A new mock-up for evaluation of the mechanical and leak-tightness behaviour of NPP containment building

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Sumary

- Industrial context
- Description of the mock-up
  - Main Design choices
  - General Design
  - Numerical models
  - Choice of the concrete
  - Monitoring
- Conclusions

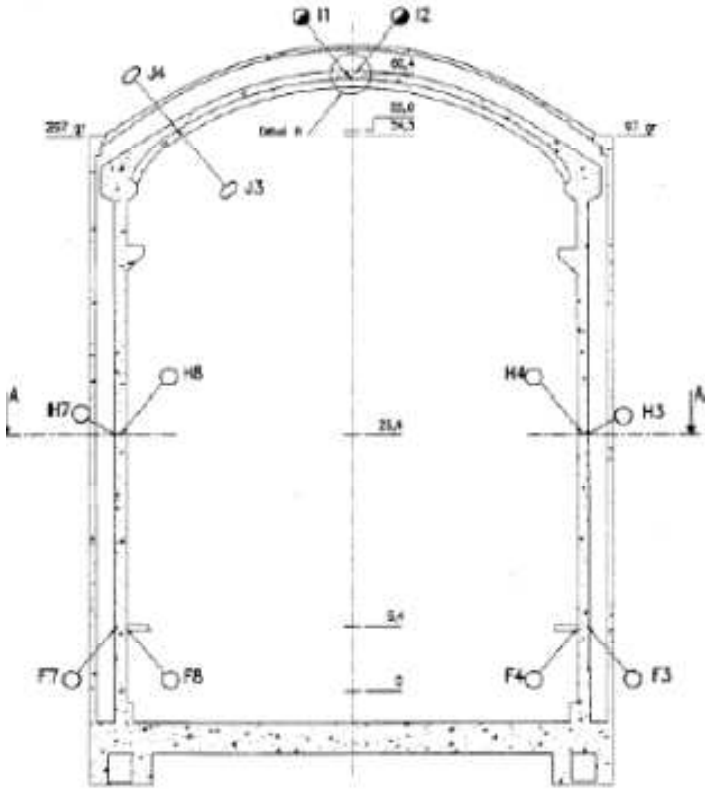
Industrial context

A ‘French specialty’ : the double-wall containment building (1300-1450 MWe NPP reactors) *[22 reactors]*

- a reinforced and pre-stressed concrete inner wall without steel liner
- an outer reinforced concrete wall assuring the protection against external effects

Active leak-tightness function :

- provided by the inner wall, the leak through the internal wall being collected in the annular space (permanently maintained slightly below atmospheric pressure) and filtrated before being released
- a regulatory criterion on the leakage rate (in case of ‘*design basis accident*’) of the inner wall
- the compliance with the rule is evaluated by measuring the quantity of air leak, obtained during a periodical pressure test (0,5 MPa) at ambient temperature.

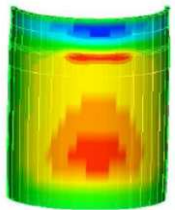


Industrial context

In the frame of the continuous effort on safety and in the perspective of NPP life extension, EDF express two main ambitions:

- to demonstrate in an indisputable way the good behaviour of inner wall in situation of ***severe accident***;
- to have a better comprehension of the ***leakage*** and its evolution with the ***ageing*** of the structure.

How to answer such questions ?



Previous experimental work of interest

Complexity

Real Structure

Material Test specimen

Size

Previous experimental work of interest

Complexity

Size

Real Structure

Large Specimen

CEOS.fr (cracking)

INSA Lyon (porosity)

Material Test specimen

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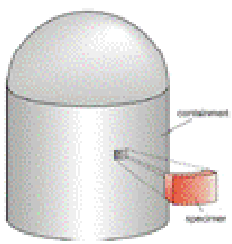
Representative volume



PACE (Karsruhe)

