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Impacts of mechanical fields on hydrogen transport in ITER divertor monoblocks

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In a few words

Objective

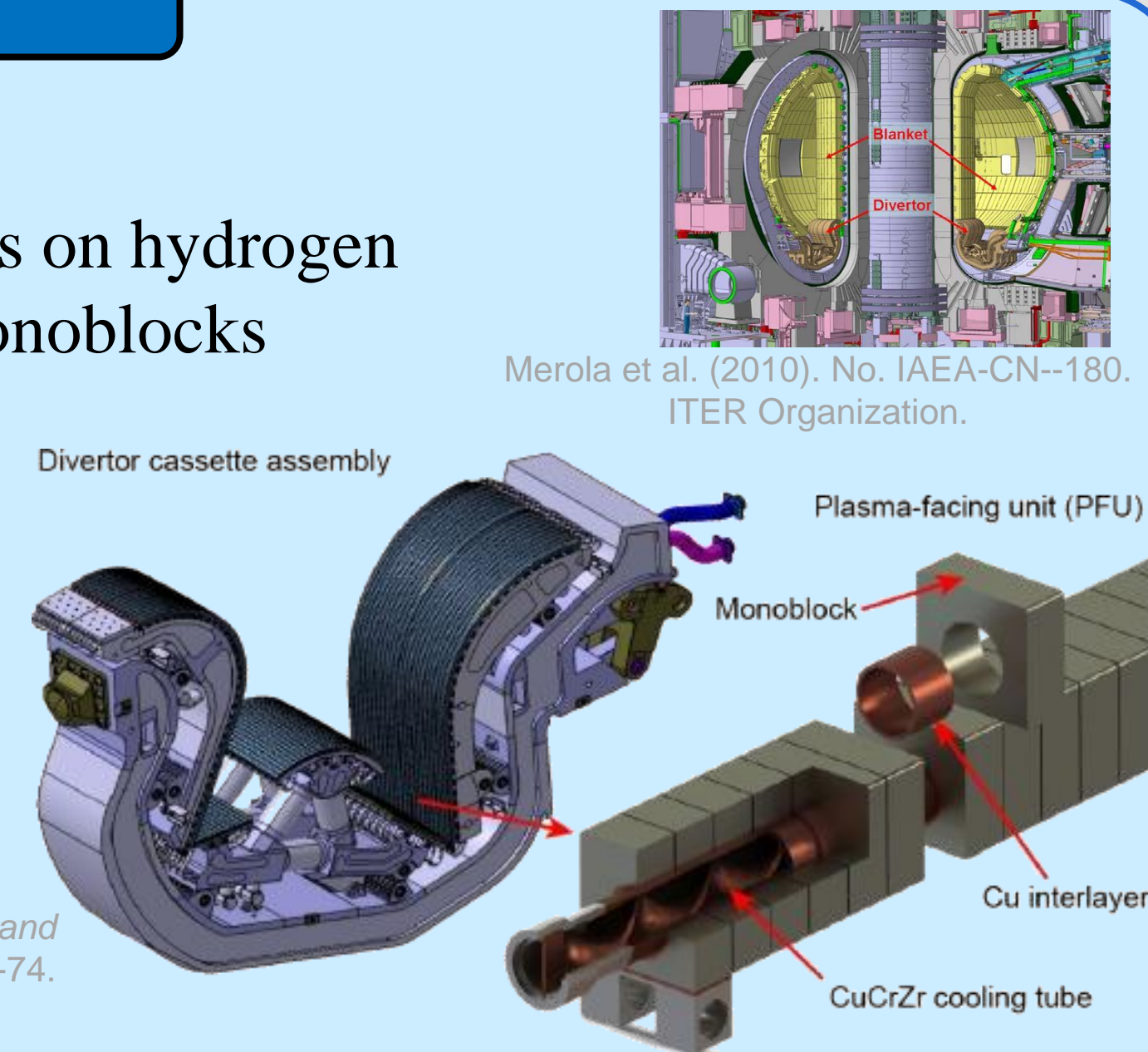
Get the role of the thermo-mechanical fields on hydrogen diffusion and retention in ITER divertor monoblocks

