CHALLENGES IN PWI MODELLING FOR METALLIC DEVICES AT THE EXAMPLE OF THE EU-DEMO TOKAMAK

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Plasma-wall interaction (PWI) processes like erosion, deposition and fuel retention are key challenges for efficient and safe long-term operation of fusion reactors. Especially with regard to design-related questions of future machines, numerical modelling of such processes gets inevitable in order to make sound decisions. For instance, steady-state PWI in full reactor-scale geometries can be assessed with the ERO2.0 code [1]. The code calculates both the erosion under ion and charge-exchange neutral (CXN) impact and the migration of eroded impurities throughout the background plasma, thereby addressing atomic processes like ionisation, recombination, and collisions with the plasma.

The present synopsis reports on comprehensive PWI modelling for metallic devices at the example of the EU-DEMO tokamak [2], which is considered to have only tungsten (W) plasma-facing components. Based on cold plasma edge conditions, the modelling reveals plasma fuel ions to contribute only marginally to both the erosion of the first wall and the divertor. It turns out instead that the gross erosion of the first wall is dominated by deuterium CXN with a relative contribution exceeding 85 %, while divertor gross erosion is driven by seeding impurities (relative contribution roughly 78 %) and self-sputtering (relative contribution roughly 22 %).

Kinetic energy distribution functions of CXN are used to calculate the induced erosion patterns across the plasma-facing components with high accuracy. This approach replaces the previous ERO2.0 assumption of mono-energetic CXN impact distributions, which are expected to deviate significantly due to the strong energy dependence of the sputtering yield. In fact, a comparison shows a reduction of the main chamber gross erosion by a factor of 2 to 3 using kinetic energy distribution functions for the EU-DEMO conditions. At the same time, fast CXN in the high-energy tail of the distribution cause finite sputtering in otherwise unaffected areas, so that additional sources appear in the main chamber. To illustrate the latter, figure 1 shows the effective sputtering yield along the wall as a poloidal profile.

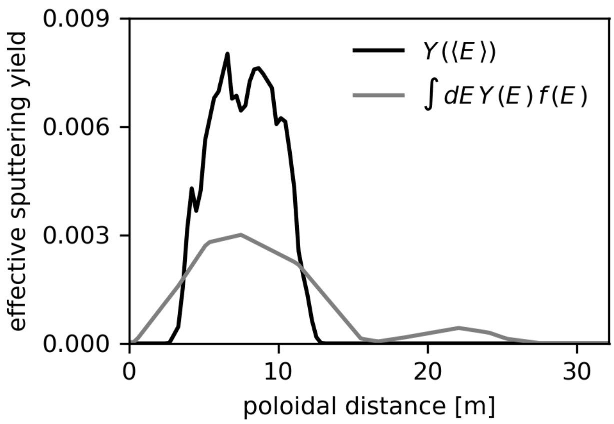

Figure 1: Effective sputtering yield obtained for the kinetic (gray) and the mono-energetic (black) energy distribution function approach.

The transport of W impurities through the plasma volume strongly depends on the location of the source, which can be seen in figure 2. For instance, only short-range W transport is observed in the divertor, thus indicating efficient divertor screening even in semi-detached conditions. In contrast, the modelling shows negligible screening of first wall surfaces, which can be attributed to long W ionisation mean free paths as a consequence of the cold and thin far-SOL. The weak main chamber screening results in a strong W transport into the divertor, which has decisive implications. On the one hand, the main chamber's low-field side of the first wall reveals large net erosion, since almost 50 % of W eroded in the main chamber is deposited somewhere in the divertor. On the other hand, strong W deposition in the divertor enhances the co-deposition and retention of plasma fuel deep in plasma-facing components as well as the formation of dust. The cold and thin far-SOL conditions therefore pose a significant risk on long-term steady-state operation.

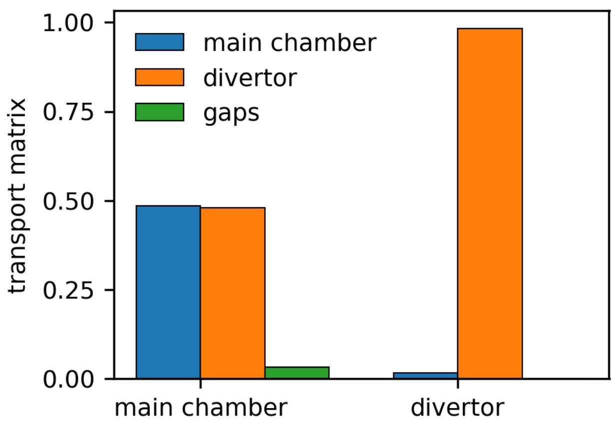

Figure 2: The figure shows the reduced transport matrix, i.e. the transport from the erosion location (x-axis) to the deposition location (y-axis).

Finally, the presented contribution is performed for the only available plasma edge solution of the EU-DEMO tokamak [3], which was generated with the SOLPS-ITER code on basis of the 2017 Baseline magnetic equilibrium. Large gaps between the last simulated plasma grid-point and the first wall up to several tens of centimeters at the top of the machine demand a careful discussion of extrapolation assumptions of plasma profiles towards the first wall in view of expected uncertainties in the modelling.

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