Mechanical, thermal and diffusional quantities remapping on an adaptive mesh to model the macroscopic fuel redistribution in pellets with the F.E. code CAST3M

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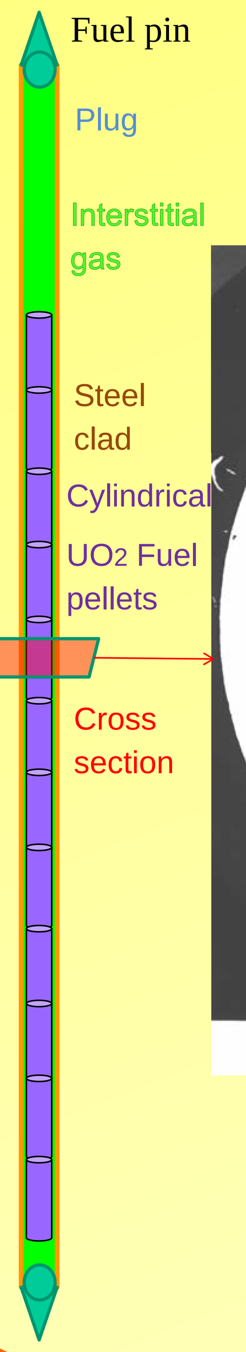
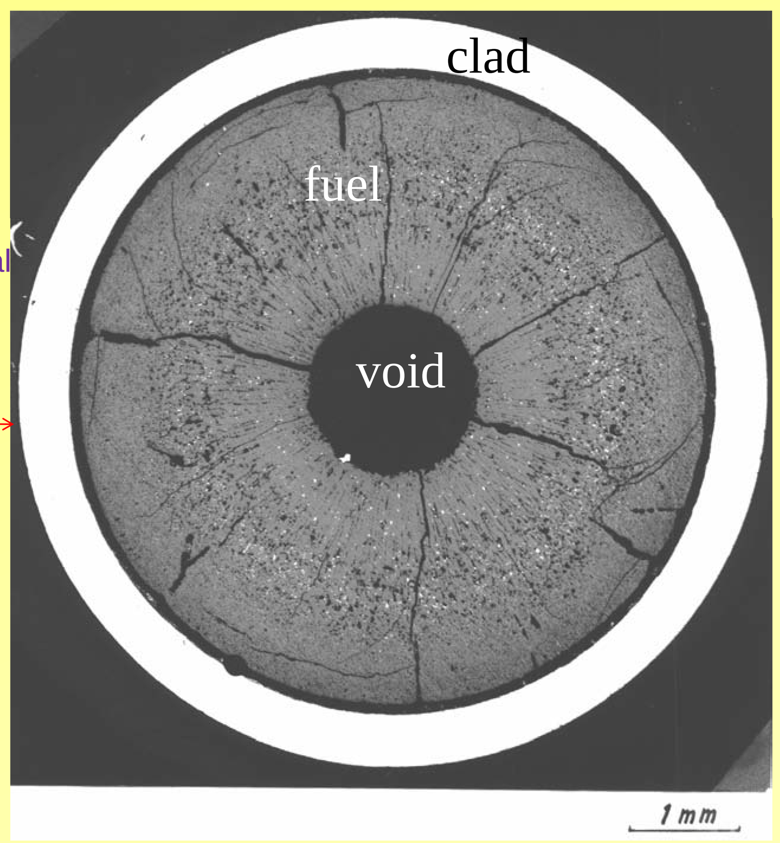
Abstract

Modelling of fuel pin behavior during irradiation associated to experiments improves the understanding of the important mechanisms that could impact fuel assembly performance. Modelling also allows to quickly test the impact of material properties on fuel behavior.
Coupled thermal, mechanical and species diffusion modelling is performed in the PLEIADES [1] fuel performance software environment which includes the finite element solver CAST3M [2]. Modelling of the central void formation in fast neutron reactor fuel requires a mesh adaptation. Physical quantities must be remapped from a mesh to the next one. We describe a CAST3M mock-up to calculate thermo-mechanical-diffusional fuel behavior during void formation.

