DE LA RECHERCHE À L'INDUSTRIE

Recent advances on the nuclear fuel behaviour simulation

MMSNF-2013 | Renaud MASSON, Fuel Behaviour Simulation Laboratory

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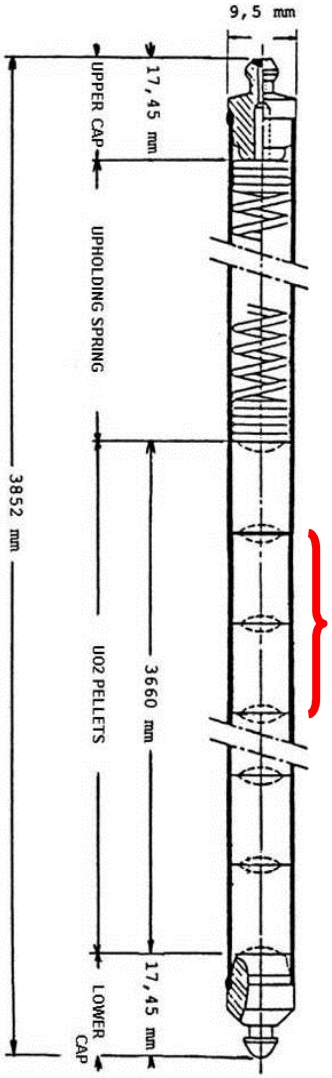
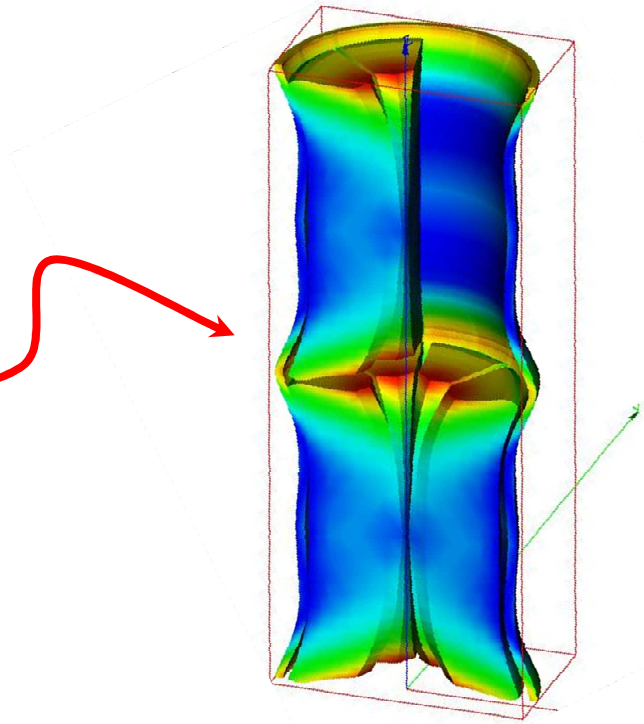
www.cea.fr

