EUROfusion

Retention and permeation modelling: mechanical and He effects; cross-code validation

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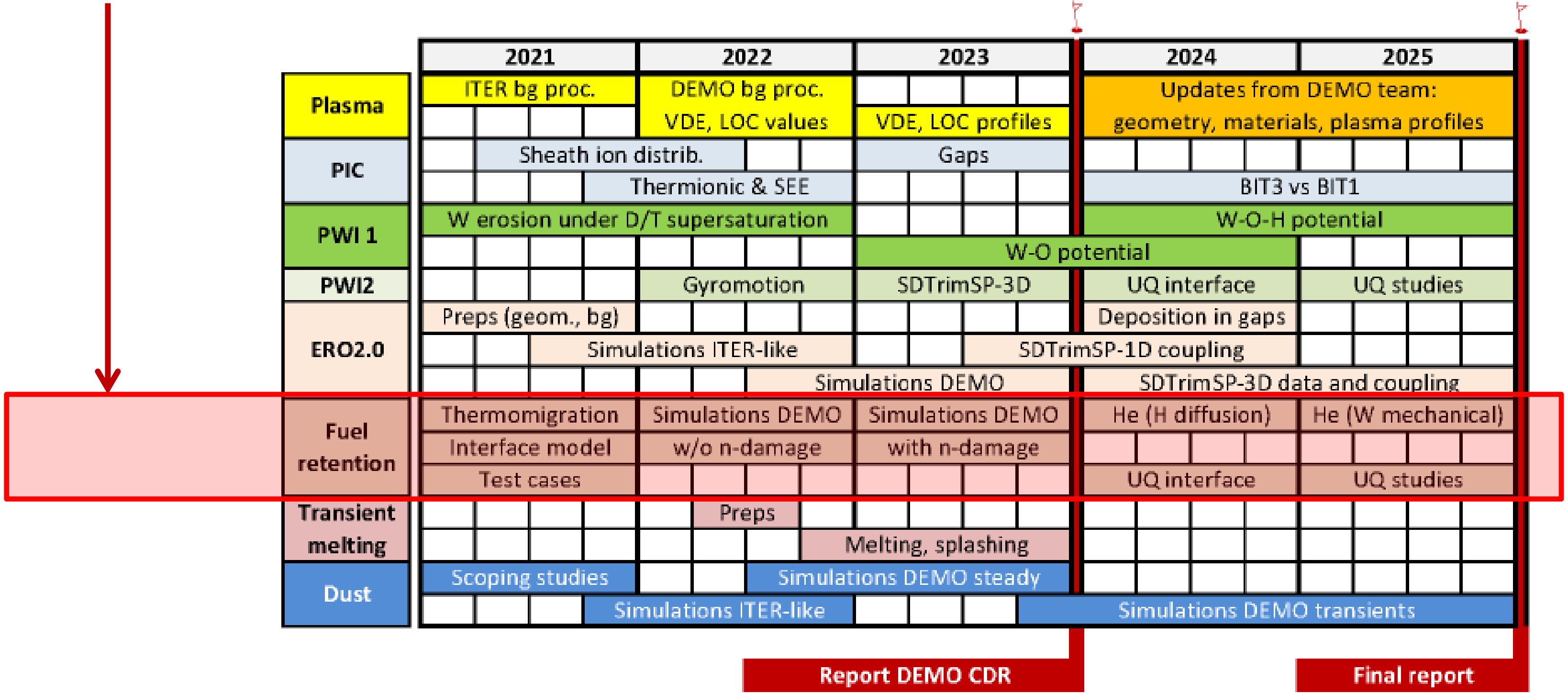
Fuel retention task

One of the TSVV#7 objectives: **Assessment of tritium in-vessel inventory (co-deposition, bulk retention with He-induced and neutron damage)**



Inventory in subsurface and bulk

Plasma

Co-deposition / Oxydes

Ions & He damages zone
Bubble & Blisters 2D/3D

Bulk 2D/3D

- Neutron damages
- He production
- Mechanical stresses

Surface &
Subsurface
(nm to µm)