Cylindrical void formation during irradiation

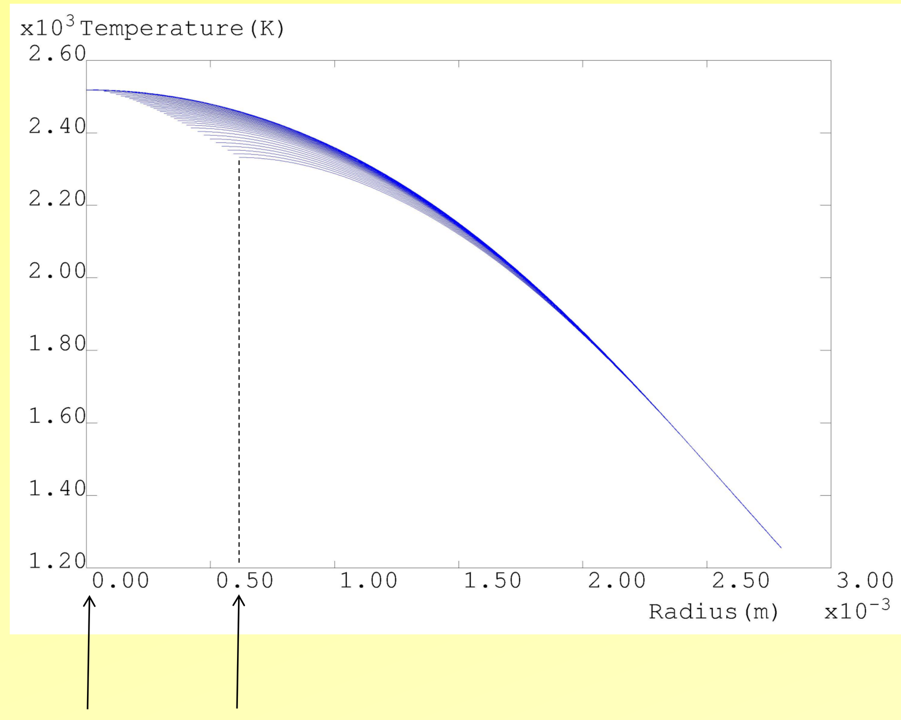
Porosity moves towards the higher temperature (vapor transport)





Phenix pin cross section after irradiation [3]

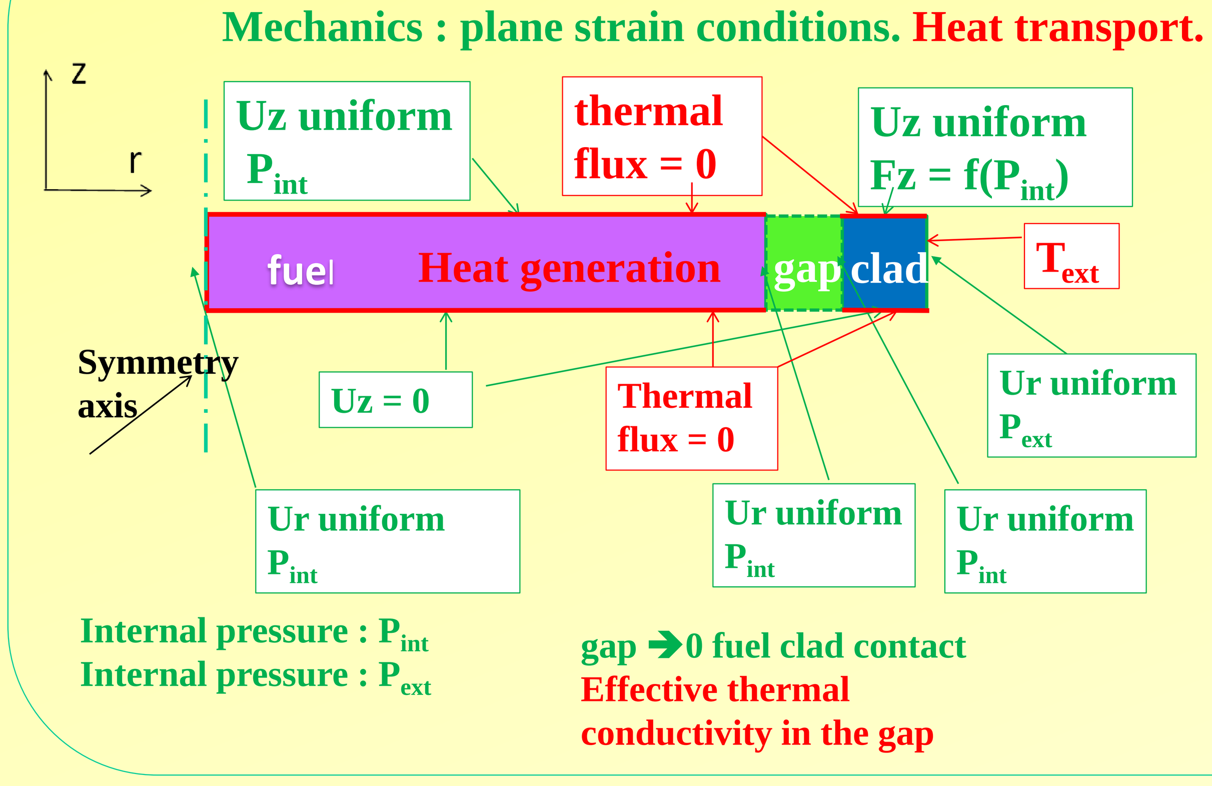
Temperature as a function of pellet radius



