IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

ANALYSIS OF CABRI DRIVER CORE NEW SAFETY DEMONSTRATION FOR FUEL RODS INTEGRITY DURING FAST POWER TRANSIENTS

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Système de management
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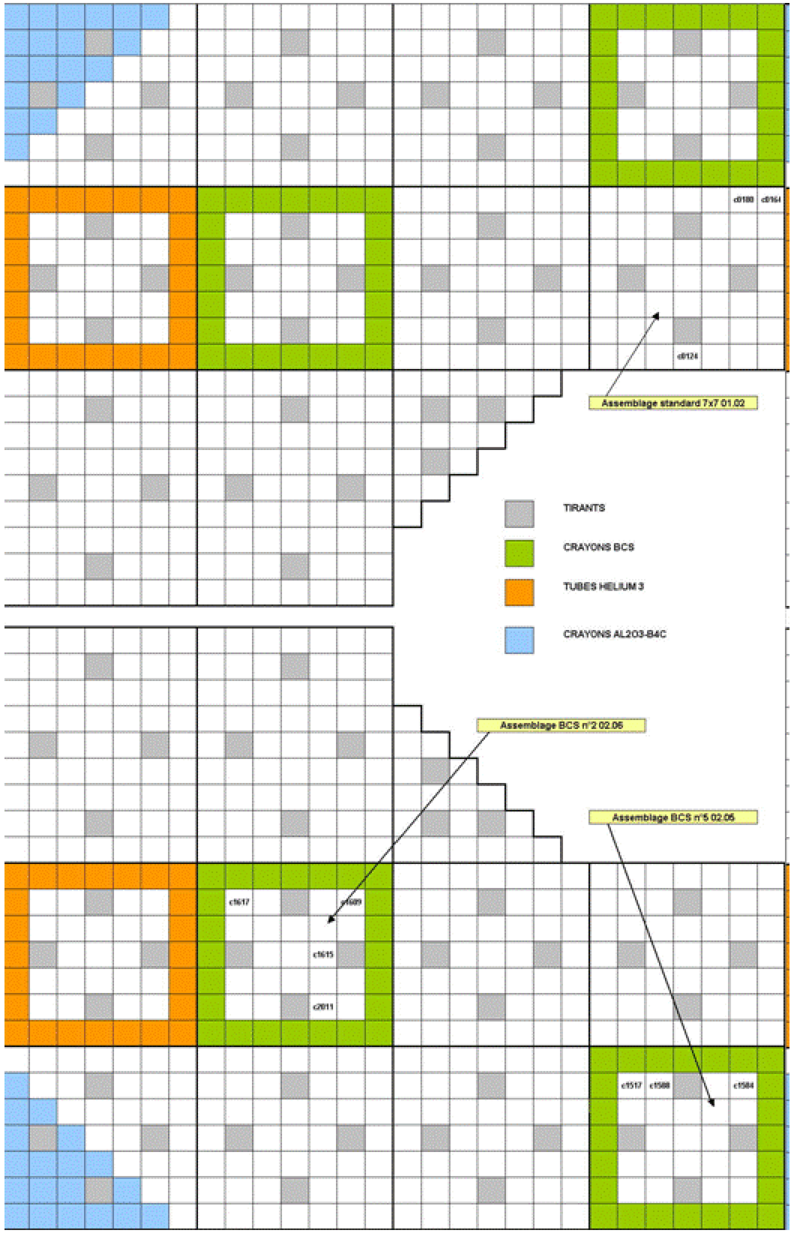
IRSN : technical support of the French Nuclear Safety Authority



- **EXPERIMENTAL LOOP**
  - Located at the center of the driver core
  - Fast power transients simulated by nuclear pulses
  - 3 $ of mean increasing reactivity with a 50 $/s ramp

- **DRIVER CORE**
  - Power of 25MW cooled with water in forced convection
  - Enriched UO_2 fuel rods, 6% in ^{235}U, stainless steel cladding material, fissile zone = 60 x 60 x 80 cm,
  - 6 control and safety rods
  - 4 transient rods (gaseous absorber rods – Helium 3)

