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## Non-linear dynamical behavior of a fuel pins bundle.

T. Catterou, V. Blanc, G. Ricciardi, Bruno Cochelin, Stéphane Bourgeois

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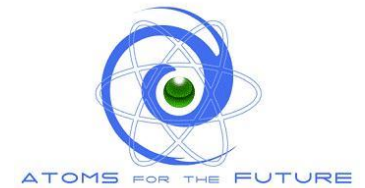
**<https://cea.hal.science/cea-02439473>**

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DE LA RECHERCHE À L'INDUSTRIE



## NONLINEAR DYNAMICAL BEHAVIOR OF A FUEL PINS BUNDLE

Thomas CATTEROU

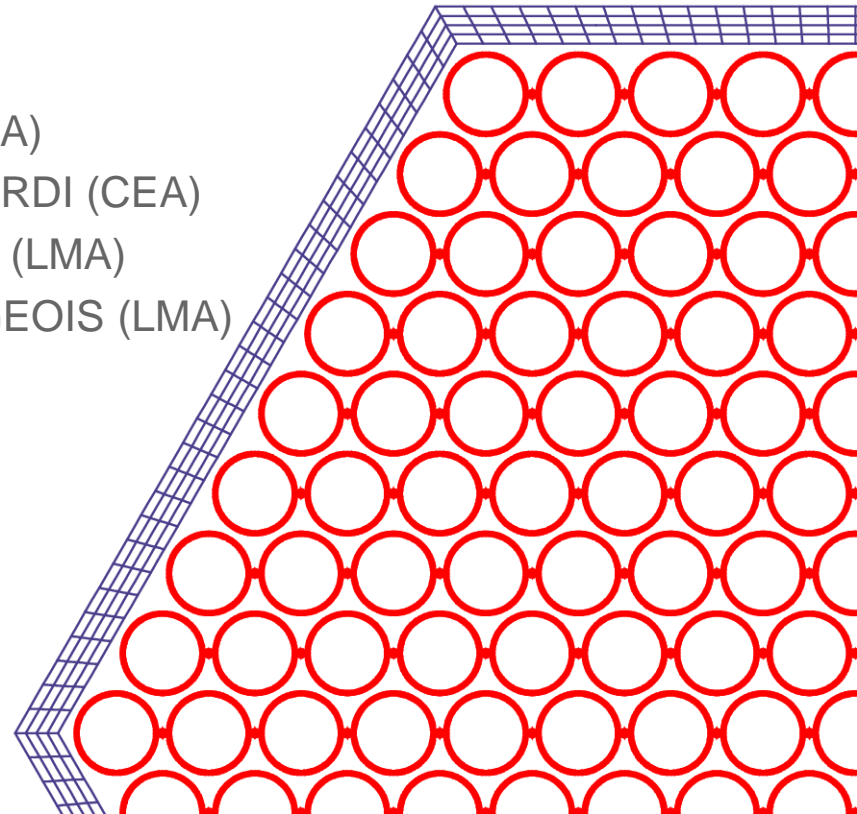
*Guided by :*

Victor BLANC (CEA)

Guillaume RICCIARDI (CEA)

Bruno COCHELIN (LMA)

Stéphane BOURGEOIS (LMA)



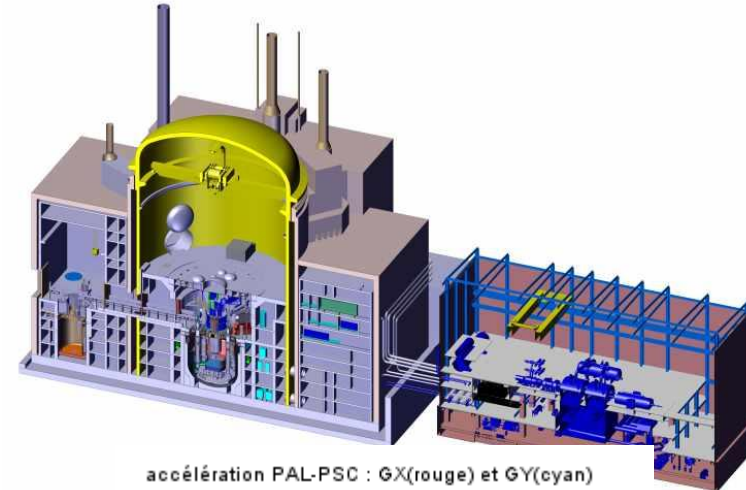
- ❑ An introduction to the Sodium Fast Reactor ASTRID
- ❑ State of the art
- ❑ Linear dynamic analysis of a fuel pins bundle
- ❑ Motivation and methodology of the study
- ❑ Non-linear behaviour, pins bundle with clearances
- ❑ Future applications

# ASTRID

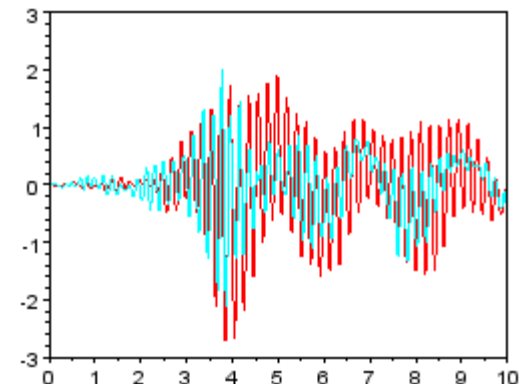
*Advanced Sodium Technological Reactor  
for Industrial Demonstration*



