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Impacts of mechanical fields on hydrogen transport in ITER divertor monoblocks

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► **To cite this version:**

Shihao Bian, Jonathan Mougenot, Yann Charles, Xavier Bonnin, Tom Wauters, et al.. Impacts of mechanical fields on hydrogen transport in ITER divertor monoblocks. 4th International Conference on Metals and Hydrogen, Oct 2022, Ghent, Belgium. . hal-03886786

HAL Id: hal-03886786

<https://hal.science/hal-03886786>

Submitted on 6 Dec 2022

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In a few words

Objective

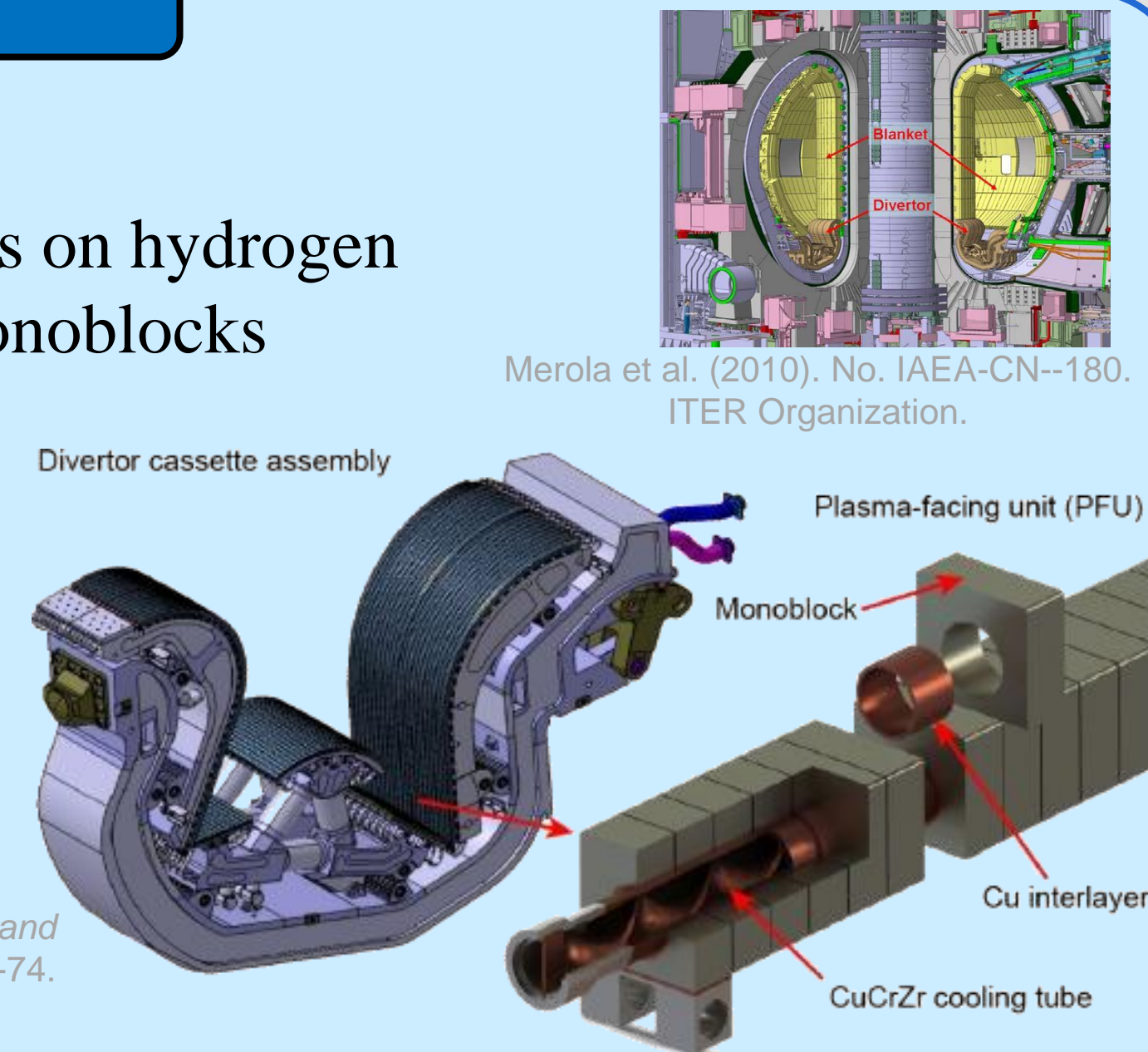
Get the role of the thermo-mechanical fields on hydrogen diffusion and retention in ITER divertor monoblocks