Method

3D finite element simulations
→ Abaqus software + User subroutines

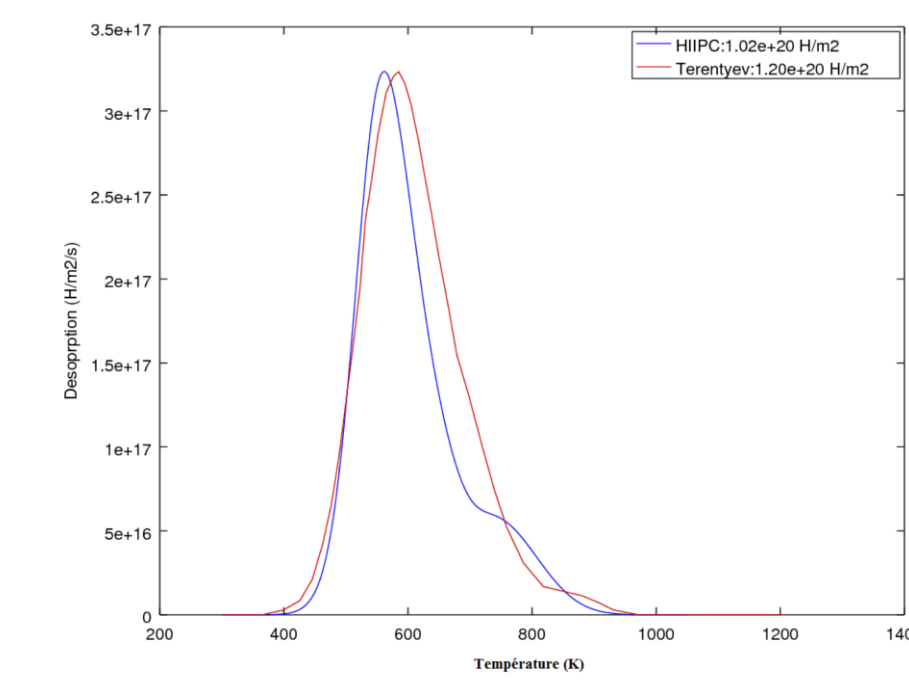
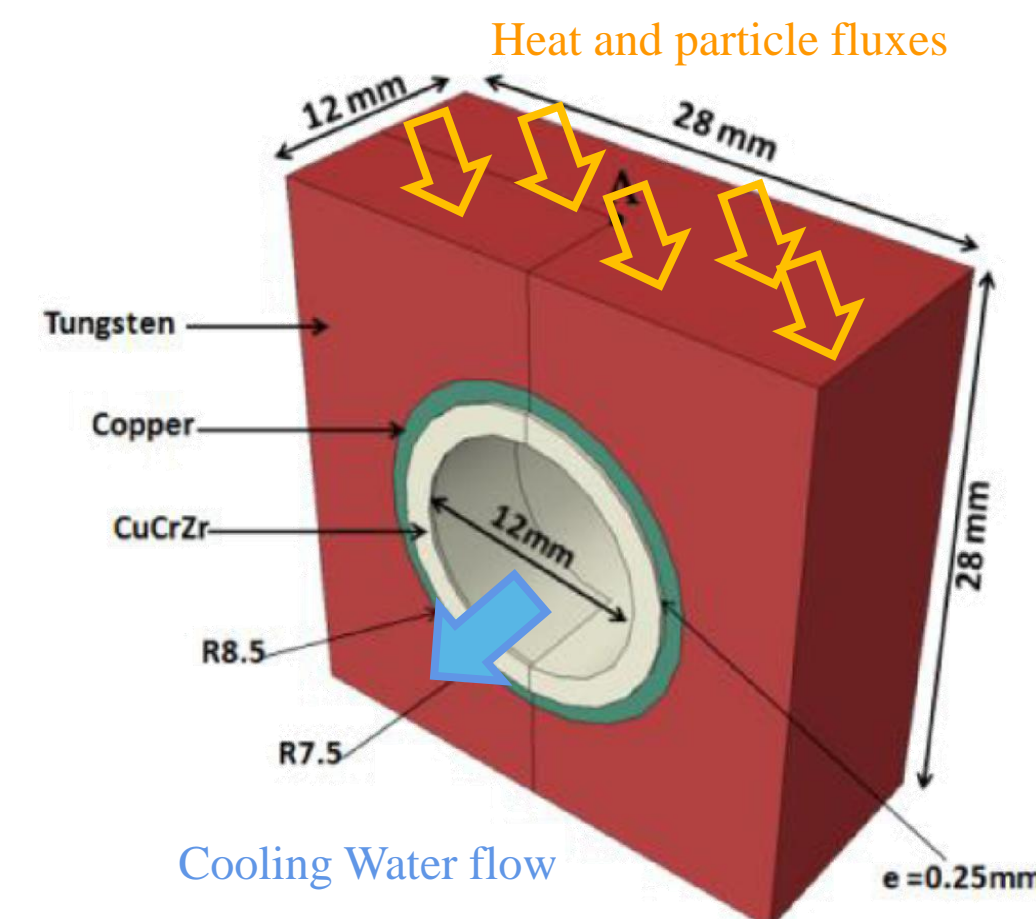
Main results