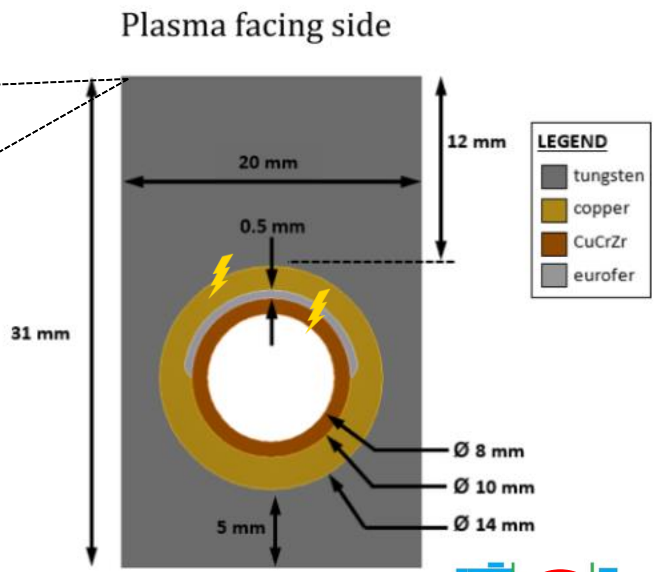
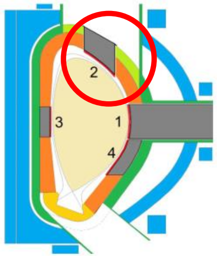


Fig. 2. Monoblock cross-section for up



Vizvary *et al.* Fusion Engineering and Design **158** (2020) 111676

Boundary conditions
(depend of simulation level)

Interfaces

Geometry / Interfaces
Scenarios (exposure, temperature…)
Material properties (diffusion, trap, solubility)

Three existing model to adress issues

Based on the resolution of a reaction-diffusion model (McNabb & Foster, TMAP…) including transient trapping

MHIMS code

Fortran code – 1D
Finite Difference (DLSODE solver)

- **Focused on surface/subsurface effects**: non-equilibrium flux balance, supersaturated layers, coverage dependant desorption energies…
- **Multi-trapping**

Hodille *et al.*, Nucl. Fusion **57** (2017) 056002

Abaqus code

Fortran subroutines – 1D/2D/3D
Finite Element (Commercial solver)

- **Includes mechanical effects**: diffusion assisted by hydrostatic pressure & traps induced by plastic strain

Benannoune *et al.* Phys. Scr. **T171** (2020) 014011

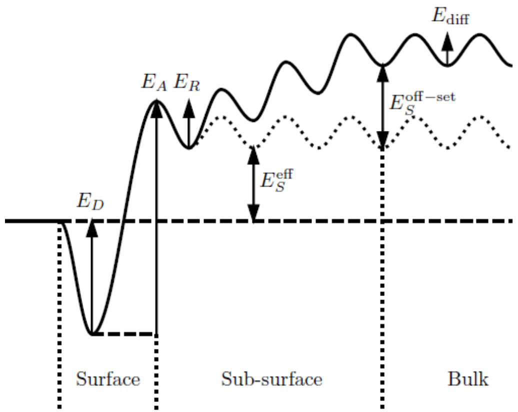
FESTIM code

Python – 1D/2D/3D
Finite Element (Fenics)

- **Tokamak scale** & high level of coupling with plasma parameters (machine learning)
- Great **optimisation of computional time**; huge effort on validation/verification processes; coupled with optimisation algorithms