Outline

- IRSN assessment of new CABRI driver core safety criteria
- SPERT and NSRR integral experiments
- Comparison of the new CABRI criteria to integral experiments
  - ✓ **Thermomechanical simulations : SCANAIR code**
- Conclusion

CABRI driver core new safety criteria

➢CEA criteria

- **Two possible failure modes of the clad**
  - Clad melting
  - Ductile rupture

- **To warrant the cladding integrity of the driver core during future tests :**
  - Maximum clad temperature set to 1300° C (margin of 150° C to the melting temperature of the stainless steel cladding material)
  - Maximum clad hoop strain must be lower than 3.65% (50% of the lowest value of the rupture elongation measured on samples representative of the clad)
  - Fuel melting not allowed : maximum fuel temperature should remain below 2800° C

➢IRSN approach

- **Past experiments**
  - Realized in SPERT and NSRR facilities on fuel rods similar to CABRI ones
  - Single fuel rod submitted to very short power transients
  - Identify the failure threshold as a maximum injected energy

- **Comparison of the new criteria with this failure threshold**
  - Use of SCANAIR code

Integral experiments

➢ SPERT experiments : description (United States 1960-70)

- **Single power burst**
- **Many types of unirradiated UO_2 fuel rods tested; among them 2 tests series with rods similar to CABRI ones (F-type and SPX)**

↳ Objective : determine the approximate injected energy (given at the axial flux peak) in fuel rods required to cause clad failure

Characteristics	F-type fuel rod	SPX fuel rod	CABRI driver fuel rod
UO2 pellet			
Diameter (mm)	10.67	5.59	9.19
Length (mm)	15.2	11.4	11.5
Density (%T.D.)	92	95	94
Enrichment (%)	4.8	3 / 10	6
End shape	flat	flat	Chamfered
Cladding			
Material	**304-SS**	**304-SS**	**Al Si 304-SS**
Outer diameter (mm)	11.84	6.35	10.0
Wall thickness (mm)	0.508	0.356	0.4
Fuel rod			
Pellet-cladding gap (mm)	0.076	0.025	0.05
Fuel length (mm)	910	460	800
Plenum gas	He	He	He
Overall length (mm)	1060	530	800

Integral experiments

➢ SPERT experiments : results

	Fuel rod type F-type	Fuel rod type SPX
Number of tests	47	7
Injected energy (cal/g)	[50, 300]	[200, 570]

7 fuel rod tests out of 54 had failed

- **Failure threshold for stainless steel clad rods : [244, 278] cal/g with reactor period [3ms, 6ms]**
- **Failure mechanism : mainly cladding melting**
- **Important cladding oxidation of failed rods**

➢ NSRR experiments : description (Japan 1970)

- Same conditions as SPERT

Objective :

- study different fuel rods behavior during fast power transients
- define an injected energy failure threshold for each type of rod

Characteristics	stainless steel clad fuel rod	CABRI driver fuel rod
UO2 pellet		
Diameter (mm)	9.54	9.19
Length (mm)	10.	11.5
Density (%T.D.)	94.4	94.
Enrichment (%)	10.	6.
Shape	Chamfered	Chamfered
Cladding		
Material	304-SS	Al Si 304-SS
Outer diameter (mm)	10.53	10.
Wall thickness (mm)	0.40	0.4
Fuel rod		
Pellet-cladding gap (mm)	0.095	0.05
Fuel length (mm)	135.	800.
Plenum gas (MPa)	He 0.1	He 0.5
Overall length (mm)	279.	800.

Integral experiments

NSRR experiments : results

- **10 tests were conducted with injected energies ranging from 114 to 457 cal/g**

NSRR results	Stainless steel clad fuel rod	Zircaloy clad fuel rod
Failure threshold energy (cal/g)	**[221, 258] => 240**	**260**
Failure mechanism **(same test condition)**	**Cladding melting**	**Oxygen-induced embrittlement**

Discussion : Integral experiments

➢ Integral experiments (SPERT&NSRR) were used to define failure criteria based on injected energy in rod during transient

- Characteristics of the rods close to those of CABRI reactor rods (UO_2 fuel, stainless steel clad)
- Thermal hydraulic conditions were similar : stagnant water at ambient temperature, atmospheric pressure
- Difference on pulse width : 5ms (NSRR) < 10ms (CABRI) < 20ms (SPERT)