- 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



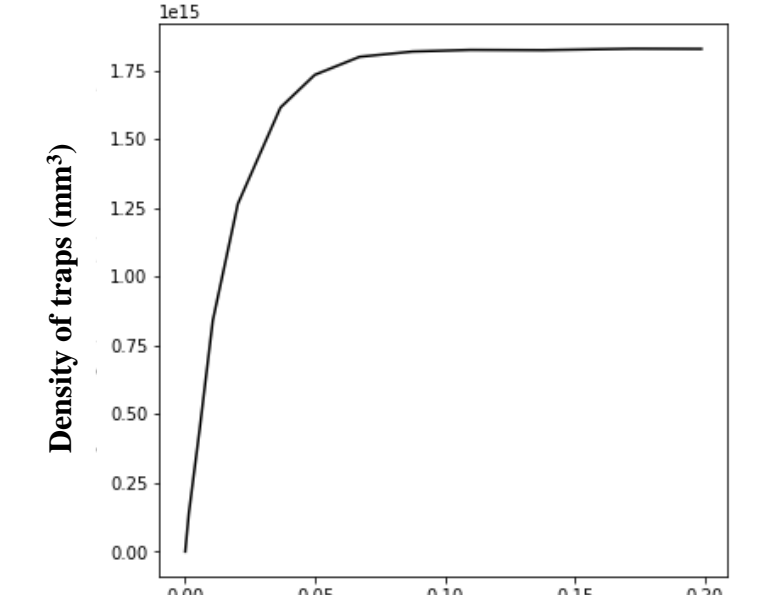
Pitts et al. (2017). Nuclear Materials and Energy, 12, 60-74.

