SIMULATION OF TUNGSTEN EROSION AND EDGE-TO-CORE TRANSPORT IN NEON-SEEDED JET PLASMAS

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The capability of simulation tools to predict the erosion and transport of tungsten (W) in fusion edge and core plasmas is assessed using JET H-mode plasma scenarios. Predicting the W density in the core plasma is a crucial part of predicting the performance of ITER and other future devices with a W first wall. In recent years, ongoing validation efforts of W erosion and transport simulations in JET with a Be/W wall have been shown to agree with experimentally inferred core plasma W densities in deuterium (D) type-I ELMy H-mode [1] and L-mode plasmas [1, 2] within an estimated modelling uncertainty of a factor of 2 (L-mode, B_t=2.5 T, I_p=2.5 MA, P_{aux}=1 MW) to 3 (H-mode, B_t=3.45 T, I_p=2.3 MA, P_{aux}=34 MW [3]). Using the ERO2.0 code [4] for W erosion and edge transport [5, 6], and the JINTRAC (JETTO and EDGE2D-EIRENE) code suite [7] for background plasma modelling and core plasma W transport, the simulated core W density profiles are consistent with experimental W densities from integrated data analysis [8], provided that the edge and core background plasmas are comprehensively optimised to match the measured conditions.

The modelling uncertainties are induced by diagnostic coverage and measurement accuracy of the plasma parameters needed for validation, by the limited ability of background plasma simulations to self-consistently reproduce the measured conditions, and to a lesser extent by approximations in the predictive W erosion and transport models. The simulation workflow was successfully validated for W erosion [9] and transport [1] in all studied unseeded scenarios, despite the W density profiles in the core plasma being highly sensitive to variations in several plasma parameters, in particular the density and temperature profiles of electrons and ions, the toroidal rotation frequency, the amplitude and frequency of ELMs, and the flux and energy spectrum of charge-exchange neutrals (CXN) incident on W plasma-facing components. The scarcity of W measurements in the edge plasma necessitates combining edge and core modelling to validate the W transport simulations.

Kinetic neutral particle transport simulations using the EIRENE code [10] predict the atomic flux and the impact energy and angular distribution, including CXN, incident on each plasma-facing component, which are made of W in the divertor and Be at the first wall. As a consequence of virtually perfect screening of W sputtered by impurity ions at the divertor targets, the predicted W influx is determined mainly by CXN-induced W sources near and above the divertor entrance. The effective sputtering and reflection yields and the initial distributions of sputtered particles are based on a database of SDTrimSP [11] simulations.

Building on these results, the simulations are now extended to include neon (Ne) seeding, high-performance D and D-T discharges, and the first assessment of predicting W in the small-ELMs ITER-baseline scenario in JET with partially detached divertor conditions in vertical target configuration [12]. The JET ITER-baseline plasmas obtained a unique dataset on core-pedestal-exhaust integration, subject to intense analysis and validation of edge and core models [13], which includes this work. In contrast to W screening by high pedestal ion temperature and low collisionality in the previously studied hybrid scenario [3], the JET ITER-baseline scenario achieves a tolerable core W concentration by low core density peaking [14], despite a significantly higher pedestal electron density. The edge plasma for the new scenarios is modelled using the SOLEDGE3X [15] code with cross-field drifts included, and the core plasma is simulated with JINTRAC (JETTO). The predicted W density in the core plasma is validated against available experimental data. The inclusion of cross-field drifts enables higher-fidelity modelling of the inner-outer divertor target asymmetry, the ion flow patterns in the scrape-off layer (SOL), and the parallel-B and radial electric field components.

The new simulations include Ne seeding, which is used to protect the divertor from excessive heat loads by radiation and reduce the amplitude of ELMs. Ne^{3+} is predicted as the largest contributor to W gross erosion in these plasmas with partially detached divertor conditions. Furthermore, Ne influences the W transport dynamics due to its impact on the density, temperature, and rotation profiles, ELM characteristics, the electric field, and the effective charge [12]. In the SOL, Ne seeding enhances the screening of W by increasing parallel-B friction and by shifting strong parallel-B temperature gradients away from wall surfaces towards the upstream.

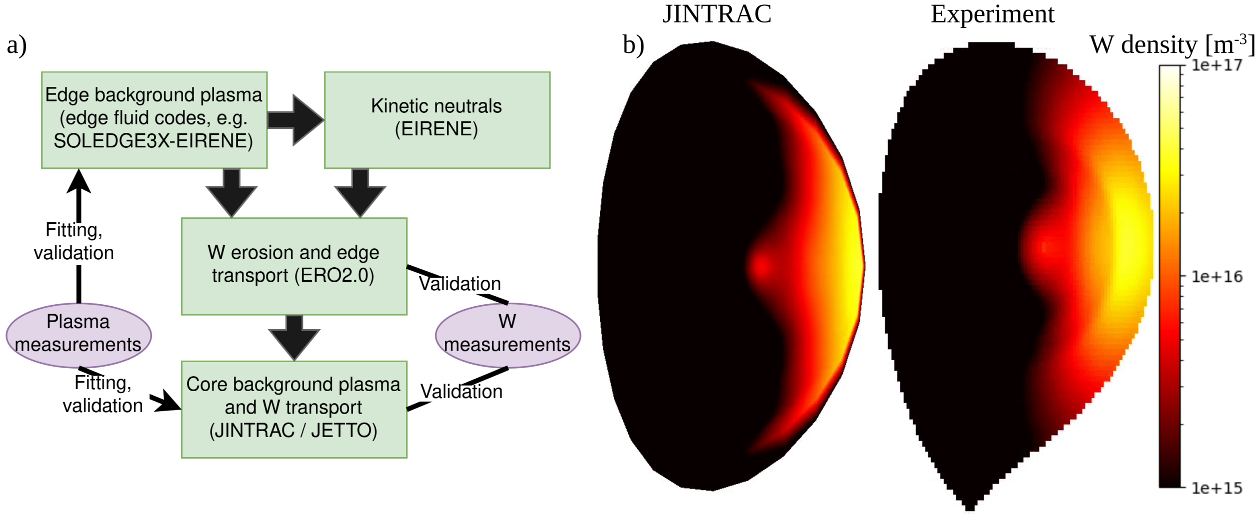

Figure 1. a) Flowchart describing the simulation workflow. b) Poloidal cross-section of the W density in the main plasma predicted by JINTRAC (left) based on W boundary conditions from ERO2.0, and inferred from JET D hybrid discharge #97781 at 9 s (right) [1].

The multi-stage simulation workflow, a team effort interfacing SOLEDGE3X, JINTRAC, and EIRENE with ERO2.0 (figure 1a), allows for improved predictive accuracy of the W density profiles (figure 1b, prior work with an EDGE2D edge background plasma [1]). The improvements are underpinned by recent development and integration of physics models regarding neoclassical transport models with rotational effects [16, 17], computationally efficient surrogate models for turbulent transport [18], a refined implementation of thermal forces [19], bivariate energy-angular atomic impact distributions [20], and nonlinear effects of material concentration on sputtering yields from mixed-material surfaces, including self-sputtering. This contribution demonstrates the current state and advancements in predicting impurity behaviour and its effect on the performance of fusion devices, and the importance of accurate background plasmas for understanding and predicting impurity transport.

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