RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

IRSN FUEL+ SOFTWARE PLATFORM TO SIMULATE FUEL BEHAVIOR IN ACCIDENTAL CONDITIONS

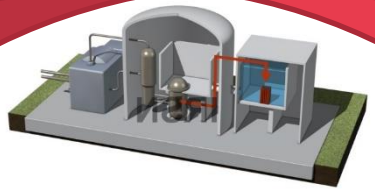
SNETP Forum – Technical Session 3: Fuel development and fuel cycle efficiency
February 3, 2021

Objectives of FUEL+ software platform: modeling the « life » of nuclear fuel

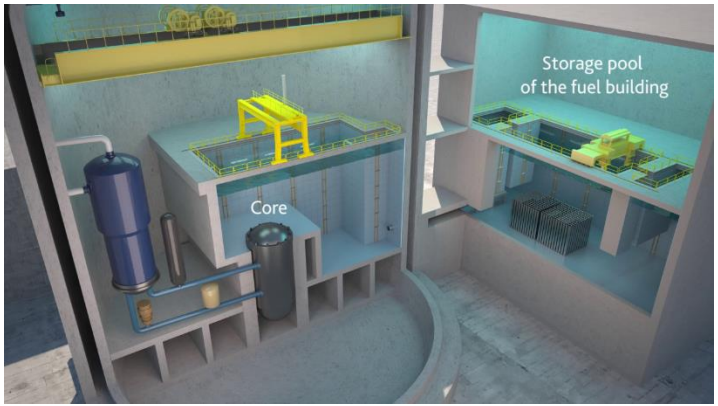
Removal from the core

Spent fuel pool

Design Basis Accident ?

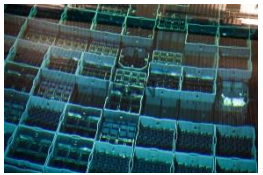


Transport to storage location

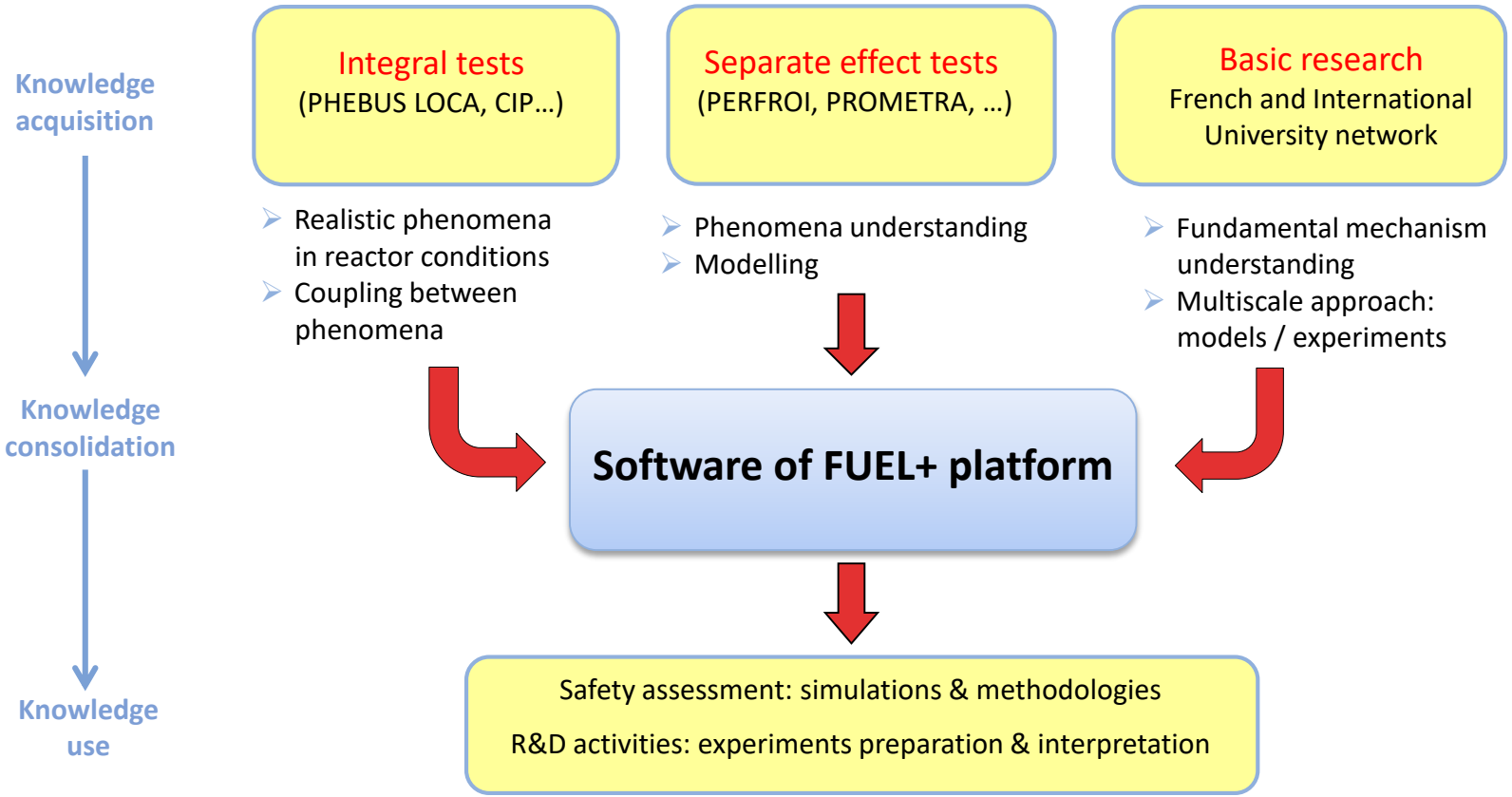


Normal operation

Long-term storage



Strategy


Knowledge acquisition
Knowledge consolidation
Knowledge use
Integral tests
(PHEBUS LOCA, CIP…)
Separate effect tests
(PERFROI, PROMETRA, …)
Basic research
French and International University network
Realistic phenomena in reactor conditions
Coupling between phenomena
Phenomena understanding
Modelling
Fundamental mechanism understanding
Multiscale approach: models / experiments
Software of FUEL+ platform
Safety assessment: simulations & methodologies
R&D activities: experiments preparation & interpretation

