EUROfusion

E-TASC General Meeting
11-15 November 2024, Max Planck IPP

TSVV-07: PLASMA-WALL INTERACTION IN DEMO

Task Wiki Contact PI

INTRODUCTION

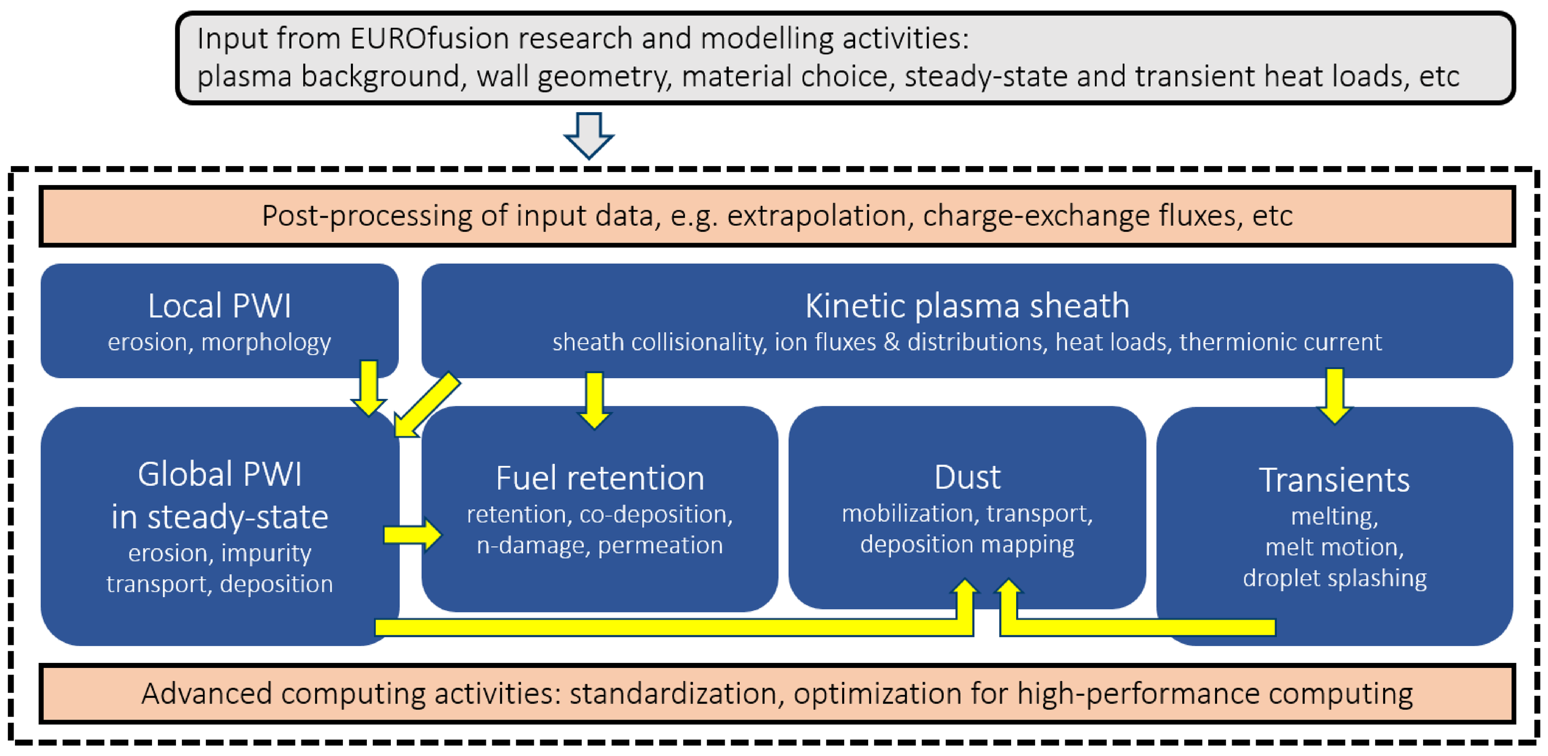
Objectives and structure

Assessment of plasma-wall interaction (PWI)

- Steady-state W erosion rates
- Preferential W re-/co-deposition locations
- Dust mobilization, survival and accumulation
- PFC response to transients: melting, splashing
- W erosion for locations affected by transients
- Tritium inventory: co-deposition, bulk retention

