Predictive simulations of impurity transport at JET

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ABSTRACT

The impact of sheared toroidal rotation on impurity transport is studied by means of predictive simulations of JET L-mode and H-mode discharges with carbon wall using the coupling between the transport codes JETTO[1] for main ions and SANCO for impurities. The simulations are based on a fluid model[2] for Ion-Temperature-Gradient (ITG) mode and Trapped-Electron (TE) mode driven turbulence and neoclassical transport. The fluid impurity transport coefficients are compared with gyrokinetic simulations using the code GENE.[3] Predictive simulations of temperatures (T_e, T_i=T_Z) and densities (n_e, n_Z) are performed while the toroidal rotation is treated interpretatively.

FLUID MODEL

- Weiland multi-fluid model[2] for main ions, trapped electrons, and impurities (one species).
- Impurity flux: $\Gamma_Z = \langle v_E \delta n_Z \rangle = -D_Z \nabla n_Z + n_Z V_Z$ where D_Z and V_Z are the impurity diffusivity and convective velocity respectively. The convective velocity has contributions from thermodiffusion (~1/Z), curvature, parallel compression and roto-diffusion.[4]
- $\Gamma_Z = 0$ gives the impurity density normalized inverse scale length $PF = -R\nabla n_Z/n_Z = -RV_Z/D_Z$.

GYROKINETIC MODEL

- Interpretative quasilinear (QL) flux-tube simulations with the GENE code.[3] The transport fluxes are computed including gyrokinetic dynamics of ions, impurities and electrons, with effects of sheared rotation.
- Trace results obtained assuming $f_Z = n_Z/n_e = 10^{-6}$.

SIMULATED JET DISCHARGES

- Predictive simulation of impurity injection experiment #67730[5] and H-mode discharge #59217.[6]

Type	No	B_{tor} (T)	I_p (MA)	P_{NBI} (MW)	$n_e(0)$ ($10^{19}/m^3$)	$T_e(0)$ (keV)	$T_i(0)$ (keV)	$v_\phi(0)$ (km s^{-1})
L-mode	67730	3.0	1.8	4.2	1.8	3.4	3.4	131
Low density H-mode	59217	2.9	1.9	11.6	5.2	5.0	6.6	216

EFFECTS OF ROTO-DIFFUSION

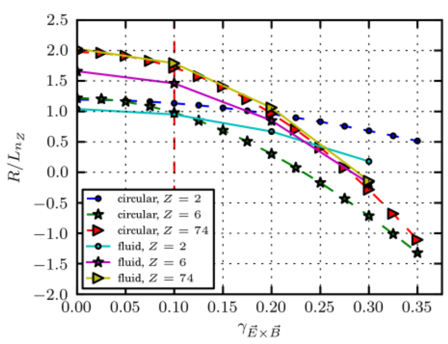

Figure 1. Effects of shear in toroidal flow on impurity density normalized inverse scale lengths ($-R\nabla n_Z/n_Z$), including contributions from roto-diffusion ($\frac{dv_\parallel}{dr}$ - pinch). The perpendicular and parallel flow shear is controlled by the parameter $\gamma_{ExB} = -\frac{r/R}{q_0}\frac{\partial \Omega}{\partial x}\frac{R}{c_s}$. Results obtained by fluid and quasi-linear GENE simulations of #67730 in the collisionless, electrostatic limit. Experimental shearing rate is indicated by the dashed line.

PREDICTIVE SIMULATIONS OF L-MODE #67730

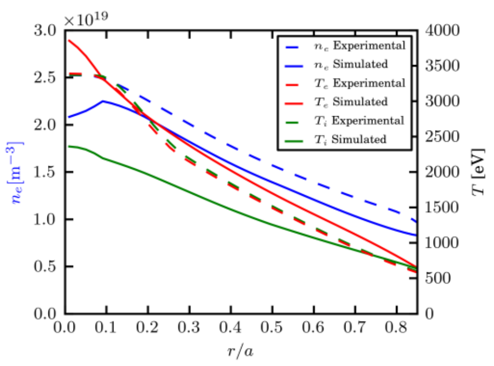

Figure 2a. Steady state experimental and simulated profiles of T_i, T_e, and n_e after 2.0 s of simulation time. ITG mode turbulence dominates transport channels.