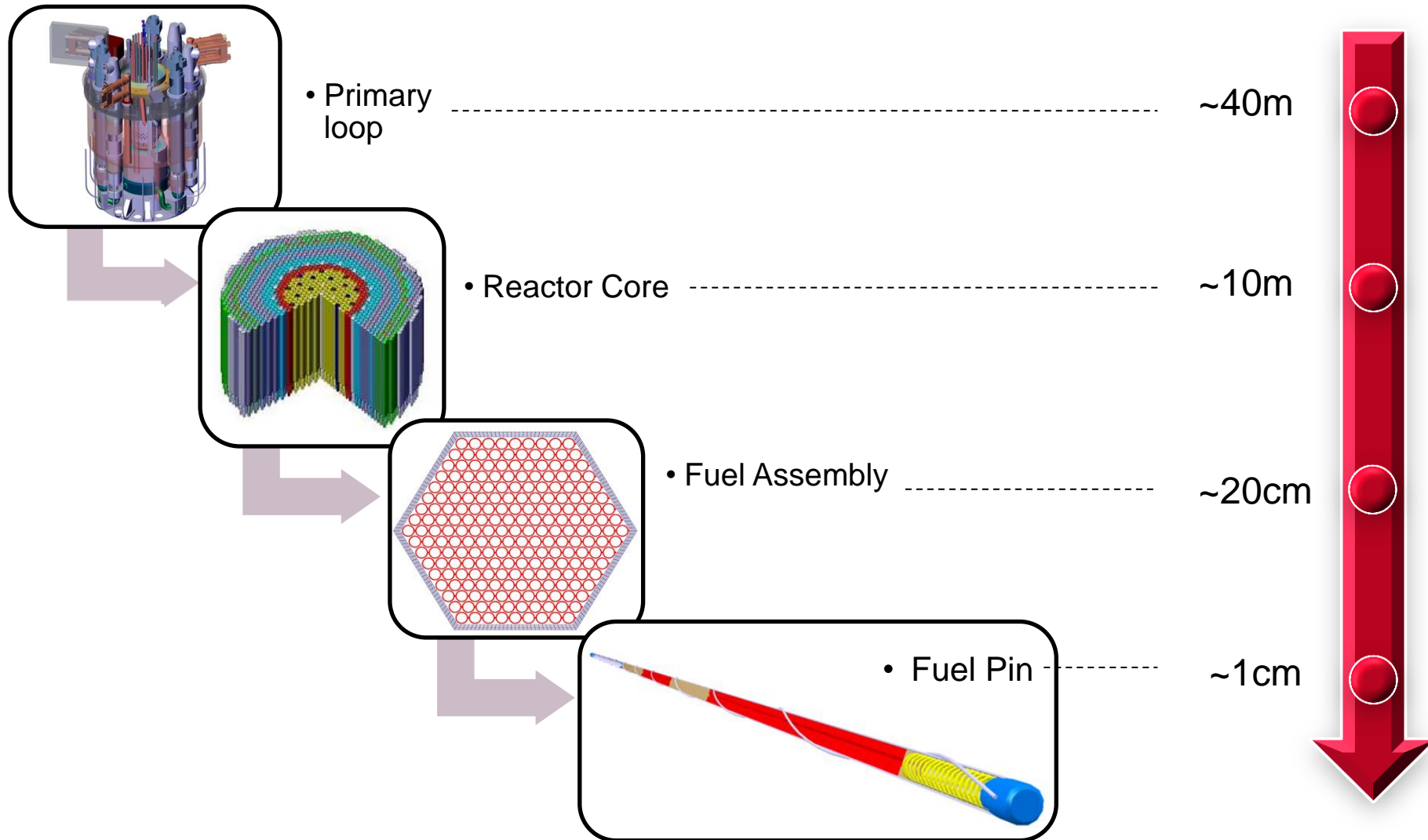
- Technological demonstration reactor
- Gen IV system
  - Safety
    - Level at least equivalent to GEN III
    - Integrating FUKUSHIMA accident feedback
  - Durability
    - Close cycle of fuel
    - Pu multi recycling to preserve natural resources
  - Operability

