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A New Method Taking into Account Physical Phenomena Related to Fuel Behaviour During LOCA

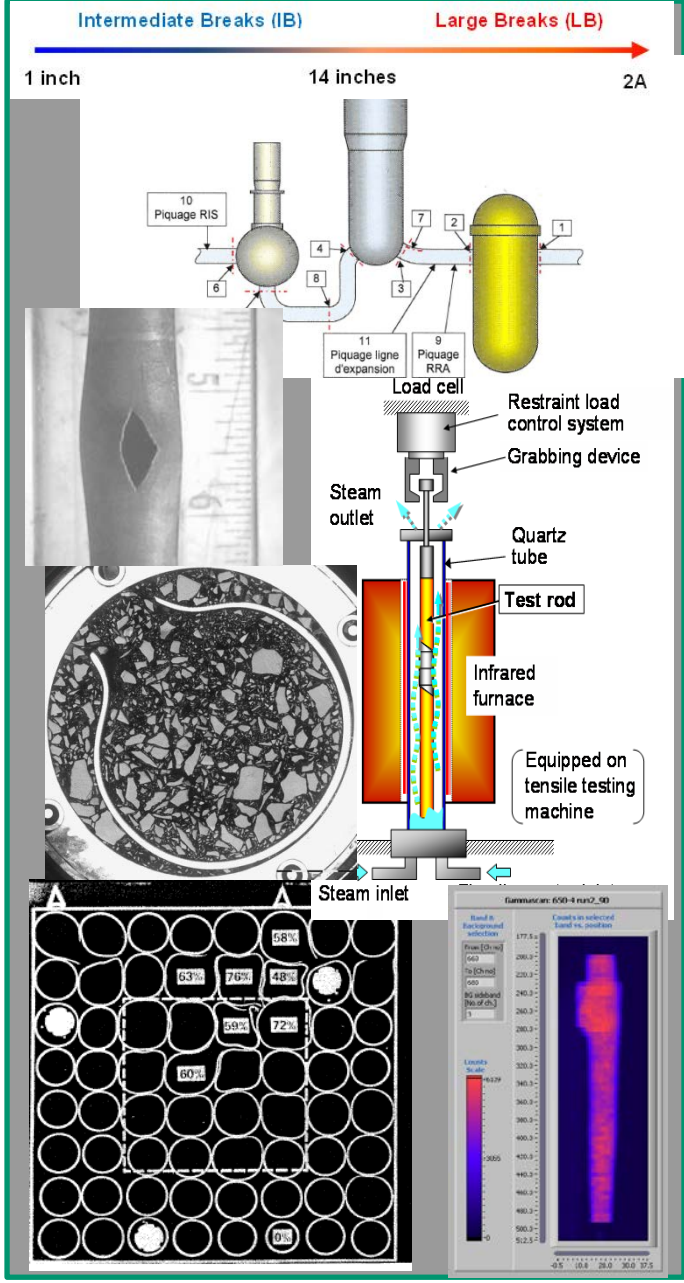
Seminar 1a - Nuclear Installation Safety - Assessment

IRSN

EUROSAFE | 2016

AGENDA

1. Context
2. Development of LOCA reference transients
3. Development of LOCA analysis method
4. How to model fuel behaviour during LOCA
5. Pending questions



1 - Context

- In **1974, AEC** (now U.S. NRC) promulgated the 10CFR50.46 and its appendix K that define **LOCA reference transients** with regard to the maximal break size, **safety criteria** and **physical phenomena** that have to be considered to demonstrate **core coolability** during LOCA
- U.S. requirements adopted in France **at the start of the French PWR nuclear program**
- **Numerous research programs** have addressed the fuel behaviour during LOCA and **new cladding materials** have been introduced in French reactors

➲ Because of these evolutions, **the French Nuclear Safety Authority (ASN) has decided to review the LOCA safety demonstration regarding core coolability**

1 - Context

- The **Advisory Committee for Reactors** got together during two meetings in **2010** and **2014** in order to
  - Review the **IRSN evaluation of EDF proposals** on the LOCA safety demonstration regarding core coolability
    - (1) **Definition of the LOCA reference transients**
    - (2) **Physical phenomena to be taken into account and LOCA safety requirements associated with safety limits to be verified**
    - (3) **LOCA analysis method assumptions**
  - Issue **recommendations** to the **ASN**
- In 2015/2016, **the new LOCA analysis method,** the so-called **CathSBI,** proposed by EDF was reviewed by IRSN

➲ **This new method will be first applied in 2017** (for the fourth 10-yearly safety review of EDF's 900 MW_e nuclear reactors, then for the next 10-yearly safety review of EDF's 1300 MW_e and 1450 MW_e nuclear reactors)

