiles of C^{6+} together with profiles of the carbon diffusion coefficient evaluated from the radial distribution of H and He like carbon lines were used to obtain the radial profiles of the all carbon ionization stages using STRAHL. Observations on TCV show that in stationary Ohmic and ECR heated L-mode discharges the profiles of carbon density are always peaked. In low current (edge safety factor $q_{95}>4$) Ohmic discharges they are noticeably more peaked than the electron density profiles. Since these discharges are dominated by anomalous transport, the convective effects, although reminiscent of those predicted by neoclassical theory, must be interpreted as being of anomalous origin. In discharges with higher safety factor, sawteeth appear to be responsible for equalizing the peaking factors for carbon and electron density profiles.

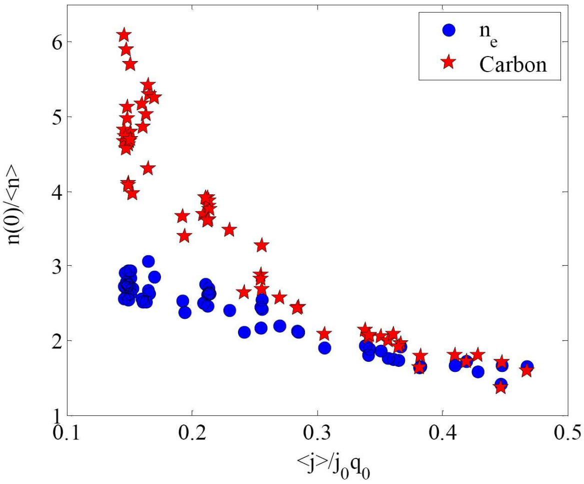

Fig. 3 Peaking of electron and carbon densities versus $<j>/(q_0j_0)\sim 1/q_{95}$