Project overview paper

D. Matveev et al, Nucl. Fusion 64 (2024) 106043



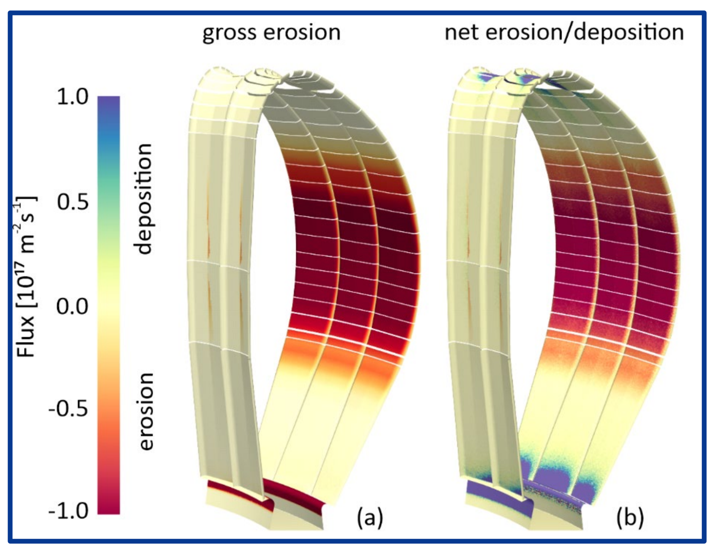
Codes & model development

ERO2.0 → PWI & impurity tracing
MIGRAINe → dust transport
MEMENTO → transient melting
BIT-1 → high density divertor sheath for ERO2.0
SPICE → thermionic emission for MEMENTO
→ heat & particle fluxes to shaped PFC
FESTIM / TESSIM → T retention & permeation
SDTrimSP / MD → erosion yields, surface effects
\+ preparing tools for uncertainty quantification (UQ)

HIGHLIGHTS

(I) Erosion-deposition mapping with ERO2.0

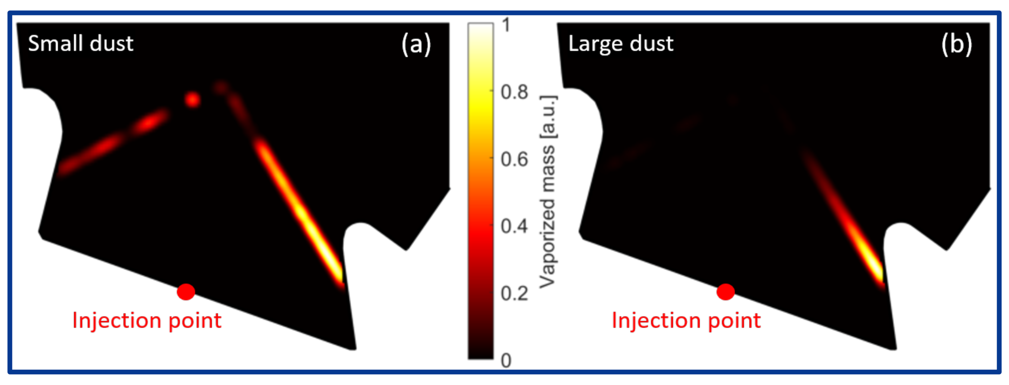
- Using baseline 2017 equilibrium with SOLPS-ITER plasma background (F. Subba, DCT)
- Extrapolation of plasma solution to the wall – major source of uncertainties
- Charge-state resolved background impurities fluxes and energy-resolved charge-exchange (CX) D fluxes
- Main wall erosion dominated by CX fluxes and divertor by seeding species
- **Work in progress:** high density divertor sheath, improved sputtering data and thermal force



(a) Gross W erosion; (b) net erosion-deposition

(II) Dust remobilization and transport scenarios with MIGRAINe

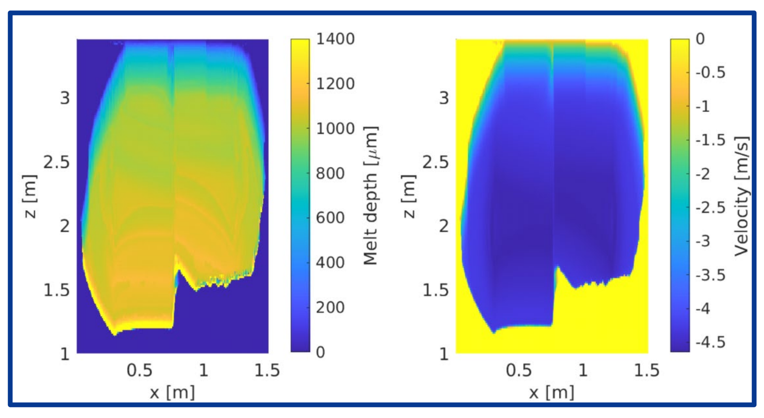
- Baseline 2017 equilibrium with SOLPS-ITER plasma background
- Tracing dust with pre-defined grain size distributions and starting speeds
- Injection sites in the private flux region
- Vaporization dominant for small grains, localized along separatrix
- **Work in progress:** other injection sites according to ERO2.0 deposition maps, iteration of single-discharge results to predict long-term inventory evolution



