Transport of Particles and Impurities in DIII–D Discharges with Internal Regions of Enhanced Confinement* **EX**

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DIII–D discharges with an internal region of enhanced energy confinement also have regions of enhanced particle confinement. Reduced core particle transport has both deleterious and beneficial effects on the plasma performance, and the understanding and control of the particle transport and density profiles is key to optimizing the performance in steady state Advanced Tokamak discharges. Discharges with significant reduction in core turbulence, where neoclassical particle transport becomes important, should have broad density profiles to optimize fusion performance and minimize the accumulation of impurities.

In DIII–D discharges with centrally peaked electron density profiles there is an accumulation and peaking of impurities in the core, Fig. 1(a), as is predicted by neoclassical theory. Although peaked electron density profiles and peaked profiles of the deuterium and tritium fuels are advantageous for increased self driven bootstrap current fraction and fusion performance, the accumulation of impurities from the neoclassical pinch terms eventually leads to a large ion defect and reduced performance. For broader density profiles, there can be a screening of impurities from a steep ion temperature gradient, as also predicted from neoclassical theory. The impurities then accumulate near the outside of the discharge, Fig. 1(b), where they are more easily removed. The broader density profile is consistent with the stability requirements of broad pressure profile and good alignment of the bootstrap current in Advanced Tokamak plasmas.

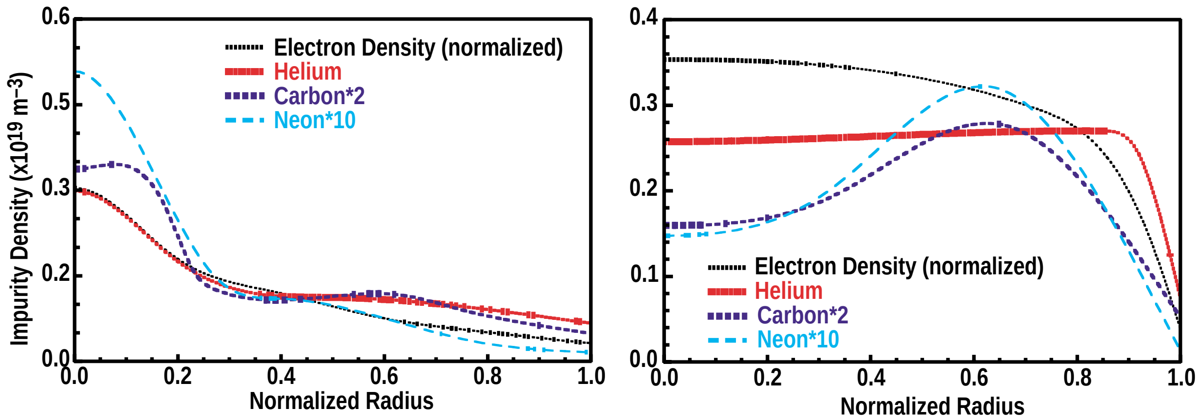

Fig. 1. (a) High Z Impurities accumulate and peak in the plasma core in discharges with peaked density profiles. (b) Broad density profiles and high ion temperature gradients screen impurities causing them to build up at the edge.

The peaked density profiles shown in Fig. 1(a) are from negative central shear (NCS) discharges with an internal transport barrier (ITB) region confined to the inner half of the plasma. In addition to the neoclassically predicted impurity accumulation it is also found that the electron particle diffusivity is close to neoclassical at the very center of the plasma, Fig. 2.

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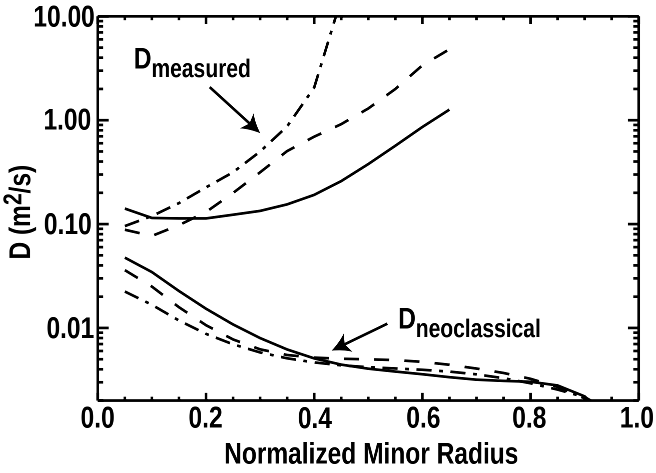

Fig. 2. Measured electron particle diffusivities for three different discharges with central ITBs compared with the corresponding Chang-Hinton neoclassical values.

The broader density profiles shown in Fig. 1(b) are from DIII–D VH–mode plasmas, which have an extended edge region of enhanced confinement. This region also has neoclassical levels of transport. In the very outer region of the plasma the ion thermal diffusivities are close to neoclassical levels and the electron particle flux becomes very low. The electron particle diffusivities, although greater than the (very low) neoclassical values, are much lower than the usual anomalous values. The ion particle diffusivities, measured by injecting trace amounts of gases such as helium, neon or nitrogen, are close to the neoclassical values.

Although the understanding of particle transport in tokamaks is not complete, the experimental evidence is clear. In anomalously transporting tokamaks, the measured particle diffusivities are close to the measured thermal diffusivities. The total particle flux, which can be small, consists of anomalously large outward diffusive and inward convection components. Impurities such as helium, carbon, neon or argon show no strong tendency to accumulate in any local region, i.e. $n_Z \propto n_e$. When the plasma has regions of enhanced confinement, where the ion thermal transport becomes close to neoclassical, then the particle transport also shows neoclassical transport behavior such as low diffusivities, and neoclassical pinch terms such as the Ware pinch and central high Z impurity accumulation or thermal screening, depending on the shape of the density profile.

In light of the above particle transport understanding, a reacting tokamak should have a broad density profile, which experimentally has been found to be consistent with a broad current profile and also consistent with good bootstrap alignment. This profile shape will minimize the tendency of impurities to accumulate in the center in both anomalous and neoclassical transport regimes. The enhanced confinement region should not be concentrated in the plasma center or have the form of a narrow barrier, but should be broad and perhaps extend out to the plasma boundary. This is consistent with good overall confinement and global stability requirements.