

Modelling helium plasma-wall interaction: tungsten erosion and impurity transport in the ASDEX Upgrade tokamak



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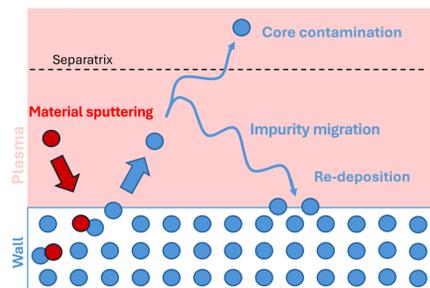
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Simulating first wall erosion and impurity transport in tokamaks

Introduction to plasma-wall interaction

- Plasma exposed material undergoes erosion, limits plasma facing components lifetime [1]
- Eroded impurities contaminate main plasma or redeposit on wall, altering its properties



Motivations...

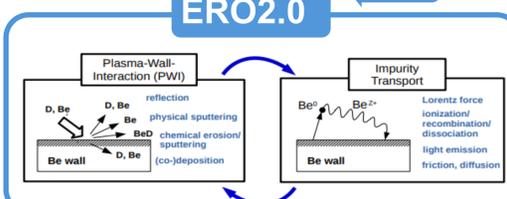
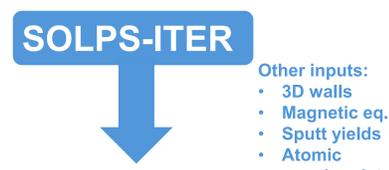
- **Modelling** of erosion and transport is crucial to support interpretation of experiments in complex systems such as tokamaks
- **Helium (He)** produced by D-T fusion reaction is unavoidably present in fusion plasmas and its influence on plasma-wall interaction (PWI) must be assessed through dedicated experiments

...and goals

- **Simulate** through state-of-the-art codes the physics of **edge plasma** and the **erosion and transport** processes experienced in the full tungsten (W) **ASDEX Upgrade** tokamak across a **full He plasma** campaign [2], comprised of low and high confinement discharges (**L- and H-mode**), evaluating:
 - Agreement of plasma simulations with Langmuir probe data and erosion simulations with available divertor marker erosion data
 - Influence of modelling assumptions (He flux charge states composition, intrinsic impurities %) on erosion results

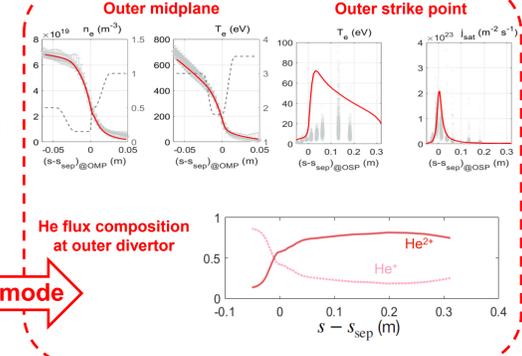
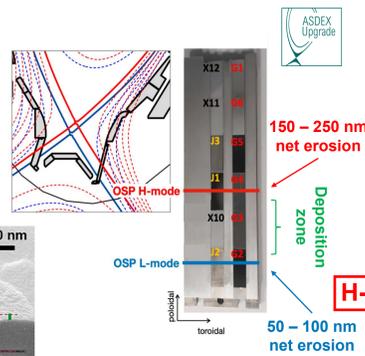
Methods: ERO2.0-SOLPS-ITER code coupling

- Edge plasma conditions simulated through 2D mean field boundary plasma code SOLPS-ITER [3]
- Result is a fixed background plasma used as input to 3D Monte Carlo ERO2.0 [4] simulations
- ERO2.0 follows 2-steps workflow: erosion calculation and transport tracing



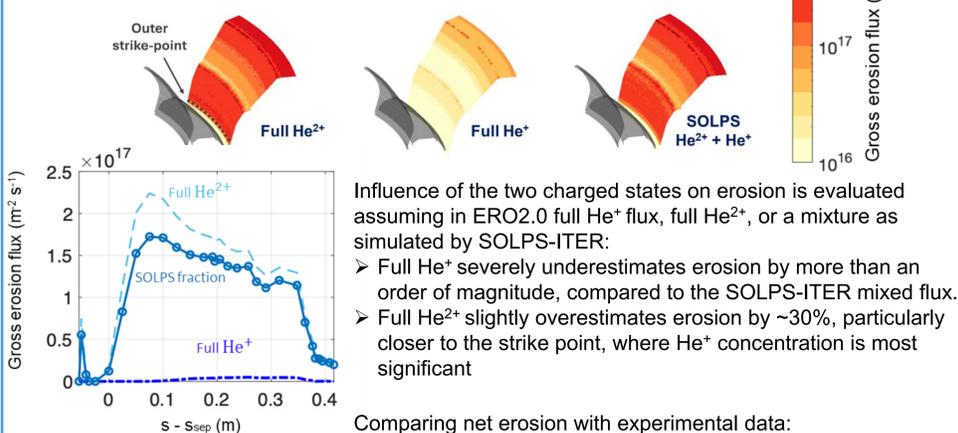
The He plasma campaign in ASDEX Upgrade

- Strike points slightly displaced to disentangle effects on divertor of the two regimes
- Net erosion experimental data available for the outer divertor, in proximity of outer strike point (OSP) [5]
- L- and H-mode background plasma obtained by benchmarking SOLPS-ITER simulations with Langmuir probes data, retrieving also He⁺/He²⁺ ion flux composition, which show He⁺ mostly present at OSP (~50%)