Method

3D finite element simulations
→ Abaqus software + User subroutines

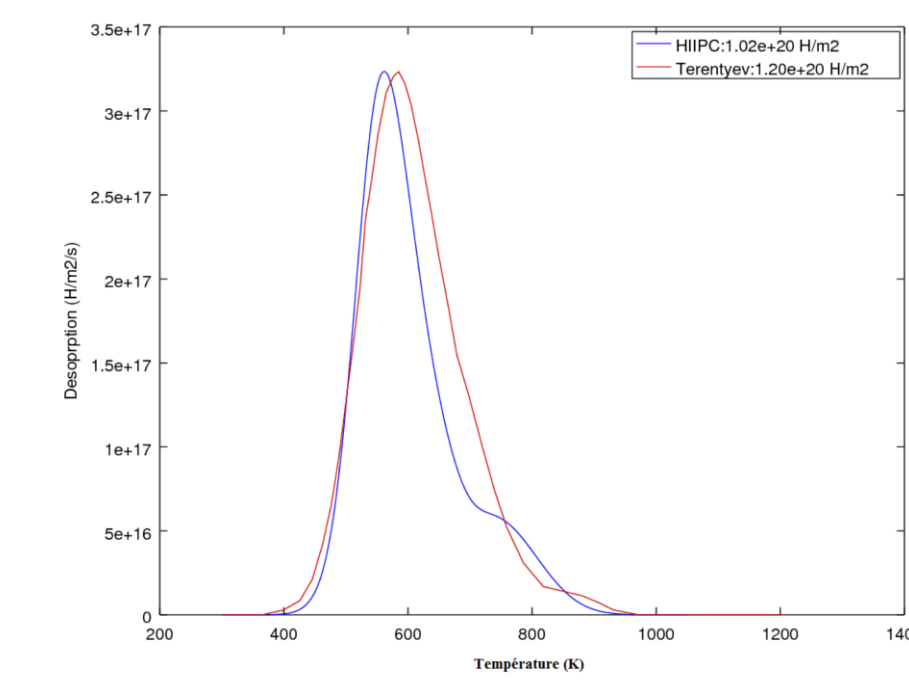
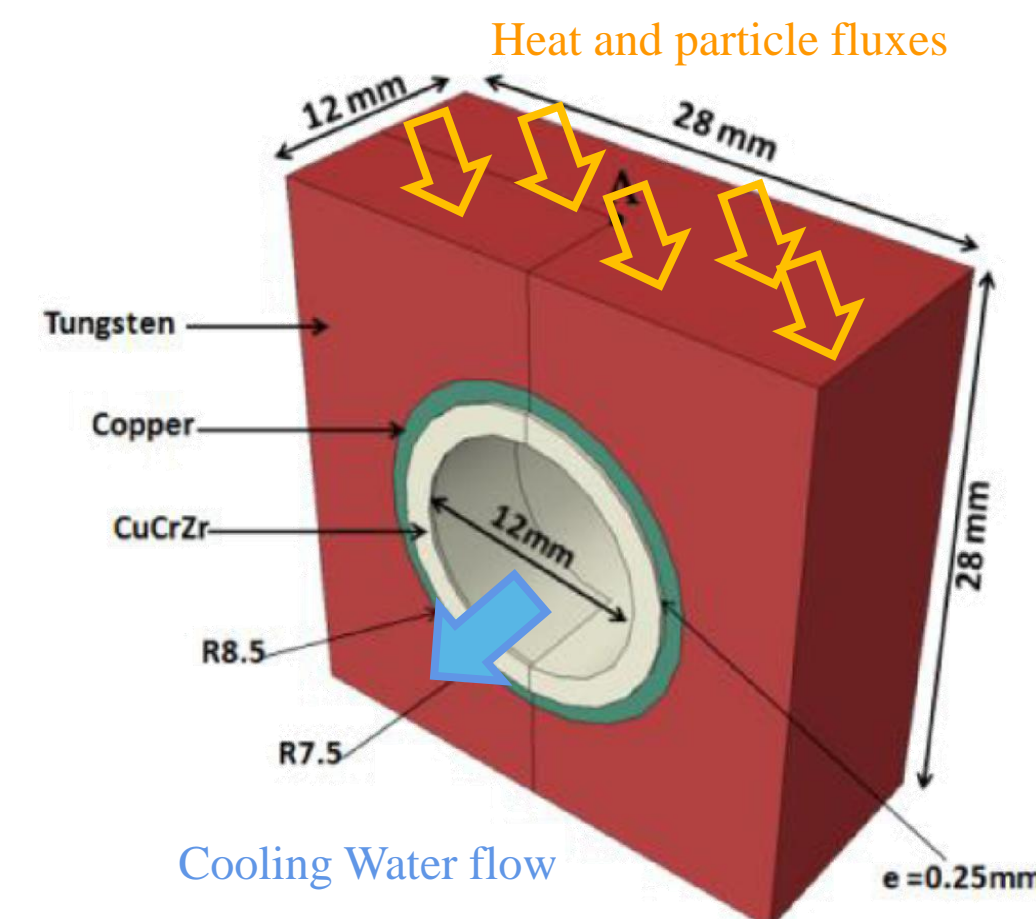
Main results