Real Structure

Previous experimental work of interest

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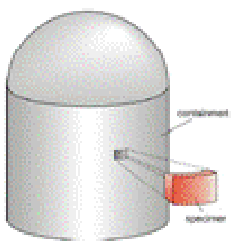
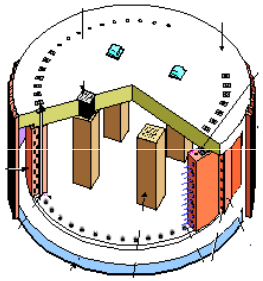


PACE (Karsruhe)

Mock-up



MAEVA

SANDIA

Real Structure

New mock-up planned by EDF :

VERCORS

(Vérification réaliste du Confinement des Réacteurs)

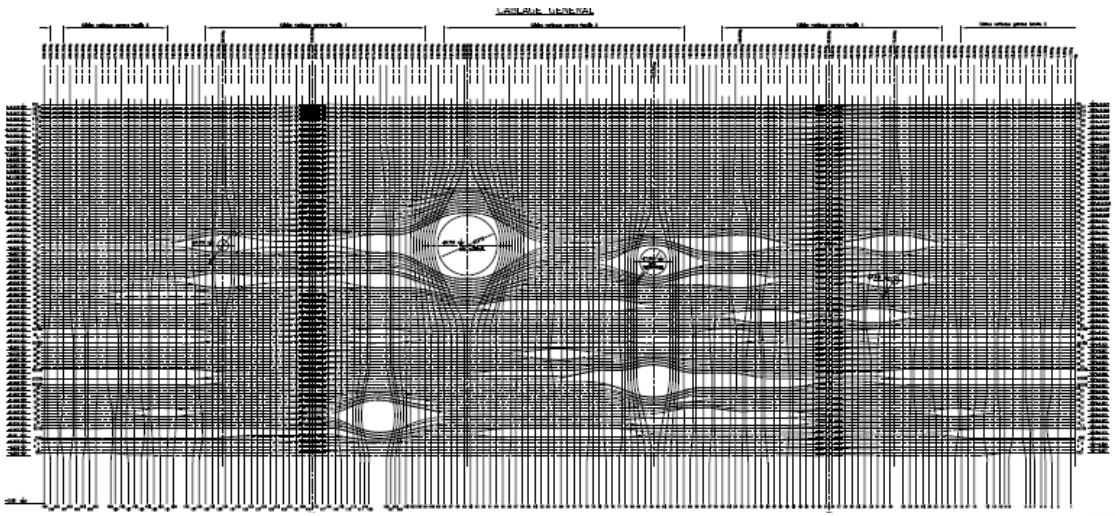
Design choices

- **Representativeness** : the mock-up has to be as close as possible to the real containment building
  - In term of ***geometry*** : the new mock-up all complexities of the containment structure: base raft, gusset, some penetrations, access hatch, dome, grouted prestressing tendons, … This is a major difference with MAEVA mock-up.
  - In term of ***mechanical loading*** : same prestress ; periodic pressure test at 0.5 MPa as in the real case
  - Severe Accident test : at the end of the program (2019)

