Tungsten dust ingress in WEST: an integrated modelling approach

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Summary Plasma Facing Components exposed to a plasma environment endure erosion, and the migration of the sputtered material towards specific areas is forming deposits that ultimately flake and can project large dusts to the plasma. In tungsten wall tokamaks, this process is of particular concern as the radiation losses of this metal are so high that a very limited contamination will be allowed in a fusion plant. Even in radiative divertor regimes, the plasma temperature at the main chamber wall might not be below tungsten erosion threshold [1]. This issue motivated a high fluence campaign in attached divertor regime on the WEST tokamak, where the flaking of tungsten deposits was observed to generate large dusts flying as UFOs to the plasma (see fig. 1), and impacted plasma operation by inducing MHD activity and disruptions in 17% of the cases [2, 3]. The modelling of these events appears therefore necessary for validating our understanding by integrated simulations, and anticipating their potential impact on larger tokamaks. In this work, the problem was split in two parts, one dedicated to the modelling of the dust ablation to identify the critical parameters charaterizing the tungsten source in the plasma, and the second dedicated to the evolution of the plasma discharge after the introduction of this source.The specific case of a dust of about 35µg, with benign effect on the plasma discharge but close to the boundary with disruptive cases (see fig. 2), is taken as a reference.

From the dust ingress to the tungsten source The transformation of the tungsten solid dust into an impurity source in the plasma is modelled with the DUSTTRACK code [5], with a SOLEDGE background for the SOL domain (temperature, density, neutral density and flows). The initial speed and direction of the dust is unknown, but the time rise of the bolometry signals is around 20ms for the total radiated power. The thermodynamic evolution of the dust, with transitions to liquid and gaseous phases, is shown in fig. 3 for a dust of 35µg expelled toward the confined plasma at a speed of 2 m/s. The influence of the dust direction and speed on the duration of the ablation and its depth in the plasma is investigated, as shown in fig. 4, suggesting

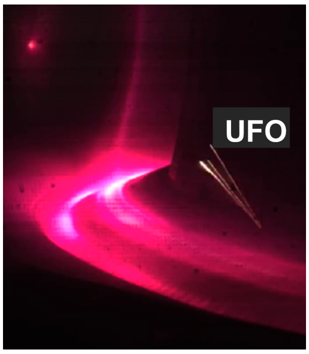

Figure 1: *Screenshot of an UFO on WEST.*

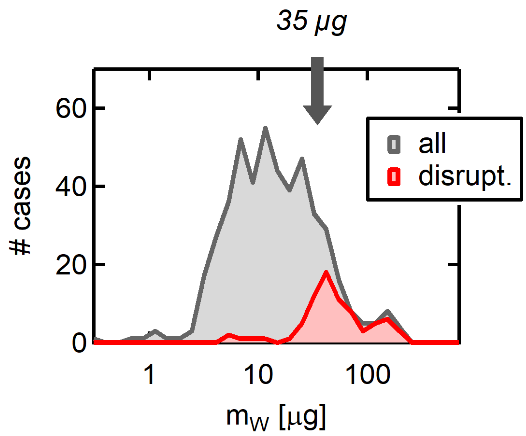

Figure 2: *Distribution of the mass of tungsten in UFOs, total and disruptive cases.*

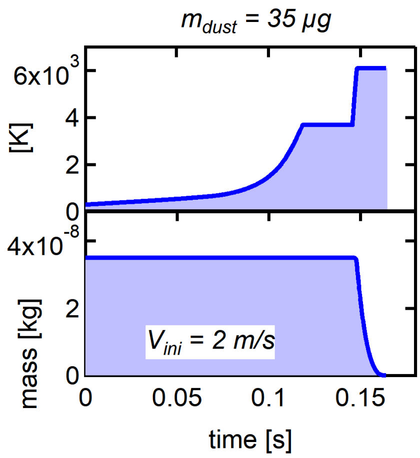

Figure 3: *Dust temperature (top) and mass (bottom) as a function of time (DUSTTRACK).*

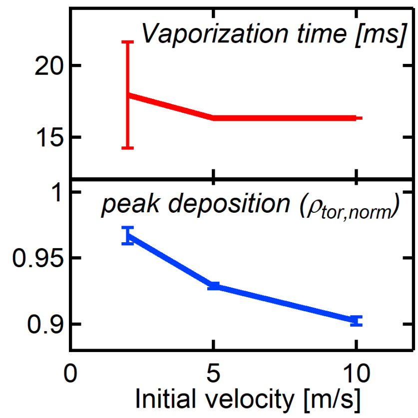

Figure 4: *Vaporization time and peak W deposition, versus the initial dust speed.*

that the duration of the source term is weakly dependent on the direction and speed of the dust, in the range 15-20 ms, close to the rise time of the total radiation. A key parameter in the transformation from liquid to vapor is the vapor pressure $P_V(T_d)$ (with T_d the dust temperature), as the mass loss rate scales as $dM_d/dt \propto P_V(T_d)$, with $P_V(T_d)$ taken from [6]. The uncertainty on this parameter directly impacts the computed duration of the source.

