

Impacts of mechanical fields on hydrogen transport in ITER divertor monoblocks

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Impacts of mechanical fields on hydrogen transport in ITER divertor monoblocks

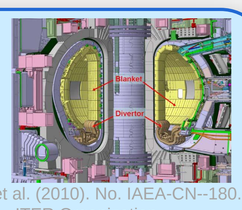
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Steel & Hydrogen COCASD

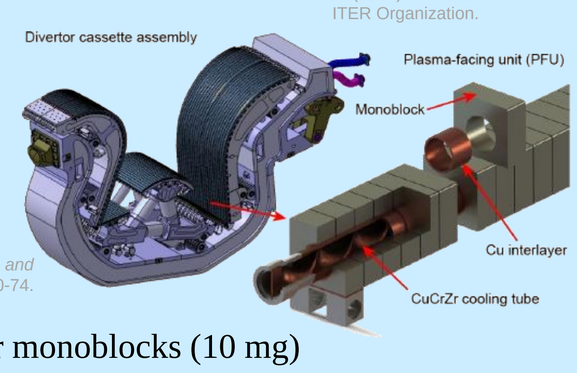
In a few words

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



Merola et al. (2010). No. IAEA-CN--180. ITER Organization.

Method
3D finite element simulations
→ Abaqus software + User subroutines

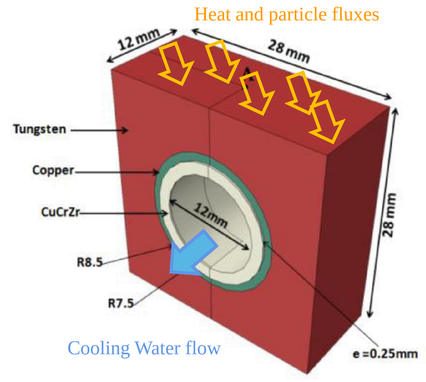


Pitts et al.. (2017). *Nuclear Materials and Energy*, *12*, 60-74.

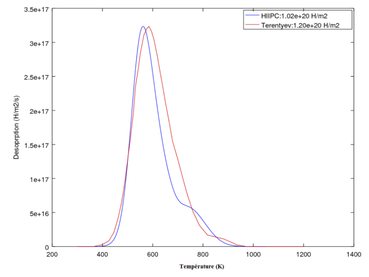
Main results
- Estimation of H retention in divertor monoblocks (10 mg)
- Estimation of the H permeated to the cooling pipes
- Estimation of the impact of the operation cycles

Model and data

Heat and particle fluxes



Cooling Water flow



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/m^3 instead of traps/m^2)

W → 2 traps
- (intrinsic): 0.87/1 eV ; 6.95 10^{16}/3.16 10^{16}mm^{-3}
- (created by plastic strain): 0.87 eV

Cu → 1 trap
0.5 eV ; 4.25 10^{15} mm^{-3}

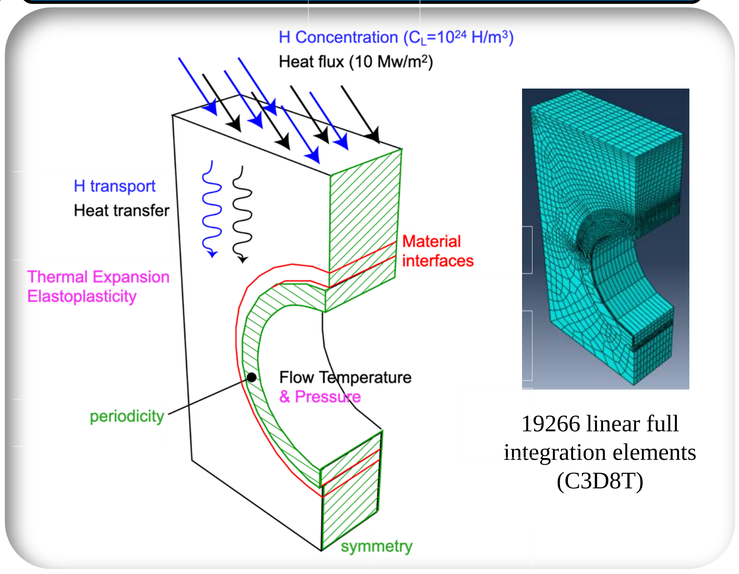
CuCrZr → 1 trap
0.85 eV ; 1.30 10^{15} mm^{-3}



