Heavy impurity transport is a key issue in metallic wall tokamaks
Collisional part can be dominant over turbulent one in the core [1]
Derivation of a fast analytical model for collisional impurity transport
Self-consistent Poloidal asymmetry and radial flux
Applicable to rotating & ICRH Heated plasmas [2]
Compared with XTOR [3,4] simulations, and with NEO [5]
Investigation on a rare case of Tungsten accumulation on WEST
ICRH-driven asymmetry could be the main mechanism

Neoclassical impurity transport
With a poloidal distribution parameterized as \( n_i/n_0 = 1 + \delta f_\| + \sin\theta + \sin^2\theta \) [1]:
\[
\mathbf{D}_{ne} = -\nabla \rho_{i} - \nabla \left( \frac{\rho_{i0}}{\rho_{i}} \right) \mathbf{E}_{i} - \nabla \mathbf{E}_{i} = \nabla \left( \frac{\rho_{i0}}{\rho_{i}} \right) \mathbf{E}_{i} - \nabla \mathbf{E}_{i}
\]

Poloidal asymmetry

Self-consistent collisional impurity transport model
Implemented in FACIT code (FaSI Collisonal Impurity Transport):
Impurity flux & asymmetry are non-linear functions of the impurity gradient
Collisional friction couples vertical & horizontal asymmetry: lifting w.r.t. the drive

The natural case (no rotation, no \( \phi \) asymmetry)

Pinch velocity is strongly reduced by poloidal asymmetry at high Z (flat n_0) [6] (fig. 1)

Numerical experiments with XTOR-ZF code [2]
Neoclassical physics [4]
Impurity conservation and momentum equations
The collisionality (\( n_0 \)) is scanned artificially
The circle in the (\( \delta, \lambda \)) plane is recovered …
… as well as the reduction of the pinch velocity (fig. 2)

Neoclassical steady-state (\( \mathbf{M}_\| = 0 \))
Poloidal asymmetry couples (fig. 3)
XTOR simulation follow same initial trajectory in (\( \delta, \lambda \))

Collisional vertical \( \phi \) - asymmetry effect

Extension of the natural case to finite \( \phi \) - asymmetry
Ion-electron collisions drive a vertical \( \phi \) - asymmetry [7]
\[
\Delta n_i = \frac{\rho_i}{\rho_0} \frac{V}{P} \mathbf{E}_{\|} = \frac{\rho_i}{\rho_0} \frac{V}{P} \mathbf{E}_{\|}
\]

Asymmetry recovered with NEO at 1st order : not used for computing impurity flux
But in fact, it strongly impact impurity flux & poloidal asymmetry in the absence of other drives (no rotation & no ICRH) (fig.4)
Only effective at low \( T_i \)

Poloidal asymmetry parameters (\( \delta, \lambda \)) move on a circle as collisionality varies

Tungsten peaking & ICRH operation: a WEST case

Rare cases of Tungsten accumulation on WEST
Low torque plasma: turbulent transport dominates [8]
Accumulation observed in some ICRH pulses (fig.7) (fig.9)

ICRH
Minority temperature anisotropy : horizontal \( \phi \) asymmetry

Tungsten peaking from FACIT consistent with ICRH drive at low \( V_{pe} \) (fig.10)
Rare events show a powerful, radiative power and core electron temperature.

Modeling of Tungsten peaking
Interpretative integrated modeling with METIS [9]
Ion temperature deduced neutron flux & \( T_N \)
Minority temperature anisotropy : EVE/AQL [10] (fig. 8)
Minority temperature screening effect not considered
Toroidal rotation not measured but (4,1) MHD mode accelerates linearly with ICRH power (fig.9)
Rotation: \( \Omega_i = V_{ei} + (V/P) \times \mathbf{J}_i \); with \( V/P \sim 0 \) km/s/MW
Tungsten peaking from FACIT consistent with ICRH drive at low \( V_{pe} \) (fig.10)

References


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