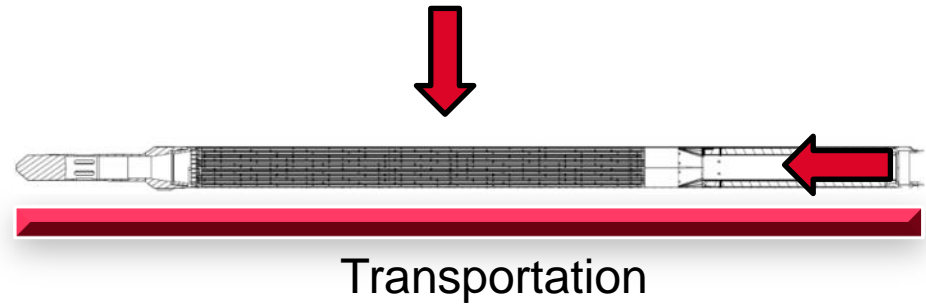
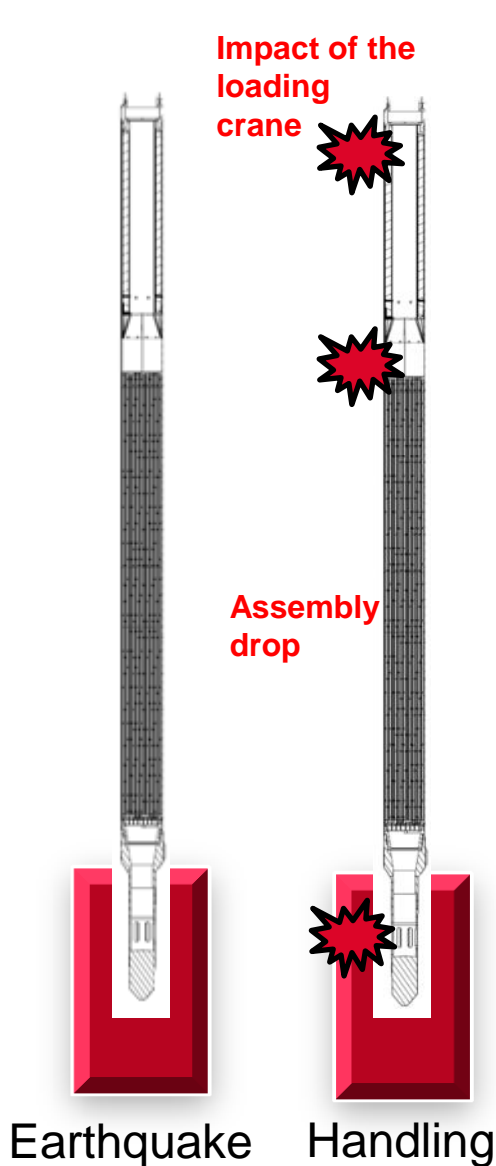


accélération PAL-PSC : GX(rouge) et GY(cyan)



## Various scales of study

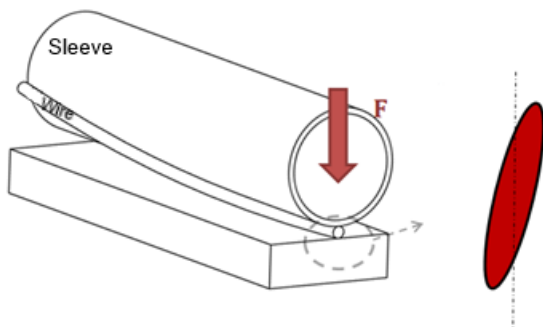
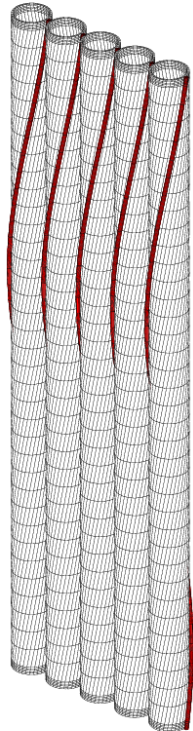




## Goals :

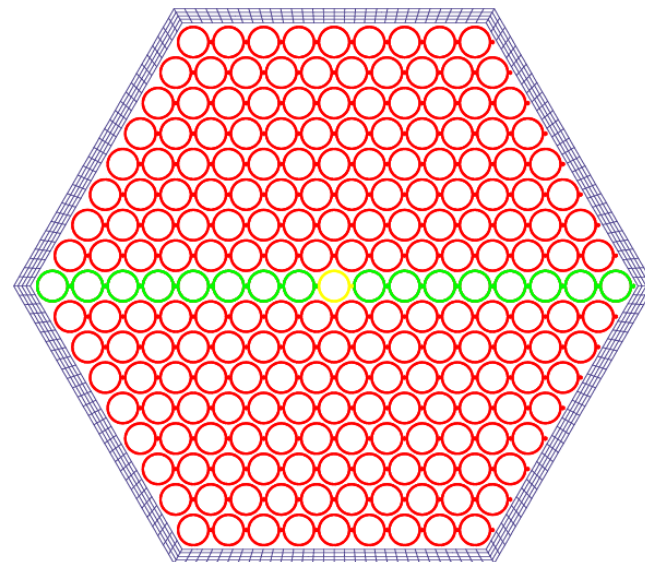
- To describe the dynamical behaviour of the fuel pins bundles with internal clearances
- To assess stresses in the pins induced by dynamic loads





## Difficulties :

- To create a numerical models with a large amount of potentiel contact (~30000)
- Identify local stress in a tube from a beam calculation (sizing studies).
- Quick and accurate calculations...