➢ The obtained results are consistent between the 2 studies

- Identified failure mechanism : cladding melting

Failure threshold energy SPERT study	Failure threshold energy NSRR study
[244, 278] cal/g	240 cal/g

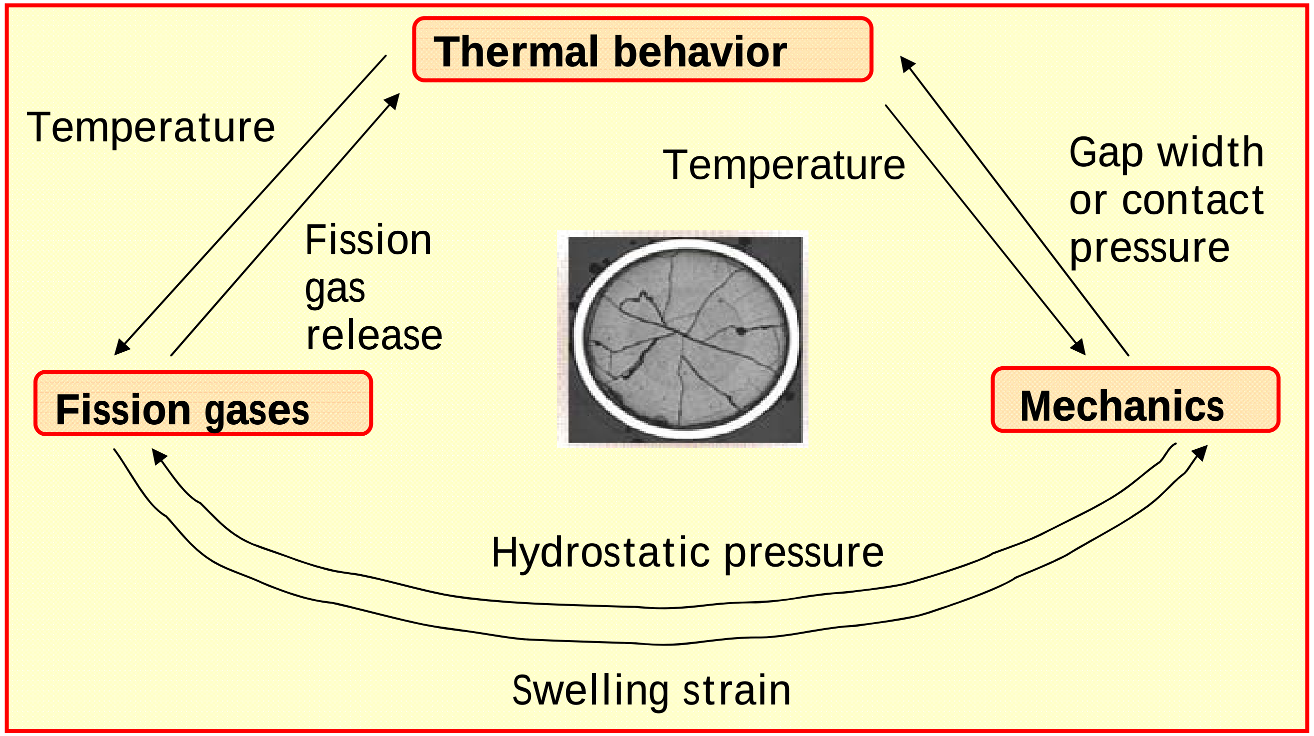
SCANAIR IRSN Code

DESCRIPTION

- Devoted to thermal mechanical simulation of one fuel rod (UO_2 or MOX) during fast power transient (RIA)
- Qualified on integral tests performed in CABRI reactor, NSRR reactor and PATRICIA CEA thermal hydraulic facility
- Three implicitly coupled modules