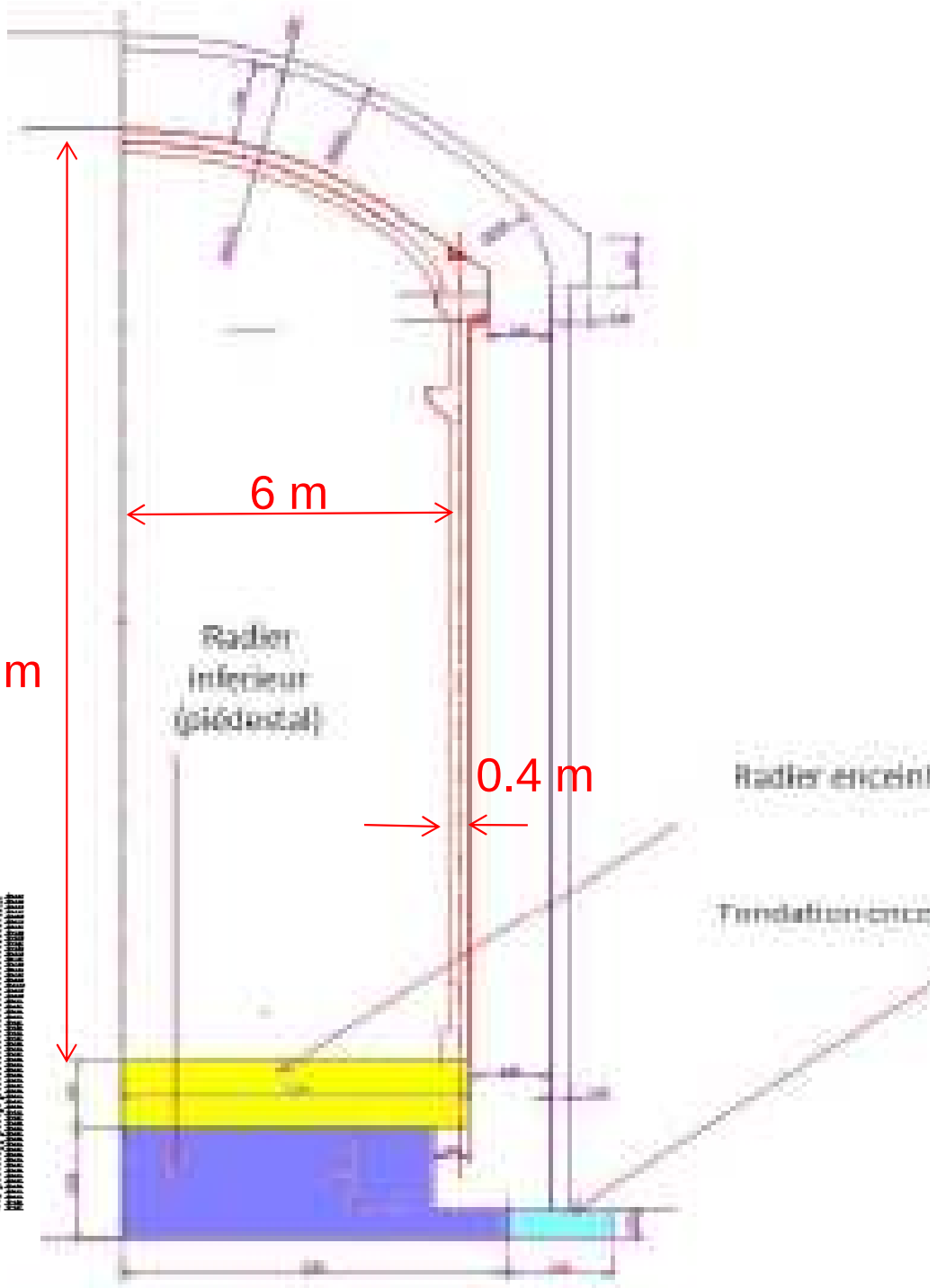
- **Accelerated aging**: in order to anticipate on the mock-up the behaviour of NPP containment walls after 40 to 60 years of operation.
  - ***Proposed solution*** is to construct the mock-up at a reduced scale (scale 1:3). The drying of the structure will be then faster, as the wall thickness will be ‘only’ 40 cm.
    - These will result in a faster drying creep which is supposed to be the main phenomenon explaining the leak rate evolution.

General Design

- Design of the mock-up
  - Scale 1:3 respected for all dimensions excepted access hatch and dome