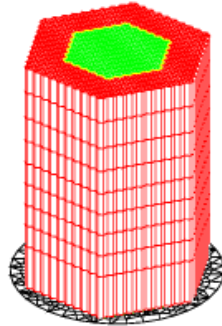




## ■ Progress in the field in the CEA

### ■ Moussalam[1], Broc [2].

*Seismic studies on Fast breeder reactor core*



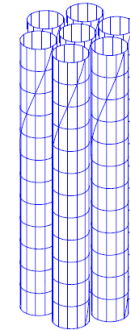
### ■ Vizcaino (2014)



*Review and study of the longest lines on one winding pitch*

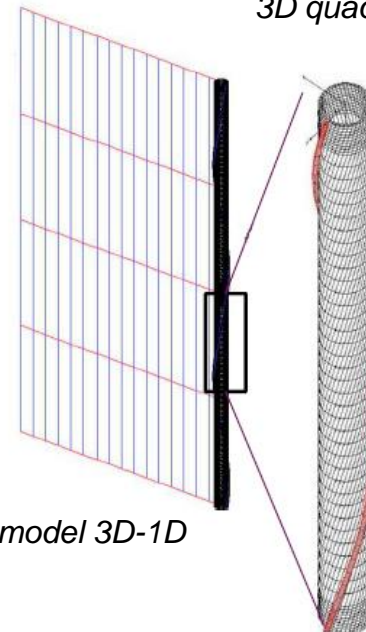
### ■ DOMAJEUR2 / Bamboo Leturq (2015)

*Thermomechanic of the pins bundle*



### ■ Catterou (2015)

*3D quadratic finite elements*



*Mixed model 3D-1D*

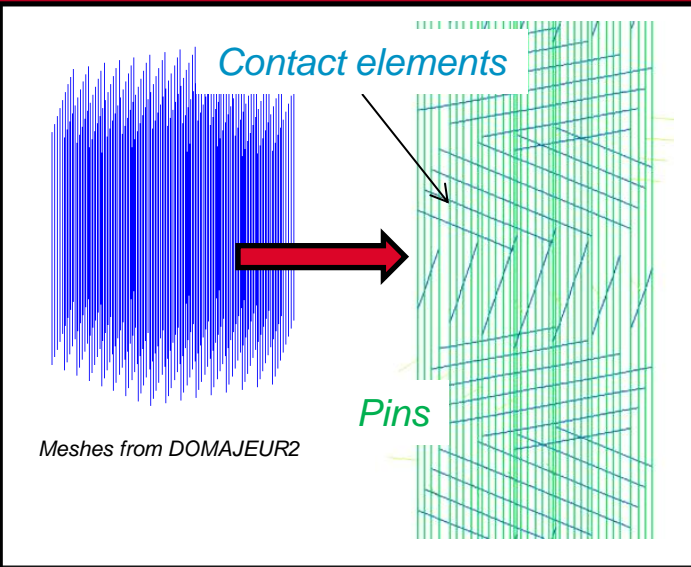
Maximum stress calculation but:

- Without clearance
- No impact effect
- Incomplete modelling of the fuel bundle.

[1] SMiRT21 (2011), "Industrial model for the dynamic behavior of [...] LMFBR core"

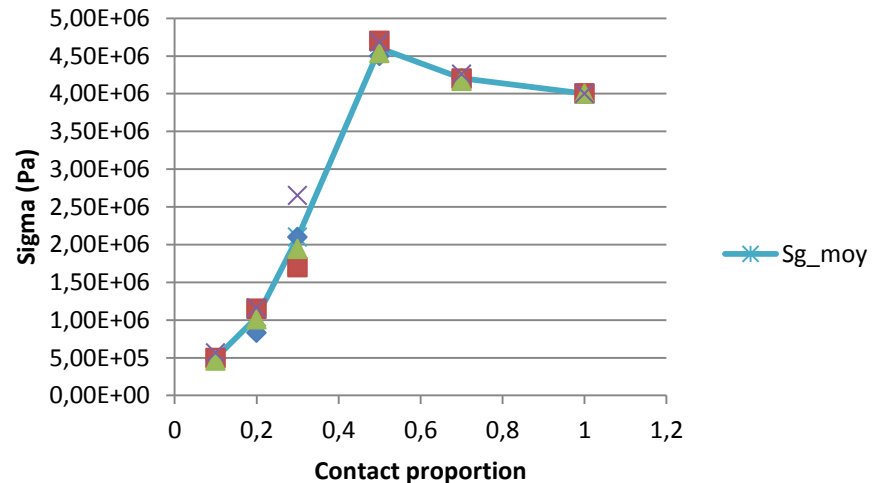
[2] SMiRT20 (2009), "Fluid Structure Interaction models for the dynamic behaviour of tube bundles [...]"