Strong link with ongoing experimental programs

OECD CABRI International Program (RIA)

ANR PERFROI (LOCA)

- Thermomechanical axis : ELFE, COCAGNE
- Thermal-hydraulic axis : COLIBRI, MASCARA, COAL

ANR DENOPI (spent fuel pool)

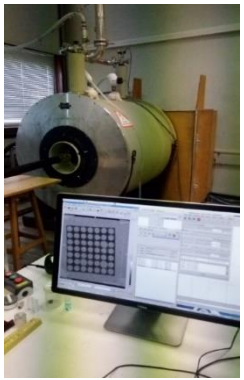
- MEDEA
- ASPIC

OECD SCIP

- Normal operation
- Ramps
- LOCA

COAL

CABRI

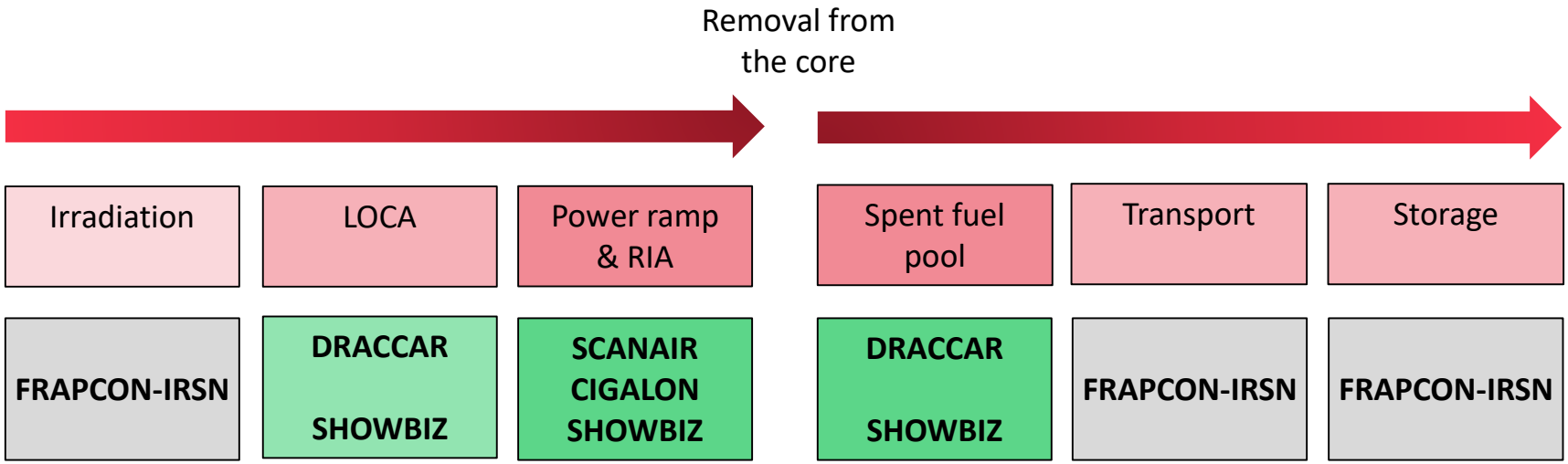


MASCARA

COCAGNE

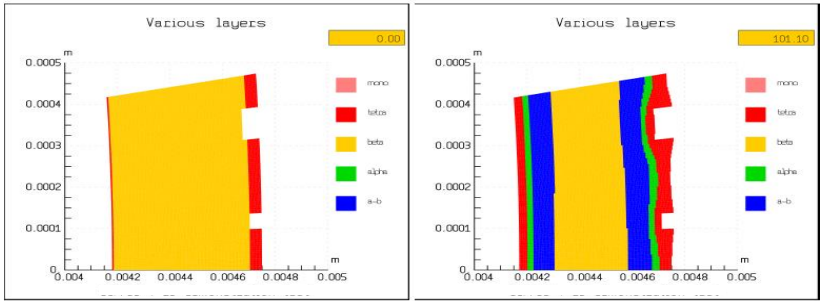
MEDEA

Objectives of FUEL+ software platform: modeling the « life » of nuclear fuel

