3D global impurity migration simulations with WallDYN and EMC3-EIRENE

L. Bock[1,2], K. Schmid[2], T. Lunt[2]

[1] *Physik-Department E28, Technische Universität München, 85747 Garching, Germany*

[2] *Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany*

1. Introduction

A challenge in modern magnetic confinement fusion experiments is the control of particle species that are not involved in the fusion process. These impurities can either be injected on purpose to control radiation losses or originate from the wall due to outgasing or erosion processes and are then transported through the plasma before being eventually pumped out or redeposited on the wall again. This cycle of erosion and deposition is called impurity migration and controls the net erosion and surface composition of the wall, impurity fluxes into the plasma and retention of gases in the wall. To interpret impurity migration measurements and wall sources the evolution of the first wall surface composition and the resulting dynamics of impurity fluxes into the plasma have to be taken into account.

A tool for that is the global impurity migration code WallDYN [1] that calculates surface compositions and impurity fluxes self consistently by combining models for implantation, erosion and reflection of impurities with a model for impurity transport through the plasma. This impurity transport is parameterized by a redistribution matrix that shows the normalized fractions of particles ending up at destination wall tiles after being started from a source wall tiles.

The first version of WallDYN used the 2D impurity transport code DIVIMP [2] and thus was limited to toroidally symmetric geometries (WallDYN2D). While the plasma and SOL in tokamaks are essentially toroidally symmetric, the first wall contains 3D features like poloidal limiters. Thus impurity migration and resulting deposition patterns are not always fully captured [4]. Making more accurate predictions for tokamaks or modeling stellarator devices therefore requires taking the full 3D structure of both SOL and first wall into account.

To that end WallDYN has been coupled to the 3D SOL and impurity transport code EMC3-EIRENE [5] (WallDYN3D).

This paper compares parameterized impurity transport results of the 2D code DIVIMP and the 3D code EMC3-EIRENE on similar plasma background solutions for ASDEX Upgrade (AUG) #32024 in section 2. Section 3 investigates the effects of a fully three-dimensional wall and SOL on ^{15}N deposition at a midplane manipulator probe (MEM) in the same shot.

2. Impurity transport comparison between DIVIMP and EMC3-EIRENE

Since WallDYN2D and hence the impurity transport of the DIVIMP code has been successfully used for many predictions resulting redistribution matrices are being used as a benchmark for WallDYN3D results. In [4] a SOLPS 5.0 background including currents and drifts with optimized background flow patterns has been used in WallDYN2D to predict ^{15}N deposition patterns. The resulting redistribution matrix is depicted in figure 1 and shows three areas with strong diagonal elements and hence dominant short range transport. Comparing to figure 2 identifies those areas to represent the main chamber (tiles 0 to 27), the outer divertor (tiles 27 to 42) and the inner divertor (tiles 42 to 54). The deposition tiles of the inner divertor furthermore indicate transport from the main chamber to the divertor tiles. A three-dimensional EMC3-EIRENE background matching the SOLPS solution was created using the same wall configuration (figure 2) and assuming toroidal symmetry of both SOL and wall. The resulting redistribution matrix in figure 3 was computed using the novel impurity tracing module of EMC3-EIRENE [5].

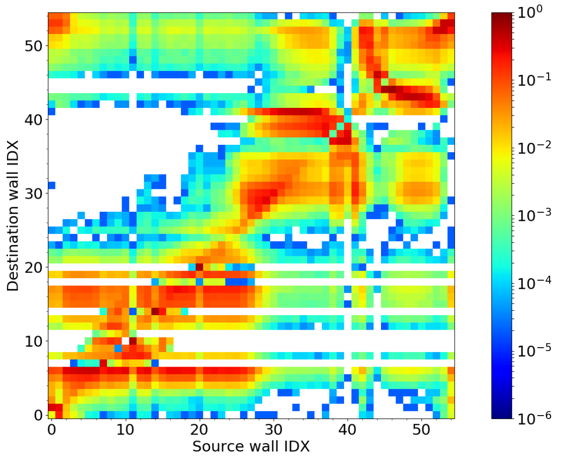

Figure 1: Redistribution matrix for ^{15}N in AUG #32024 from DIVIMP on a SOLPS 5.0 background solution with currents and drifts.