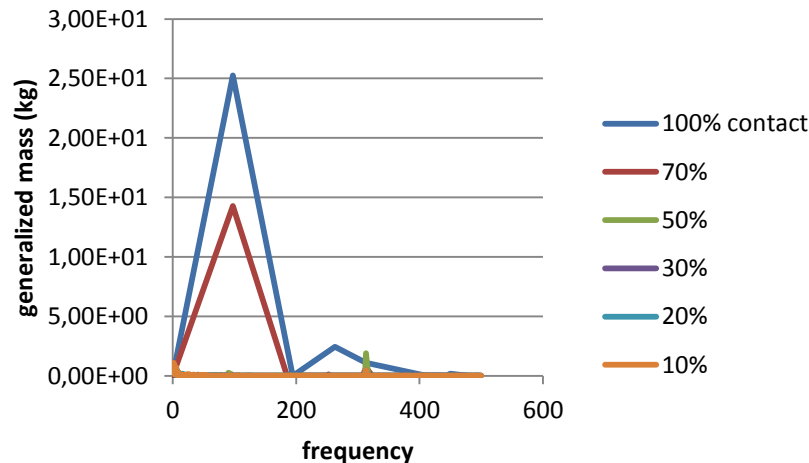
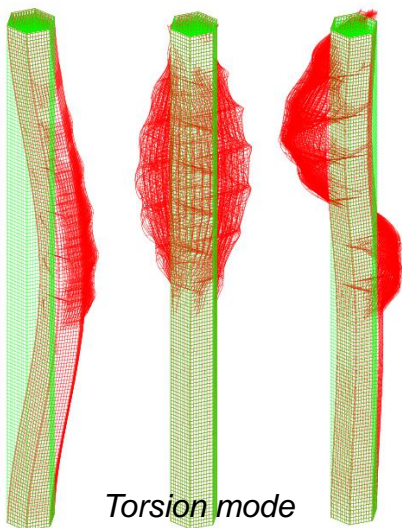
■ Dynamic analysis  
 Input : imposed acceleration on the first mode

### Maximum stress



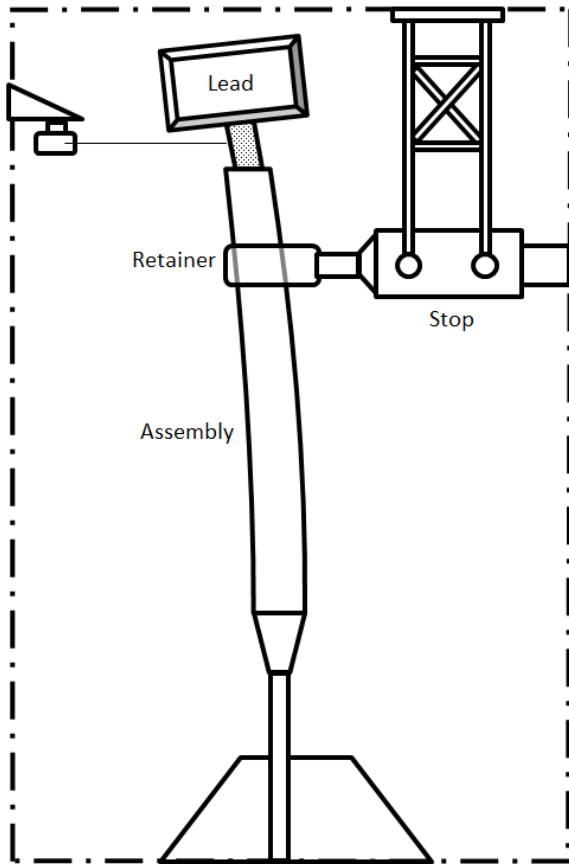
■ Modal analysis

Mode 1    Mode 2    Mode 3



**Observations:**  
 Results are very dependant of the presence and the characterization of the contact elements.

■ Experimental equipment : BELIER (CEA)

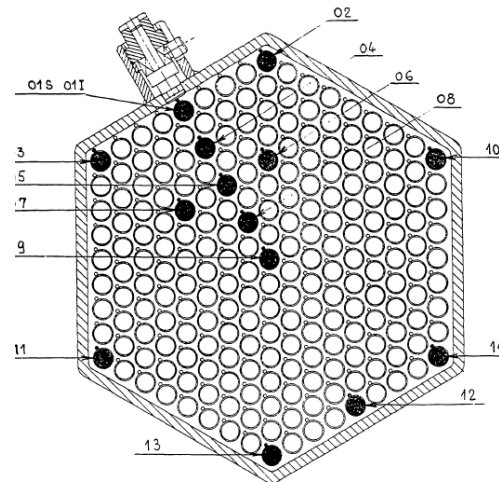


■ Tests in CEA Cadarache between 1989 and 1995

■ In air and in water

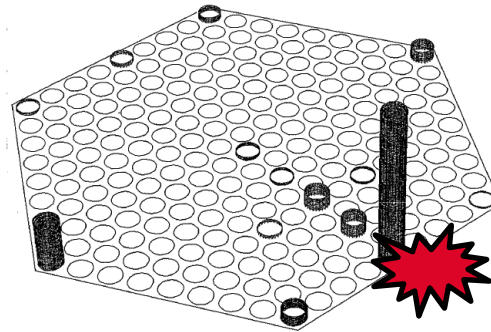
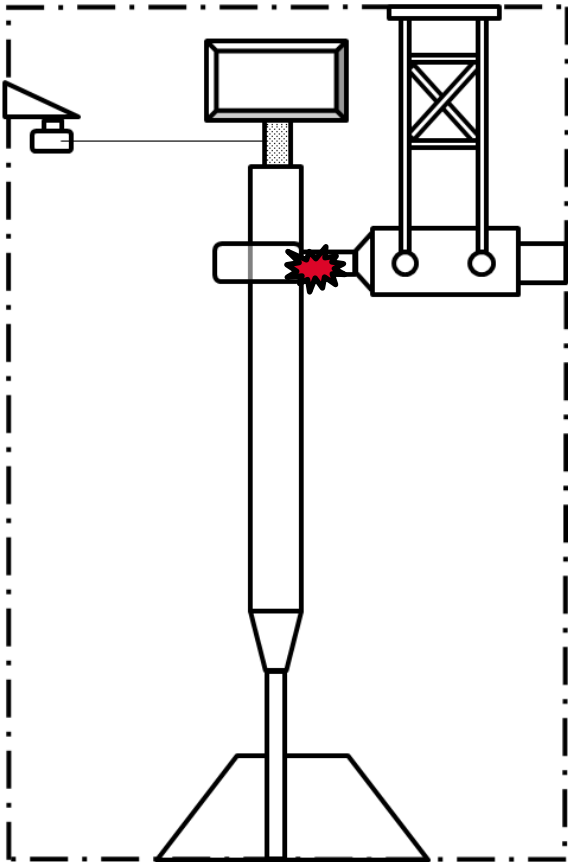
■ Homogeneous clearance or without clearance

