ADVANCED MECHANICAL RESOLUTION IN CYRANO3 FUEL PERFORMANCE CODE USING MFRONT GENERATION TOOL

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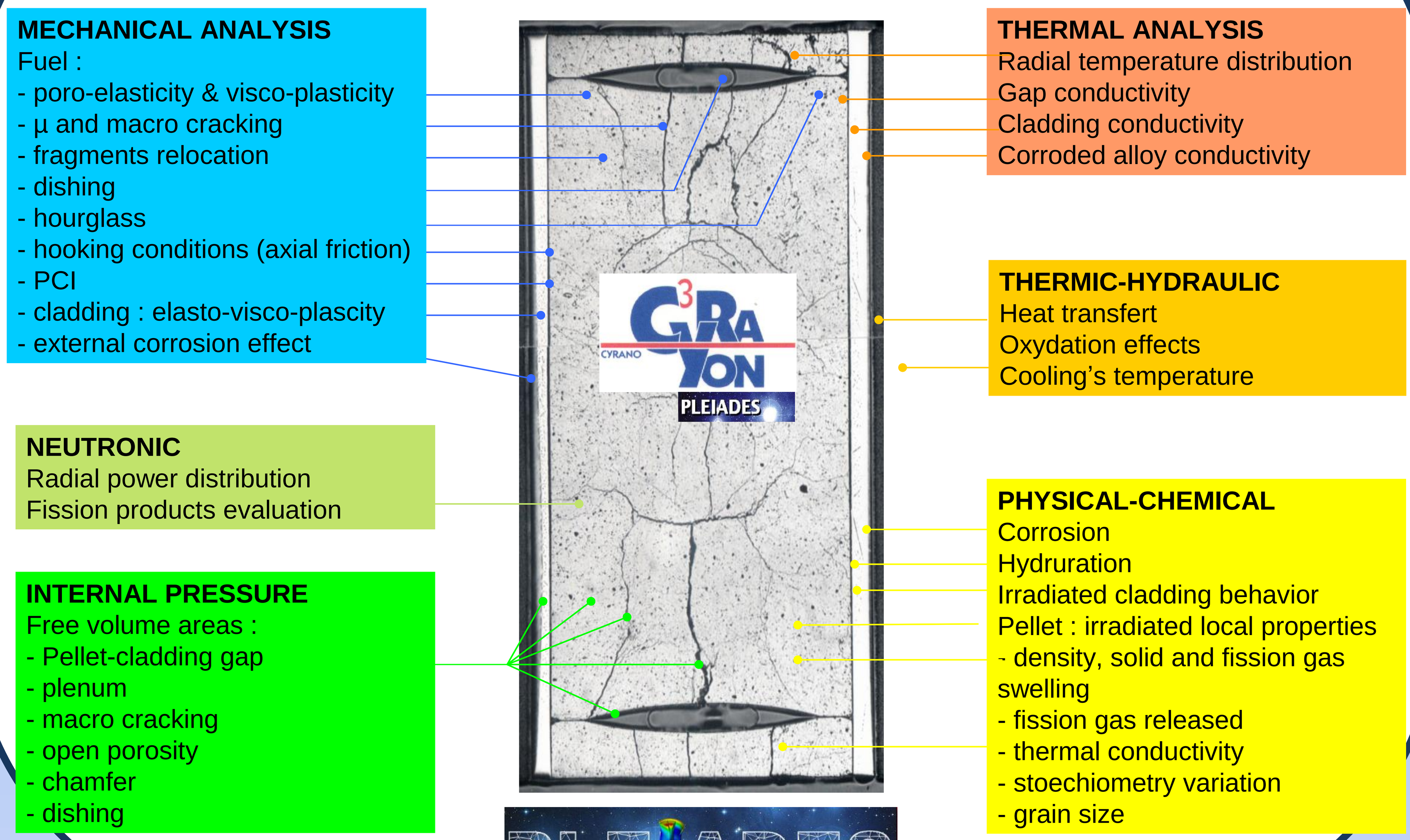
CYRANO3 fuel performance code



MFRONT code generator

MRONT translates a set of physical equations into C++ instructions for local mechanical resolution :

