Recent progress on neoclassical impurity transport in stellarators with implications for a stellarator reactor

Stefan Buller, Per Helander, Håkan Smith, Albert Mollén, Sarah Newton, István Puszai

E-mail: `stefan.buller@ipp.mpg.de`

Abstract. Accumulation of impurities in the core of the plasma is a potential problem for a fusion reactor based on the stellarator concept. In stellarators, unlike tokamaks, the collisional transport is not independent of the radial electric field. The radial electric field is expected to point inwards at reactor-relevant ion temperatures, and this is thought to cause inward impurity fluxes, and thus impurity accumulation. This interpretation has historically been backed up by numerical calculations using pitch-angle scattering collision operators, using codes such as DKES that has been the workhorse of neoclassical transport in stellarators for decades.

However, pitch-angle scattering collisions are not sufficient to accurately describe neoclassical transport at high collisionality. It has recently been shown that when momentum conservation is enforced in the collisions, the transport of a highly-collisional impurity becomes insensitive to the radial electric field [1]. Thus, the role of the radial electric field has to be reevaluated.

The insensitivity to the radial electric field is due to a cancellation between the flux due to the parallel impurity flow and the ion-impurity friction when integrated over the flux-surface. The cancellation hinges on the assumption that the impurity density is constant on the flux surface. However, for a highly-charged impurity – such as tungsten – even a slight variation in the electrostatic potential on the flux-surface can lead to a notable flux-surface variation in the impurity density, which destroys the cancellation and causes the radial electric field to drive impurity transport [2, 3]. Depending on the details of how the potential varies along the field line, the radial electric field can even drive a flux in the opposite direction, so that an inward field drives an outward flux [2, 4]. Thus, the electrostatic potential variation on the flux surface could be a design consideration for avoiding impurity accumulation.

We will use the adjoint solver [5] in the collisional transport code SFINCS to calculate, in a reactor stellarator scenario, the derivatives of the impurity transport with respect to the flux-surface electrostatic potential variation. Unlike current experiments, tungsten impurities in a reactor will be in the plateau collisionality-regime, where the existing high-collisionality analytical theories do not apply. For this regime, we optimize the electrostatic potential variation to minimize impurity accumulation, and compare this optimum to the potential variation caused by trapped particles intrinsic to the plasma, and the variation due to fast particles from heating and fusion. Thus, we will deduce whether flux-surface electrostatic potential variations are a feasible tool for impurity control in a stellarator reactor.

References

[1] Helander P *et al.* 2017. *Phys. Rev. Lett.* **118**, 155002.
[2] Calvo I *et al.* 2018. *Nuclear Fusion* **58**, 124005.
[3] Buller S *et al.* 2018. *Journal of Plasma Physics* **84**, 905840409.
[4] Buller S *et al.* 2019. *Nuclear Fusion* **59**, 066028.
[5] Paul E J *et al.* 2019. *Journal of Plasma Physics* **85**, 795850501.