Delaporte-Mathurin *et al.* Sci Rep **10** (2020) 17798

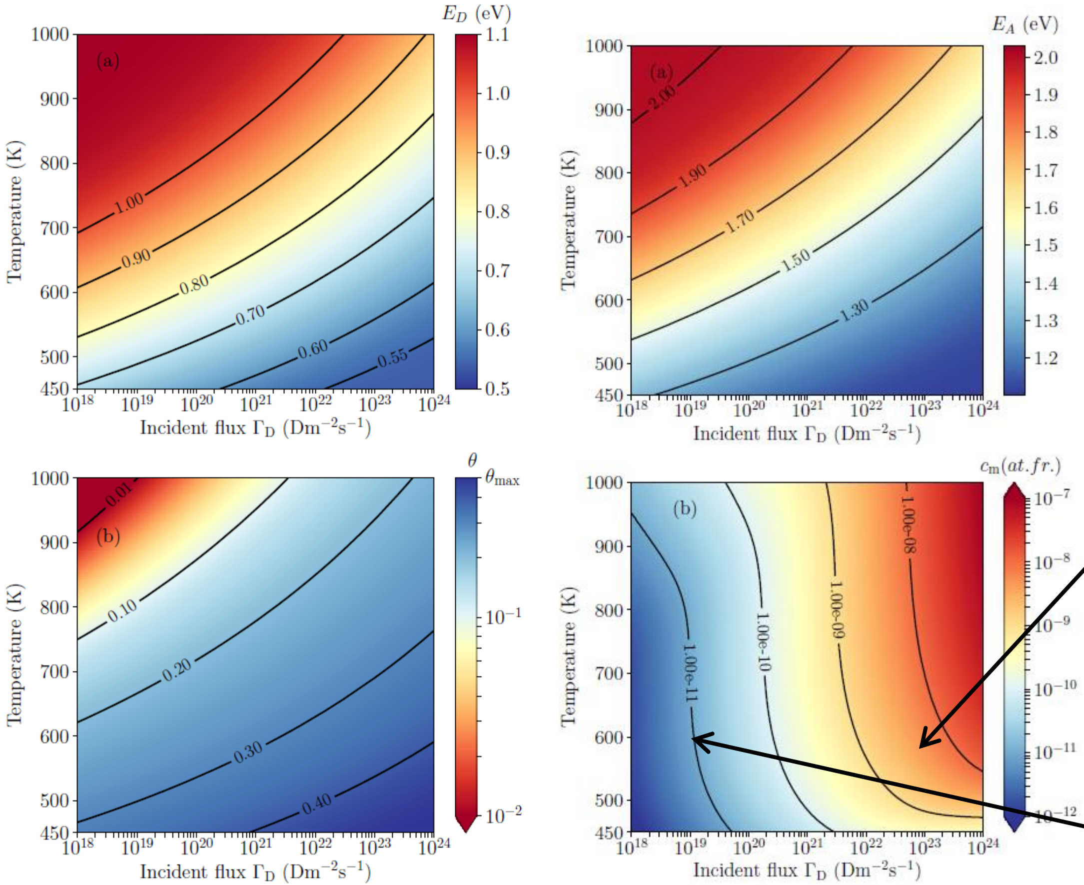
MHIMS: Coverage dependent desorption energy



Steady-state modelling to **derive coverage dependance of activation energies from 2 sets of experimental data**

E.A. Hodille *et al.* Nucl. Fusion **60** (2020) 106011

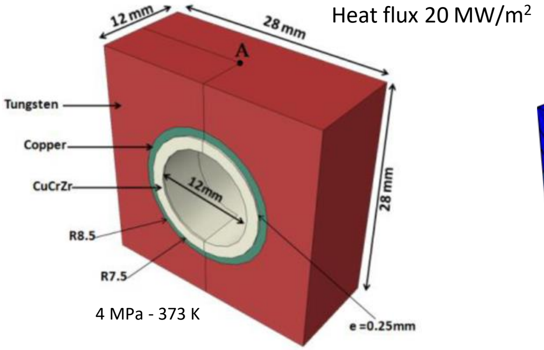
Increasing temperature leads to a Θ decrease and so to an increase of E_D