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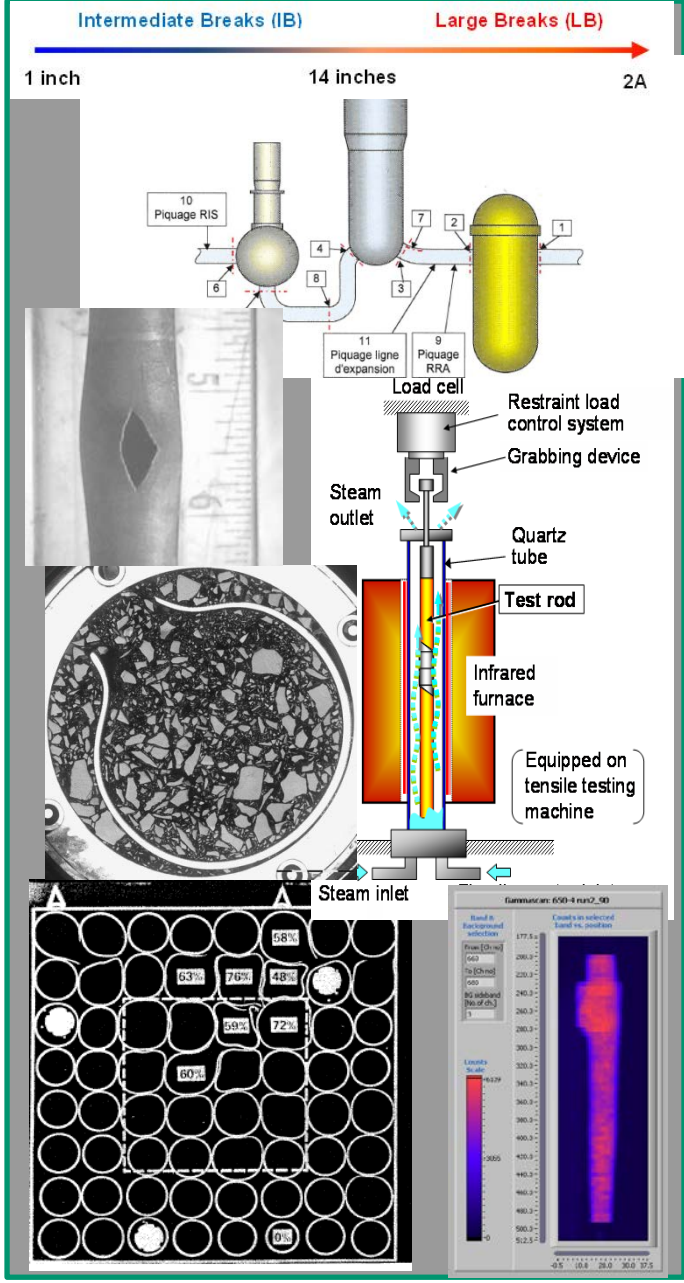
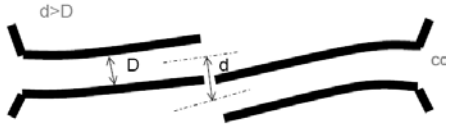


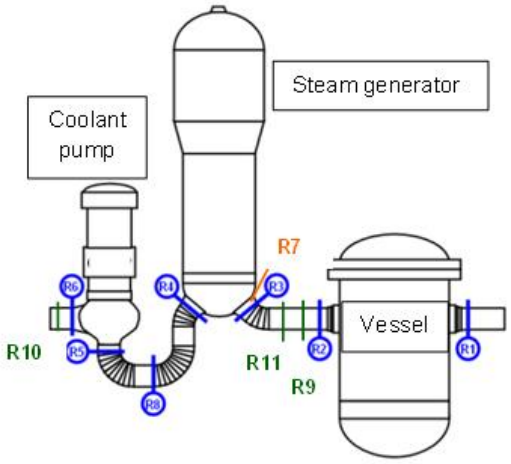
2 - Development of LOCA Reference Transients

- **In the current French LOCA safety demonstration**
  - The **thermal-hydraulic analysis**, aimed at checking core coolability, is carried out for **breaks of any location** and **any size**: from intermediate to large breaks up to the double-ended guillotine break (called 2A break)



2A Break

  - In contrary, the **mechanical analysis**, aiming at checking the resistance of the internal structures of the reactor vessel and the fuel assemblies, is performed for a selection of **eleven conventional breaks which are mostly IB** (notably 6 guillotine breaks limited in size because of the existence of pipe whip restraints)