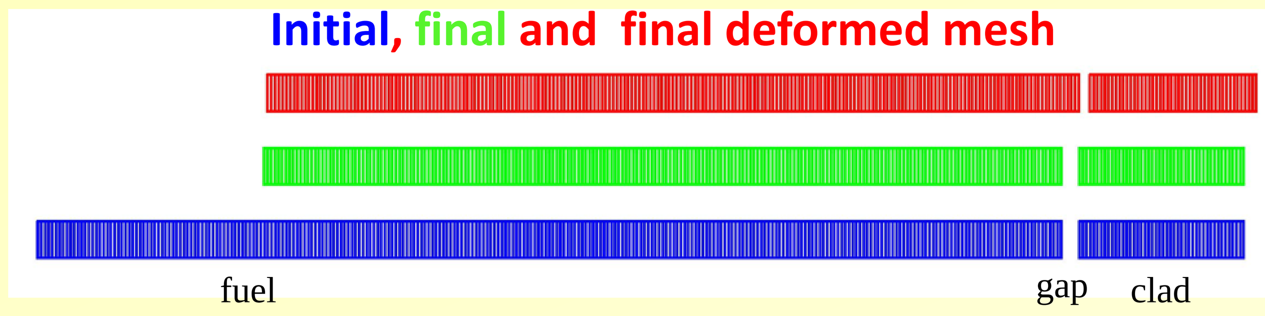
Modelling of a two-dimensional fuel pin

Boundary conditions

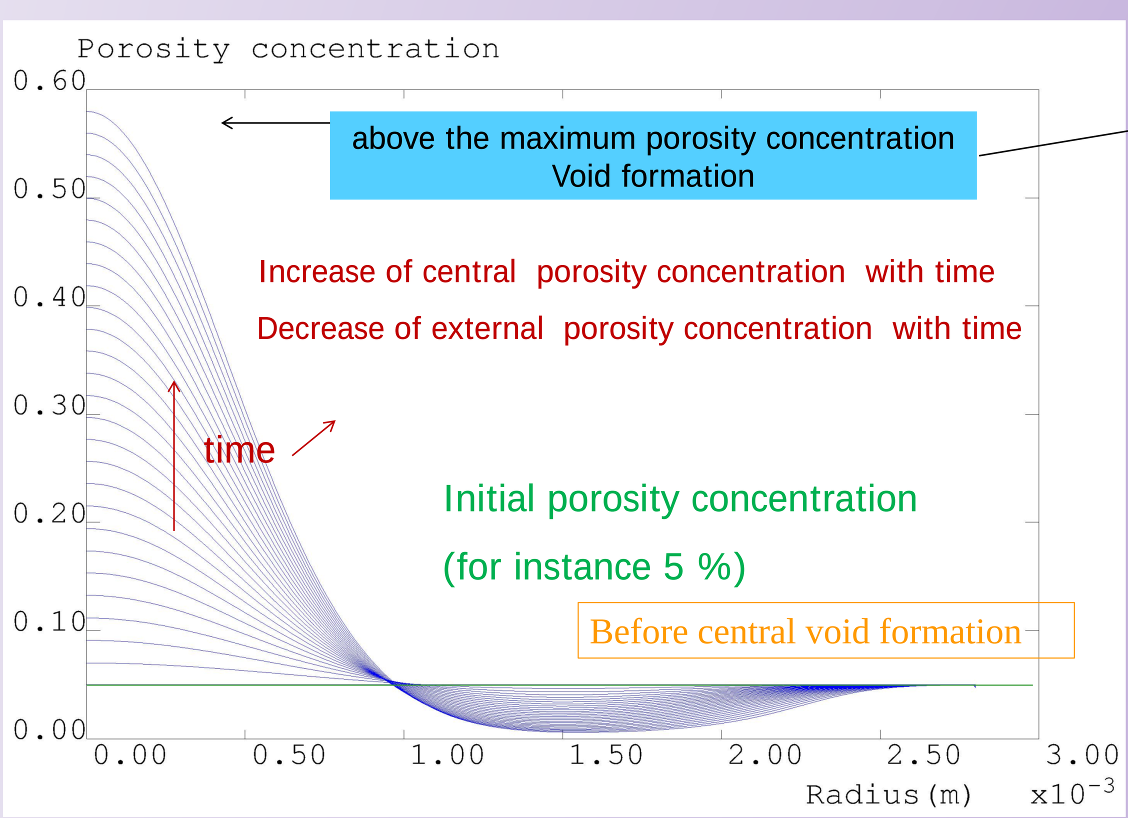
Mechanics : plane strain conditions. Heat transport.