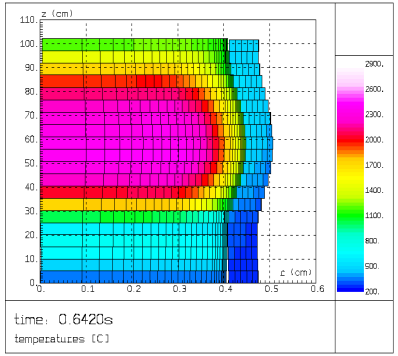


Objectives of FUEL+ software platform: at different scales

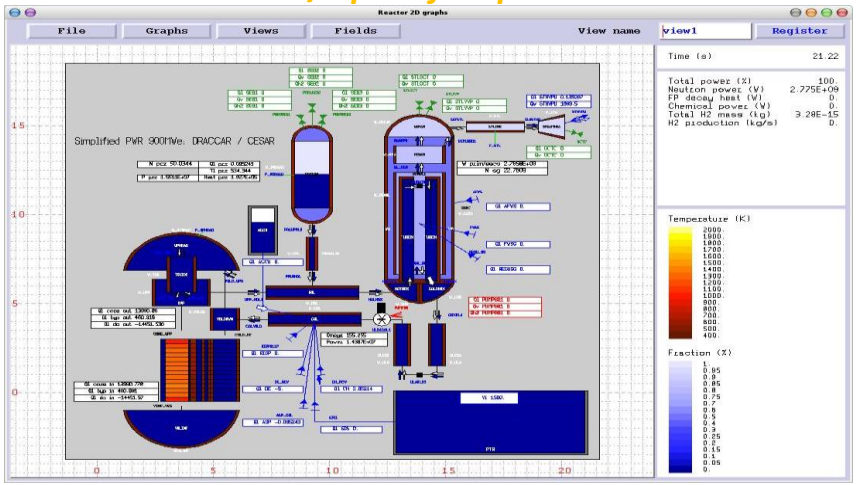
Local scale



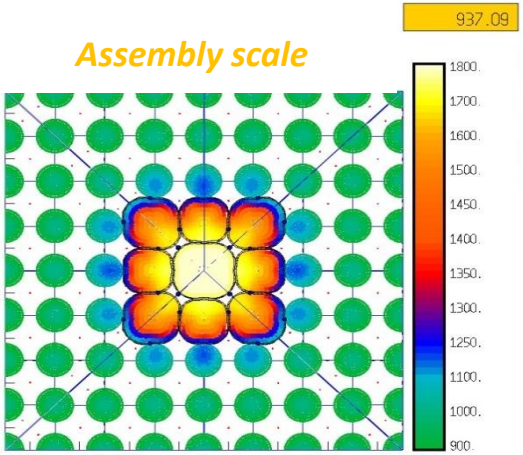
Fuel rod scale



Reactor / Spent fuel pool scale



Assembly scale



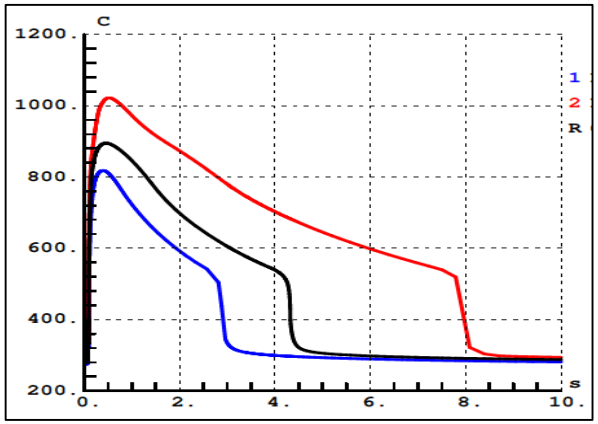
Objectives of FUEL+ software platform: facilitate studies

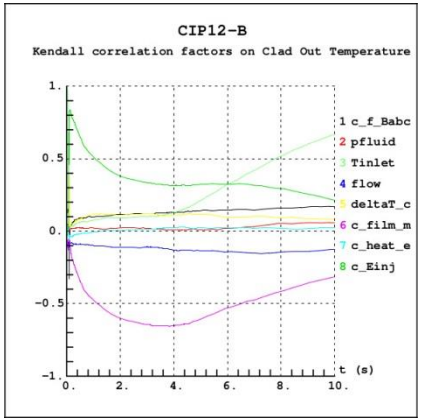
Integrated tools to achieve

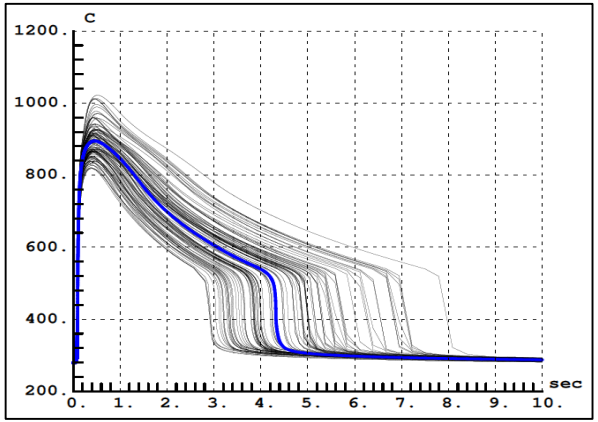
- Propagation of uncertainties
- Sensitivity studies