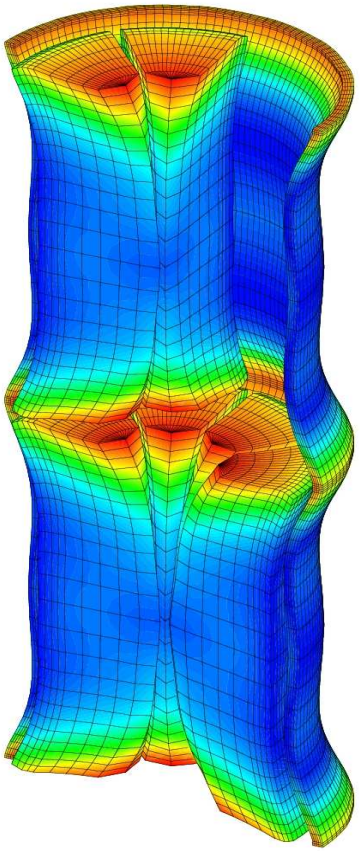
An example of fuel behaviour simulation

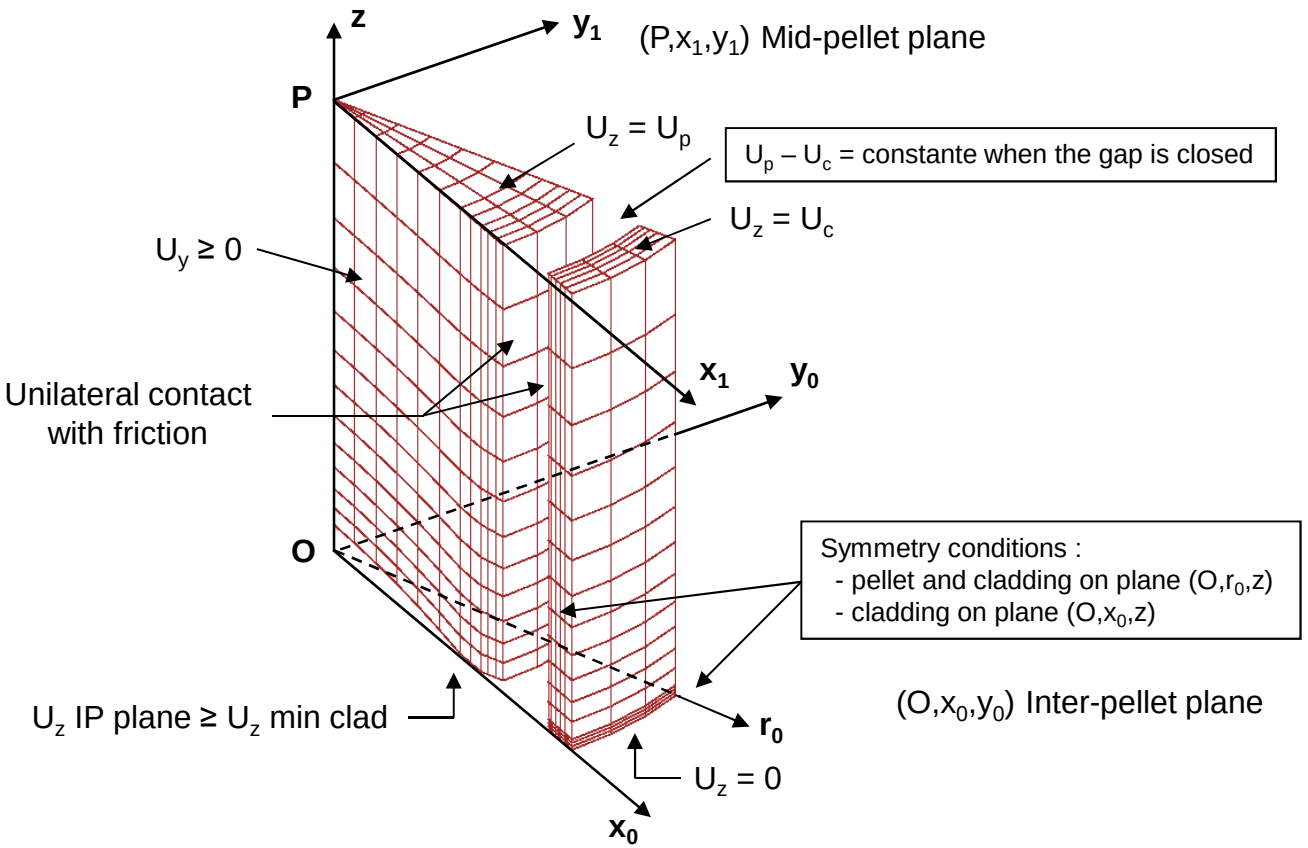




An example of fuel behaviour simulation

How does it work: a 3D model

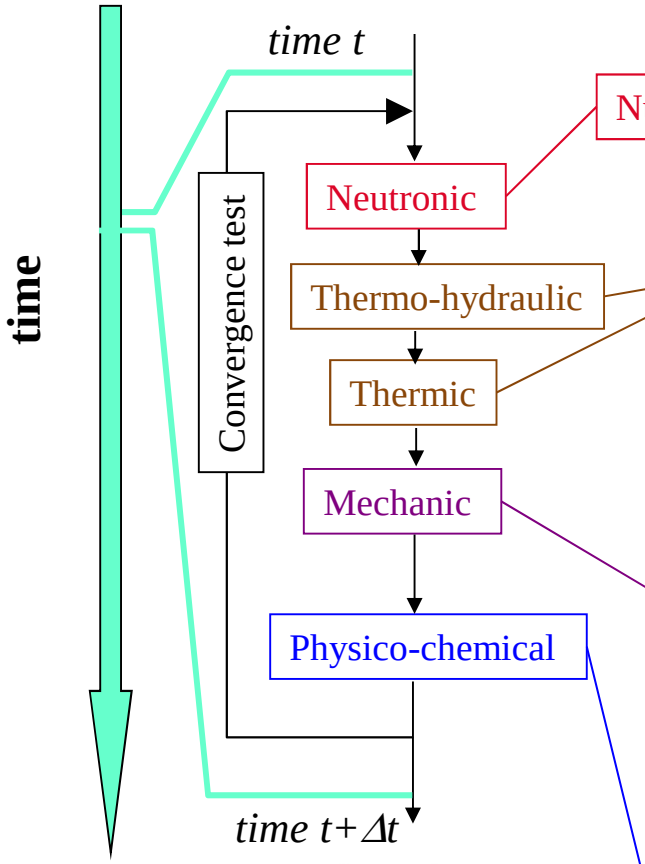




621 mesh elements :
- 396 in the pellet fragment
- 225 in the piece of cladding

only ¼ of a pellet fragment
and the overlying piece of cladding

How does it work: a multi-physics problem



$$P_V^{local} \infty \Phi(r).\sum_{pf} \overline{\sigma}_{pf}.C_{pf}(r).E_{pf}$$

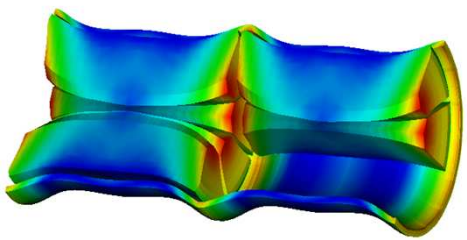