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

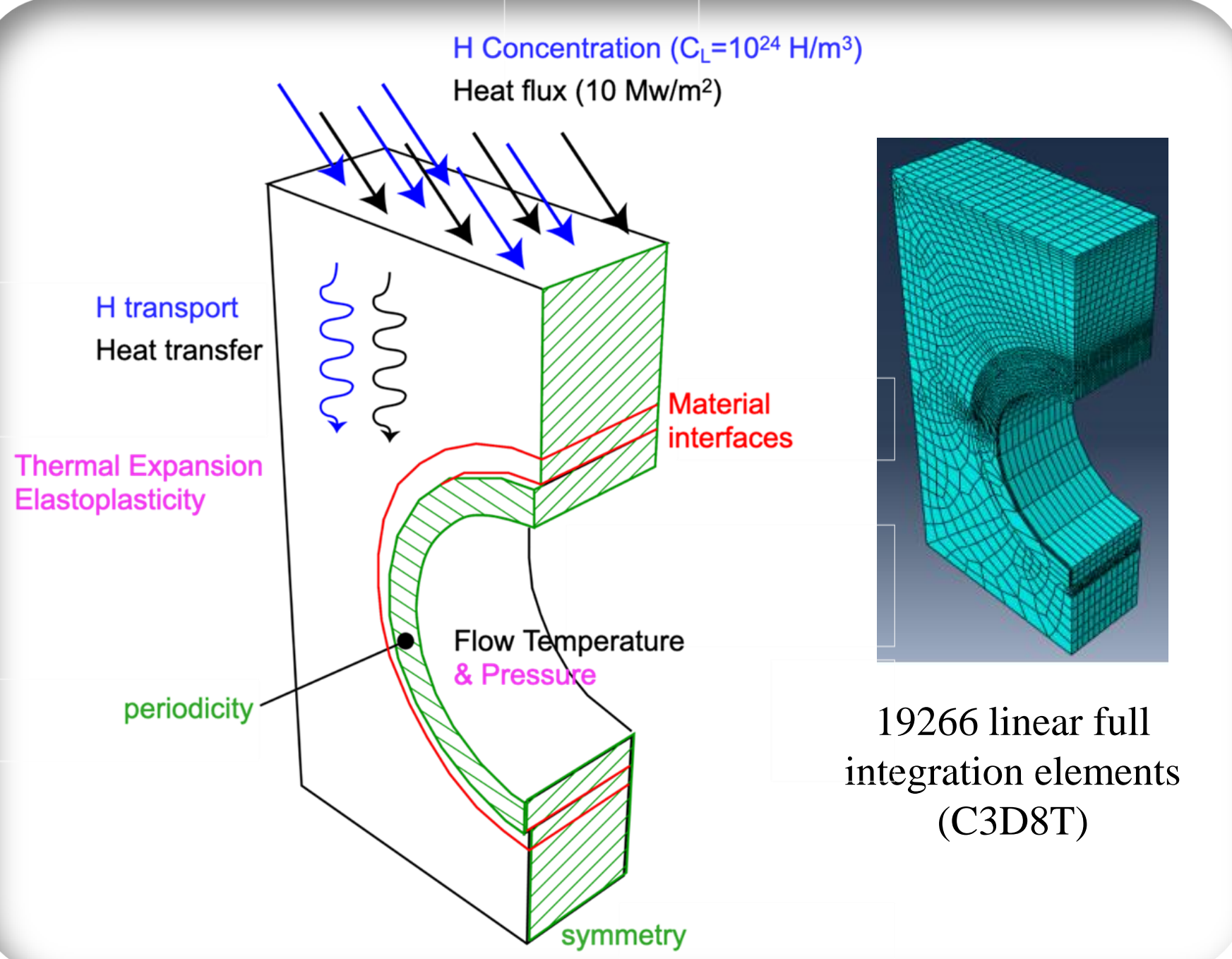