Input data

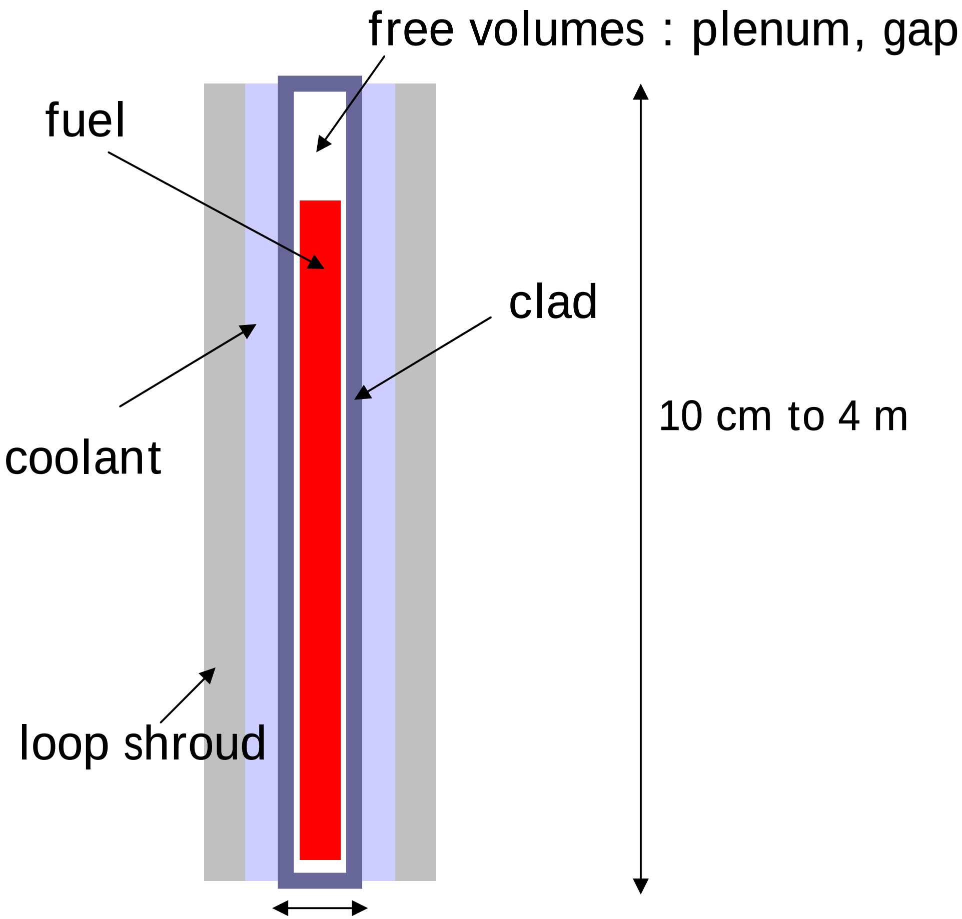
- Irradiation software
- Characterization examinations
- Power pulse