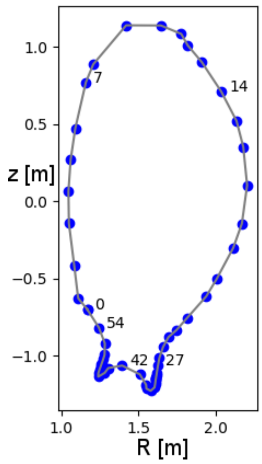

Figure 2: The discretized wall used for WallDYN simulations in figures 1, 3 and 4.

As in figure 1 the matrix exhibits features of dominant short range transport and deposition of particles from the main chamber in the inner divertor. However the main chamber redistribution in figure 3 indicates more short range transport than in figure 1 and more particles from the low-field side of the chamber end up at the inner divertor tiles as indicated by contributions from source tiles up to index 28. The SOLPS solution from figure 1 was mapped to a toroidally symmetric EMC3-EIRENE grid and the resulting redistribution matrix from EMC3-EIRENE is depicted in figure 4. It indicates a symmetric redistribution of impurities in the main chamber but features of transport from the main chamber to the inner divertor appear to be missing.

Empty spaces in the inner divertor region furthermore illustrate that the SOLPS plasma does not fully reach up to the used wall configuration.

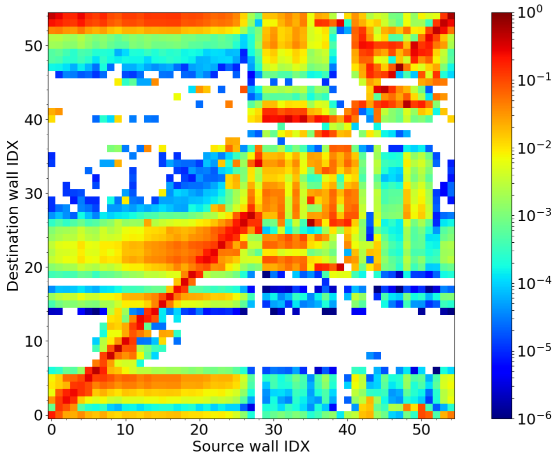

Figure 3: ^{15}N redistribution matrix for AUG #32024 from EMC3-EIRENE using a toroidally symmetric EMC3-EIRENE background solution matched to the SOLPS solution used in figure 1.

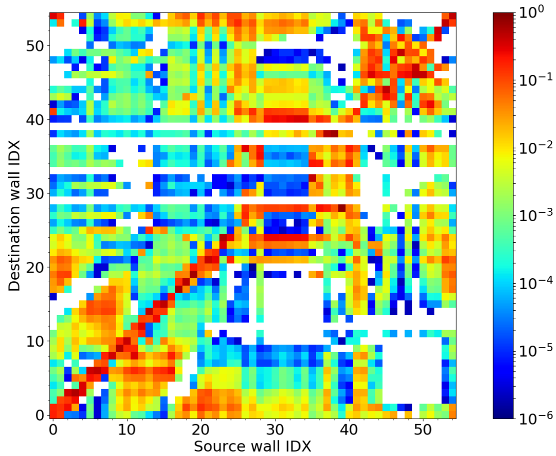

Figure 4: ^{15}N redistribution matrix for AUG #32024 from EMC3-EIRENE. The background solution is mapped from SOLPS (figure 1) to a toroidally symmetric EMC3 grid.