2 - Development of LOCA Reference Transients

- **For the newly defined safety LOCA demonstration**
  - **Same break sizes for both thermal-hydraulic and mechanical analysis**
    - Maximum break size < 28 inches - depends on plants type
    - Break opening times obtained by dynamic calculations (instead of the historical 1 ms)
  - **Thermal-hydraulic analysis:** Focus on an **improved modelling of the physical phenomena under IB LOCA conditions** rather than focus on the 2A break
  - **Mechanical analysis:** EDF will have to take into account the **stretch operating conditions effects** for the future LOCA studies

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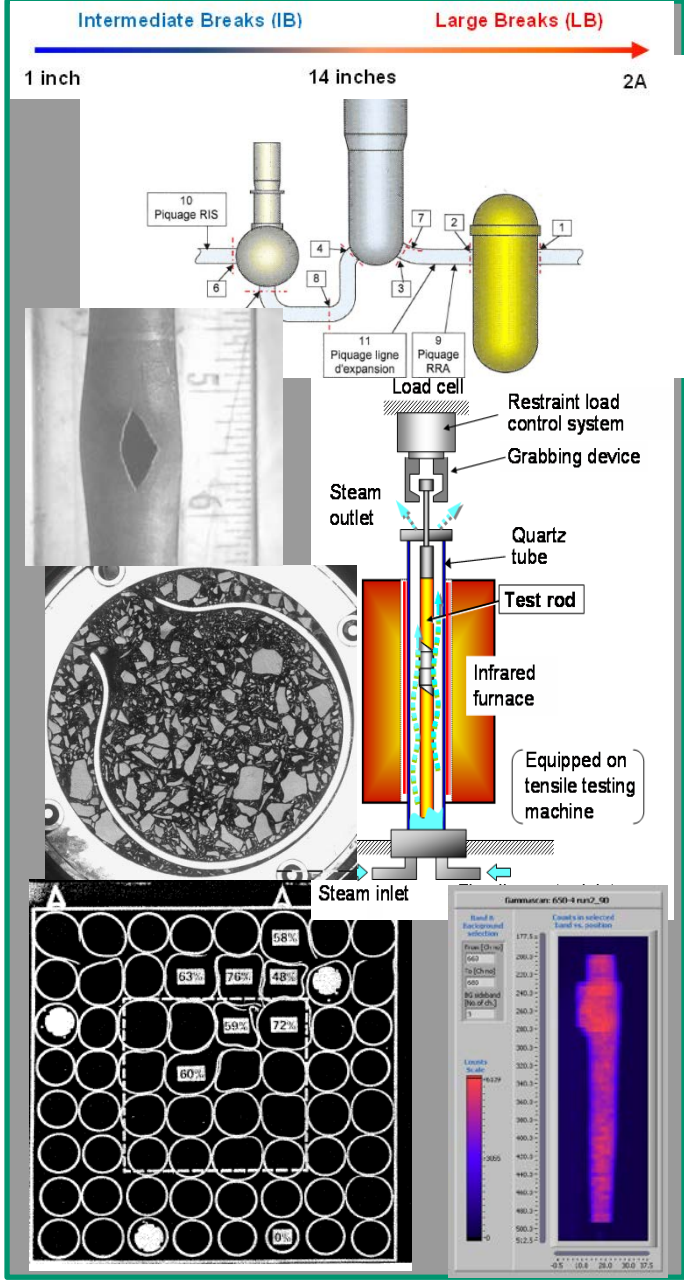


3 - Development of LOCA Analysis Method

- **Current French LOCA analysis method (so-called Deterministic Realistic Methodology)** based on
  - **CATHARE** code (best-estimate thermal-hydraulic system code) associated with **mono-dimensional modelling of the vessel and fuel behaviour**
  - With conservative assumptions for initial and boundary conditions, taking into account **uncertainties** with a **deterministic approach**

- **EDF's new CathSBI method** proposed for **IB LOCA studies** is based on
  - **CATHARE** code with **multidimensional thermal-hydraulics modelling of the vessel** and **enhancement of fuel behaviour modelling** taking into account clad ballooning and burst, flow blockage, contacts between neighbouring rods and fuel relocation
  - A **new statistical approach**

3 - Evolution of LOCA Analysis Method

- **New statistical approach**
  - Takes into account **elementary uncertainties** affecting the **key parameters** in the calculation of the interest parameters during IB LOCA (i.e. peak cladding temperature)
  - Takes into account **coupled effects between key parameters** due to uncertainties propagation
  - **Ensures the conservatism** of the safety LOCA studies: in 2014, ASN requested EDF to use a **deterministic way** or an approach ensuring a penalizing range of variation for **the most influential uncertainties** (for example rod internal pressure)

