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A survey of the behavior of impurities in tokamak plasmas

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In a fusion reactor plasma, impurities are present due to multiple sources. In the center, He ash is produced by fusion reactions, at the edge plasma facing components can release impurity atoms and impurities are actively seeded to reach a tolerable heat exhaust. The consequent impurity density profiles will be the result of a combination of the strength of the sources and of the transport, determining the concentration levels and the profile shapes. As a consequence of the strong increase with charge of collisional transport, the transport of highly charged impurities is generally determined by a combination of collisional and turbulent transport, where the collisional (neoclassical) transport is rarely negligible. Light impurities, like He, are usually more strongly governed by turbulent transport. The relative roles of collisional and turbulent transport also depend on the plasma region. Collisional transport can prevail close to the center, where turbulent transport is weak, and in regions of reduced turbulence, like in the transport barrier of the H-mode pedestal. While turbulent transport does not produce strong mechanisms of impurity accumulation, collisional transport can produce strong impurity convection towards the plasma center, critically depending on the relative strength of the main ion density and temperature gradients and the collisionality regime. Plasma toroidal rotation also strongly increases neoclassical transport and can affect the direction of the convection. Turbulent transport can counteract the unfavorable neoclassical convection by increasing the diffusion. Decades of tokamak operation allowed the development of methods to avoid impurity accumulation by controlling both the strength of the sources and the transport in the edge region, as well as preventing strong neoclassical accumulation to occur in the center, where the profiles of the radiated power density connect edge and core effects. Progress in theory is also allowing these operational methods to be increasingly understood and their effects to be predicted.

Speaker's Affiliation

MPI für Plasmaphysik, Garching

Member State or IGO

Germany

Primary authors: DUX, Ralph (Max-Planck-Institut für Plasmaphysik, Garching, Germany); Dr ANGIONI, Clemente (Max-Planck-Institut für Plasmaphysik)

Presenter: DUX, Ralph (Max-Planck-Institut für Plasmaphysik, Garching, Germany)

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