Nuclear power deposition

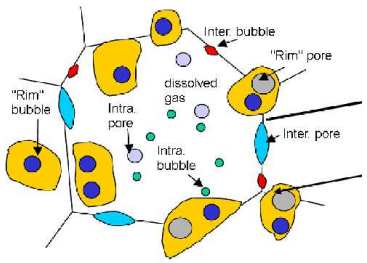
$$\rho.c_p.\frac{dT}{dt} = div\lambda gradT + p_V^{local}$$

Power evacuation from the fuel element and thermal field

$$\begin{cases} div\overline{\overline{\sigma}}_M = 0 \text{ on } \Omega \\ \overline{\overline{\sigma}}_M.\vec{n} = \vec{\phi}_{BC} \text{ on } \partial\Omega_\phi \\ \vec{u} = \vec{u}_{BC} \text{ on } \partial\Omega_u \end{cases}$$

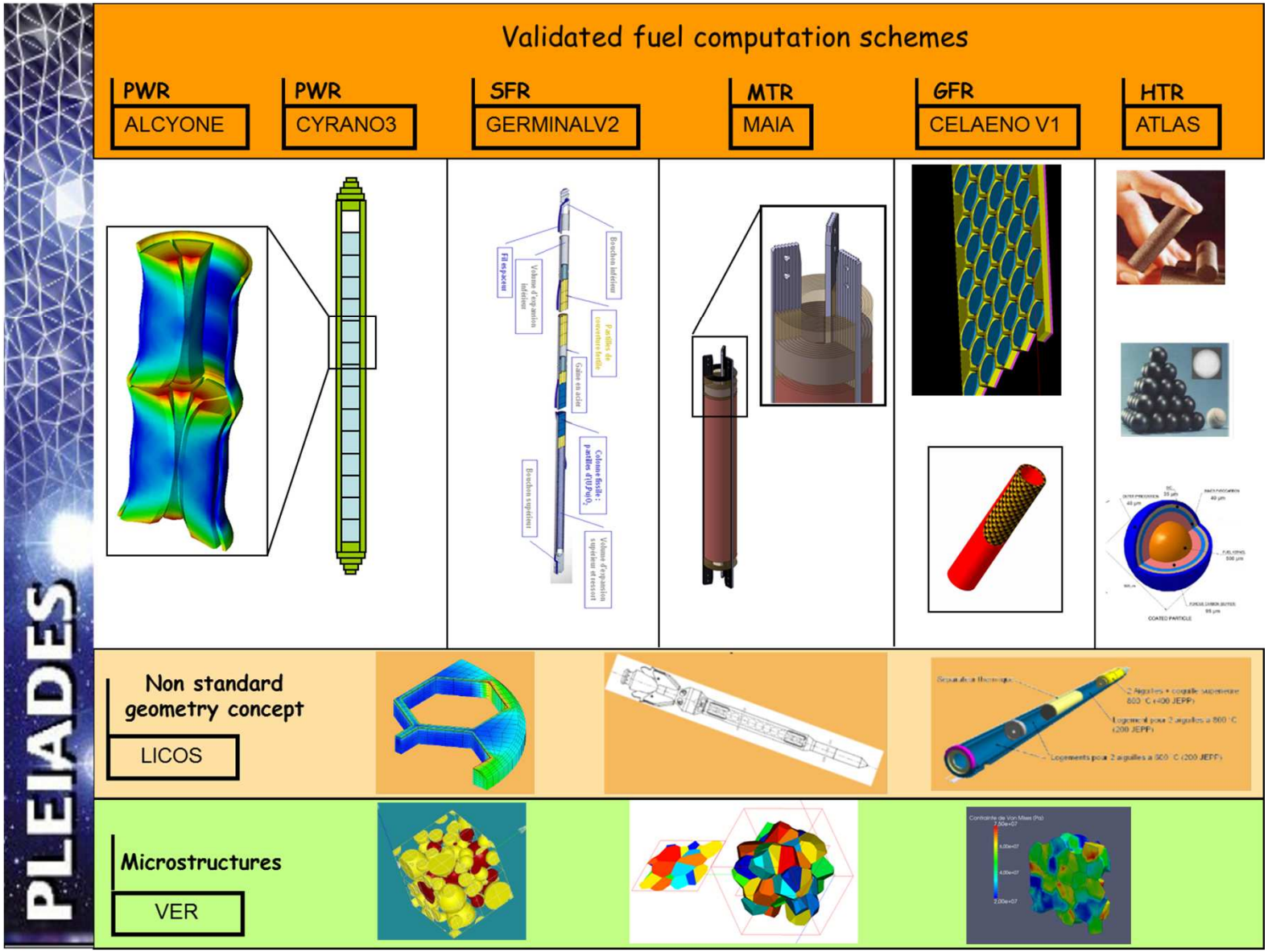
Mechanical state (strain, stress, cracking, creep,…)