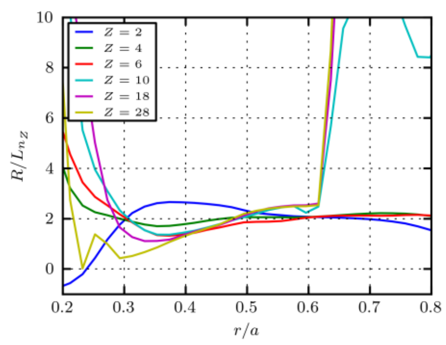

Figure 2b. Simulated impurity density normalized inverse scale lengths at steady state. These are consistent with interpretative results[7] at mid radius whereas neoclassical effects dominate for small and large radii resulting in large R/L_{nZ}.

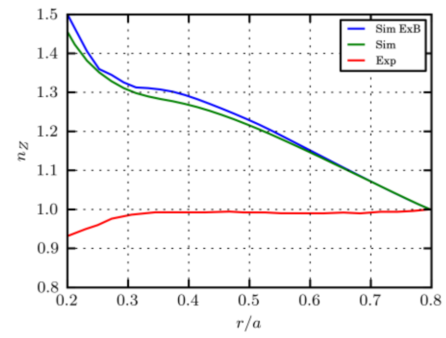

Figure 3. Comparison of simulated and experimental[8] normalized C profile for #67730. C profile flat or hollow in L-mode discharge, not reproduced by simulations.

PREDICTIVE SIMULATION OF H-MODE #59217

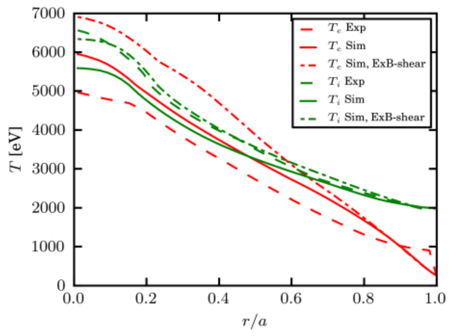

Figure 4. Steady state experimental and simulated profiles of T_i, T_e, (with/without ExB-shearing) of low density H-mode discharge #59217 after 2.5 s of simulation time.

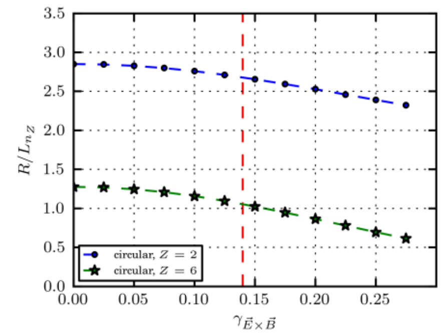

Figure 5. Effects of shear in toroidal flow on R/L_{nZ}, including contributions from roto-diffusion. Results obtained by quasi-linear GENE simulations of #59217 in the collisionless limit. Experimental shearing rate is indicated by the dashed line.

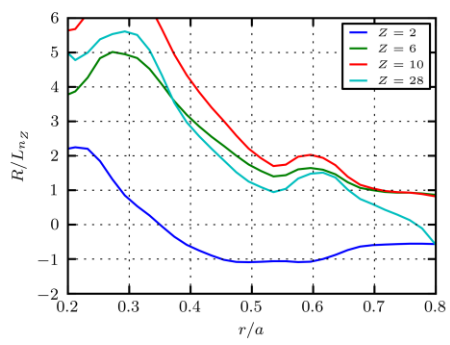

Figure 6. Simulated impurity density normalized inverse scale lengths at steady state for H-mode discharge 59217 with ExB-shearing included. Neoclassical effects are important for r/a ≤ 0.5. In the H-mode simulations the electron density is treated interpretatively.

CONCLUSIONS

- Good agreement in R/L_{nZ} between interpretative fluid and QL GENE simulations, including effects of roto-diffusion.
- Weak effects of roto-diffusion on R/L_{nZ} for considered JET discharges.
- Predictive JETTO/SANCO simulations give R/L_{nZ} consistent with the interpretative simulations[7] at mid radius.
- C profile flat or hollow in L-mode discharge, not reproduced by simulations.
- Neoclassical effects are dominant in inner core region resulting in a significant increase in R/L_{nZ}.

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