- Estimation of H retention in divertor monoblocks (10 mg)
- Estimation of the H permeated to the cooling pipes
- Estimation of the impact of the operation cycles



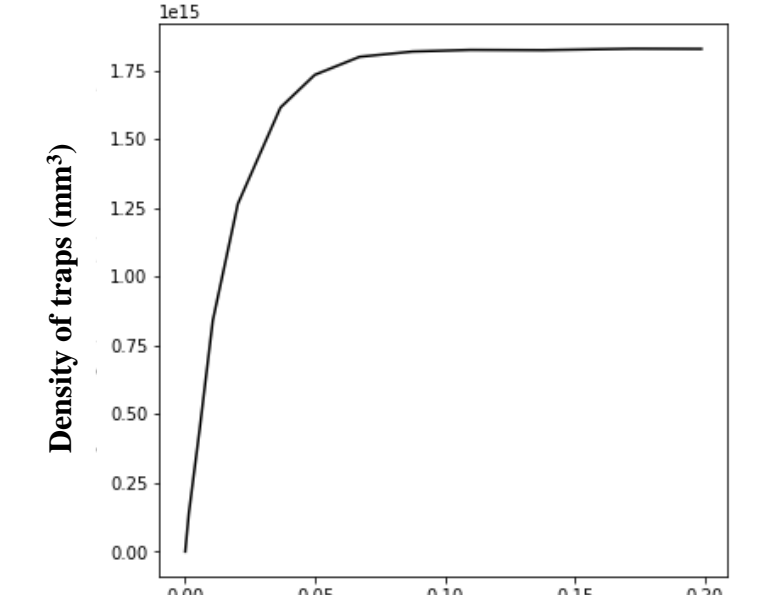
Pitts et al. (2017). Nuclear Materials and Energy, 12, 60-74.

Model and data



Terentyev D et al. (2015). Journal of Applied Physics, 117(8): 083302

Reproduction of H desorption in deformed W to determine the trap density (in traps/m³ instead of traps/m²)



Traps created by plastic strain

$$N_T^{created}(\epsilon_p) = 1.85 \times 10^{15} (1 - e^{-57.6\epsilon_p})$$

W → 2 traps

- (intrinsic): 0.87/1 eV ; 6.95 10¹⁶/3.16 10¹⁶mm⁻³
- (created by plastic strain): 0.87 eV