Cu → 1 trap

0.5 eV ; 4.25 10¹⁵ mm⁻³

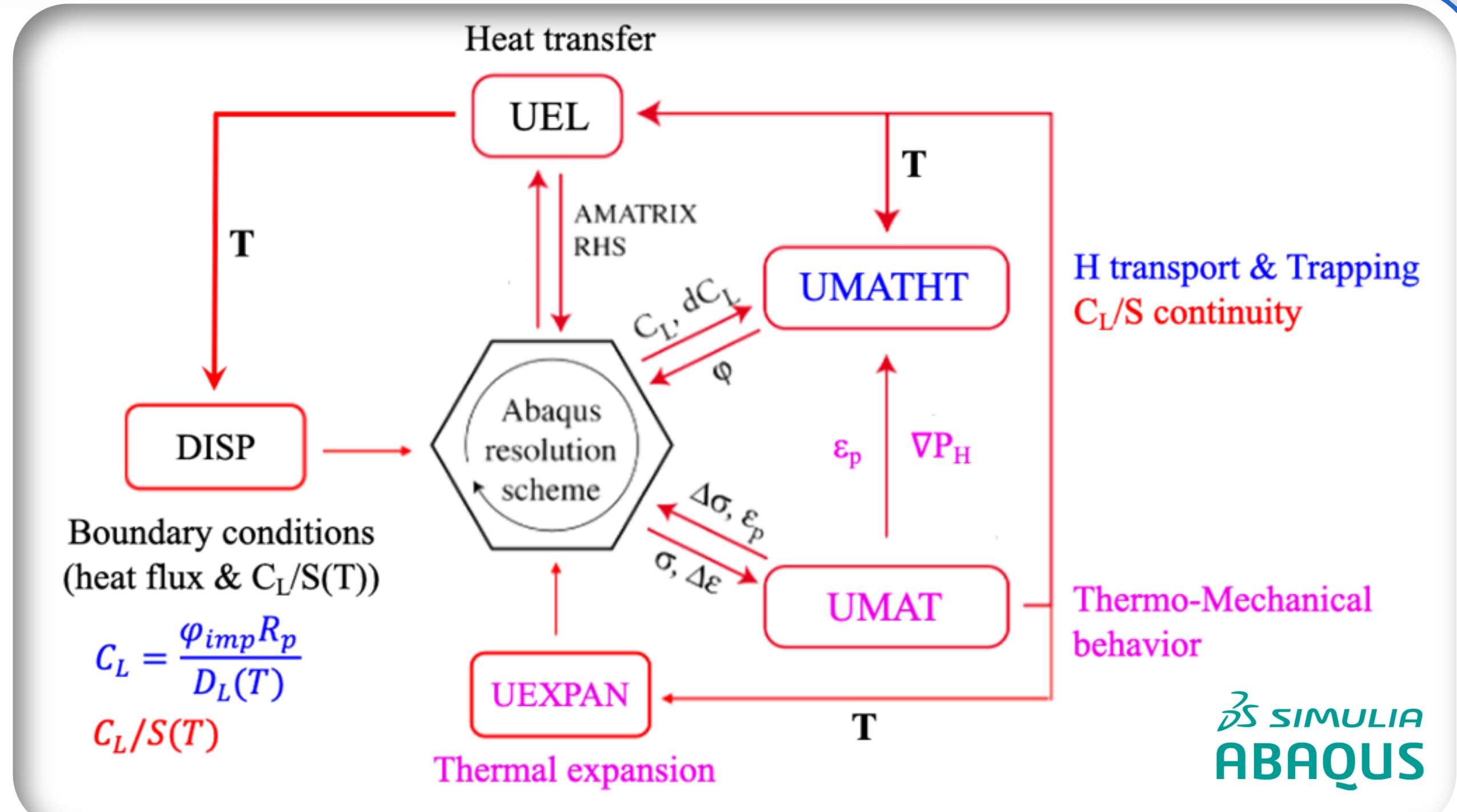