Goal: carry out these studies very simply and quickly from the data deck

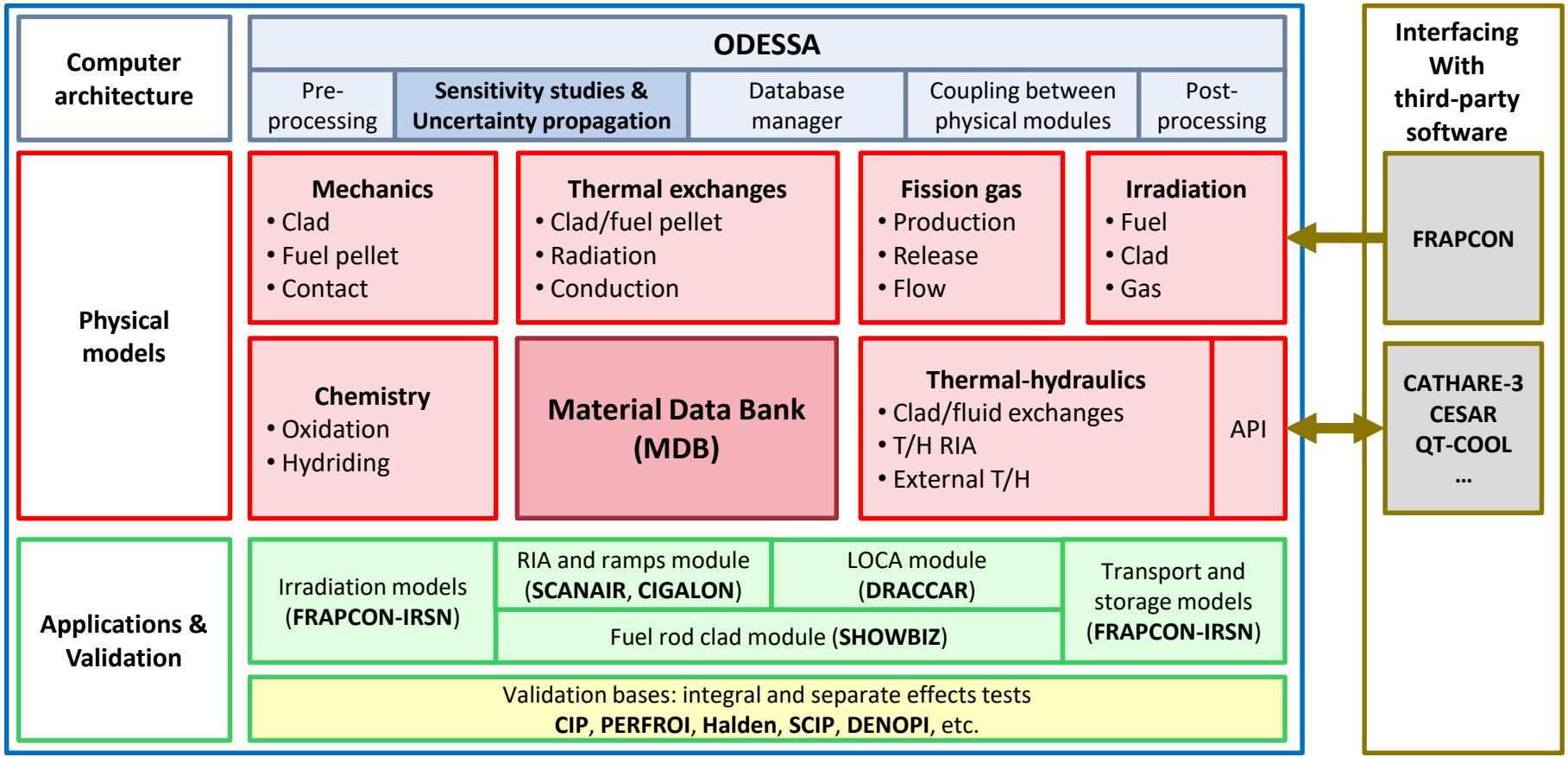
- Sampling
- Run all calculations
- Post-processing of results
  - ✓ Uncertainty band / percentiles
  - ✓ Correlation factors (Kendall, Pearson, Spearman,…)







FUEL+ architecture



The IRSN SHOWBIZ code

Objectives

- Studying Hydrogen and Oxygen weakening behavior in Zirconium alloys during DBA for 1D to 3D geometries
  - ✓ O diffusion, crystallographic state, phase change
  - ✓ H diffusion, hydride precipitation, radialization in low T transients
  - ✓ Thermomechanical behavior, oxide cracking, burst
- Modular, easy coupling to higher scale FUEL+ codes (DRACCAR, SCANAIR)

Development framework

- Fully developed by IRSN
- Co-financed by EDF and Framatome
- Used by IRSN

Link with experimental programs

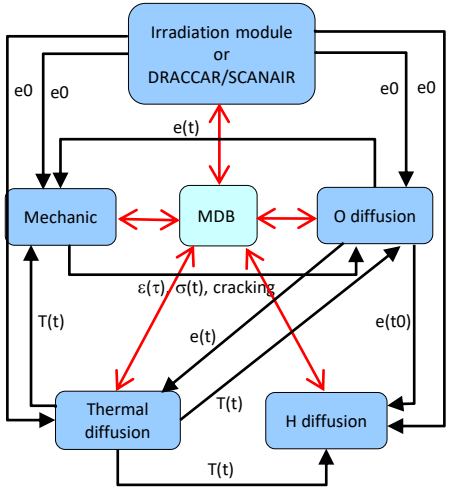
- Closely linked to the thermomechanical axis of the PERFROI program directed by IRSN and funded by the National Research Agency (ANR)
- Validation based on IRSN MARGO-R, CRACKOX, EDGAR, SCIP tests

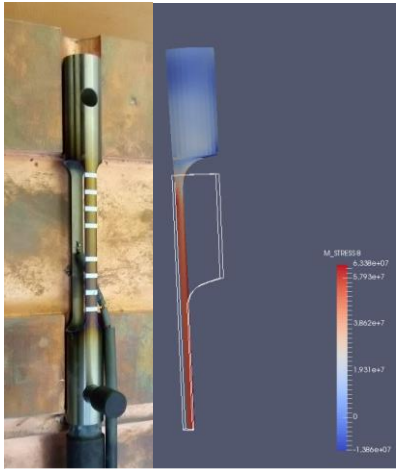
Used for

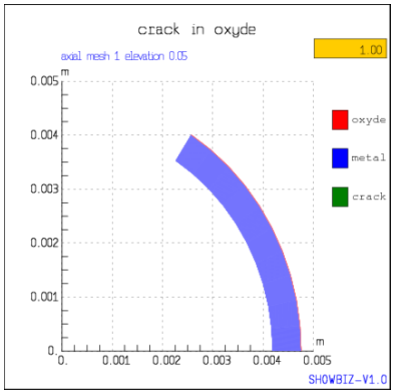
- Preparation / interpretation of tests
- Knowledge capitalization on DBA

