Predictive modelling of beryllium erosion, transport and deposition in ITER plasmas

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ITER will be constructed with beryllium (Be) main chamber first wall armour. It is expected that an important contributor to its lifetime will be the sputter erosion due to steady state plasma thermal particle fluxes under long pulse, burning plasma conditions. Migration of the eroded Be is also the key driver of fuel retention and a potential major contributor to dust formation. High fidelity modelling of the erosion and migration process is required to quantify the wall lifetime and to provide refined estimates of the growth of in-vessel dust and tritium inventories with the ITER Research Plan. It is also required to generate synthetic signals to test the two major systems which ITER is putting in place for the monitoring of erosion and migration (main chamber visible spectroscopy and an in-vessel viewing system). This modelling must account for the 3D structure of the first wall panels (FWP), which are shaped to protect plasma impact on leading edges arising from radial misalignments between components. In this contribution, we present a comprehensive study of global Be migration in ITER using the 3D Monte-Carlo code ERO2.0 [1]. This code simulates the steady-state erosion flux, taking into account the subsequent transport of eroded impurities using a kinetic approach and the trace impurity approximation. The simulations are performed using toroidally symmetric input plasma backgrounds obtained by combining SOLPS simulations extended to the wall using the OSM-EIRENE-DIVIMP code package. These are then further combined with a shadowing model using magnetic field line tracing to provide a 3D correction for the flux patterns. The outcome of the simulations are:

(1) The Be gross erosion fluxes due to different sputtering mechanisms (impact from D ions or charge-exchange neutrals as well as self-sputtering); the highest erosion flux is typically found at the top of the main chamber, in the secondary X-point region.

(2) The Be deposition fluxes in the main chamber/divertor and the resulting Be net erosion/deposition.

(3) The Be charge-state resolved particle densities and the intensity of emission lines such as Be I 457 nm and Be II 527 nm.

Extensive studies have been performed to examine the sensitivity of the Be erosion and transport to a variety of key simulation parameters. These include variations in the plasma background (e.g. far-SOL density, flow, magnetic configuration, input power and ion species (He, H, DT)), the cross-field particle diffusivity for the Be ions, the distributions of energy and angle for ions and neutrals impacting the Be surfaces, and the fraction of Be released in the form of BeD molecules. The upper limit of the net erosion rate from these new full machine simulations is similar, but nevertheless higher than that found previously from an previous study of an isolated FWP with an older version of the ERO code [2]. The main uncertainty of the modelling is related to the particle fluxes to the wall and their respective energies. For example, for the baseline DT Q=10 scenario, T_e=10 eV is assumed, leading to high impact energies and Be sputtering. Furthermore, the Be redeposition is very sensitive to the assumed plasma density, temperature and flow. For instance, in the baseline case 90% of the eroded Be is redeposited in the main chamber, while in the low-power hydrogen case it is only 44% and the remaining Be is deposited in the divertor.

[1] J. Romazanov et al., Nucl. Mater. Energy 18 (2019) 331–338
[2] D. Borodin et al., Phys. Scr. T145 (2011) 014008