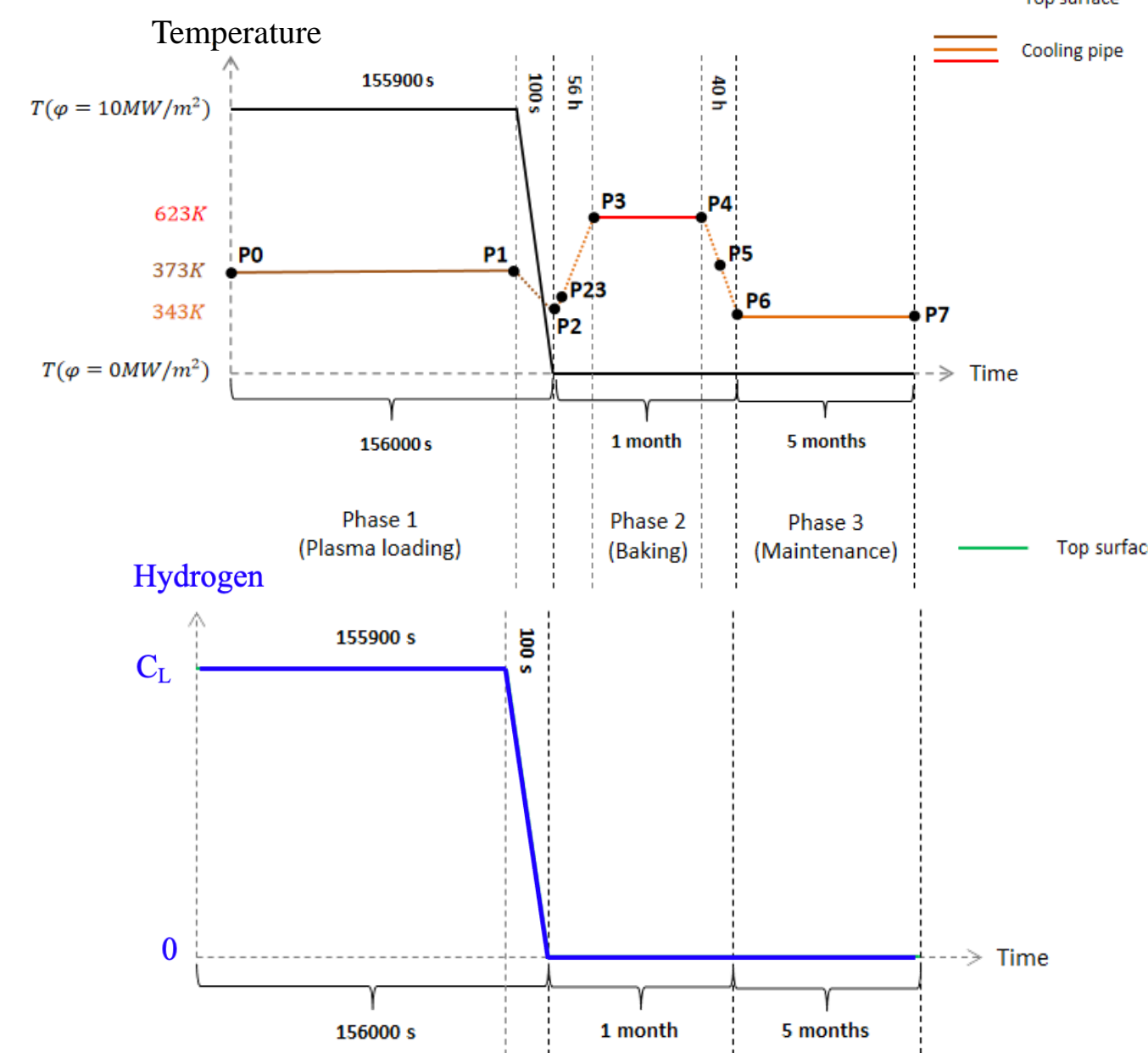
CuCrZr → 1 trap