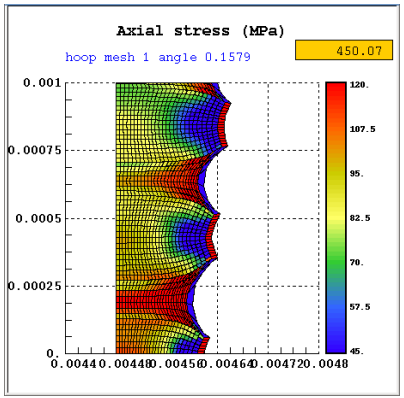
Perspectives

- Secondary hydriding (LOCA, defective rods)
- Validation on mechanical experimental tests from PERFROI









The IRSN SCANAIR code

Objectives

- Simulation of the thermo-mechanical behavior of a fuel rod during a RIA transient
- Evaluation of the clad failure
  - ✓ During the PCMI phase
  - ✓ During the DNB phase

Development framework

- Fully developed by IRSN
- Co-financed by EDF
- Used by IRSN, EDF, SSM (Sweden), VTT (Finland)

Link with experimental programs

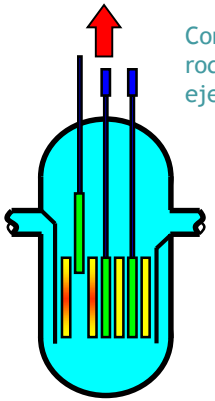
- Closely linked to the CIP program
- Validation based on CABRI, NSRR, BIGR, SPERT tests

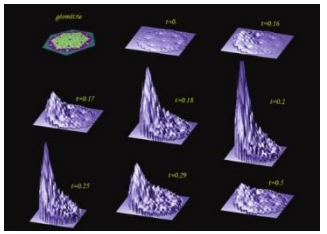
Used for

- Preparation / interpretation of CIP tests
- Safety studies
- Knowledge capitalization related to RIA

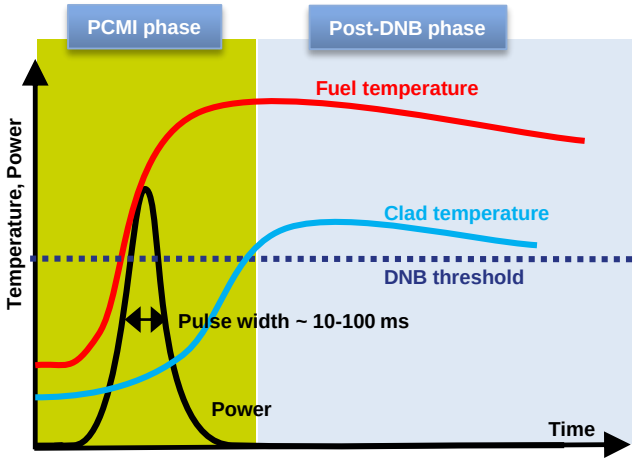
Perspectives

- Validation on the CIP tests
- Development of a base irradiation version of SCANAIR





Neutron power evolution in the core



The IRSN CIGALON code

Objectives

- Estimate the mechanical consequences of a fuel-coolant interaction caused by the rupture of a cladding during an RIA type test
- Simplified modeling with 3 connected systems
  - ✓ For multiple phenomena insufficiently characterized with a parametric approach allowing envelope evaluations and / or sensitivity studies

Development framework

- Fully developed by IRSN
- Co-financed by EDF
- Used by IRSN

Link with experimental programs

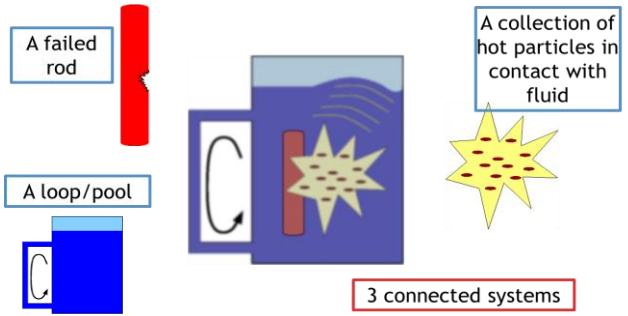
- Closely linked to the CIP program
- Validation based on NSRR, SPERT PBF, KROTOS tests

Used for

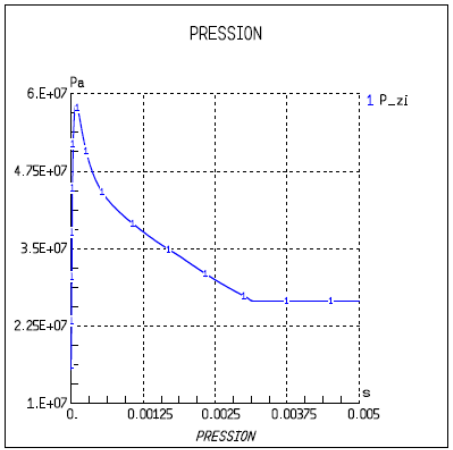
- Safety assessment of CABRI reactor
- Preparation / interpretation of CIP tests
- Knowledge capitalization

Perspectives

- Validation on CIP tests
- Integration of PhD modeling work



CIP like calculation



The IRSN DRACCAR code

Objectives

- Simulation of the 3D thermo-mechanical and reflooding behavior of one or more fuel rod assemblies during a loss of coolant accident (LOCA)
  - ✓ Ballooning, burst, fuel relocation, embrittlement of rods
  - ✓ Blockage, contact between rods, reflooding

Development framework

- Fully developed by IRSN
- Co-financed by EDF and Framatome
- Used by IRSN, EDF, Framatome and ENEA

