Long-distance transport of carbon and beryllium in an ITER edge plasma

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A key issue with carbon fiber composite for an ITER divertor component is tritium (T) codeposition resulting in unacceptably high T accumulation. Eroded carbon (C) and hydrocarbons migrate and redeposit at other locations, forming hydrogen-rich codeposition layers. Furthermore, since a portion of beryllium (Be) atoms eroded at the first wall of ITER migrates towards the divertor region, a Be deposition appear on the divertor components C and W as well. In this paper, a predictive modeling of long-term T retention in the divertor of ITER is performed by EDDY, which calculates impurity release, transport and redeposition on plasma facing walls.

In order to simulate the erosion and redeposition for the ITER PFCs, the EDDY is coupled to an ITER SOL/diverter plasma configuration calculated using a plasma code, SOLPS. The EDDY calculates physical sputtering characteristics, i.e., the sputtering yield and species, energy and angle of sputtered atoms from a C diverter plate and a Be first wall. At the C plate, chemical sputtering yield depending on the surface temperature, ion flux and energy, is taken from Roth formula. Ionizations and dissociations of the sputtered particles in plasmas are calculated using rate coefficients according to existing empirical formulae. The interaction of ionized particles with the plasma is caused by friction and thermal forces parallel to the local magnetic field lines and cross-field diffusion perpendicular to it, in addition to the gyromotion. Each particle has a probability to return to the wall surface and to stick (deposite) on it after transport through the plasma. Thus, deposition profiles of C and Be in the whole area of ITER PFCs. Since the deposition layers are also re-eroded by the bombardment of plasma ions, the net deposition profiles is calculated assuming the same sputtering yields as the substrates. In addition, empirical scaling laws of atomic D/C and D/Be ratios for the deposits, depending on surface temperature and incident energy and flux, are used to the deposited C and Be profiles for evaluating T inventory in the ITER divertor components and the first wall.

The T retention rate in the C deposits was estimated to be 0.44 mg/s, 1.11 mg/s and 5.95 mg/s on the inner and outer targets and the dome, respectively, whereas in the Be deposits, it was 0.84 mg/s, 0.52 mg/s and 0.20 mg/s, respectively. Using a discharge duration of 400 s, the number of discharges after which an in-vessel T safety limit of 700 g is reached is predicted to be 193 – 601, depending on whether the deposits at the dome edges are pumped out the divertor or not. However, the physical and chemical re-erosion of the deposits must be enhanced, e.g., by a factor of ten, compared with that of the substrate, which reduces the deposition and the retention rate. Furthermore, recent experiments shows strong mitigation of chemical erosion of a C target with the Be deposition, which reduces chemical sputtering of the C target, and then C deposition flux. Such sputtering characteristics of the deposited and mixed layers are taken into account, where a molecular dynamics for hydrogen interaction with the layers is applied for determining the sputtering yields.