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

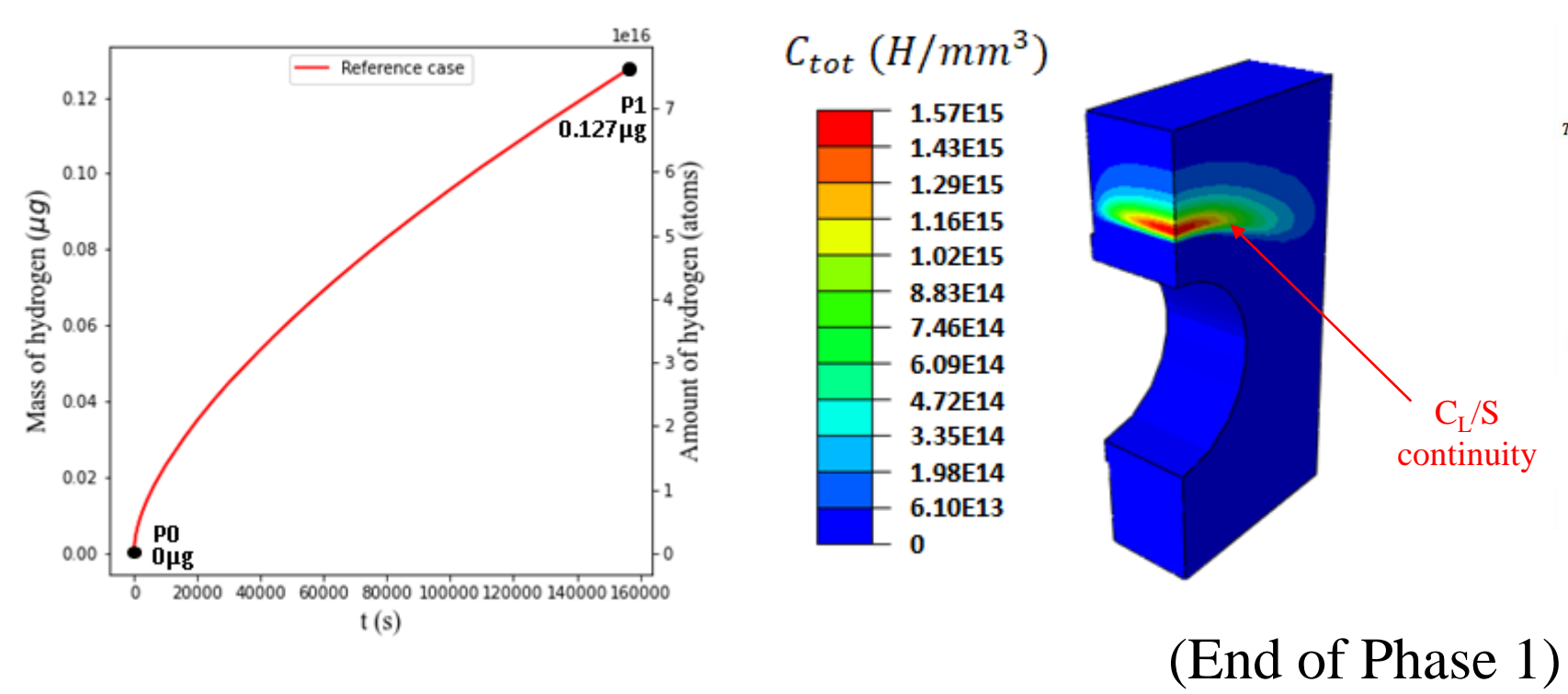
Implantation

« coupled temp displacement »

Simultaneous resolution

Results

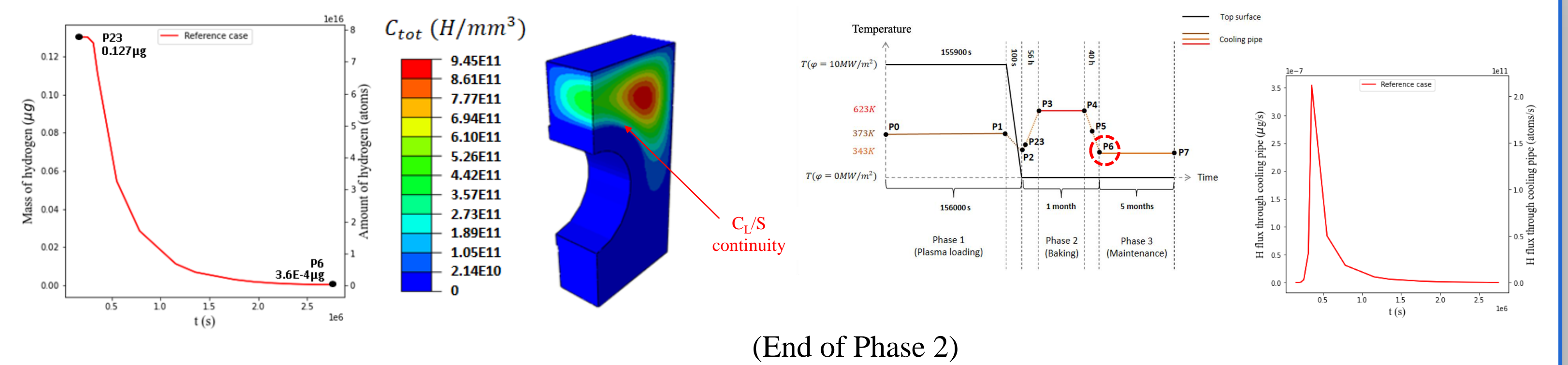
Phase 1



(End of Phase 1)

