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Plasma-material interaction in the main chamber of fusion reactors: the role of high-Z and low-Z wall materials on erosion, dust, fuel retention, and fuel recovery methods

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Plasma-material interaction (PMI) imposes a number of challenges on the operation of a next step fusion device or reactor associated with the lifetime of components, the sustainability of the tritium cycle, and ultimately with safety aspects. The underlying critical processes under steady-state plasma operation can be splitted into two categories: (i) erosion, transport, deposition, and dust formation described in general in the term material migration and (ii) co-deposition, implantation, diffusion, and permeation labelled in general as fuel retention. The role and strength of the individual process depend primarily on the choice and energy of plasma or projectile species (D ,T and seeding species Ar, Ne, etc.) and plasma-facing or target materials (low-Z species like C, Be, Li etc.- and high-Z species like W. Mo, steel, etc.). DT fusion neutrons can induce additional damage to the materials in the main chamber above a damage threshold resulting in enhancement of e.g. fuel retention above roughly half a dpa, which is in the order of the end of lifetime damage in the only full burning device under construction - ITER. In a reactor of DEMO size with much higher neutron dose, neutron induced effects will play the dominant role in the retention process.

Here, we present an overview of the different processes, how they interact with each other, and define potential limits. Predominantly experimental results from the JET and ASDEX Upgrade tokamak will be use to describe the differences between plasma operation in low-Z and high-Z first wall in deuterium. A massive reduction of the material migration and fuel retention by a factor 10-20 have been identified in both device when transferring from carbon-based materials towards a metallic material device, but adaptation of the operational space was required with tungsten. Comparison between different fuel isotopes will be addressed in particular with the aid of JET, which operated recently in H, D, T and DT, and allows to establish and extrapolate previous non-T operation towards reactor like conditions. However, none of the present-day tokamak operation can directly contribute to the assessment of the role of neutrons on the PMI processes. Here, we rely on accompanied research in dedicated laboratories, which can mimic the impact of neutrons by heavy ion, proton or fission neutron impact. Modelling is used to transfer the physics towards fission neutrons in the lack of a facility to mimic material damage by 14MeV neutrons.

The overall physics understanding regarding PMI will be brought into perspective of a DEMO-like device. The proposed modelling tools to address the critical issues first wall erosion, dust production, and tritium retention will be briefly introduced and linked to recent revised assessments done for the PFPO and FPO phases in ITER. The preliminary status of corresponding plasma edge (SOLPS-ITER) and plasma-material interaction modelling (ERO2.0) for the European DEMO - without consideration of neutron impact - will be presented.

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