- Various modelling hypotheses : tridimensional, plane strain, plane stress, etc.
- All kind of mechanical phenomena, such as plasticity, viscoplasticity and damage.
- Explicit (Runge-Kutta) and Implicit integration schemes

```
@ComputeStress {  sig = D*eel;}
@Integrator {real sigeq = sqrt(sig|H*sig);
  n    = H*sig/sigeq;
  feel       -= deto - dp*n;
  dfeel_ddp   = n;
 // Primay creep
  fp        -= K1*dt*sigeq+K2*dt;
  dfp_ddeel  = -theta*dt*K2*(n|D);
```

MFRONT instructions

MFRONT → *Compilation* → **Libfile.so**

Dynamic library that can be linked to different target codes

A viscoplastic law implementation

Developed for Zirlo^{TM} cladding material [9]

Valid for normal and incidental conditions

Constitutive equations :

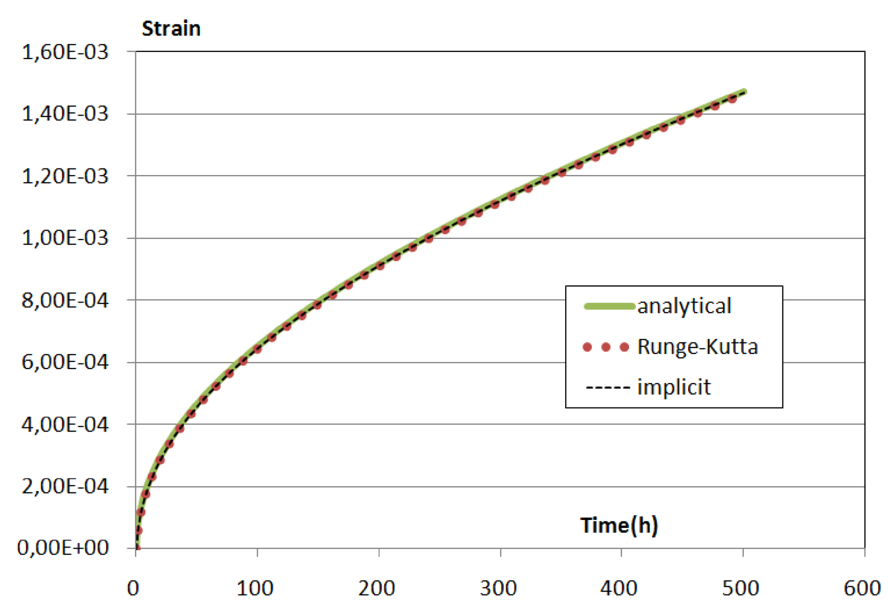
$$\varepsilon_{an}^{eq} = \frac{2}{\sqrt{3}}\left[\varepsilon_{sp}\left(1-e^{-C\sqrt{\dot{\varepsilon}_s t}}\right)+\dot{\varepsilon}_s t\right]$$

$$\varepsilon_{sp} = B\,\dot{\varepsilon}_s{}^{b} * \left[2-\tanh(D\dot{\varepsilon}_s)\right]^{d}$$

$$\dot{\varepsilon}_s = \frac{AE}{T}e^{-\frac{Q}{RT}}\left[\sinh\left(\frac{2}{\sqrt{3}}a_{irr}\frac{\sigma_{eq}}{E}\right)\right]^{n} + C_0\phi^{C_1}\left(\frac{2}{\sqrt{3}}\sigma_{eq}\right)^{C_2}$$

$$a_{irr} = a\left[1-A_1\exp\left(-A_2\varphi^{A_3}\right)\right]$$

Isotropic Von Mises behaviour
Primary and secondary creep terms
Irradiation and thermal creep
Effect of fast neutron flux Φ
Effect of fast neutron fluence φ
Effect of temperature T



