Progress and challenges in understanding core transport in tokamaks in support to ITER operations

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Fusion performance in tokamaks depends on the core and edge regions as well as on their nonlinear feedbacks. The achievable degree of edge confinement under the constraints of power handling in presence of a metallic wall is still an open question. Therefore, any improvement in the core temperature and density peaking is crucial for achieving target performance. This has motivated further progress in understanding core transport mechanisms, to help scenario development in present devices and improve predictive tools for ITER operations. In the last decade, detailed experiments and their interpretation via the gyrokinetic theory of turbulent transport have led to a satisfactory level of understanding of the heat, particle, and momentum transport channels and of their mutual interactions. This talk will present some highlights of the progress, which stems from joint work of several devices and theory groups, in Europe and worldwide within the ITPA (International Tokamak Physics Activities) framework. The remaining challenges concern mostly the achievement of predictive capabilities of plasma profiles via integrated modeling, which best accounts for the nonlinear interactions inherent to the multi-channel nature of transport. However, this requires faster, reduced models, and the extent to which they capture the complex physics described by nonlinear gyrokinetics must be carefully evaluated. In a longer term the use of neural networks and high power computers will allow to achieve the best compromise between accuracy and speed.

Amongst the recent developments in transport understanding, particular emphasis will be given to: the importance of nonlinear electromagnetic effects and fast ion populations on the stabilization of ion-scale turbulence, potentially leading to a boost in neutron production; the role of multi-scale interactions between ion- and electron-scale turbulence, which may limit performance in electron heated machines such as ITER; the dependence of core transport on the isotope mass of the main gas, of relevance for reactor Deuterium-Tritium operations; the control of heavy impurity accumulation, impacting scenario development in metallic wall devices. For each topic, a brief survey will be given of present understanding, based on experiments and their interpretation using neoclassical and gyrokinetic theory, and of the capabilities of reduced models to correctly describe the physics needed for reliable integrated modeling and projections to future devices, pointing out where further work is still required.

* See the author list of X. Litaudon, Nucl. Fusion 57, 102001, (2017)
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