The Physics of Confinement Improvement with Impurity Seeding in DIII–D*

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Clear increases in confinement (from $H_{89P} \approx 1$ to $H_{89P} \leq 2$) and simultaneous reductions of long-wavelength turbulence have been observed in L–mode discharges in DIII–D which are directly correlated with external impurity injection. These observations provide an opportunity to understand the mechanism for confinement improvement with impurity seeding observed in a number of tokamaks, including in ISX-B (Z–mode), TEXTOR (RI–mode), TFTR and ASDEX-U. Impurity seeding can be used to produce a radiative mantle to reduce heat fluxes to the first wall material.

Significant confinement improvements are observed with impurity injection (Ne, Ar, and Kr) into L–mode edge, negative central shear plasmas in DIII–D. Neon produces the strongest effect in the plasma, relative to Ar and Kr. Compared to similar reference discharges without impurity injection, the global confinement time as well as the neutron rate in neon-injected discharges are nearly doubled. Reductions of long wavelength ($0 < k_\perp < 3$ cm^{-1}) turbulence at normalized radii $\rho \leq 0.7$, observed on Beam Emission Spectroscopy (BES) and Far Infrared scattering diagnostics), and reduced edge turbulent particle flux observed with edge Langmuir probes are correlated well with the confinement improvement.

Transport analysis and theory-based simulations are used to understand the fundamental physics involving confinement improvement with impurity injection. TRANSP transport analyses show that reduction of transport coefficients with neon injection are observed in all transport channels, with a reduction of up to a factor of 5 in the ion thermal diffusivity, substantial reduction in toroidal momentum and particle diffusivity, and modest (≤1.5) reduction in electron thermal diffusivity. Profile analyses of the impurity species scan with a fixed radiative loss fraction show that the reduction of transport coefficients is largest with lower Z. Gyrokinetic linear stability simulations of these plasmas show a reduction in the growth rate of ion temperature gradient (ITG) driven modes as a result of impurity density gradients and dilution effects on the main fuel ion turbulence. The measured E×B shearing rate increased, suggesting that the impurity induced reduction of growth rates is acting synergistically with E×B shearing suppression to decrease turbulence and transport. A particle-in-cell simulation in toroidal geometry is used to compare saturated fluctuation amplitudes with turbulent measurements. Results of simulations with the GLF23 model will be discussed to study the relative importance of reduction of turbulence growth rate, E×B shear suppression and change in density profiles in the experiments with different quantities and species of injected impurity.

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