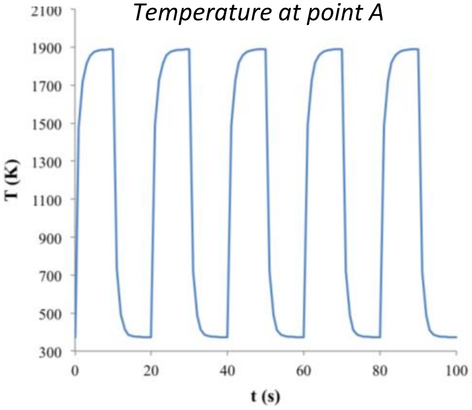


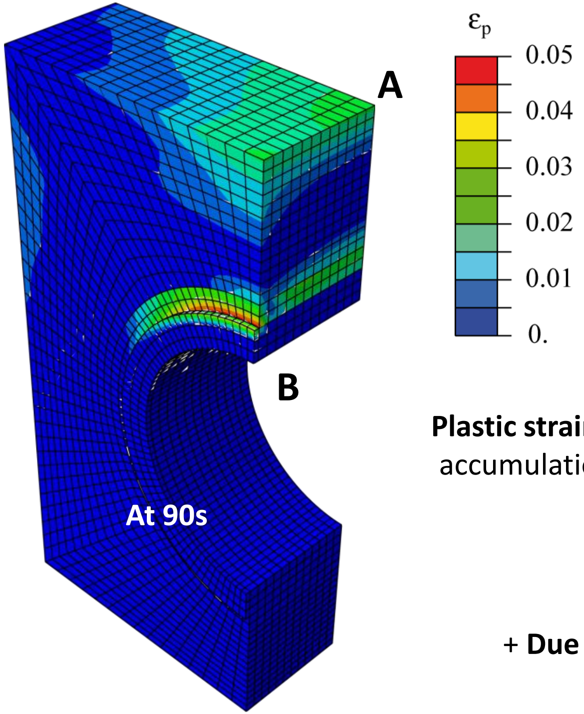
Exponential increase with temperature for a given flux where E_A is constant

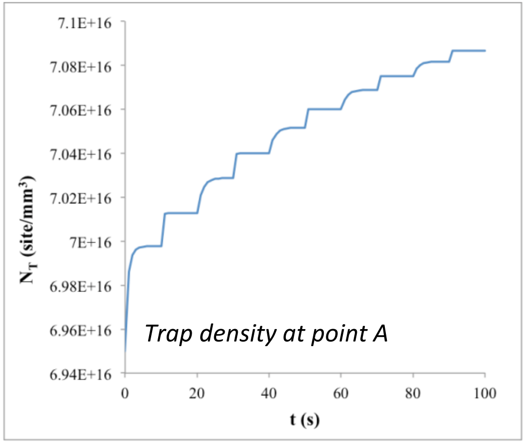
More complex shape where E_A is non constant

Abaqus: Mechanical field effect







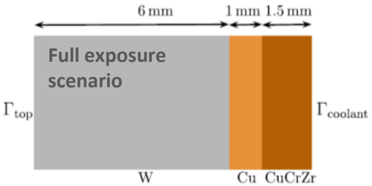


Plastic strain induced by thermal expansion with accumulation over time. Thorn singularity [3] on cooling tube at point B

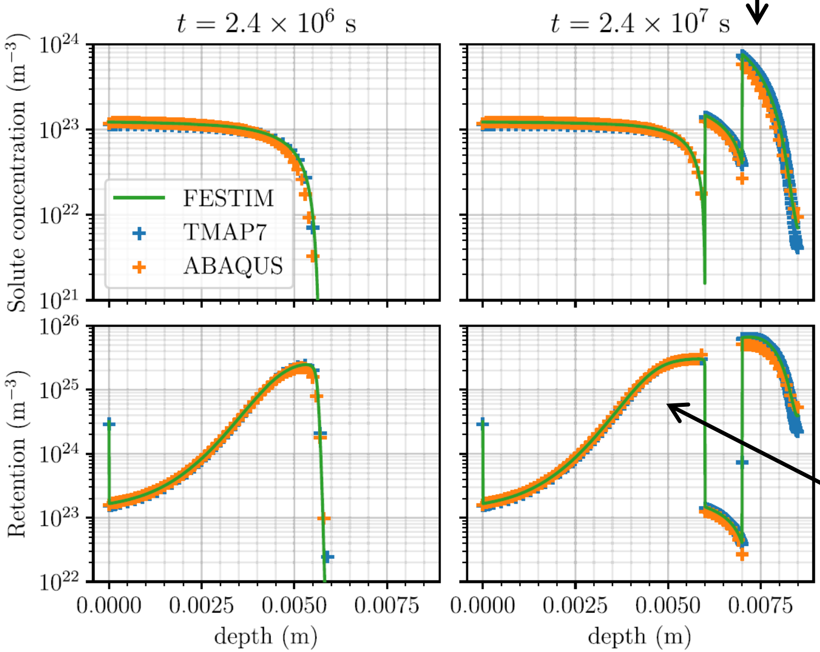
+ **Due to hydrostatic pressure, the overall diffusion is deeper**