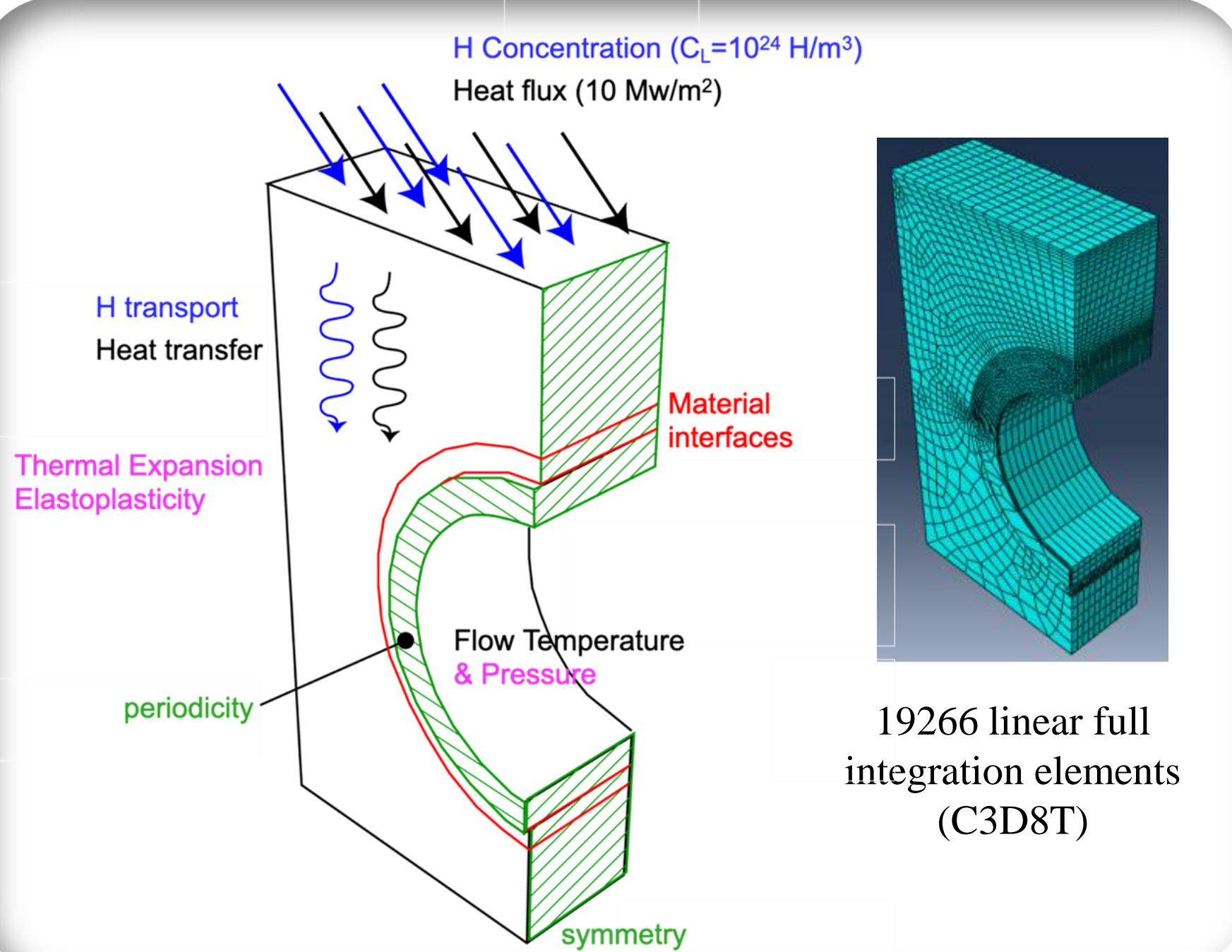
Cu → 1 trap

0.5 eV ; 4.25 10¹⁵ mm⁻³

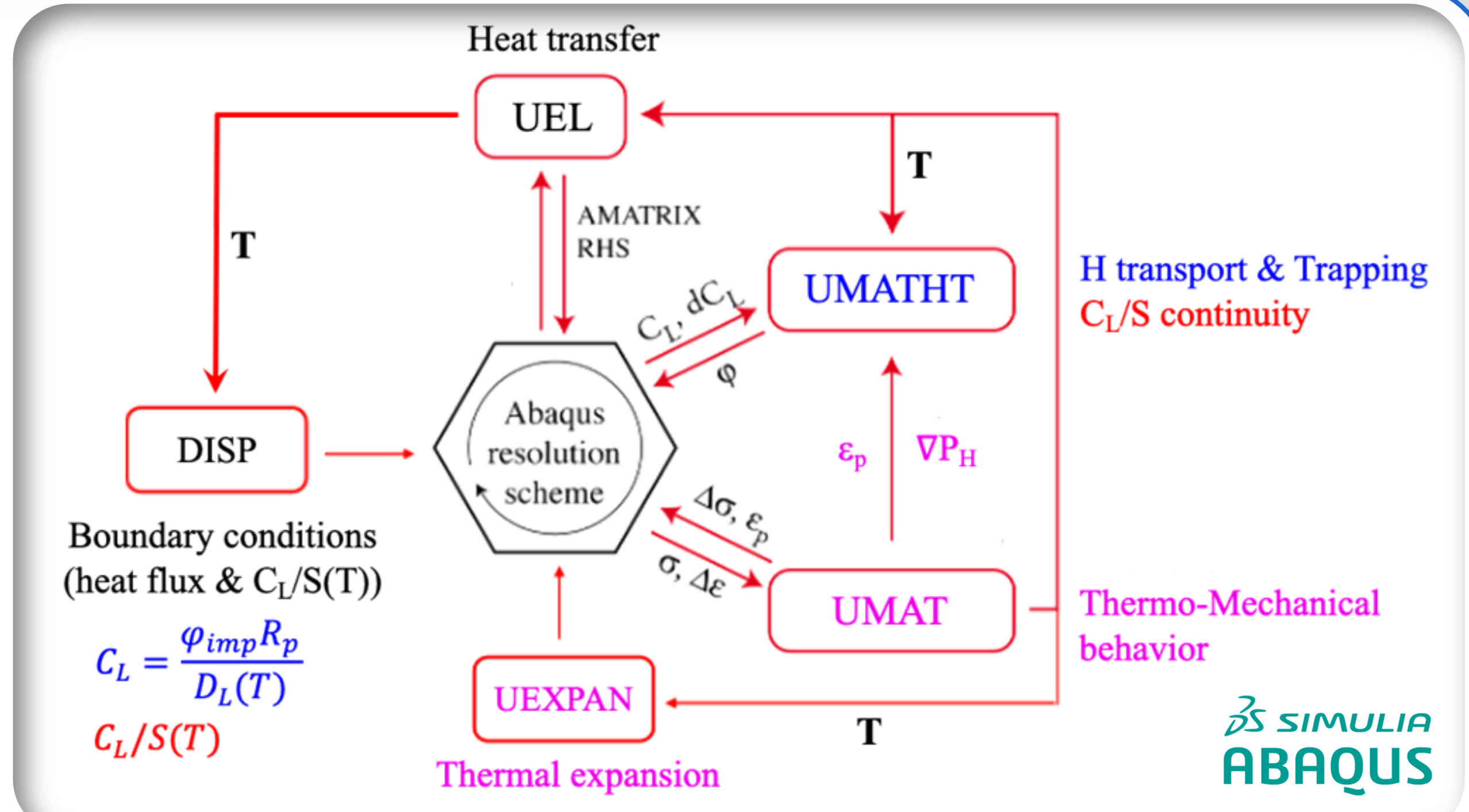
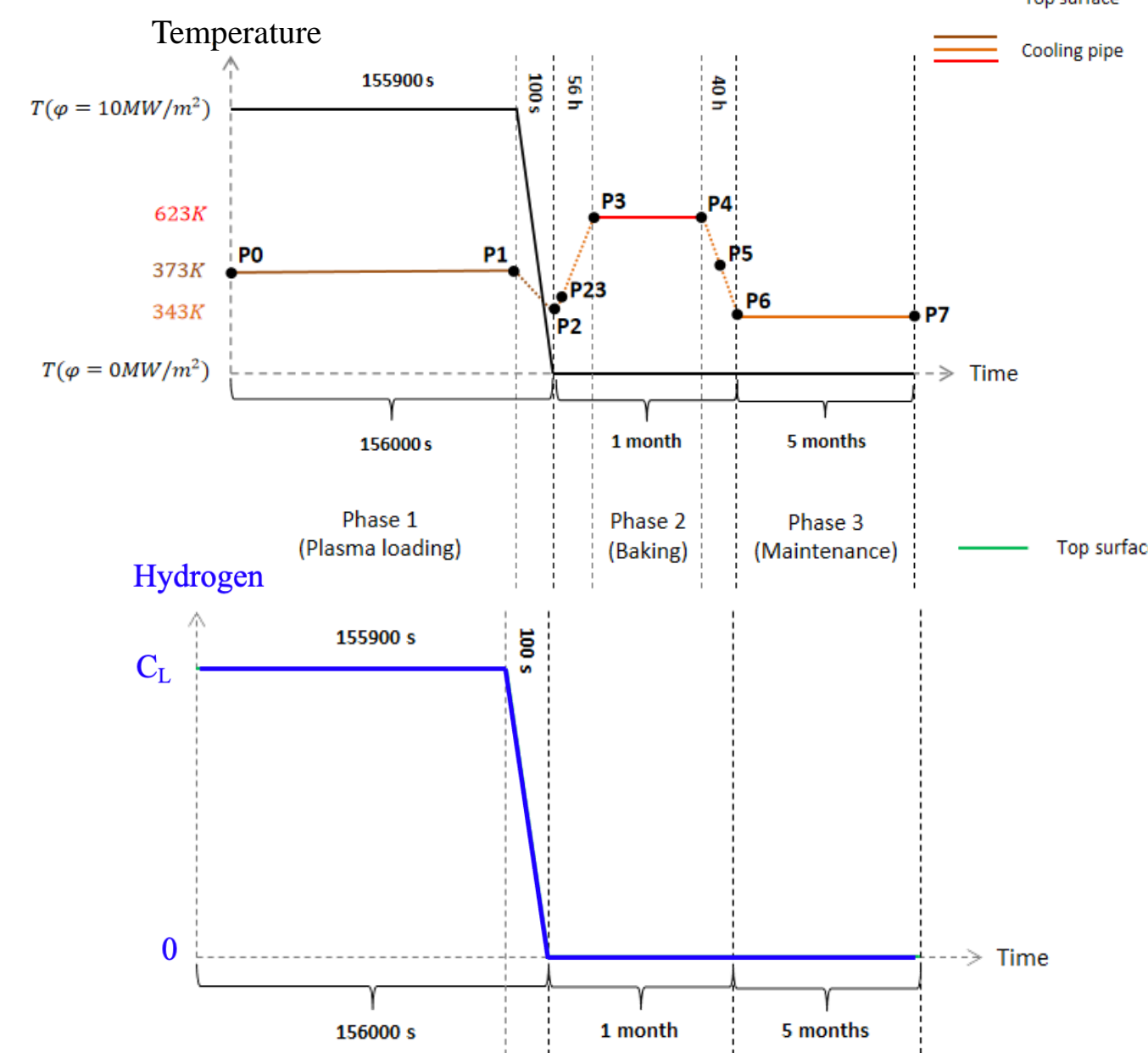
CuCrZr → 1 trap

0.85 eV ; 1.30 10¹⁵ mm⁻³

Modelling



Loading scenario



Elasticity: $E(T)$ & $\nu(T)$ Plasticity (Isotropic Hardening): $\sigma_y = \sigma_0(T) + K(T)(1 - e^{-C(T)\epsilon_p})$ Thermal expansion: $\epsilon_{th} = (\alpha(T) \Delta T)I$

H transport equation: $\frac{\partial C_L}{\partial t} + \frac{\partial C_T}{\partial t} = \nabla(D_L(T)\nabla C_L + \frac{D_L(T)V_H}{RT} C_L \nabla P_H)$ H trapping equation: $\frac{\partial C_T}{\partial t} = \frac{k}{N_L} C_L(N_T(\epsilon_p) - C_T) - pC_T$