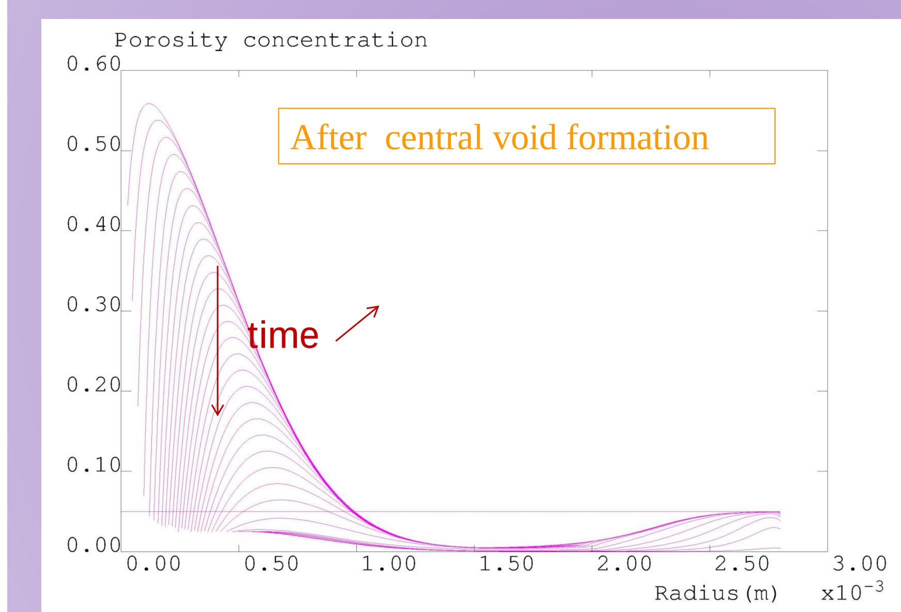
Initial, final and final deformed mesh

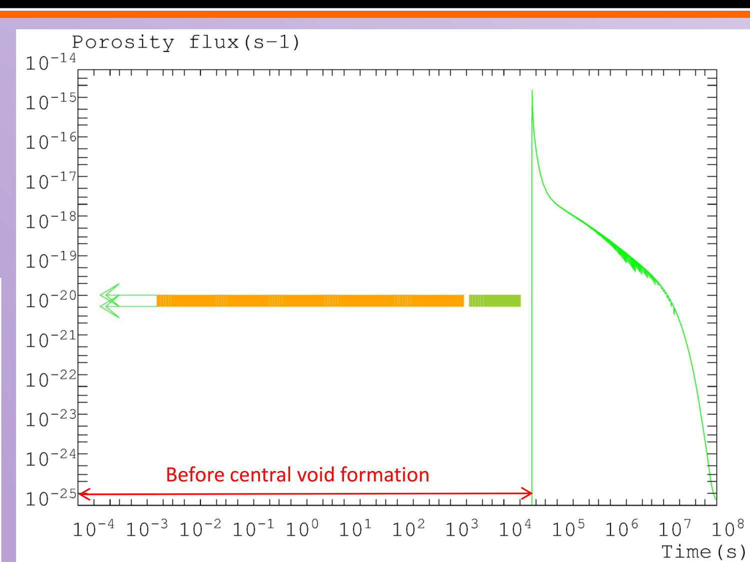


Porosity diffusion via Fickian and Soret mechanisms $J= -D(\nabla C+A\ \nabla T\ C)$