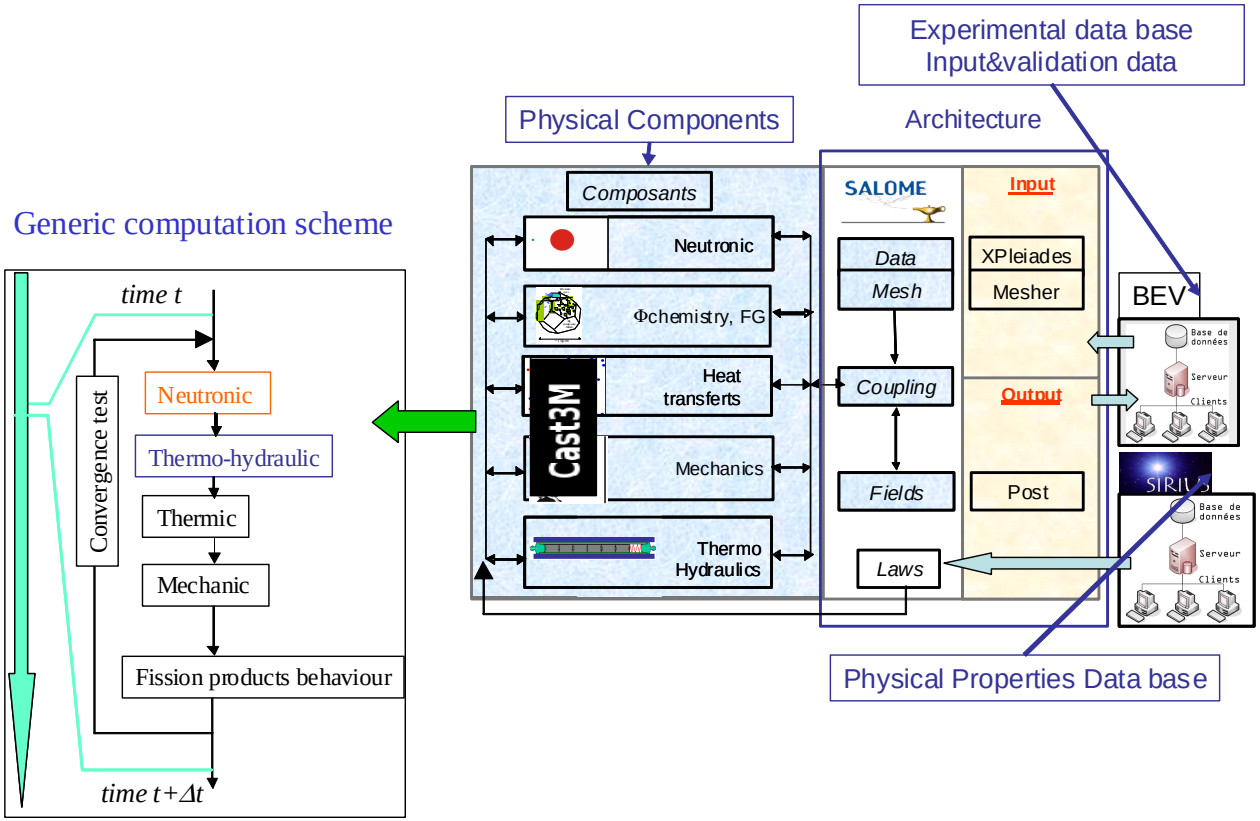


Behavior of fission products (production, swelling and release, microstructural evolutions, …)

How does it work: FP codes

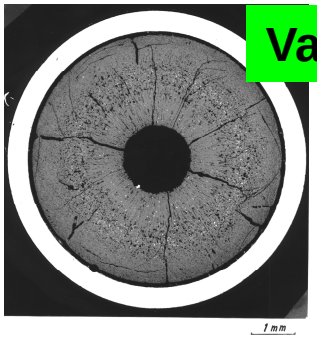


How does it work: FP code in an unified plateform (PLEIADES)