W dust evaporation maps :
(a) Small dust (5-20 µm)
(b) Large dust (30-50 µm)

(III) Simulations of transient melting with MEMENTO

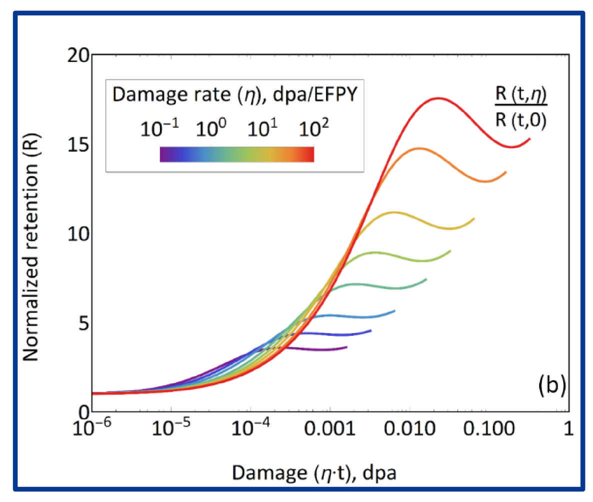
- Thermionic electron emission scaling laws provided by dedicated PIC simulations
- 65 GW/m² thermal quench (TQ) for 4 ms leads to negligible melt displacement
- 300 MW/m² current quench (CQ) for 200 ms with TQ-overlapping wetted area leads to
  - sustained melt pool of ~1 mm thickness
  - likely splashing at PFC edges
- **Work in progress:** spatiotemporally varying CQ heat fluxes provided by WPDES lead to strong reduction of melt volume, but splashing is still possible



Melt during upper VDE with overlapping TQ and CQ

(IV) Tritium retention and permeation with TESSIM and FESTIM

- Soret effect reduces T inventory and time to steady-state retention
- 3D effects for divertor monoblocks:
  - Outgassing at side surfaces reduces retention
  - Surface limited recombination reduces baking efficiency
- New model for neutron-induced traps and retention/permeation at first wall :
  - n-damage can increases retention by orders of magnitude, at the same time reducing the permeation flux
- **Work in progress:** H trapping at He clusters, uncertainty quantification methods



Retention in W monoblock as a function of neutron damage and damage rate

PROGRESS AND ACHIEVMENTS

✓ Developed and integrated new models into the involved codes that are now ready to reliably address PWI in reactor-scale devices
✓ Achieved most of milestones for 2021-2024 and will continue the work in 2025 according to plan (with adjustments)
✓ Highlighted and partly addressed the lack of input data: plasma-to-wall extension, CX distributions, transient heat loads and plasma profiles, high density sheath physics

OUTLOOK AND PERSPECTIVES

Capitalize on dedicated experiments under WPTE to perform focused validation effort ✓ **to advance through collaboration with WPTE**

- Validation of steady state erosion in full W device with relevant divertor geometry and impurity seeding: ERO2.0 in AUG experiments (WPTE 2025 proposal submitted)
- Validation of dust evaporation and impurity deposition: MIGRAINe + ERO2.0 workflow in AUG boron powder injection experiments (WPTE 2025 proposal submitted)
- Validation of thermo-mechanical response of W PFCs under runaway electrons (REs) loading: GEANT4 + MEMENTO (+ LSDYNA) (WPTE 2025 proposal submitted)

Address the frontier problem of PFCs damage by runaway electrons (REs) created during disruptions ✓ **to advance through collaboration with TSVV9**

- High sensitivity of PFCs response to details of REs impact characteristics – such information can be obtained only from nonlinear MHD codes such as e.g. JOREK
- Modelling of explosive response of W PFCs under REs loading: GEANT4 (energy deposition) + MEMENTO (heat transfer) and later LSDYNA (flow and fragmentation)

Expand the codes with reactor-relevant physics beyond the initial project scope ✓ **to advance through collaboration with WPPWIE**

- Effect of multiple isotopes on wall erosion and fuel retention/permeation to allow for predictive simulations of reactor start-up and cleaning sequences
- Elaborating the neutron damage model from phenomenology to physics and accounting for the role of thin deposited layers on permeation
- ERO2.0 coupling to core transport codes and addressing edge turbulent transport effects on PWI ✓ **to advance through collaboration with TSVV4 and TSVV6**

Towards DEMO and beyond

- Framework test applications (VNS, DTT, BEST, …) and development of surrogate models for iterative design-cycle applications with fast turn-around times

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