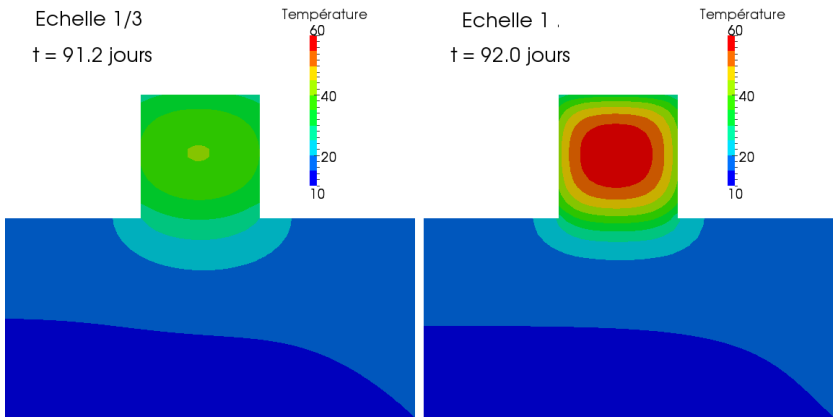
Map of the prestress tendons



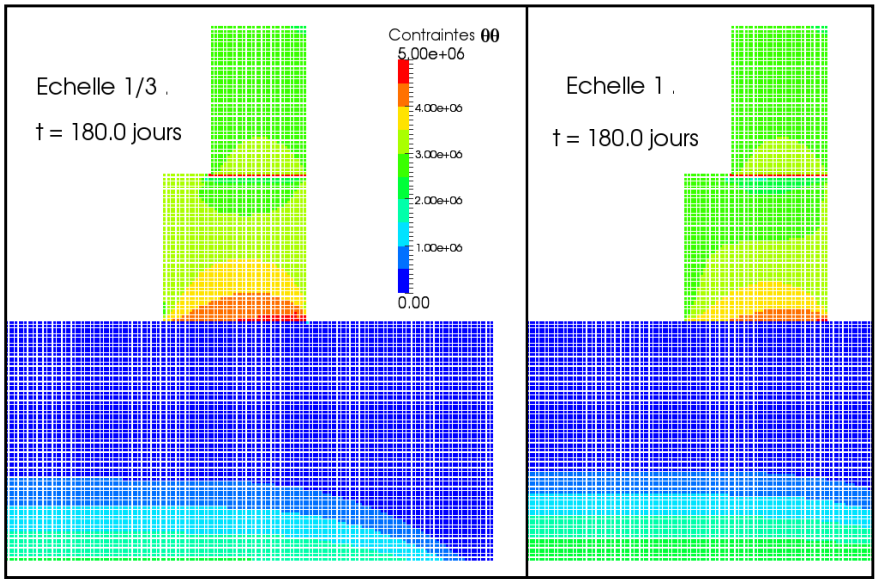
Geometry of the mock-up

Mechanical models in support to the design

- Specific thermo-mechanical study of the structure at Early Age
  - Part of interest : base raft, gusset and first part of the cylinder
    - These parts are the most susceptible to cracking due to the various dimensions (vertical cracks)
  - This study will be used in support to the specification of the realization of the mock up
    - If all parameters are equivalent, the temperature and in consequence the circumferential stress at early age will be smaller in the mock up than in real structure
    - Solutions studied to increase temperature : heating of the concrete ? Heating of the formworks ?