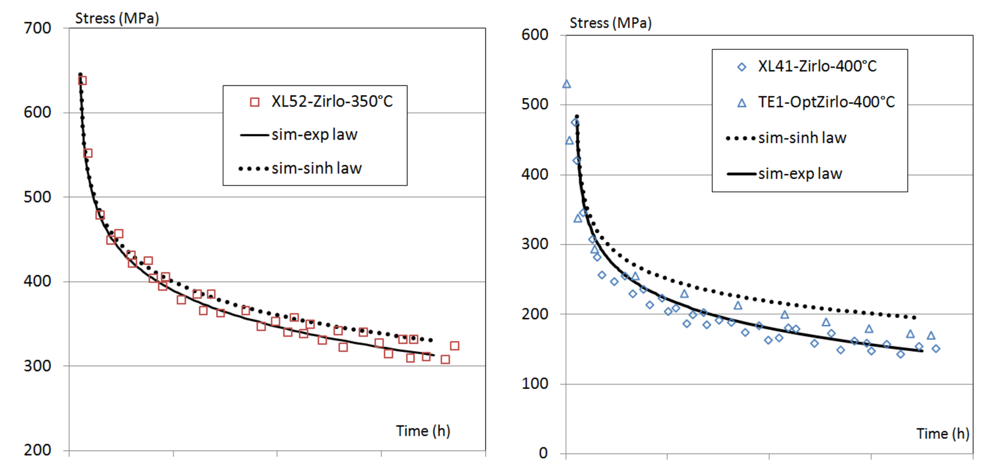
Comparison between an analytical solution and MFRONT explicit and implicit implementations

Verification of MFRONT implementation

- implicit and explicit schemes
- comparison with time-explicit creep response of the constitutive law
- simulation of MFRONT implemented law thanks to MTEST software

Comparison with a reference solution

- stress-relaxation tests (irradiated) [9]
- simulation of MFRONT implemented law thanks to MTEST software
- comparison with the exponential approximation from [9]



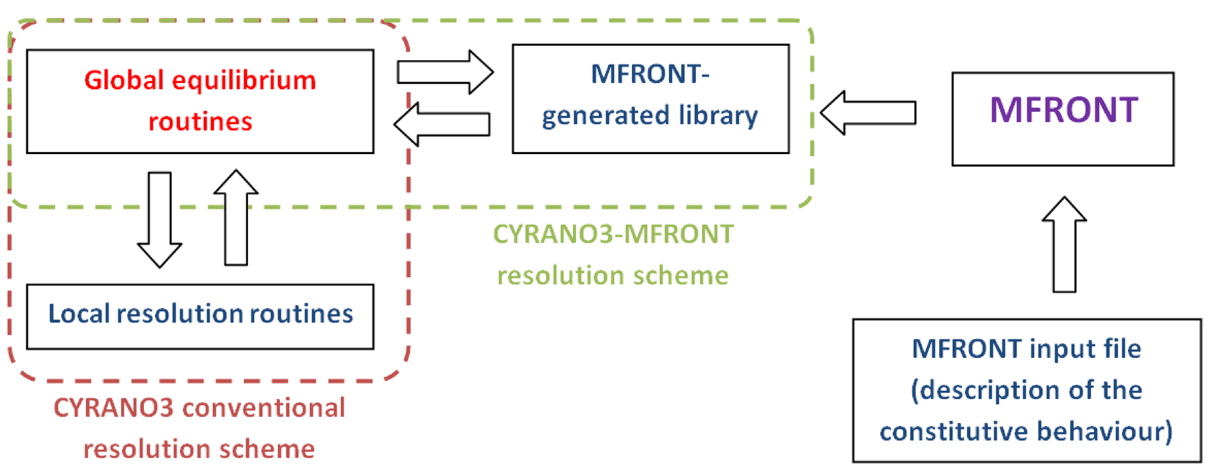
Comparisons between experimental results from [9] and simulations using different approximations of the creep law

