Validation of low-Z impurity transport theory using charge exchange recombination spectroscopy at ASDEX Upgrade

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Impurities are unavoidable in fusion plasmas and potentially highly problematic as they result in fuel dilution and radiative energy losses. Accurate predictions of fusion plasma performance, therefore, require a validated theoretical description of impurity transport, which in turn requires high accuracy measurements of the impurity populations in present day devices. Recent work at ASDEX Upgrade (AUG) demonstrated the importance of an often-neglected contribution to the CX emission, the n=2 neutral beam halo, for accurately determining the gradient of low-Z impurity density profiles [2]. This is a critical ingredient for theory validation, as the measured and predicted normalized impurity density gradients are the most commonly and easily compared quantities for theory validation. Previous work at AUG made this comparison for a database of helium and boron density profiles [3] and demonstrated strong discrepancies between experiment and theory as well as clear differences between the impurity species. Motivated by this work, this database has been expanded to include also neon measurements and dedicated experiments were performed to separately identify the diffusive and convective components of the boron particle flux [4]. The transport coefficients from these experiments have been compared to both linear and flux-matched non-linear simulations using the gyro-kinetic code GKW and demonstrate quantitative agreement in the diffusion coefficient for most cases, together with a systematic under prediction of the observed outward convection. To resolve the discrepancy between the measured and predicted convective velocities a variety of effects have been tested, including the impact of the neoclassical distribution function on the turbulent impurity flux [5] and the inclusion of fast ions in the gyro-kinetic simulations. Lastly, the convection, diffusion and normalized gradients calculated by GKW are compared to those from GENE and against the results from an integrated modeling approach using ASTRA coupled to NEO and QualLiKiz. In this contribution an overview of these works will be given with the aim of determining how best to develop reliable predictive capability of the impurity density behavior in future devices.

[1] A. Kappatou, et al. Plasma Phys. Control. Fusion 60 (2018) 055006 [2] R. M. McDermott, et. al. Plasma Phys. Control. Fusion 60 (2018) 095007 [3] A. Kappatou, et. al., Submitted to Nuclear Fusion, 2019 [4] C. Bruhn, et. al. Plasma Phys. Control. Fusion 60 (2018) 085011 [5] P. Manas, et. al. Plasma Phys. Control. Fusion 59 (2017) 035002