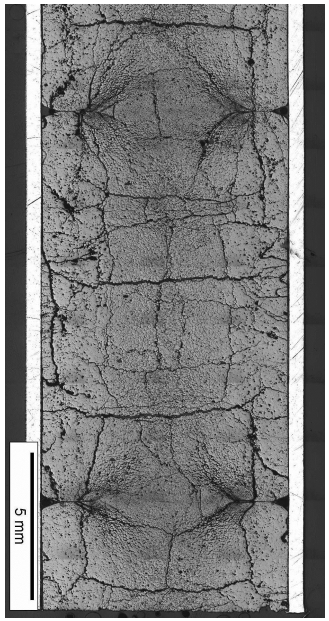


« 10 years », 09/2013

Fuel Behaviour Simulation: four main scientific axis



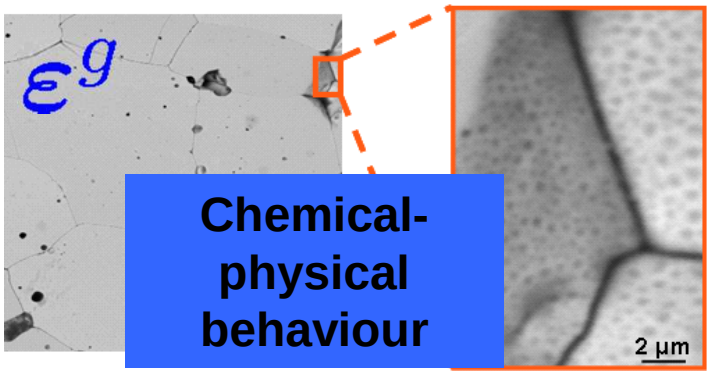
Validation



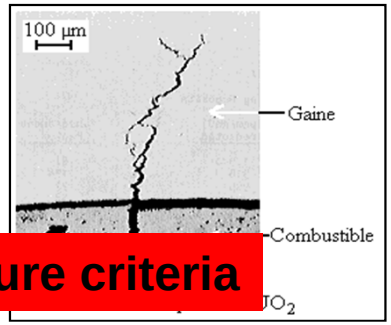
$$\int_{\Omega} \boldsymbol{\sigma} : \boldsymbol{\epsilon}(\boldsymbol{u})\, dV = \int_{\partial\Omega} \boldsymbol{F}^{ext} \boldsymbol{u}\, dS$$

ε^{vp}

Constitutive laws



Chemical-physical behaviour



Fracture criteria

Irradiation effects on the creep behaviour of UO2 fuels

High temperature ➔ Fuel viscoplastic behaviour : isotropic creep model

$$\dot{\varepsilon}^{vp} = \dot{\varepsilon}_{ath}(\sigma) + \dot{\varepsilon}_{th}(\sigma, T)$$

irradiation induced creep

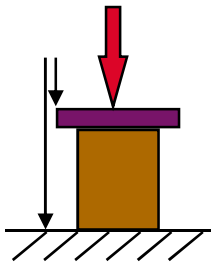
thermal viscoplastic creep

$$\dot{\varepsilon}_{th} = (1-\theta)\dot{\varepsilon}_{diff}(\sigma, T) + \theta\dot{\varepsilon}_{disloc}(\sigma, T)$$

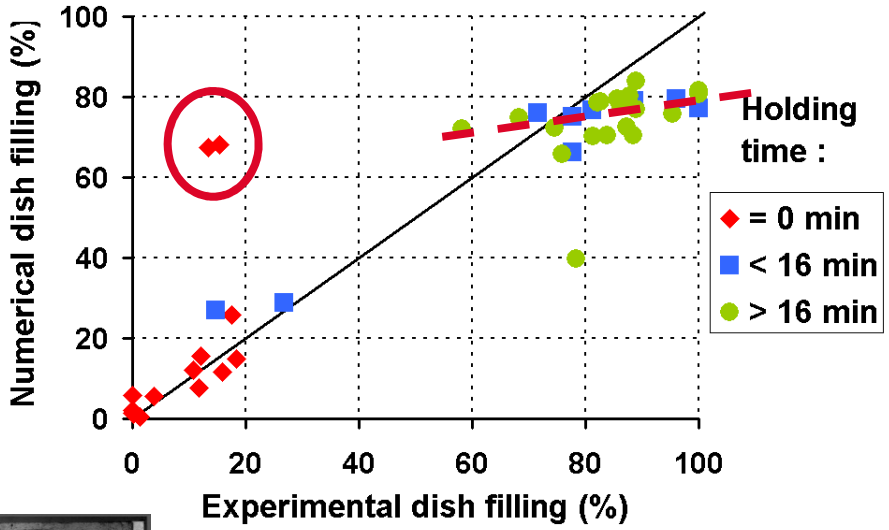
$$\theta(\sigma, T) = \frac{1}{2}\left(1 + \tanh\left(\frac{\overline{T}(\sigma) - T}{h}\right)\right)$$