■ Some instrumented pins on the height of the impact.

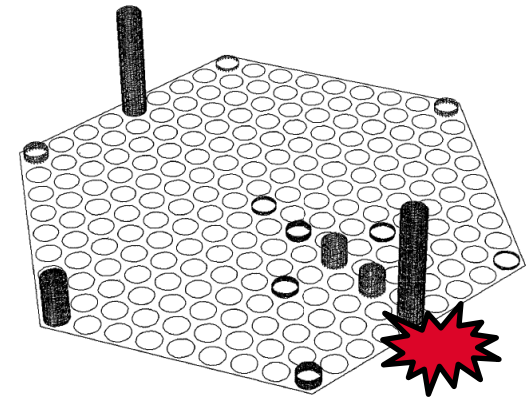


● *Instrumented pin*

## ■ Experimental equipment : BELIER (CEA)



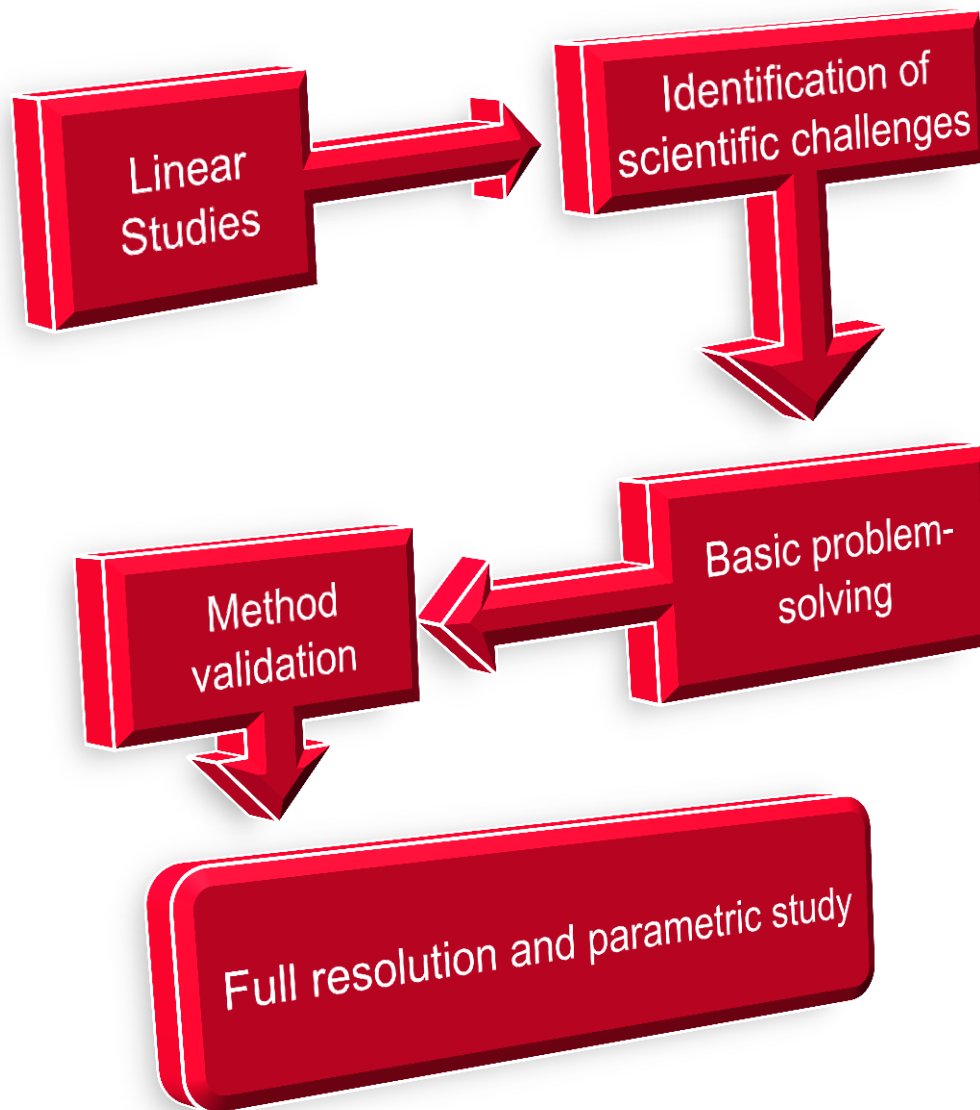
Pins bundle without clearances



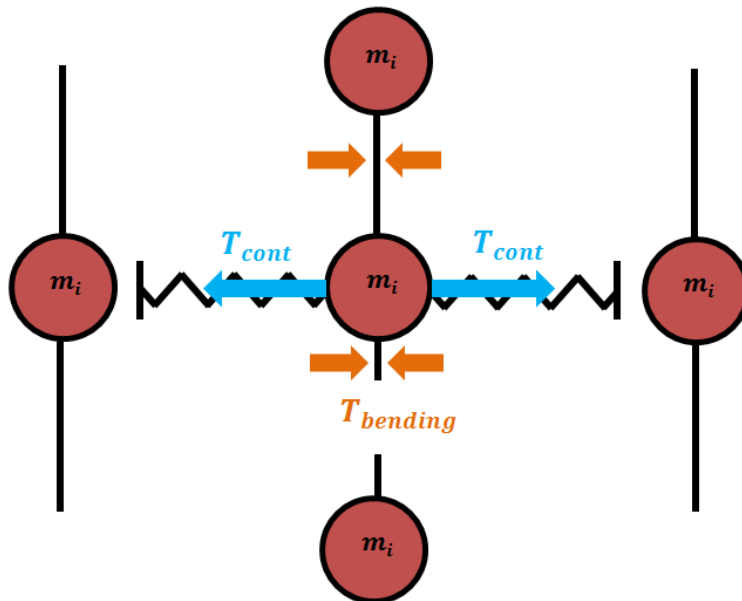
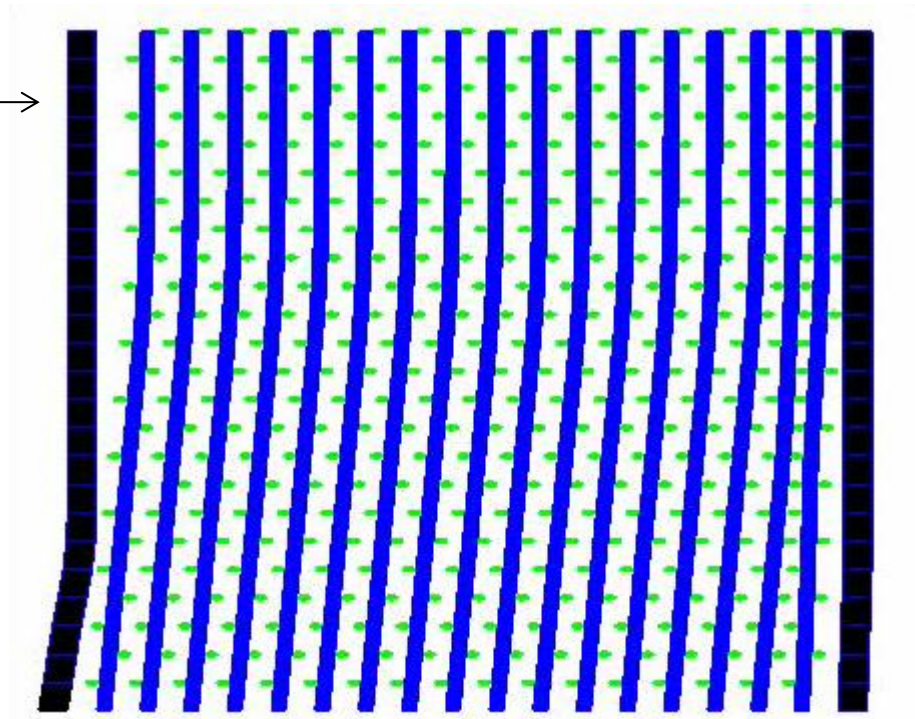
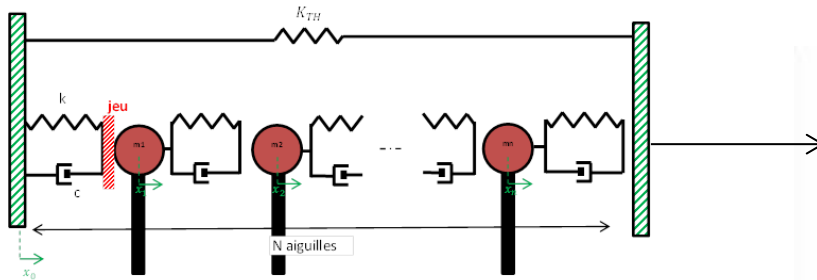
Pins bundle with homogeneous clearances

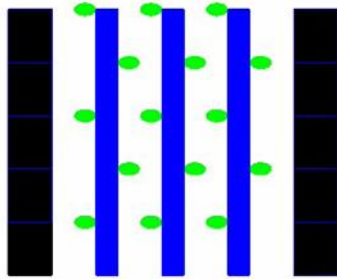
- Which is the most critical situation ?
- Are there particular clearance distributions which could be more harmful?

→ Necessity to model clearances in the bundle.