Comparison of temperature

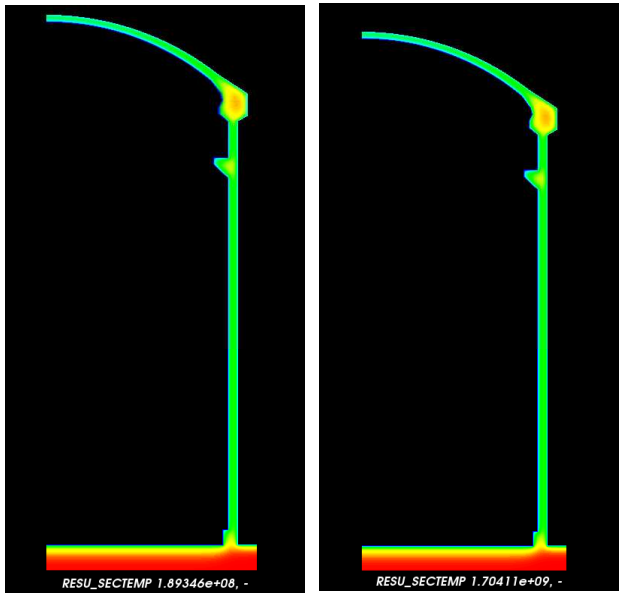


Comparison of circumferential stress

Mechanical models in support to the design

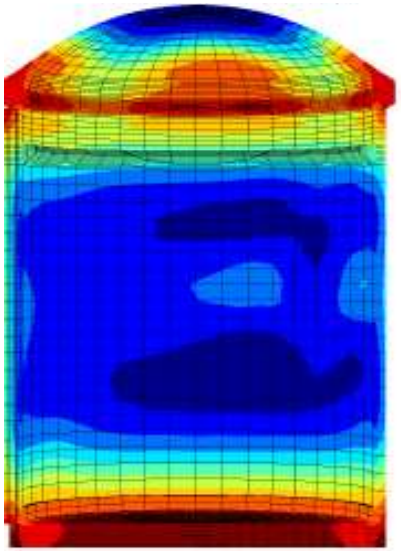
- Ageing (delayed strain)
  - All the structure has to be analysed
  - Two steps : drying and creep
  - Influence study : internal temperature ; material properties

Comparison of water content



VERCORS at 6 years / Reactor at 54 years

Stress during pressure test



- Thermo-mechanical behaviour (during pressure tests and severe accident test)
  - Comparison of stresses at the two scales
  - Definition of the severe accident loading to be applied to the mock-up
  - Comparison of potential damaged zones
  - *Support to the specification of the monitoring*

Choice of the concrete

- Mechanical properties :
  - Young Modulus : 33 to 35 GPa (at 28 days)
  - Resistance in compression : 42 to 45 MPa (at 28 days)
  - Creep rate : equivalent to the mean value observed on EDF NPP

  } representative properties of real containment buildings

- Size of the aggregates
  - Maximal aggregates size on site : 24 mm
  - Direct application of 1:3 ratio : maximal aggregates size = 8 mm

    ➔ *Inconvenient : the thermal and porous behaviour of such concrete ("micro-concrete") would be too different from classical concrete*
  - Decision : maximal aggregates size from **14 mm to 16 mm**

    ➔ An adaptation of the cover thickness is then necessary : 15 mm (scale 1:3) → 20 mm

- The validation of three different mixes is on-going
  - Creep test, cracking, energy, thermal dilatation coefficient, ... and other parameters which are pertinent for concrete characterization

- During the construction : test specimens will be realized to finely characterized the concrete

