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LOCAL MULTISPECIES PARTICLE AND ENERGY TRANSPORT IN THE TFTR TOKAMAK

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Studies of local multispecies thermal particle and energy transport in L-mode and supershot deuterium plasmas have been performed on the Tokamak Fusion Test Reactor (TFTR). These studies were undertaken to help gain insight into the anomalous transport properties of the bulk plasma. Such experimental and theoretical studies are valuable for ITER: the relationship of local helium ash and metallic particle transport to local energy transport will be determining factors in plasma current,[1] helium pumping[2], and divertor material requirements.[3] In addition, differences between electron and ion transport will have important implications for plasma fuelling scenarios. Here, attention has been focused on supershots and L-Modes of the same toroidal field, plasma current, neutral beam heating power. The particle transport of thermal He^{2+} following a small helium gas puff[4] and Fe^{24+} introduced by laser ablation[5] in similar plasmas have been examined using charge exchange recombination spectroscopy. This has permitted the comparison of impurity transport over a wide range of nuclear charge and mass. Electron transport has been studied with particle balance analysis and by examining the perturbed electron flux after the helium gas puff.[6] This allows for helium and electron transport to be studied using the same gas puff, providing an unambiguous comparison of the transport of the two species. Along with energy transport analysis from power balance, these results have been compared to theoretical predictions of the ratios of heat and particle fluxes based on electrostatic quasilinear transport theory.[7]

For the L-Mode and supershot, the helium diffusivity D_{He}, iron diffusivity D_{Fe} and electron diffusivity $D_e \equiv -\partial\Gamma_e/\partial\nabla n_e$ inferred from the perturbations are radially hollow and are roughly comparable in magnitude and shape (figure 1). They are also comparable in magnitude and shape to the effective electron diffusivity $D_e^{eff} \equiv -\Gamma_e/\nabla n_e$ inferred from particle balance and the effective thermal conductivities χ_i^{eff} and χ_e^{eff} inferred from power balance. The relation between the thermal transport coefficients is similar to that observed previously[8], i.e. $\chi_i^{eff} \geq \chi_e^{eff}$ across most of the plasma cross section for both plasma types. All diffusivities are 1-2 orders of magnitude larger than neoclassical values, except possibly at the magnetic axis. The fact that $D_{He} \sim D_{Fe} > D_e^{eff} \sim \chi_e^{eff}$ suggests that electrostatic turbulence is the dominant transport mechanism as opposed to magnetic stochasticity. Reductions in χ_i^{eff} at $r/a < 0.4$ in the supershot as compared to the L-mode are accompanied by similar reductions in the D_{He} in the same region, suggesting a common particle and energy transport mechanism for the working ions Also, He^{2+} and Fe^{24+} are characterized by larger inward convection in the supershot than in the L-mode. For both plasma types the average helium and iron convective flux is larger in magnitude than predicted by neoclassical theory.

These results have been compared to predictions from electrostatic drift wave theory. Measured radial profiles (e.g. $n_e(r)$, $n_{carbon}(r)$, $T_e(r)$ and $T_i(r)$) and calculated radial profiles (e.g. thermal ion density, fast ion density, and q(r)) have been used with a quasilinear model of electrostatic drift waves to calculate the ratios of particle and thermal fluxes. The ordering of the measured transport coefficients ($D_{He} \sim D_{Fe} \geq D_e^{eff}$, $\chi_i^{eff} \geq \chi_e^{eff}$, $D_{He} \sim \chi_i^{eff}$) are reflected in the predictions of the quasilinear treatment. This treatment also predicts that the η_i and trapped electron modes should be unstable at r/a = 0.5 and r/a = 0.9 in the supershot, but stable or nearly stable near the magnetic axis (r/a = 0.12), consistent with the measurements of strongly radially hollow thermal and particle diffusivities in these plasmas.

The observed differences between transport coefficients, which are well outside of measurement uncertainties, suggest important clues regarding the underlying transport mechanisms. For example, $D_e \neq D_e^{eff}$ in the supershot while in the L-Mode the two are much more similar. One possible interpretation of this is that the underlying dependence of electron transport on the electron density gradient is stronger in supershots than in L-Modes. In addition, the ions and electrons have different transport properties that can be seen in the raw data: the electron perturbation is found to arrive in the core of the L-Mode after the He^{2+} perturbation from the same gas puff, underscoring the need to characterize each species separately if any particle transport picture is to be viewed as complete. The issue is more than academic since differences between ion and electron particle transport have important implications for helium ash removal requirements as well as for reactor fuelling schemes.

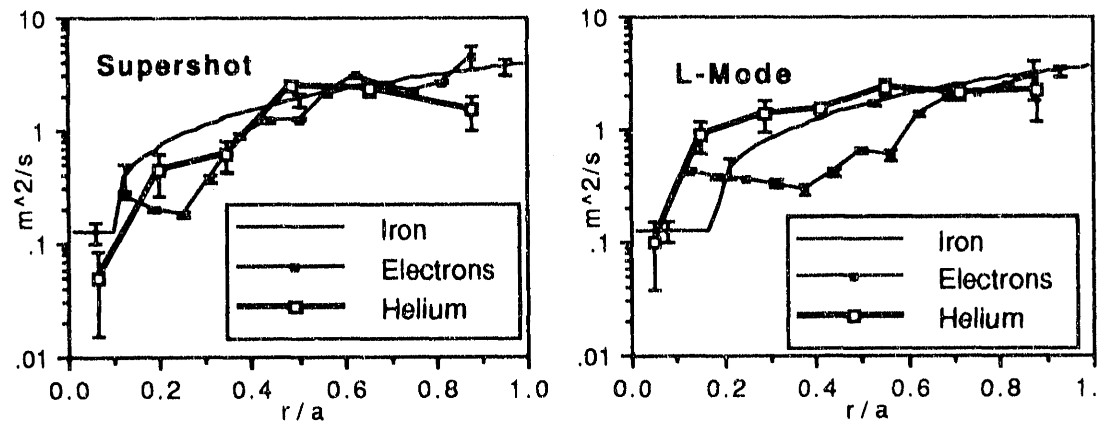

Figure 1. Radial profiles of D_{He}, D_{Fe}, and D_e inferred from perturbations.

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