Link with experimental programs

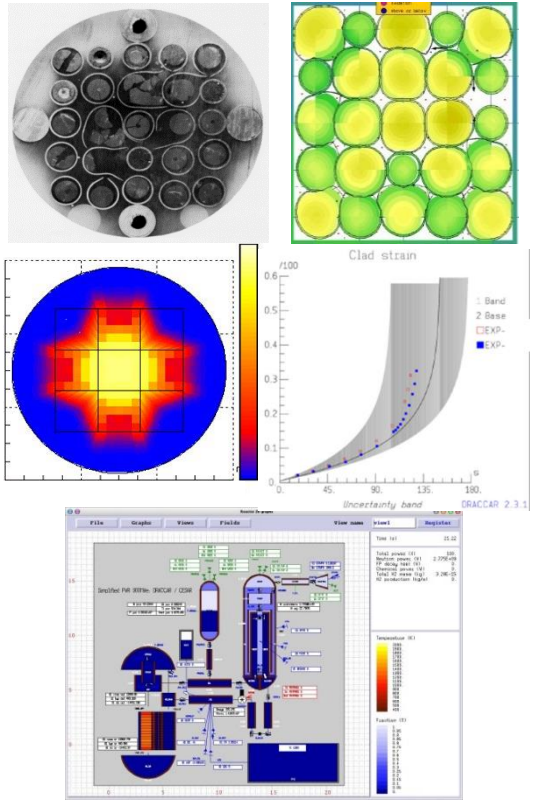
- Closely linked to PERFROI and DENOPI programs directed by IRSN and funded by the National Research Agency (ANR)
- Validation based on PHEBUS, HALDEN, SCIP, QUENCH, REBEKA, SFP,…

Used for

- Preparation / interpretation of tests
- Safety studies
- Knowledge capitalization related to LOCA and loss of cooling SFP

Perspectives

- Multi-scale modeling, uncertainties quantification
- Validation on experimental tests from PERFROI program