3. Nitrogen deposition at the midplane in AUG #32024

In [4] predictions of WallDYN2D overestimate the deposition of ^{15}N at the MEM by more than a order of magnitude. To investigate the influence of three-dimensional wall and SOL features an EMC3-EIRENE grid covering 60° of ASDEX Upgrade including two poloidal limiters and the MEM has been created. The grid has increased resolution in both poloidal and toroidal direction at the MEM to resolve features like the radial deposition fall-off length. A poloidal cross section of the grid with mapped wall elements is depicted in figure 5 where the filled red area indicates the vessel and the structures on the right-hand side the mapped limiters and the MEM. In total 2228 wall tiles are considered in the 3D configurations, where the MEM is covered by tiles 2218 to 2227. Again the SOLPS solution used in figure 1 is mapped to the grid and the impurity distribution is calculated with EMC3-EIRENE. A snippet of the resulting ^{15}N redistribution matrix illustrates transport to the MEM (tiles 2218 to 2227) in figure 6. In total a fraction of 3.56 % of the total deposited particles reaches the MEM while it only covers 0.32 % of the total tile area. The above average fraction results from the exposed probe position 2 cm in front of the limiters. Even if these numbers indicate strong deposition at the MEM a full WallDYN3D simulation is necessary to take effects like reflection, erosion and re-emission into account.

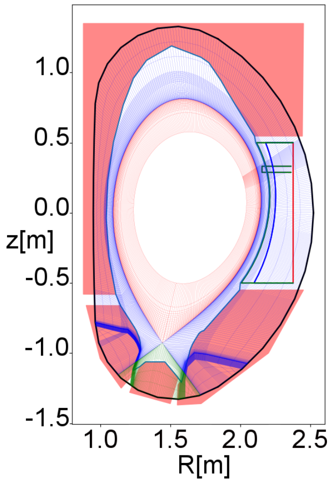

Figure 5: Poloidal cross section of the grid including wall elements, projections of limiters and a higher resolved MEM.

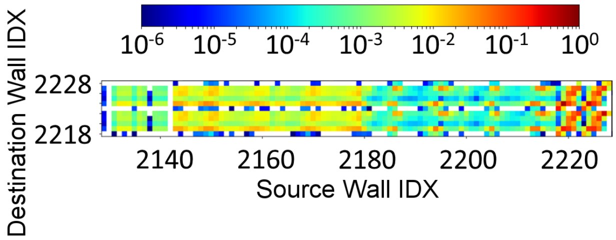

Figure 6: Snippet of the ^{15}N redistribution matrix covering the MEM on tiles 2218 - 2227. The background solution is mapped from SOLPS to EMC3-EIRENE.

4. Conclusions and Outlook

In section 2 the redistribution matrices from the 2D code DIVIMP and the 3D code EMC3-EIRENE on similar or even mapped background solutions were compared. In general the novel impurity transport model in EMC3 captures the same trends like dominant short range transport and deposition from the main chamber at the inner divertor as DIVIMP. DIVIMP however predicts more redistribution in the main chamber which is likely related to the different core models in both codes that are being further investigated.

A snippet of a first redistribution matrix of a full 3D impurity migration simulation for AUG is depicted in section 3. This is a first step to include influences of three-dimensional features of SOL and wall in WallDYN simulations. To that end an EMC3-EIRENE grid covering 60° of AUG, two poloidal limiters and the MEM was created. A 2D SOLPS solution from AUG #32024 was mapped to the grid to eventually compare WallDYN3D and WallDYN2D ^{15}N deposition predictions at the MEM. The significant fraction of deposited particles at the MEM of 3.56 % results from its exposed position 2 cm in front of the limiters. A WallDYN3D simulation using this redistribution matrix is currently running to get first areal density results at the MEM.

References

[1] K. Schmid et al, Journal of Nuclear Materials, Volume 463, 2015, Pages 66-72

[2] P. Stangeby et al, Journal of Nuclear Materials, Volumes 196-198, 1992, Pages 258-263

[3] R. Schneider et al, Contributions to Plasma Physics 46 (1-2)

[4] G. Meisl et al, Nuclear Materials and Energy, Volume 12, 2017, Pages 51-59

[5] K. Schmid, T. Lunt, Nuclear Materials and Energy, Volume 17, 2018, Pages 200-205