From the tungsten source to plasma discharge evolution The response of the plasma to the tungsten source is investigated using the High Fidelity Pulse Simulator (HFPS), a version of JINTRAC coupled to IMAS [8], and to the ITER Heating and Current Drive workflow (using the LHCD model of METIS in the present case). In an interpretative mode (only the current and are current source are evolved), it was shown that the MHD destabilization induced by

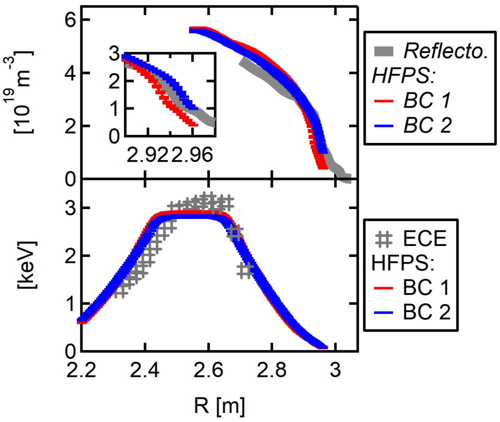

Figure 5: *Electron density and temperature profiles from reflectometry and HFPS simulations with different n_{sep}.*

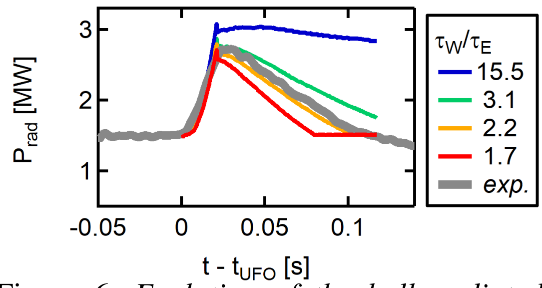

Figure 6: *Evolution of the bulk radiated power from bolometry and HFPS simulations at different W escape velocities.*

large dusts is a consequence of the large cooling of the core plasma that leads to an increase of the minimum of the safety factor and the destabilization of the 2/1 resistive MHD mode, as observed experimentally. Here, we use the HFPS in a predictive mode up to the plasma separatrix, evolving the electrons, the main ion (D), nitrogen and tungsten species, with a self-consistent plasma radiation. The electron density is controlled by gas puff with a feedback on the line integrated density, the nitrogen content is controlled by the same technique calibrated on the experimental effective ion charge, while tungsten is controlled using the bulk radiative power as a reference. Turbulent transport is modelled with TGLF [9], and neoclassical transport with NCLASS. The separatrix density and temperature is imposed by a scaling on the power crossing the SOL, based on SOLPS-ITER results, with $n_{e,sep} \propto P_{SOL}^{0.55}$ and $T_{e,sep} \propto P_{SOL}^{0.34}$ [10], in order to relate the edge condition to the expected variation of the separatrix power that follows the dust ingress.

In the pre-UFO phase, the simulation is found to be in fair agreement with the experiment, in terms of temperature and density profiles, when using the SAT1 saturation rule, while a correction of the trapped-passing boundary by a factor 0.4 is needed with the SAT2 saturation rule, pointing to a possible disagreement in the collision operator model, that remains to be understood. The separatrix density is found to have little impact on the core confinement in the controlled scheme that is used (see fig. 5). The dust ingress is modelled as a gaussian tungsten source applied in the edge region for a duration consistent with the DUSTTRACK result, i.e. in the range 10-20ms, with an amplitude corresponding to a tungsten content of about 35µg. The tungsten confinement time is controlled by an escape velocity at the separatrix, and the

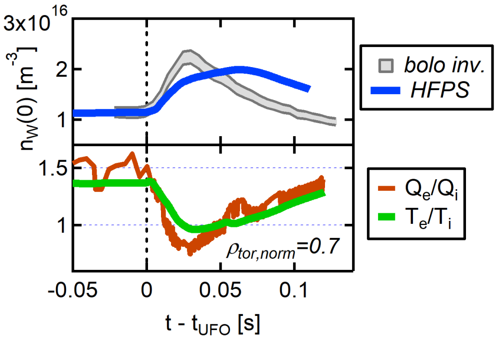

Figure 7: *Core W density evolution, T_e/T_i and Q_e/Q_i at $\rho_{tor,norm} = 0.7$.*

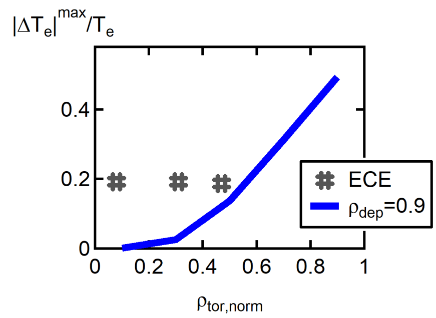

Figure 8: *Relative T_e variation during the UFO from HFPS simulations and ECE diagnostic.*

decay rate of the radiated power is used to calibrate this parameter. We find that a good match is obtained for a tungsten confinement time about twice the energy confinement time (see fig. 6), a value that is consistent with experimental evaluations in no ELM regimes [11].

The impact of the dust ingress on the confined plasma is also evaluated from the core tungsten concentration, that shows a similar increase but on a slower time scale compared with bolometry signal inversion (fig.7). The ratio of electron to ion heat flux and temperatures decrease during the event in the direction of an ITG-dominated regime, as observed in LBO events [12]. The propagation of the electron temperature variation is however strongly attenuated far from the plasma edge, in contrast with ECE measurements (fig. 8). This mismatch could be related to either the accuracy of the turbulent transport model, or to the underestimate of the pinch velocity at high collisionality in NCLASS, (the inward pinch computed with FACIT [13] is larger by a factor of two). Further investigations are therefore needed to fully capture the plasma response to medium size dust ingress, and explore disruptive events.

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