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ERO2.0, a code for three-dimensional modelling of global material erosion, transport and deposition in fusion devices

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Erosion of plasma-facing components (PFC) due to sputtering by impinging ions and neutrals is one of the key challenges on the road to fusion power. Erosion will be a contributor to the overall PFC lifetime estimation, and to impurity production that can potentially lead to radiative collapse. Moreover, PFC erosion is directly linked to the key issues of fuel retention by co-deposition and dust production. For predictive modelling of these effects in ITER and other fusion devices, the impurity transport and plasma-surface interaction (PSI) Monte-Carlo code ERO2.0 [1] has been developed. ERO2.0 is a massively parallel 3D code, capable of performing global erosion and deposition simulations of all relevant PFCs installed in the full-size reactor vessel. In this contribution, we provide an overview of recent and ongoing ERO2.0 applications to JET and ITER, highlighting the importance of 3D aspects of the PSI modelling.

ERO2.0 has been validated by applying it to model beryllium (Be) erosion and transport in the main chamber of the JET ITER-like wall (ILW) for different operating conditions covering limiter and divertor configurations. Parameter scans included a fuelling scan in limiter configuration and a power scan in divertor configuration resulting in ohmic, L- and H-mode plasmas shown in Figure 1(a). The corresponding 2D plasma backgrounds used as input to ERO2.0 were obtained mainly from EDGE2D-EIRENE simulations [2] extrapolated to the 3D contour of the JET wall.

We observe good agreement with experimental measurements from passive spectroscopy, including spectrally filtered wide-angle cameras with 2D resolution (see Figure 1(b)) as well as integrated lines-of-sight of spectrometer chords. We show that taking into account the 3D shape of the Be limiter tiles and the resulting complex magnetic shadowing patterns is crucial to reproduce the experimental measurements. Moreover, ERO2.0 qualitatively mimics the predominant Be transport into and Be deposition in the inner divertor, which was observed by post-mortem analysis of JET PFCs [3].

Following this code validation on JET, ERO2.0 has been used to predict the erosion of the Be first wall panels (FWP) in the ITER main chamber. Eight cases were studied, representing different plasma conditions or modelling assumptions, as summarised in Figure 2. The study covers ITER plasmas from the Pre-Fusion Power Operation (PFPO) and fusion power operation (FPO) phases and includes variations of density, scrape-off layer (SOL) flow velocity, heating power, magnetic configuration (separation between primary and secondary separatrices) and plasma species (H, He, D-T). The reference case #1 represents the baseline H-mode plasma in DT with Q=10 and 500 MW of fusion power.

The corresponding input plasma backgrounds, obtained from OEDGE simulations, were provided by the ITER organisation (IO). The OEDGE simulations are based on SOLPS solutions, and additionally use the ITER Heat and Nuclear Load Specifications (HNLS) [4] combined with an onion-skin model (OSM) to extend the computational grid to the wall [5].

In general, we observed that the regions of highest Be gross erosion are found on FWP 4-5 (inner wall), 8-9 (top) and 18 (outer wall near the divertor), as shown in Figure 3. An important result is that in all of the investigated FPO cases (#1-5), the major part of the eroded Be is redeposited in the main chamber. In case #1, this fraction amounts 90%, with the remaining 10% deposited in the divertor. This is in strong contrast to the comparable JET H-mode simulations, where more than 60% of the Be is deposited in the divertor. Comparably large fractions of up to 53% are however observed at ITER for the Pre-Fusion Power Operation (PFPO) cases #6-8, which have plasma parameters closer to the ones at JET. This suggests that Be long-range transport to the divertor is increasingly suppressed at high heating power and in particular high density plasma conditions in the far-SOL.

In case #2, a high imposed background SOL flow (Mach number 0.5) led in the ERO2.0 simulations to an entrainment of Be impurities and more than doubled their transport to the divertor, compared to case #1. In case #3, a lower density was assumed in the far-SOL plasma parameters, leading to a ~3x lower Be gross erosion and a ~2.5x higher Be deposition fraction in the divertor. Cases #4 and #5 have a different magnetic configuration that uses the minimum allowed distance between the primary and secondary separatrices, Δrsep=4 cm, in contrast to Δrsep=9 cm for the other cases. This leads to an elongated plasma shape and strong plasma-wall interaction around the machine apex, which for case #5 resulted in a 3x higher Be erosion compared to case #1. Cases #6-8 represent H and He plasmas from the ITER PFPO phase. These cases show a significantly lower (by one order of magnitude) Be gross erosion rate, compared to their FPO counterparts. Furthermore, the Be transport to the divertor is significantly increased.

One of the main modelling uncertainties in the ERO2.0 modelling are the plasma parameters near the surface, which determine the impact energy and angles of the plasma particles impinging on the surface, and thereby the sputtering yields. In particular, the HNLS assumes very high plasma temperatures (Te=10 eV and Ti=20 eV in the reference case #1) in the far-SOL of the entire main chamber area, leading to highly conservative predictions regarding the Be source strength. An exponential decay of the plasma parameters Te, ne, Ti would likely lead to a substantial reduction of the Be erosion. Quantification of this reduction is aim of upcoming ERO2.0 studies.

Moreover, in the present simulations, a perfectly smooth plasma-facing surface was assumed. However, micro-scale roughness is usually present in plasma-exposed surfaces, and can reduce the net erosion by re-deposition in the microstructures [6]. In addition, the smooth surface assumption leads to more shallow ion impact angles (and thereby increased erosion) when compared to a rough surface. Thus, the presented erosion and deposition rates represent upper limits for the expected values in ITER which will use Be PFCs with a roughness on the micrometer scale.

References

[1] J. Romazanov et al., Nucl. Mater. Energy 18 (2019) 331–338
[2] S. Wiesen et al., EDGE2D/EIRENE Code Interface Report, JET ITC-Report, 2006.
[3] A. Widdowson, et al., Nucl. Fusion 57 (8) (2017) 086045
[4] R. A. Pitts et al., J. Nucl. Mater. 2011, 415(1 Suppl), S957.
[5] S.W. Lisgo et al., J. Nucl. Mater. 438 (2013) S580–S584
[6] A. Eksaeva et al., Nucl. Mater. Energy 19 (2019) 13–18

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