Three-Dimensional Edge Transport and the Impact on Plasma Surface Interactions with Resonant Magnetic Perturbation Fields in Tokamaks

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Three-dimensional (3D) magnetic perturbation fields are applied to high temperature plasma experiments to optimize the transport in the plasma edge and the resulting plasma wall interaction. While 3D magnetic field topologies are inherent to stellarator devices, the application of small, external 3D magnetic perturbation fields is a new and promising approach in tokamaks to control cyclic edge instabilities causing impulsive heat and particle loads to the first wall. The external 3D field applied breaks the axisymmetry assumed for a tokamak and the standard assumptions for plasma edge transport potentially have to be reconsidered. As a consequence, the resulting plasma surface interaction is governed by the 3D field structure. The impact on the eventual erosion and deposition balance of the divertor and first wall material is so far unclear.

In this talk, experimental results will be surveyed on the formation of such a 3D plasma boundary. The stationary plasma edge transport is studied with a Monte-Carlo fluid plasma and kinetic neutral transport model (EMC3-Eirene) in direct comparison to the experiment at TEXTOR and DIII-D. It is shown that a 3D plasma boundary is induced resulting in 3D plasma surface particle and heat fluxes. Experimental quantification of the resulting material erosion at the wall elements shows that the net-erosion characteristic in a 3D boundary is highly dependent on the actual location in the 3D topology. The consequences of these experimental observations for RMP ELM control at ITER are addressed using EMC3-Eirene modeling. This includes addressing the impact of 3D scrape-off layer flow structures discovered on particle transport, plasma fueling and neutral exhaust.

Recently, the impact of a plasma response to the external magnetic control fields applied on this 3D plasma edge formation and the consequent divertor heat and particle fluxes have been addressed. It is shown experimentally, that an internal plasma response can cancel a large part of the resonant field amplitudes at the divertor separatrix. The 3D shape of the boundary starts to become negligible. As soon as the plasma response decays a significant 3D deformation is seen experimentally and the intersection domains of the 3D boundary with the divertor target agrees with field line tracing results using vacuum magnetic fields. However, when extrapolating to ITER, a large uncertainty exists presently on the actual level of plasma response. In consequence, the impact of the 3D boundary on the divertor erosion properties at ITER and hence also on the impurity source cannot be specified. This will be demonstrated on recent results from EMC3-Eirene modeling including a series of different plasma response results from linear and non-linear, single and two fluid MHD modeling.