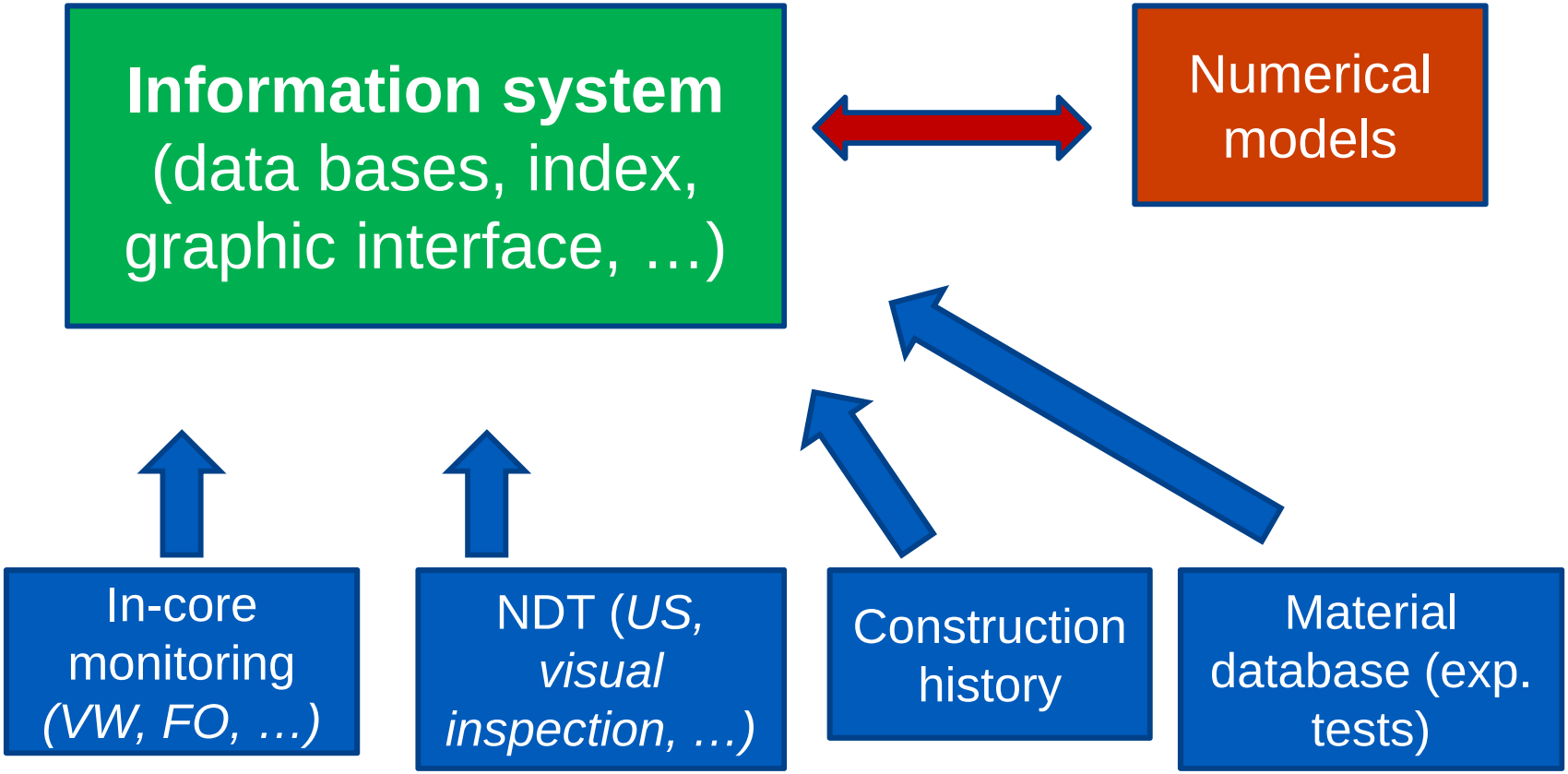
Monitoring

- Thermo-mechanical behaviour
  - Temperature : thermocouples and optic fibers
  - Strain : vibrating wires and optic fibers
  - Water content : Pulse and TDR
  - Strain gauges and optic fibers on the wall
  - NDT : visual inspection, ultrasonic inspection, radar, image correlation …
  - *Dedicated structures for destructive analysis*

Inside the concrete

- Leakage
  - Detection through thermal techniques ? (optic fiber or IR thermography)
  - Detection through acoustic techniques ? (optic fiber)
  - Chemical tracers ?

A necessity: an adapted information system



External Collaboration

- Creation of a Scientific committee with external experts in support to the project

- Participation (or support) of EDF to french National Research Projects and provision to our partners of the results obtained on the VERCORS mock-up (as soon as they are available)
  - Project ‘MACENA’ in the frame of ‘Nuclear Safety’ program, dedicated to thermo-mechanical behaviour at high temperature (in connection to the severe accident test)
  - Project ‘END’ in the frame of ‘Nuclear Safety’ program, dedicated to containment monitoring and NDT
  - …

- EDF plans to organize an international benchmark in 2015-16 (after the first pressure tests results and before the ‘Severe Accident’ test)

Conclusions

- Main objectives of the new mock-up VERCORS
  - To estimate and to give confidence in the behavior of the containment building in case of severe accident
  - To understand the various leak path of the containment building
  - To estimate experimentally the effects of the ageing

- This mock-up will be built in 2013 (*EDF R&D Les Renardières, 75 km south from Paris*) and tested from 2014 to 2020

- A mock-up in support of both industrial and research objectives

- A mock-up in support to partnerships between EDF and all interested academic or industrial partners

Thank you for your attention !