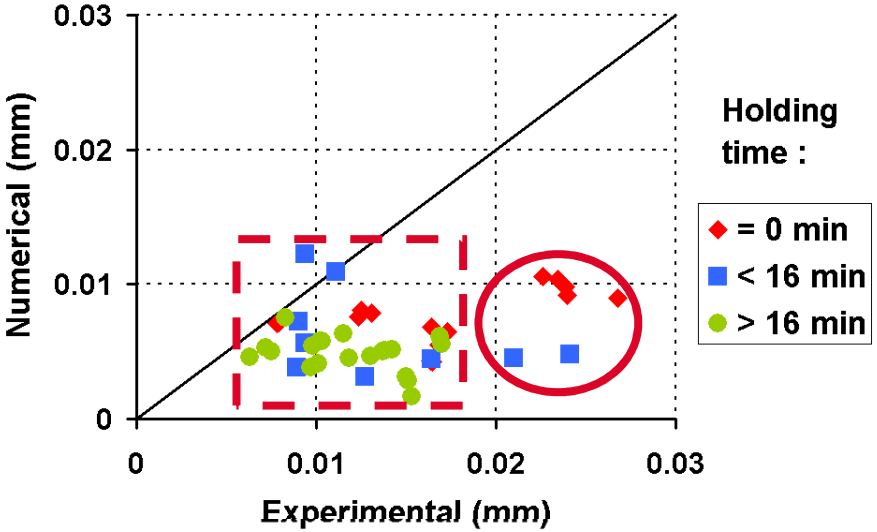
function of repartition

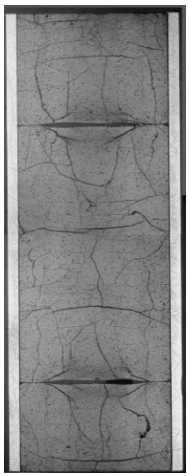
➔ All parameters of this model are adjusted on non-irradiated samples and this model is used to represent irradiated rods.

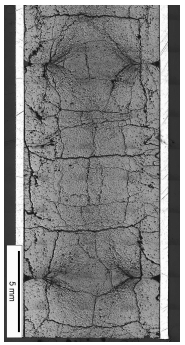


3D PCMI simulations (nominal+transient)

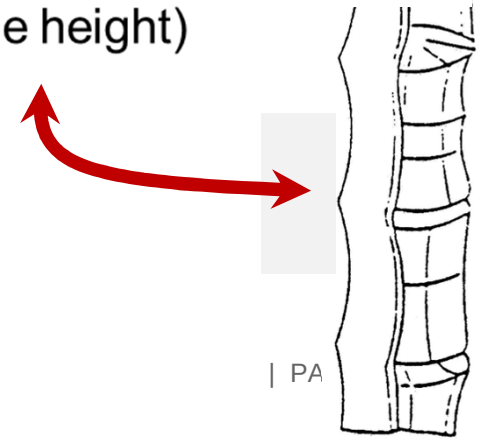








(IP ridge height)



Irradiation effects on fuel creep behaviour of UO2 fuels

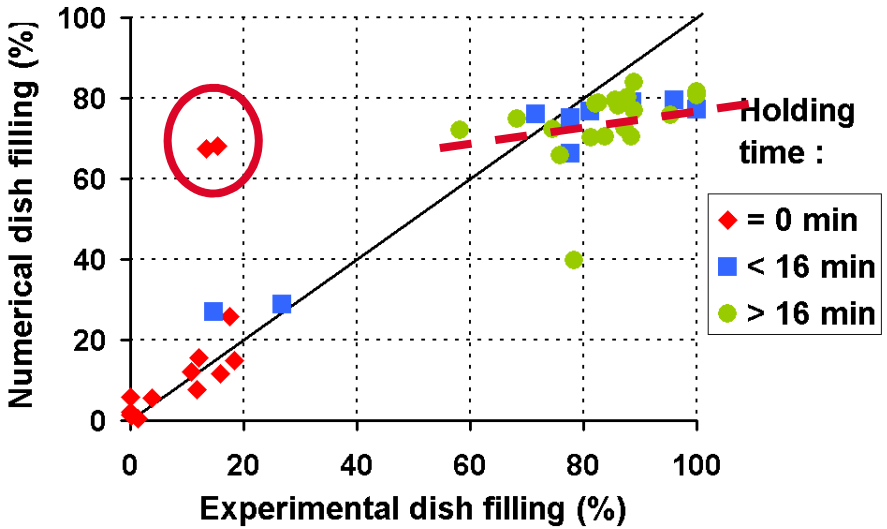
Expression of thermal creep model:

$$\dot{\varepsilon}_{th} = (1-\theta)\dot{\varepsilon}_{diff}(\sigma,T) + \theta\dot{\varepsilon}_{disloc}(\sigma,T)$$

$$\theta = \frac{1}{2}\left(1+\tanh\left(\frac{\overline{T}(\sigma)-T}{h}\right)\right) \exp\left(-\beta BU^2\right)$$