Bian *et al.* SOFT **31** (2020)

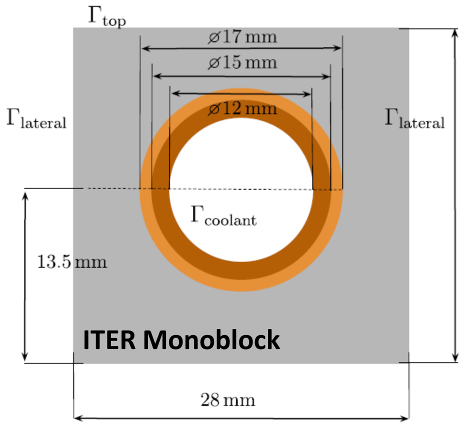
FESTIM: Interface



Chemical potential continuity induces jumps of concentration at material interfaces



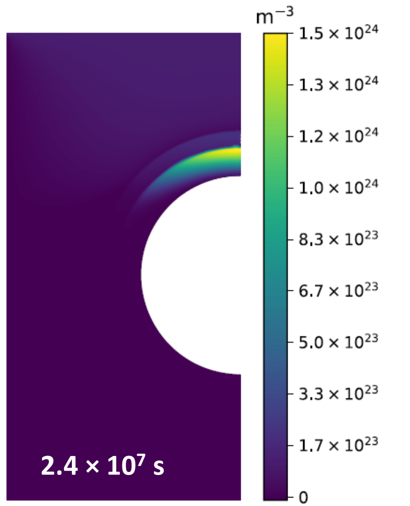
Good agreement between FESTIM; ABAQUS & TMAP results



(b) 2D geometry

Impacts on 2D calculations

Solute concentration



Delaporte-Mathurin *et al.* Nucl. Fusion **61** (2021) 036038

Work plan for 2021

Year 1: ITER-like plasma case	
M1.6	Validation of the interface model of FESTIM is completed.
M1.7	Common test cases for retention modelling are identified.
M1.8	HPC optimization requirements for the codes are identified, the respective work initiated.

M1.6 Equilibrium interface model is enough / Focus on impurities

M1.7 Based on our published case? Add thermomigration (Soret effect)?

(+) He transport model & bubble growth (*work in progress*)

M1.8 Not required for our codes

Code diffusion or restriction? (co-funded existing codes; full open source discussions)

Experimental results of diffusion across interfaces PWIE (W/Eurofer & W/Cu or others)
Interface description (graded interface? Impurities?)
Material data (Soret coefficient)

Work plan for the next years

Year 2: SOLPS DEMO solution	
M2.8	Neutron damage model with damage stabilization is implemented in FESTIM and TESSIM-X (validation not yet completed).
M2.9	TESSIM-X, MHIMS and FESTIM simulations of H retention under DEMO conditions (without n-damage) and relevant material structures are performed.
M2.10	IMAS compatibility requirements for the codes are detailed and the work is initiated.

Experimental results of neutron damage (as possible !)
Neutrons PKA and cascade damage

Year 3: Conceptual design review	
M3.7	TESSIM-X and FESTIM simulations of H retention under DEMO conditions (with n-damage) and relevant material structures are performed and cross-validated.
M3.9	Integrated results regarding W erosion (steady state and transients) and T retention for the DEMO conceptual design review are reported.
M3.10	Intermediate results on IMAS interfaces implementation are reported.

M3.9 Impacts of W erosion on the boundary conditions of MRE codes

Work plan for the next years

Year 4: Extended analysis	
M4.6	Role of He clustering on H diffusion and retention is assessed.
M4.8	IMAS compatibility is implemented.

(M4.6) He damage (traps concentration and evolution) given by He transport and bubble growth model and then included in H transport code

Year 5: Final reporting	
M5.2	Role of He clustering on mechanical properties of W is assessed.
M5.7	HPC optimization completed.
M5.8	IMAS compatibility between codes and their interfacing is complete and tested.
M5.9	Integrated results on W erosion (steady state and transients) and T retention are reported.

Questions/remarks?