Traps created by plastic strain

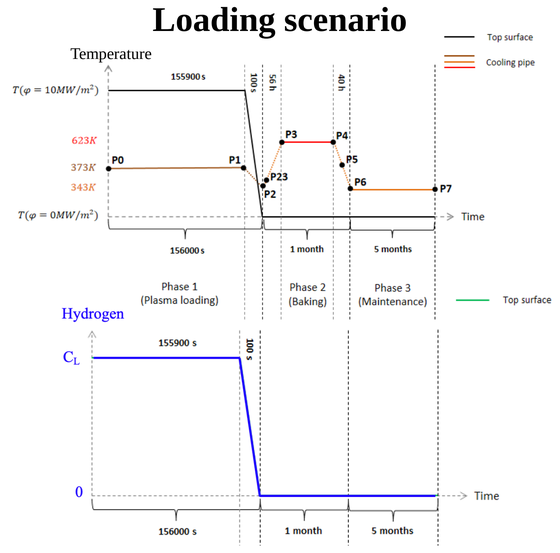
$$N_T^{created}(\varepsilon_p) = 1.85 \times 10^{15}(1 - e^{-57.6\varepsilon_p})$$

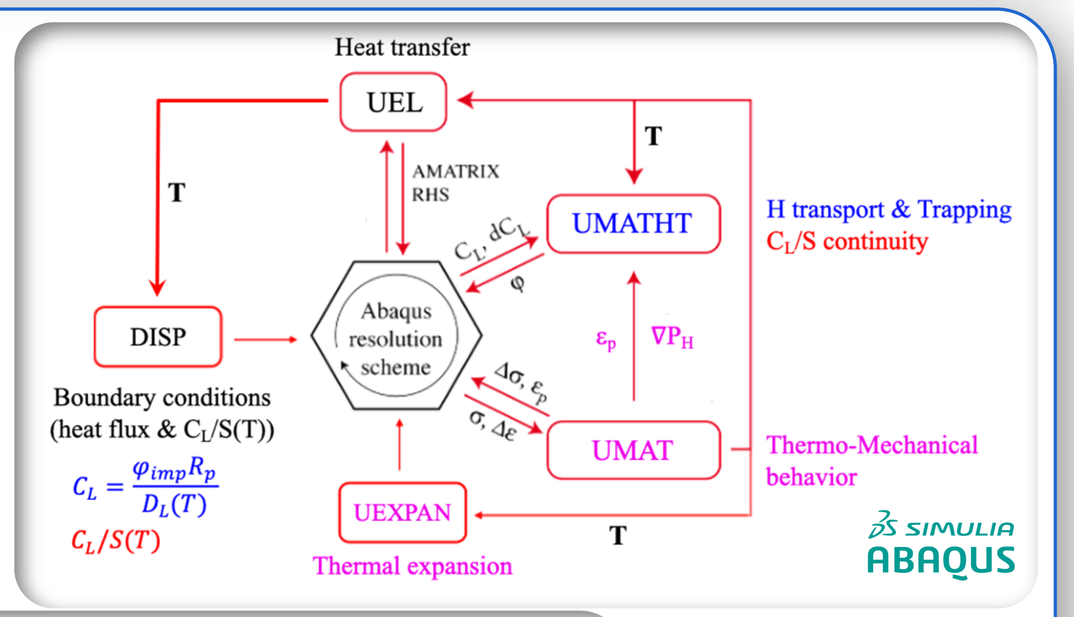
Modelling



19266 linear full integration elements (C3D8T)

Loading scenario





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

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: $\frac{\partial C_T}{\partial t} = \frac{k}{N_L} C_L(N_T(\varepsilon_p) - C_T) - pC_T$

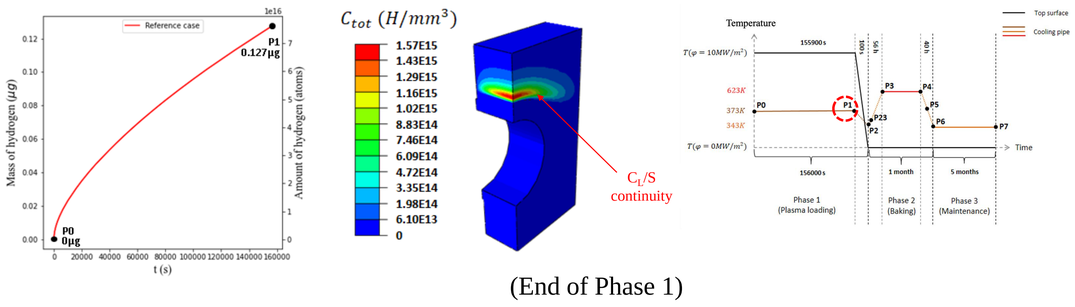
Heat transfer : $\rho(T)C_p(T)\frac{\partial T}{\partial t} = \nabla(\lambda(T)\nabla T)$ Material interfaces: $C_L/S(T)$ continuity

