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Interpretative modeling of impurity transport and tungsten sources in WEST boundary plasma

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The contamination of core plasma by high-Z impurities, especially tungsten (W), is the main reason of very high level of radiated power in WEST [1] experiments. Determining the main sources of core contamination is indeed a key aspect in preparing a high confinement scenario for the second phase of WEST operation that will start at the end of 2020. Intrinsic light impurities, mainly oxygen and carbon, play a dominant role in the sputtering of W on plasma facing components (PFCs) and it is crucial to investigate their transport and spatial distribution in edge and SOL plasmas. In this contribution, we present a detailed analysis of WEST experiments supported by numerical modeling performed with the transport code SOLEDGE-EIRENE providing a clear picture of the impact of light impurities to W sources from divertor and main chamber PFCs.
SOLEDGE [2, 3] is a unique numerical tool for this kind of studies for two main reasons: firstly, it handles complex and realistic wall geometries thanks to the penalization technique allowing us to properly taking into account the interaction between the plasma and the multiplicity of objects located in the vessel. Secondly, with the recent implementation of multi-fluid collisional closure [4] it is now possible to estimate properly the parallel dynamics and poloidal distribution of light impurities in the edge and SOL plasmas, determined by the competition between thermal gradient and friction forces, without relying on the trace approximation.
We focus on a series of shots related to the experiment on "High power test of ITER-like plasma-facing components, exposure of pre-damaged PFC", supported by the EUROfusion program. During these discharges, 4MW have been injected for about 5s, in lower single null, L-mode plasmas with 2.3MW of total radiated power, 4*10^19 m-2 of central line integrated density and plasma current of 500 kA with a height of the X point of about 115 mm above the lower divertor target plate. From experimental analysis it was clear that important contributors to W sputtering are oxygen but also carbon which comes probably from antennas limiters and lower divertor W-coated PFCs [5].
The input parameters for SOLEDGE simulations are the separatrix density at the outer mid-plane and the total injected power into the simulation domain that have been obtained combining measurements from reciprocating Langmuir probe, fast-sweep reflectometry and bolometry diagnostics. Radial transport coefficients for plasma density and temperature have been settled to D = 0.3m^2/s and χ = 1m^2/s respectively, values from which the SOL width recovered in the simulations is in agreement with the one measured in WEST experiments. The simulations results are then analyzed comparing density and temperature profiles at the lower divertor targets with experimental data from locally embedded Langmuir probes as well as the total radiated power with respect to the one obtained from bolometry measurements. In order to determine the percentage of light impurities present in the discharge, we consider simulations with oxygen as an effective medium Z charge impurity for sputtering. A parametric scan on oxygen concentration is performed, assuming from 1% to 4% of oxygen injected in SOLEDGE at the inner boundary of simulation domain. The simulations with 2% of oxygen are the ones matching quite well both divertor target profiles as well as total radiated power (see Fig.1).

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To go further into the simulation/experiment comparison we look at the poloidal distribution of oxygen. The simulation results show a strong asymmetry between oxygen concentrations at the inner divertor target with respect to the outer one. This asymmetry has been measured in the experiments thanks to the WEST Vacuum UltraViolet (VUV) spectroscopy system with a moving line of sight in the poloidal plane, allowing one to retrieve the relative information on the angular position of the oxygen light emission.

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The detailed force balance analysis on simulation results shows that thermal gradient forces are stronger at the outer divertor target pushing the oxygen toward upstream location and producing its depletion in this region. This result is in agreement with O IV (O^(3+)) line from VUV spectroscopy signals, as showed in Fig. 2. We have also computed the sources of W due to sputtering from both deuterium and oxygen ions in

the series of simulations previously presented. One observers that the in-out asymmetry in W gross erosion source reverses for “oxygen-driven”vs “deuterium-driven”case. First data analysis from visible spectroscopy diagnostic confirms that for high input power the contribution from lower divertor inner target is much larger than that from outer target. Other key contributors are the baffle and antenna protection [6]. These findings are informing future plans to control these light impurities and W sources. First, to reduce the oxygen content in the plasma it will be important to continue to improve wall conditioning using both glow discharge cleaning as well as active boronization techniques. In addition, the development of a robust semi-detached divertor plasma scenario will permit to operate below the sputtering threshold of light impurities, reducing strongly W sources and opening the way to high confinement scenarios.
References:
[1] J. Bucalossi and the WEST team, 2014, Fusion Eng. Design 89, 907-912. [2] H. Bufferand et al. 2015, Nucl. Fusion 55, 053025. [3] G. Ciraolo et al, 2019, Nucl. Mat & En., 20, 100685 [4] H Bufferand et al, 2019, Nucl. Mat. & En., 18, 82. [5] G. J. van Rooij et al, 2020 Phys. Scripta, in press [6] A Gallo et al, to be submitted to Nuclear Fusion.

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