Heat transfer: $\rho(T)C_p(T)\frac{\partial T}{\partial t} = \nabla(\lambda(T)\nabla T)$ Material interfaces: $C_L/S(T)$ continuity

$E(T)$ & $\nu(T)$: Young's modulus & Poisson ratio / σ_y : yield stress / $\sigma_0(T)$: elastic limit / $K(T)$ & $C(T)$: material parameters / ϵ_p : plastic strain / $\alpha(T)$: CTE

C_L & C_T : diffusing & trapping concentration of H / D_L : diffusion coefficient of H / V_H : molar volume of H / P_H : hydrostatic stress

k & p : trapping & detrapping parameters / N_L & N_T : density of lattice sites & trapping sites / $S(T)$: solubility of H

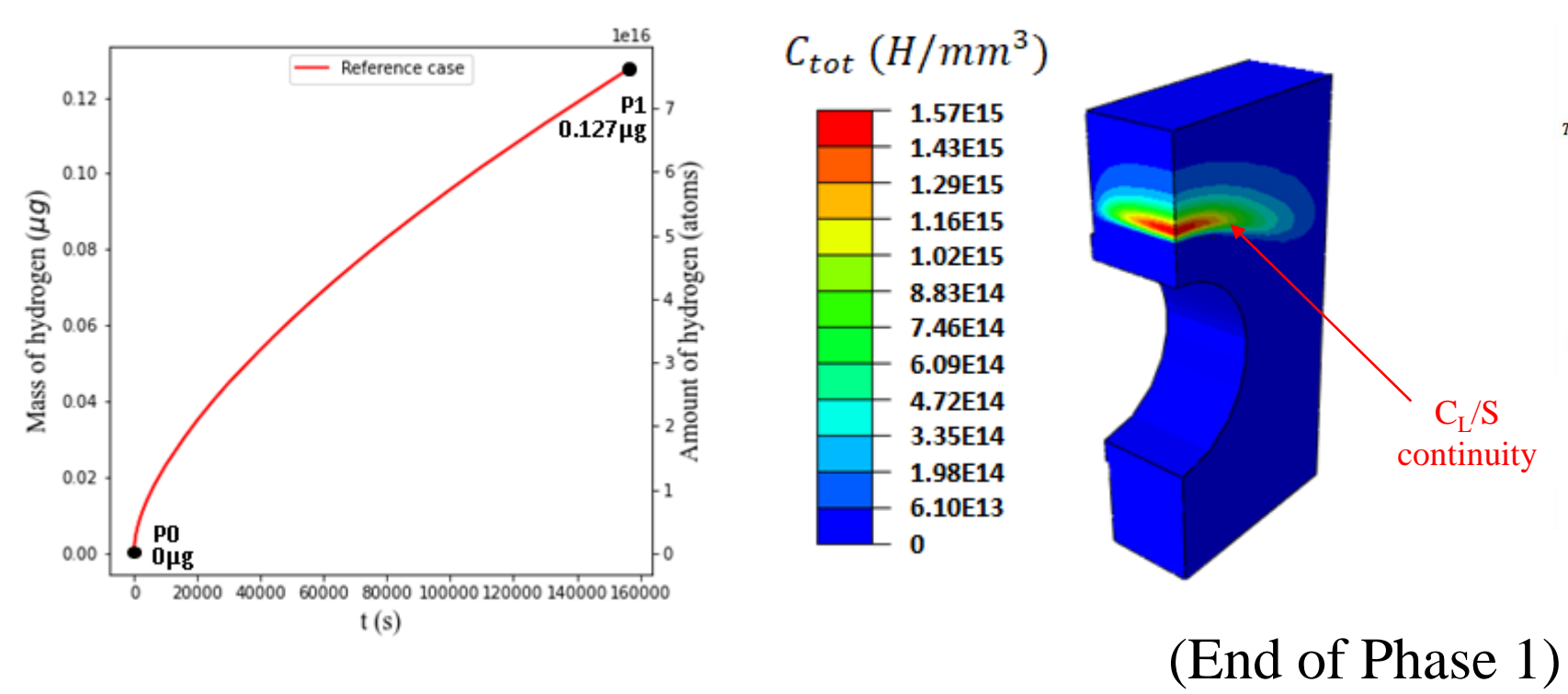
Implantation

« coupled temp displacement »