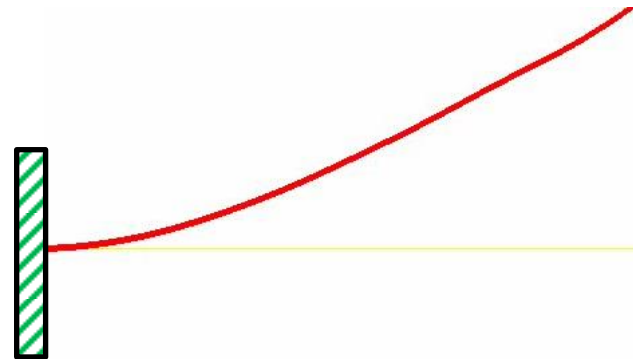
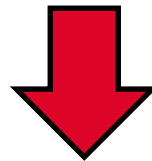
- Use of a mass-spring system  
**Aborted, bad simulation of the bending.**





- Use of a mass-spring system  
**Aborted, bad simulation of the bending.**

- Resolution of an elementary problem analytically and with the finite element software CAST3M



- Integration scheme approval
- Study on the influence of the contact moment search algorithm
- Determination of the stability barrier of the numerical solution

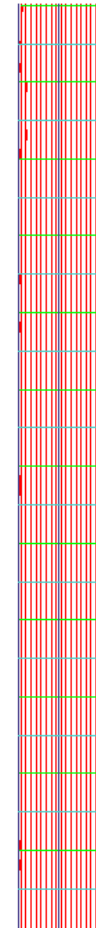
*Experimental calculation of the behavior of a pin in a transport configuration*



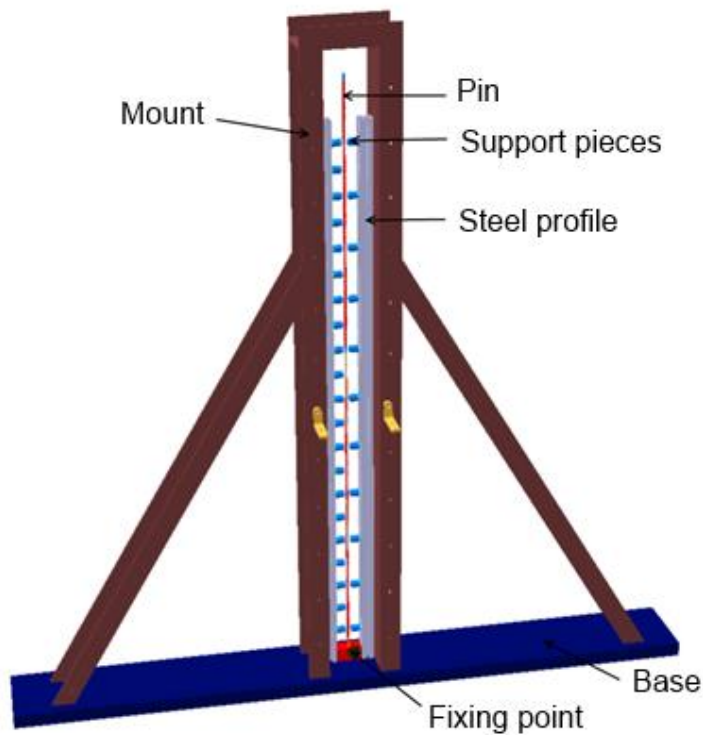
**To come**

- Calculation on a 2D then a 3D pin's beam.
- Statistical analysis of the influence of the repartition of clearances in the beam.
- Experimental validation

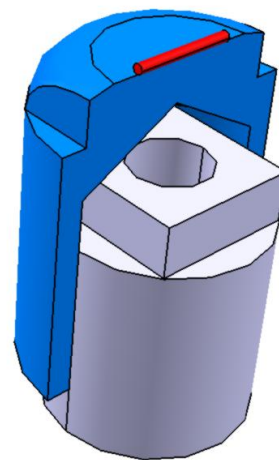
*Experimental calculation of the dynamic of a line of pins*



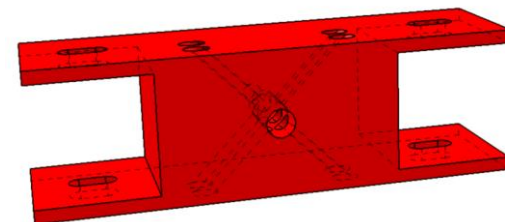




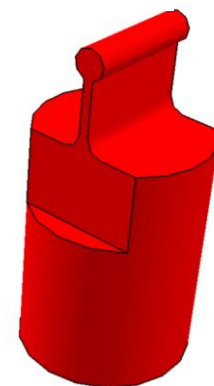
**CARNAC**



*Support pieces*



*Fixing point*



## Goals:

- To identify the influence of clearances on the dynamical behavior of one pin.
- To validate numerical model

- Small and numerous clearances in the pins beam influence strongly the dynamical behavior of the structure.
- Difficulty to estimate if a study without clearance is conservative or not.
- Some points must be examined carefully to ensure a right answer:
  - The integration scheme
  - The force law and the contact model
  - The estimation of the contact moment and period

- Integration scheme validation.
- Contact detection algorithm validation.
- 3D pins bundle model achievement.
- Statistical study of the impact of clearance and its repartition.

Thank you for  
your attention !