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

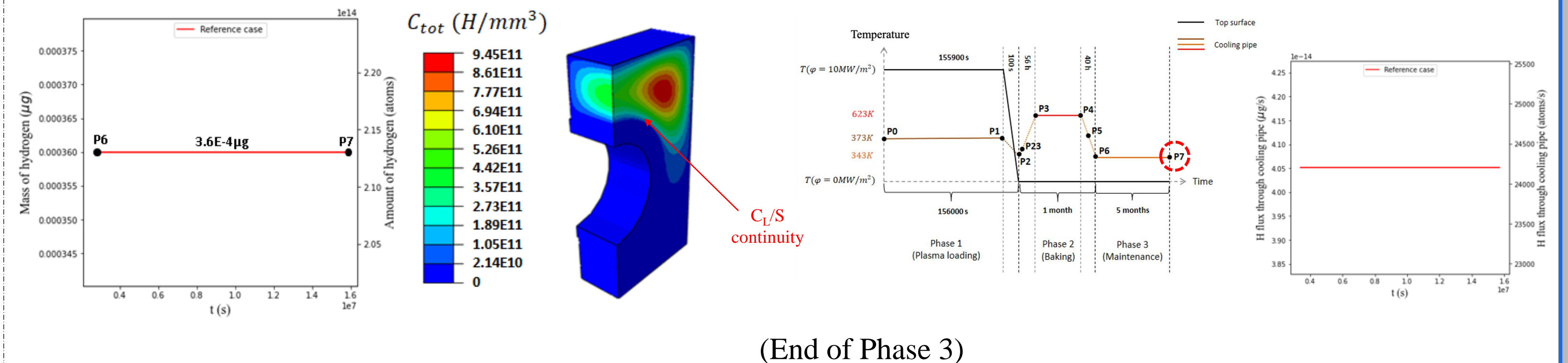
Phase 2



(End of Phase 2)

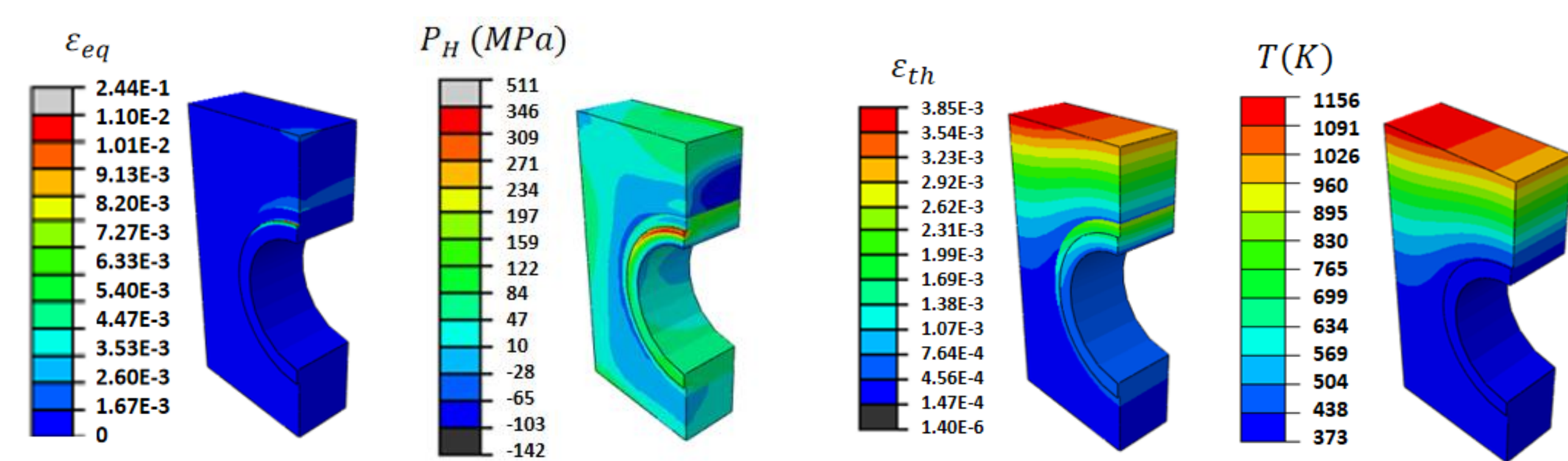
- * 0.3% of H remained mainly in the half upper part of W
- * 47% of H passed towards cooling pipe

Phase 3



(End of Phase 3)

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



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