Simultaneous resolution

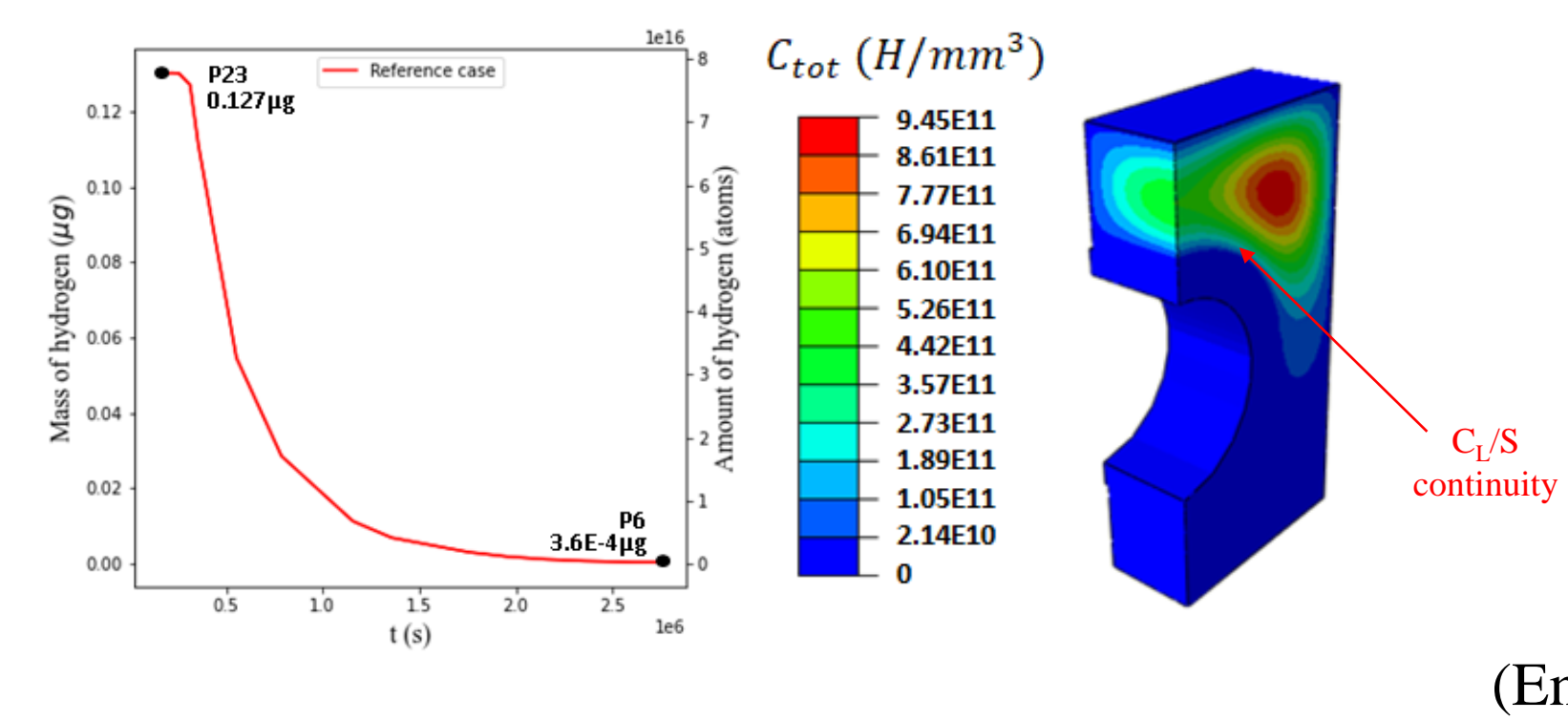
Results

Phase 1



(End of Phase 1)