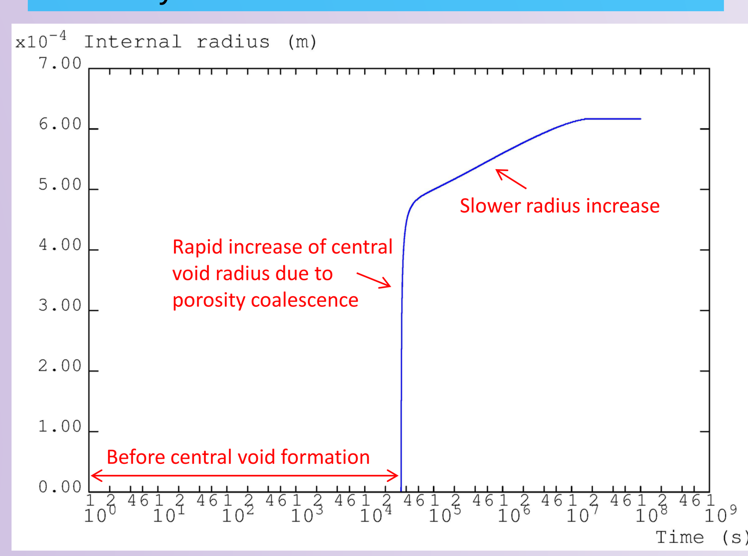


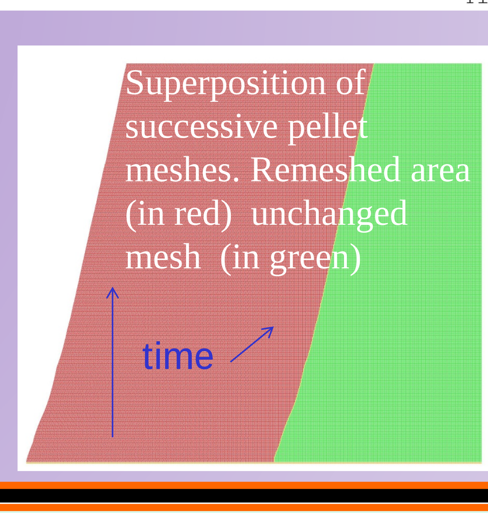
Sink of porosity at the internal pellet radius





Porosity flux controls internal radius increase





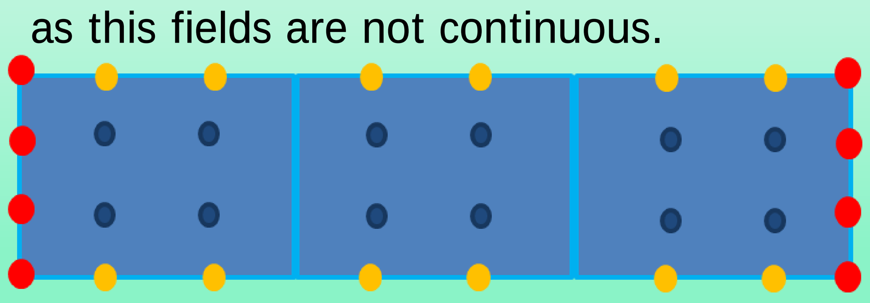
Re-meshing and remapping when void radius increases

Transfer of the physical quantities from a mesh to the next one

Quantities defined at the mesh nodes (Temperatures, concentrations, displacements) are transferred using interpolation with finite elements shape functions.

Stresses, internal variables, strains and material properties defined at Gauss points are not associated to shape function. Their gradient is needed to transfer them to the new mesh but is difficult to define as this fields are not continuous.