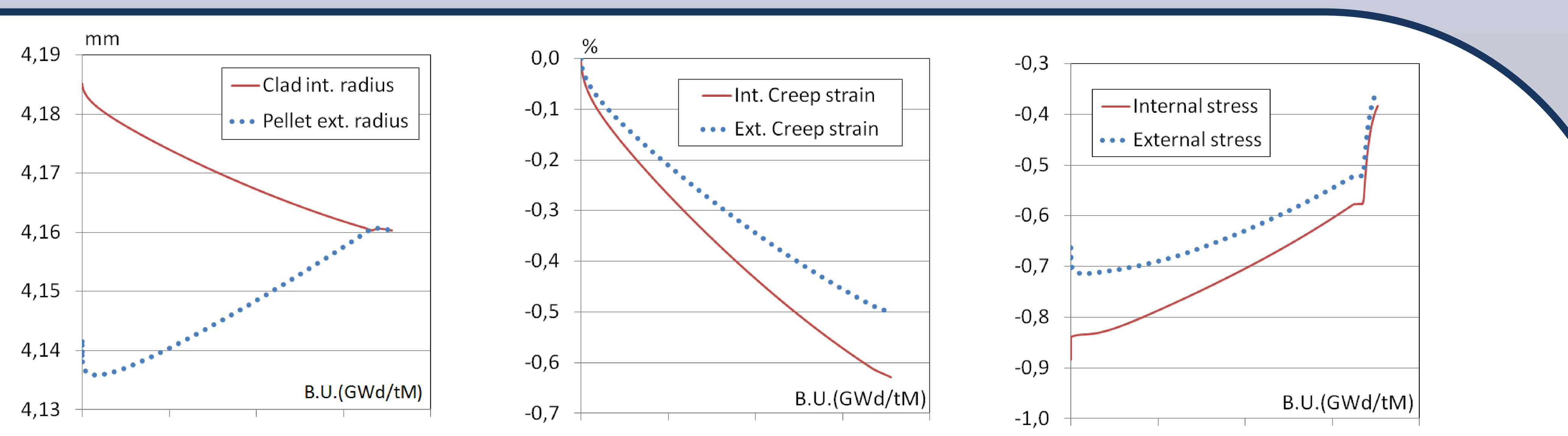
CYRANO3 computation

CYRANO3 case study

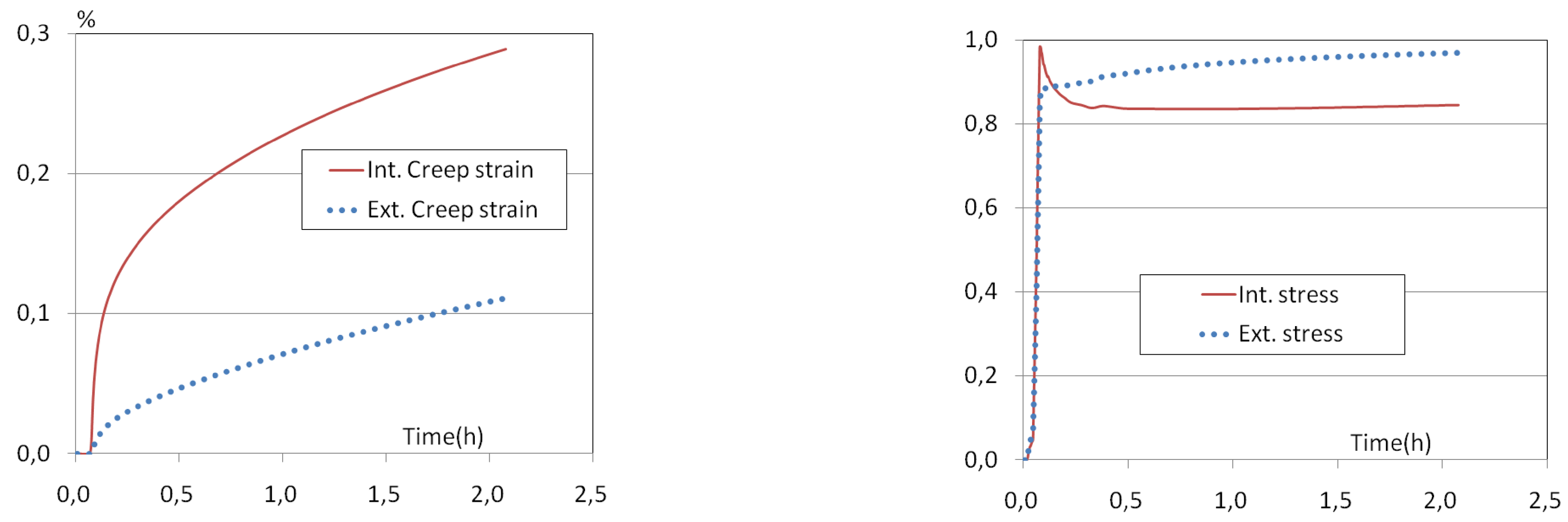
- irradiation of a typical PWR UO2/Zirlo^{TM} rod at 180W/cm up to 35GWd/tM (step 1);
- 100W/cm/min power ramp up to 350W/cm + 2 hours holding time (step 2).

Typical PWR severe incidental conditions...





Results of step 1 computation – evolutions as a function of rod burn-up left : pellet and cladding radii center : cladding inner and outer creep strain right : cladding inner and outer normalised hoop stresses



Results of step 2 computation – left : cladding inner and outer creep strain right : cladding inner and outer normalised hoop stresses