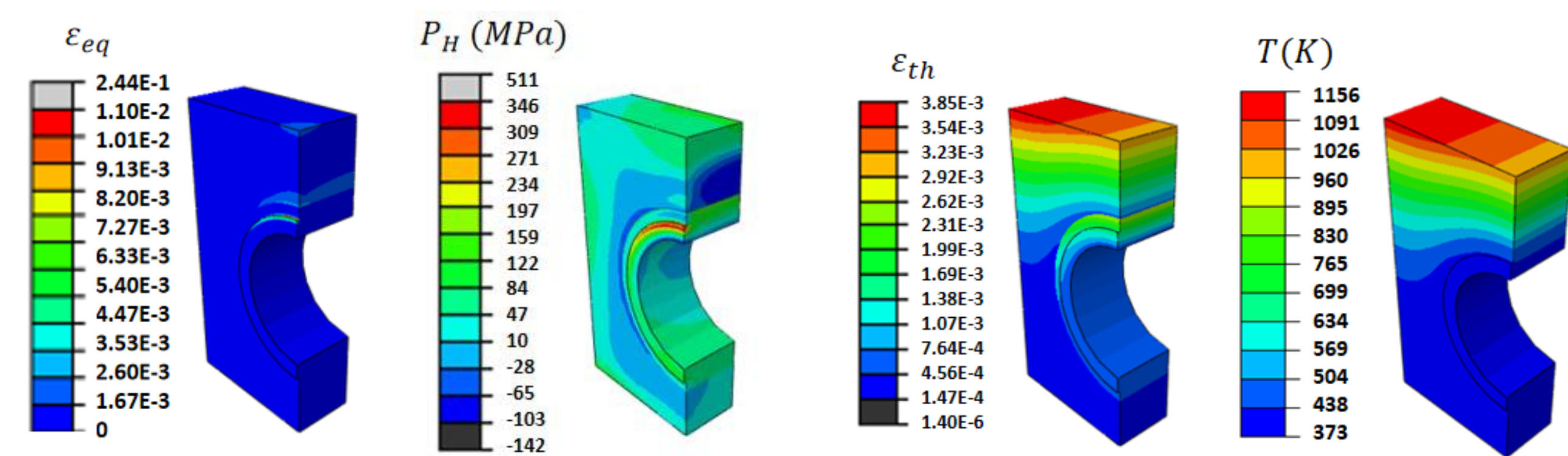
Phase 2



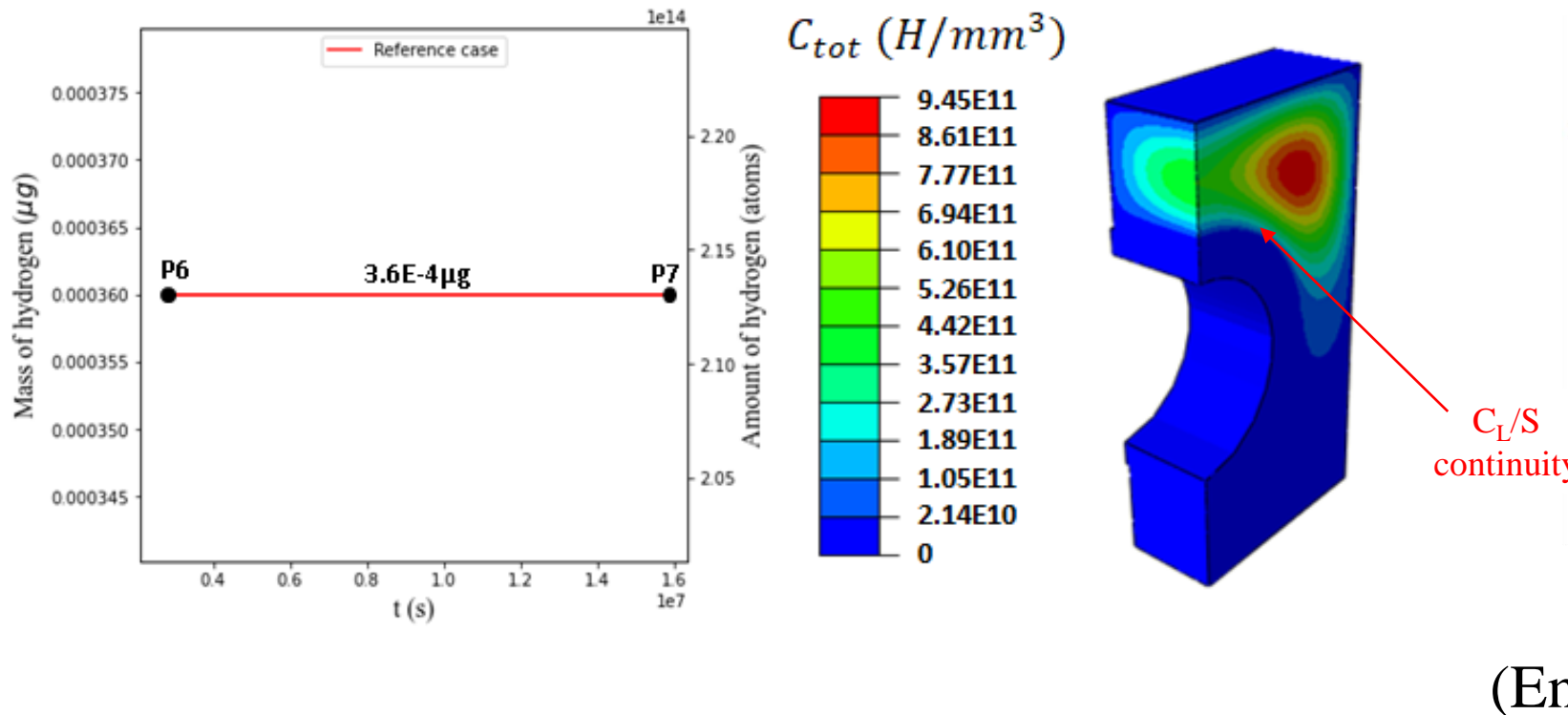
(End of Phase 2)

- * H stored in W, near the W/Cu interface
- * Estimation of total H for all divertor monoblocks (assuming same exposure conditions) : 10 mg

- * 0.3% of H remained mainly in the half upper part of W
- * 47% of H passed towards cooling pipe



Phase 3



(End of Phase 3)

- * ϵ_{th} mismatches at bi-material interfaces → plastic strain
- * T gradient & plastic strain → stress field (P_H)

- * No impact of the maintenance phase on remaining amount of H