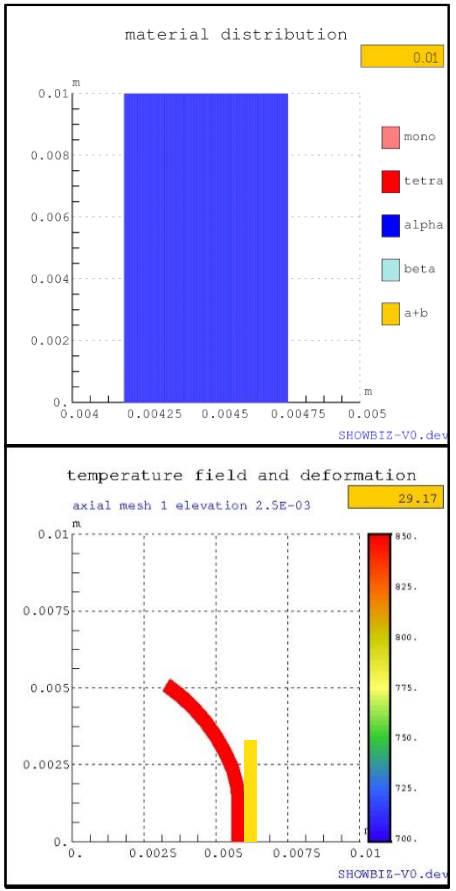


Examples of simulations

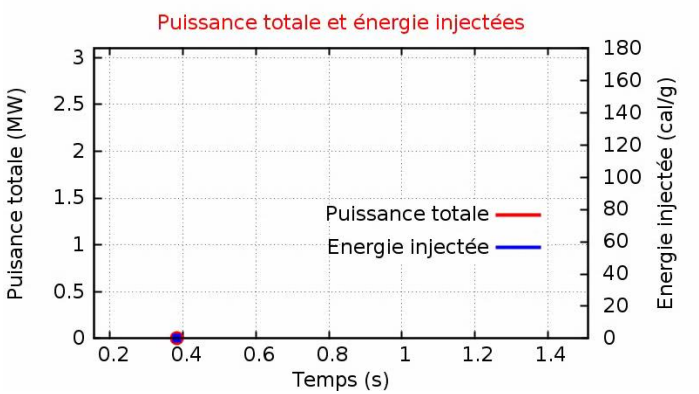
Example of SHOWBIZ simulations

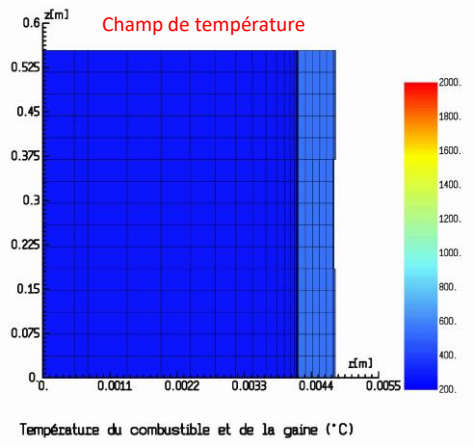
- Diffusion of oxygen in the clad

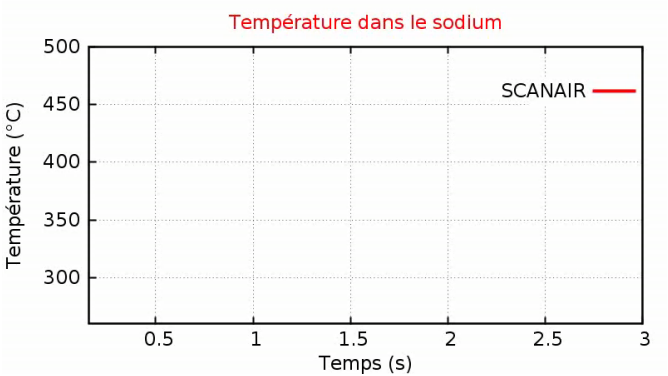
- Creep of the clad and contact

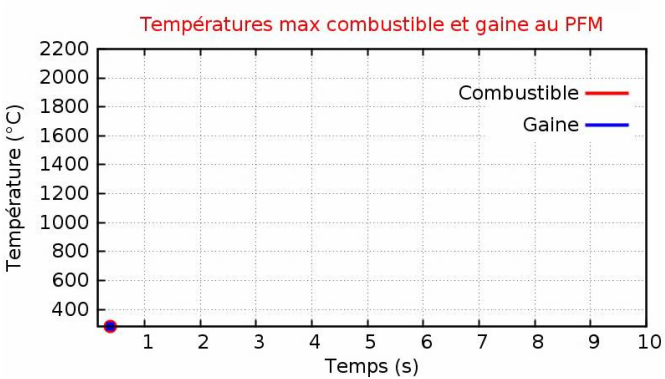


Example of SCANAIR simulation: REP-Na6 test (thermal behavior)

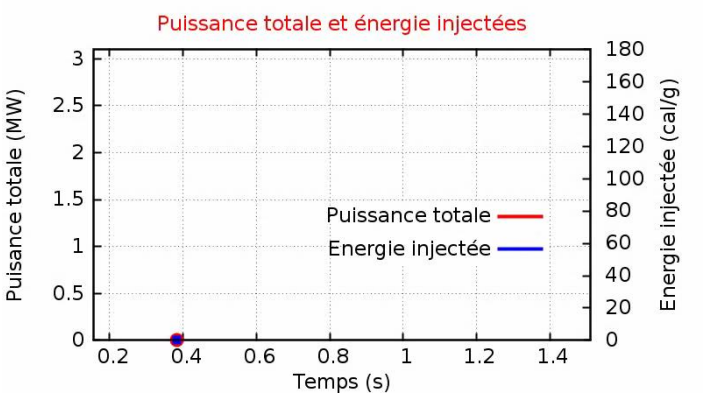


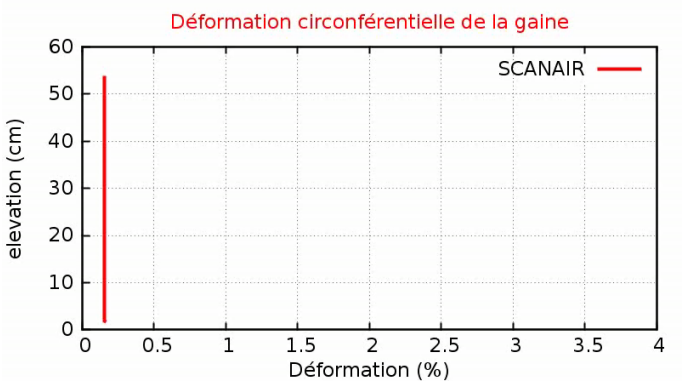


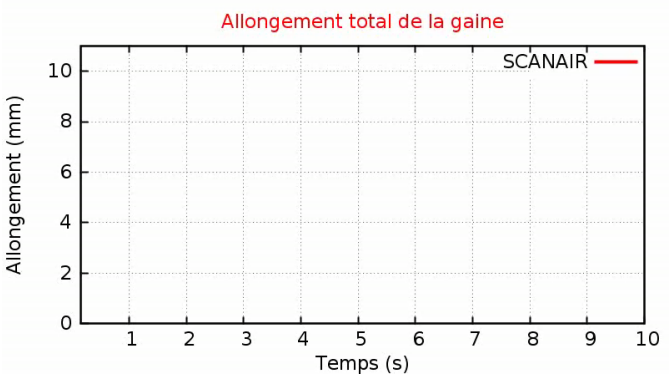


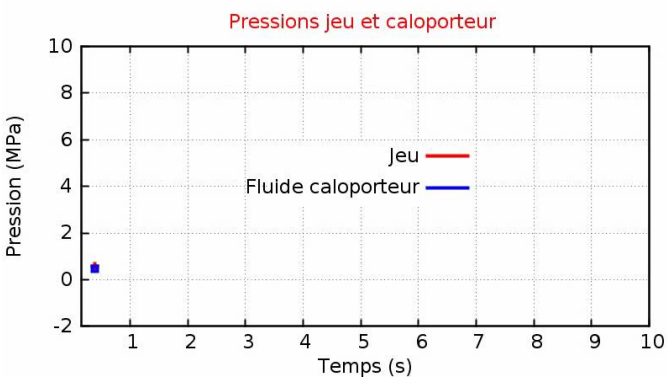


Example of SCANAIR simulation: REP-Na6 test (mechanical behavior)