Construction of an auxiliary mesh



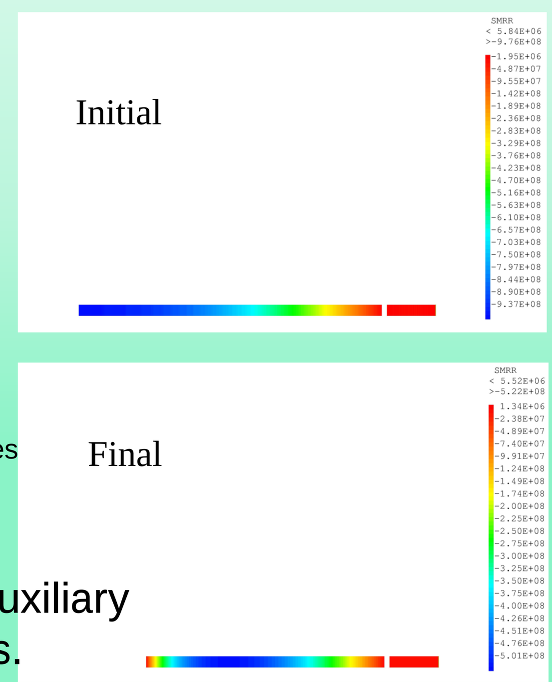
: Initial Gauss Point

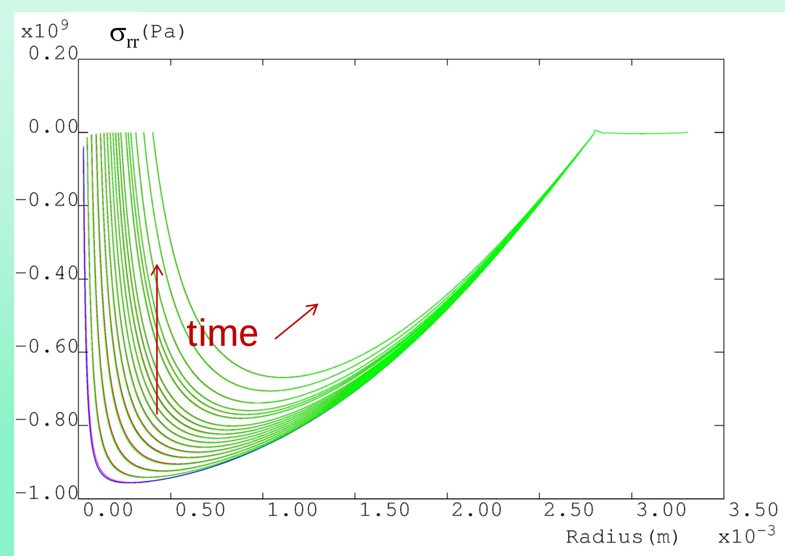
: Additional nodes of the auxiliary mesh on the upper and lower pellet mesh boundaries

: Additional nodes of the auxiliary mesh on the internal and external pellet mesh boundaries

Values of the physical quantities on the boundary nodes are calculated from the boundary conditions or geometrical properties. The physical quantities, defined at auxiliary mesh nodes, are transferred from the auxiliary mesh onto the new mesh Gauss points by an interpolation based on conformed finite element shape functions.

Illustration of results : σ_{rr} stress component





Stress profiles at successive times

Conclusion and perspectives

A CAST3M mock-up was developed to calculate coupled thermo-mechanical diffusion processes in a fast reactor fuel pin. Remeshing and remapping of the physical quantities allow to model the central void creation and extension. The calculated void evolution is similar to that observed experimentally. In this first study, fuel and clad are elastic. Mock-up should be extended to remapping of the internal variables associated to non-linear mechanical behavior of the components (creep, plasticity) in order to perform realistic numerical simulation of fuel irradiation.

[1] B. Michel, C. Nonon, J. Sercombe, F. Michel, and V. Marelle, Simulation of pellet cladding interaction with the PLEIADES fuel performance software environment , Nuclear Technology, Vol. 182, p. 124 -137, May 2013.
[2] Cast3M (CEA, DEN) : http://www-cast3m.cea.fr/
[3] CLEFS CEA - N° 55 - ÉTÉ 2007, Systèmes nucléaires du futur - Génération IV.

DÉPARTEMENT DE MODÉLISATION DES SYSTÈMES ET DES STRUCTURES

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