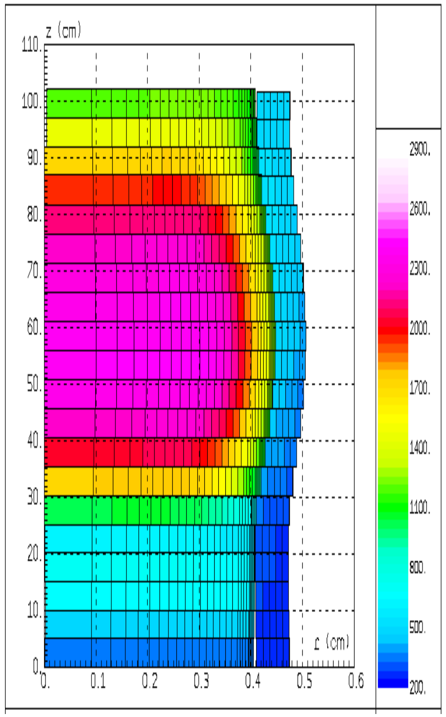


SCANAIR IRSN Code

GEOMETRY MODELISED BY SCANAIR

- Fuel rod in a fluid channel
- Pellet and clad fine meshed axially and radially



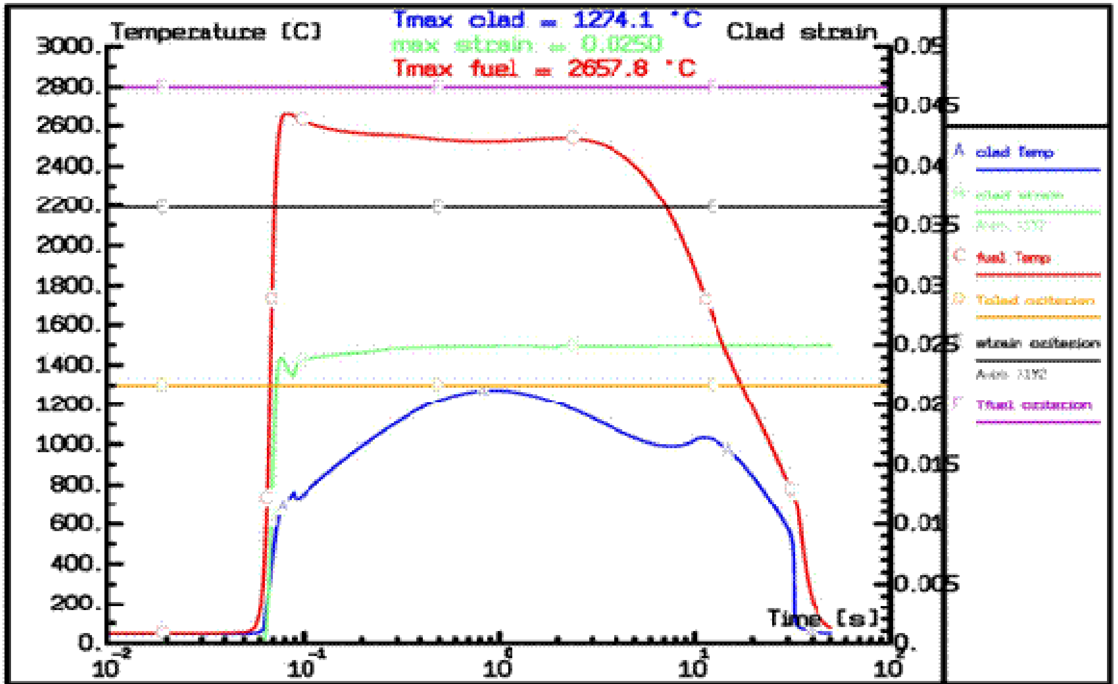


Example of temperature field in fuel rod

Comparison of new CABRI criteria to integral experiments

CABRI DRIVER CORE FUEL ROD CALCULATIONS

- Only 10ms power transients are considered (most penalizing case)
- Three calculations performed with different sets of hypothesis (uncertainties on power, rod geometry, physical properties…)
  - to maximise clad temperature (clad temperature criterion)
  - to maximise clad strain (clad hoop strain criterion)
  - Best-estimate



Fuel, clad Temperatures and clad hoop strain versus time

Conservative calculation (clad temperature)

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Comparison of new CABRI criteria to integral experiments

MOST SEVERE TEST FORESEEN IN CABRI

10 ms pulse	Maximum values	Injected energy
Conservative calculation (clad temperature)	T=1274.1° C	231 cal/g
Conservative calculation (clad strain)	eps=2.50%	231 cal/g
Best-estimate calculation	T=860° C | eps=1.36%	195 cal/g

CALCULATIONS TO REACH THE NEW SAFETY CRITERIA

- Tuning power to reach the criteria values

10 ms pulse	Injected energy
Clad temperature = 1300° C	236 cal/g
Fuel temperature = 2800° C	246 cal/g
Clad hoop strain = 3.65%	287 cal/g

- Cladding melting comes first
- Safety criteria proposed by CEA in the same range as the limit found in the past, based on integral experiments

Conclusion

❑ **CEA proposed an innovative analytical approach to insure the cladding integrity of the CABRI driver core**

➢ Set limits of physical values representative of the fuel rod failure mode

❑ **IRSN used an integral approach based on past experiments (NSRR and SPERT facilities)**

➢ Identify a failure threshold energy for stainless steel clad fuel rods similar to CABRI ones

➢ Comparison of this threshold to CEA criteria thanks to SCANAIR computations

❑ **This study shows the consistency of new criteria with the failure limit of past integral experiments**

➢ **It constitutes one of the important items which leads French Nuclear Safety Authority to accept the safety demonstration of the driver core fuel rods for the new experimental program in CABRI facility**

Thank you for your attention

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