Erosion modelling results in L-mode

The role of He charge states on W erosion



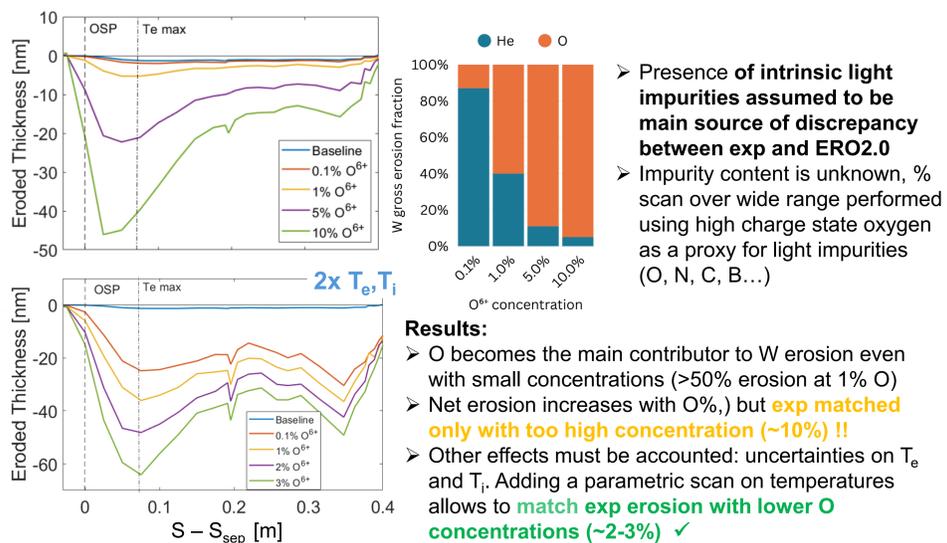
Influence of the two charged states on erosion is evaluated assuming in ERO2.0 full He⁺ flux, full He²⁺, or a mixture as simulated by SOLPS-ITER:

- Full He⁺ severely underestimates erosion by more than an order of magnitude, compared to the SOLPS-ITER mixed flux.
- Full He²⁺ slightly overestimates erosion by ~30%, particularly closer to the strike point, where He⁺ concentration is most significant

Comparing net erosion with experimental data:

50-100 nm Exp net erosion vs **~1 nm ERO2.0 net erosion** **Needs improvement !!**

The role of intrinsic impurities



➤ Presence of **intrinsic light impurities assumed to be main source of discrepancy between exp and ERO2.0**

➤ Impurity content is unknown, % scan over wide range performed using high charge state oxygen as a proxy for light impurities (O, N, C, B...)

Results:

- O becomes the main contributor to W erosion even with small concentrations (>50% erosion at 1% O)
- Net erosion increases with O%, but **exp matched only with too high concentration (~10%) !!**
- Other effects must be accounted: uncertainties on T_e and T_i. Adding a parametric scan on temperatures allows to **match exp erosion with lower O concentrations (~2-3%) ✓**

Erosion modelling results in H-mode

He charge states

He⁺ influence lower than L-mode: full He²⁺ flux good approximation of real flux composition

The role of intrinsic impurities

Like in L-mode, O % scan performed to fill the gap with **experimental erosion: 150-250 nm at OSP**

Net erosion increases several times, however reaching max ~35 nm erosion, with erosion peak also far from strike point.

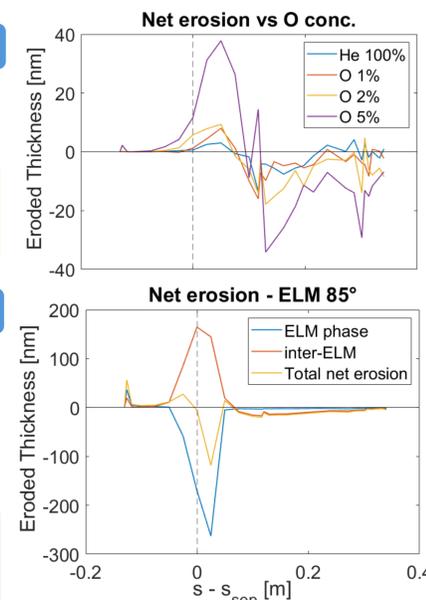
Needs improvement !!

The role of edge localized modes (ELMs)

Differently from L-mode, H-mode is characterized by periodic burst of particles and energy that dominate erosion. Modelled in ERO2.0 by imposing 1 keV He flux on OSP area, close to magnetic incidence angle. Intra-ELM and regular inter-ELM time steps are alternated

Intense net erosion during ELMs, followed by high net deposition of eroded W during inter-ELM phase. Resulting net erosion profile shows erosion peak comparable with exp clos to OSP and deposition peak inside OSP

Good agreement ✓



Conclusions and future perspectives

- Background plasma successfully produced with SOLPS-ITER for both L-mode and H-mode regimes, retrieving He charge states distributions, which showed that plasma is mostly He²⁺ with relevant He⁺ presence at the strike points
- Erosion by He⁺ less important compared to He²⁺ in both scenarios. Slightly influences gross erosion at OSP in L-mode, almost negligible in H-mode.
- L-mode experimental erosion only matched by assuming presence of intrinsic impurities (represented by O). More realistic agreement obtained when assuming combination with other uncertainties, such as higher temperatures
- H-mode experimental erosion matched when including description for edge localized modes transients in the modelling

- Validate W migration simulation results by comparing with W density in plasma measures (e.g. from bolometry)

References

- [1] Roth J. et al, J. Nucl. Mater. (2009) 390-391 1-9
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- [3] Bonnin X. et al, Plasma Fusion Res. 11 (2016) 1403102
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This work has been carried out within the framework of the EUROfusion Consortium (WP-PWIE), partially funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200—EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Part of this work is funded by Eni S.p.A. in the framework of the Contract N. 4400010490.