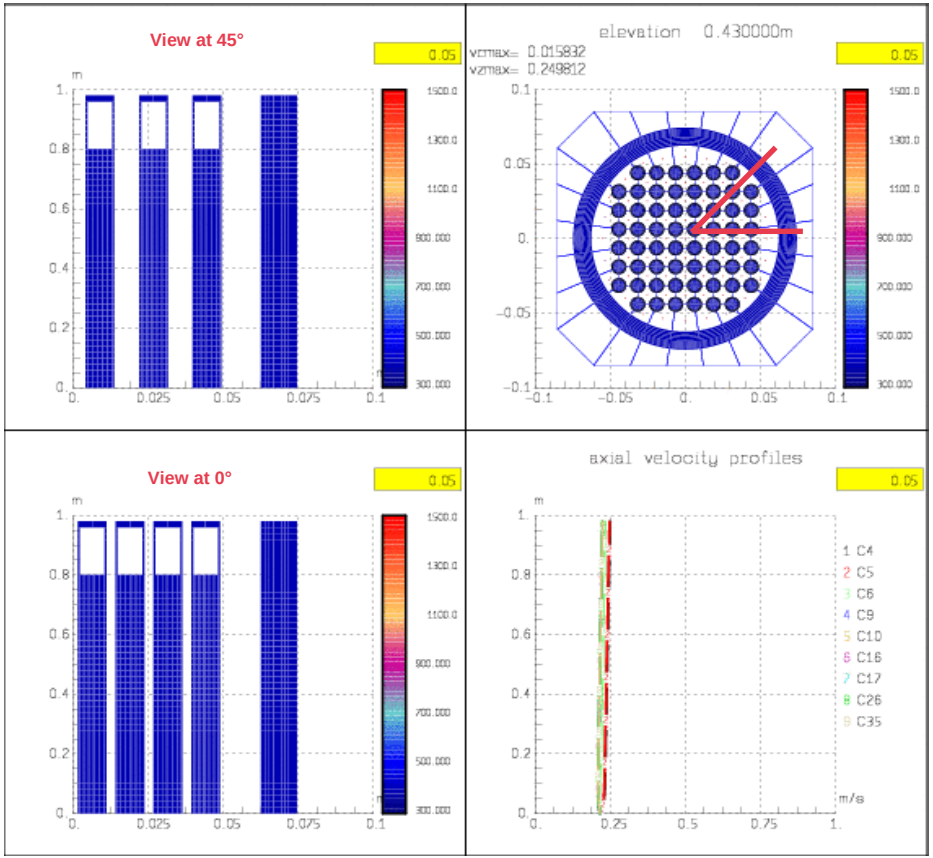
Example of DRACCAR simulation: pre-calculation of an experiment

Geometry

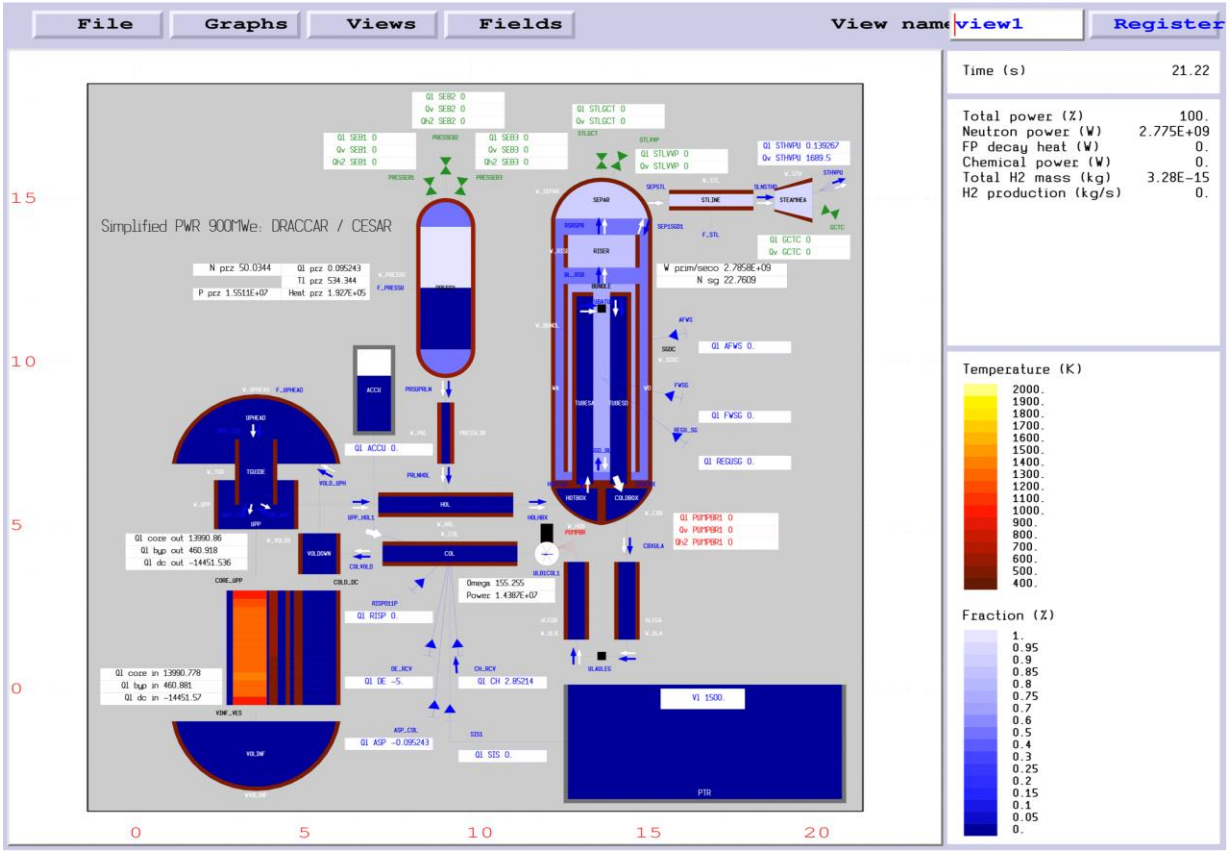
- 60 rods, height 0.8 m
- 16 (central) irradiated rods
- 44 as received rods
- Cylindrical shroud

Transient

- P = 2 bar
- 121°C = Tsat
- Constant steam flow = 1.9 g/s
- Homogeneous horizontal power
- Initial rod pressure = 60 bar at 25°C



Example of DRACCAR simulation: LOCA in PWR



Thank you for your attention