$E(T)$ & $\nu(T)$: *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

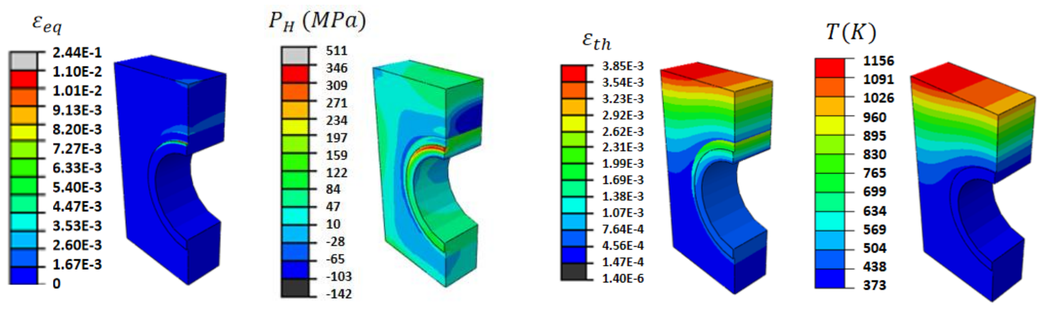
Results

Phase 1



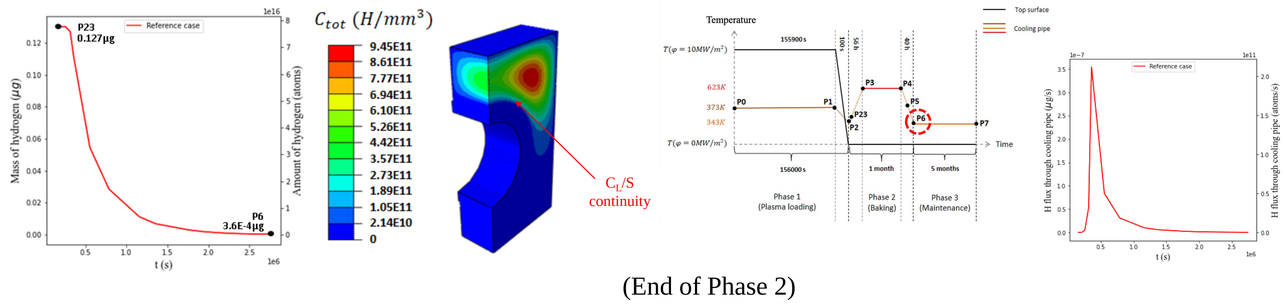
(End of Phase 1)

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



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

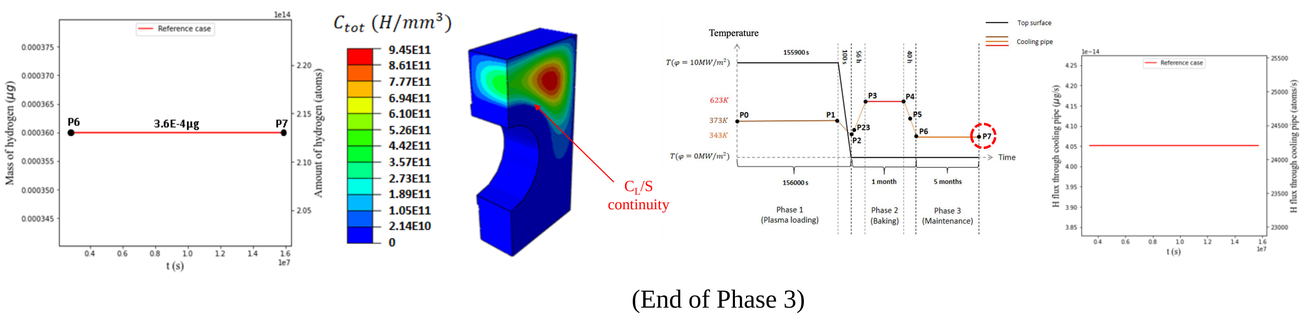
Phase 2



(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

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