new parameter

burnup



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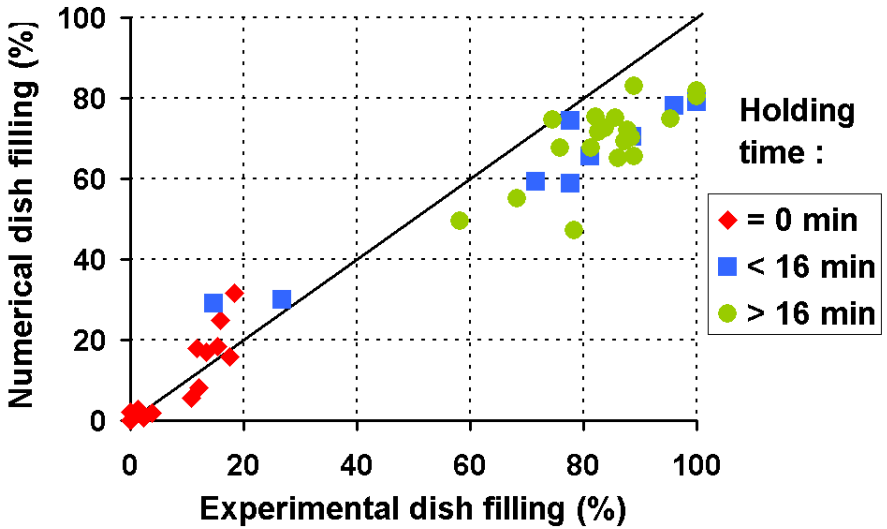
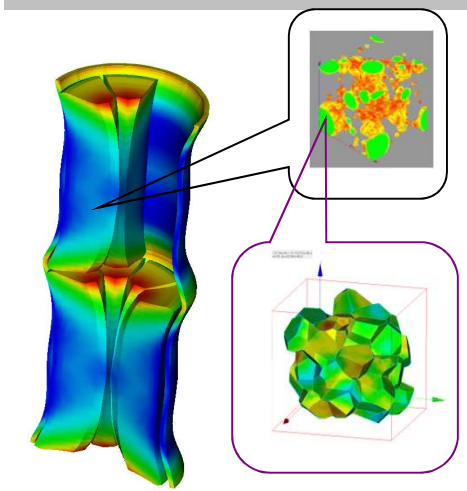


- Rods without holding time are better modelled.
- Same trend for rods with a long holding time.
- 10% deviation for rods with a long holding time.

CONCLUSIONS

Constitutive laws

- Adjustment of fuel creep behaviour law based on post-ramp EPI (dish, ridges) and 3D simulations
  Julien et al., Top Fuel Conference, 2012
- Development of deductive approaches (full-field calculations and homogenization)



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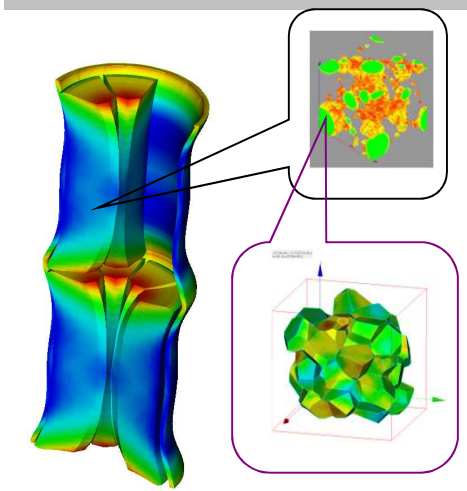

Chemical-physical behaviour

- Central hole formation (SFR fuels)
  V. Bouineau et al., SMIRT, 2011
- Release of volatile fission products
  B. Baurens et al., MMSNF, 2013

