Influence of tokamak plasma rotation on turbulent impurity transport

F.J. Casson[1], R.M. McDermott[1],C. Angioni[1], Y. Camenen[2], R. Dux[1], E. Fable[1], B. Geiger[1], A.G. Peeters[3], T. Pütterich[1], M. Reinke[4], M. Sertoli[1], et al., and ASDEX Upgrade team

[1] Max-Planck-Institut für Plasmaphysik, Garching bei München, Germany
[2] Aix-Marseille Université, France
[3] University of Bayreuth, Germany
[4] MIT-Plasma Science and Fusion Center, MA, USA

To achieve optimum fusion performance, future reactors will need to control the build-up of impurities in the plasma core. Low mass impurities degrade the fusion rate, while higher mass impurities determine radiation losses and impact plasma control. The design and operation of future reactors will, therefore, benefit greatly from predictive capability for modelling impurity transport under different plasma conditions. The tools for modelling turbulent impurity transport have now reached the stage of development at which it is possible to make quantitative comparisons with experiment, a necessary validation before they can be applied with confidence to predictions for future devices.

Such comparisons demand excellent diagnostics and careful study of systematic uncertainties. For lower mass impurities (amenable to localised measurement by charge exchange), we demonstrate that the experimental correlations in a database of ASDEX Upgrade H-mode plasmas can be quantitatively reproduced by quasi-linear gyrokinetic simulation within the estimated uncertainties. The peaking of the measured boron profiles show a strong anti-correlation with the plasma rotation, via a relationship explained and reproduced by the theory. It is demonstrated that a roto-diffusive component of the impurity flux (the off-diagonal coupling between rotation and particle transport) is required for the modelling to reproduce the measured hollowness of the boron density profile [1,2].

For heavier mass impurities (more suited to tomographic reconstruction from radiation measurement), even a small electric field generated by poloidal asymmetries can generate a significant effect, which both simulations and diagnostic assumptions must allow for in order to permit quantitative comparison. We examine the influence on transport of two demonstrable causes of poloidal asymmetry, the centrifugal force [3], and minority ion heating [4].

In the limit of trace impurities, a perfect separation between turbulence (determined by the bulk species) and impurities is obtained. This separation allows the impurities to be used as an internal plasma diagnostic for the turbulence, which sensitively depends on both parallel and poloidal symmetry breaking mechanisms. The comparisons between simulation and measurement thereby allow a subtle and stringent test of state-of-the-art turbulence models, and build confidence in their predictive power for impurity transport.

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