CONCLUSIONS

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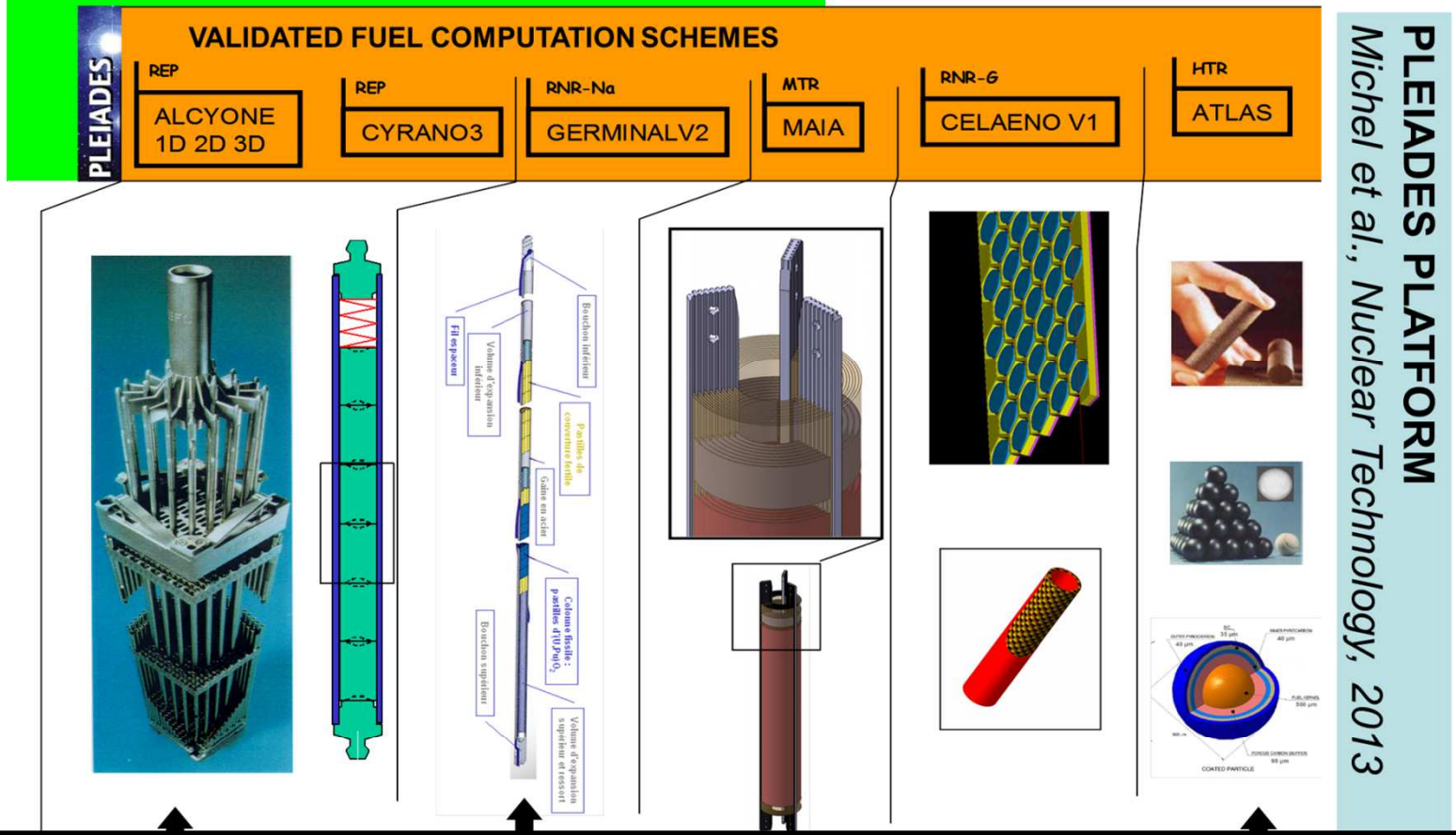


PLEIADES PLATFORM

Michel et al., Nuclear Technology, 2013

400 study cases, 1D-2D-3D simulations:

- Various fuels and claddings ;
- Nominal, off-normal as well as accident conditions (RIA, LOCA)

100 study cases:

-Various oxyde fuels and claddings

- Nominal and transient conditions (in progress)

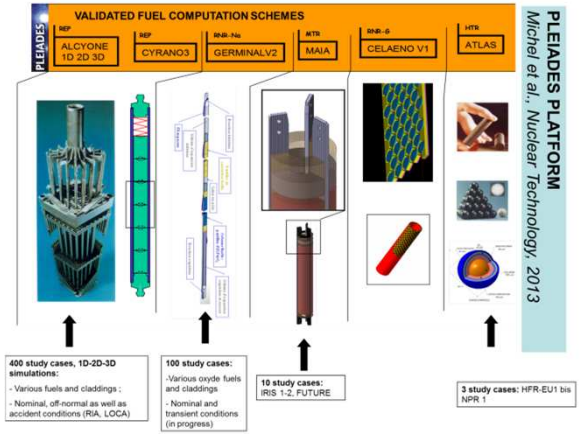
10 study cases:
IRIS 1-2, FUTURE

3 study cases: HFR-EU1 bis NPR 1

CONCLUSIONS

Validation

- PWR : *C. Struzik et al., Top Fuel Conference, 2012*
- SFR : *M. Lainet et al., FR13, 2013*



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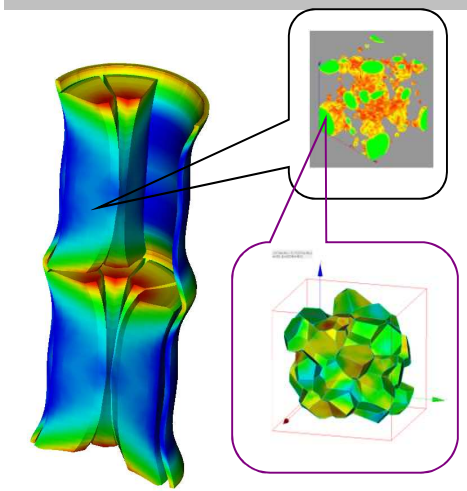

Fracture criteria

- A local defect correction method
L. Barbie et al., ECT, 2014
- Closed-form solutions for PCMI
J. Sercombe et al. ,NED, 2013

Many thanks for your attention !

This work has been done with the financial support of EDF and AREVA