Key parameters

Initial and boundary conditions

Code models

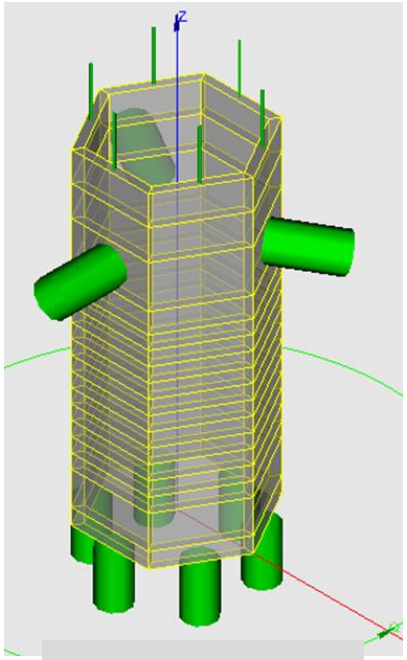
Variable parameters defining scenario

- IRSN analysis focussed on the statistical approach validity - **Main IRSN issues**
  - **Some elementary uncertainties** still need **to be justified**
  - **Consideration of ASN's request by EDF is not sufficient:** most influential parameters and penalizing approach must be justified

➲ **New statistical approach still needs more robustness**

3 - Development of LOCA Analysis Method

- **Vessel new modelling**
  - Use of the CATHARE 3D module is needed in the core and the downcomer to **simulate thermal-hydraulics 3D phenomena**



Downcomer model

- Allow the cold water injected by ECCS to go down in the boiling downcomer water and to reach the core (with 1D module, cold ECCS water is “floating” above high void fraction mixture and is lost at the break)
- Model the cross-flows in the gas phase during high-pressure core uncovery ➔ “Chimney effect” has a direct positive influence on hot rod cooling

- IRSN analysis focused on CATHARE modelling qualification - **Main IRSN issues**
  - Significant benefit effect of vessel new modelling
  - Lack of validation of CATHARE 3D module

➲ **Justifications of vessel modelling choices are still expected and experimental programs are ongoing to validate CATHARE 3D module**

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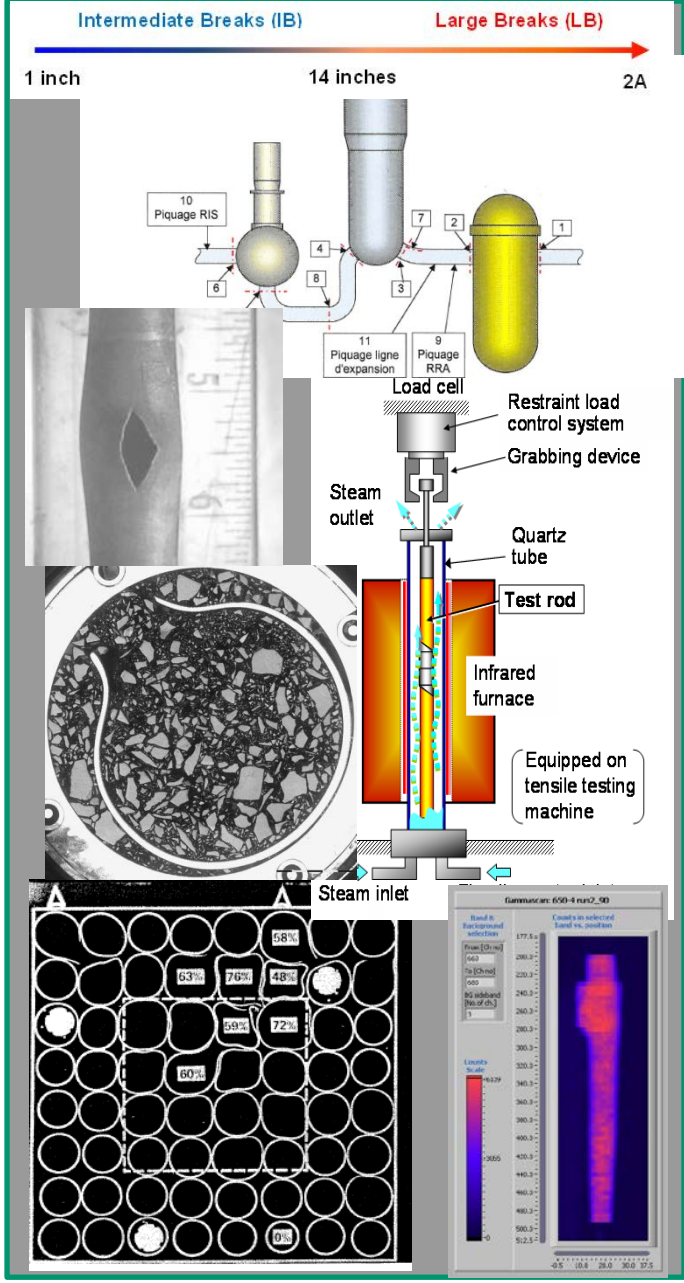
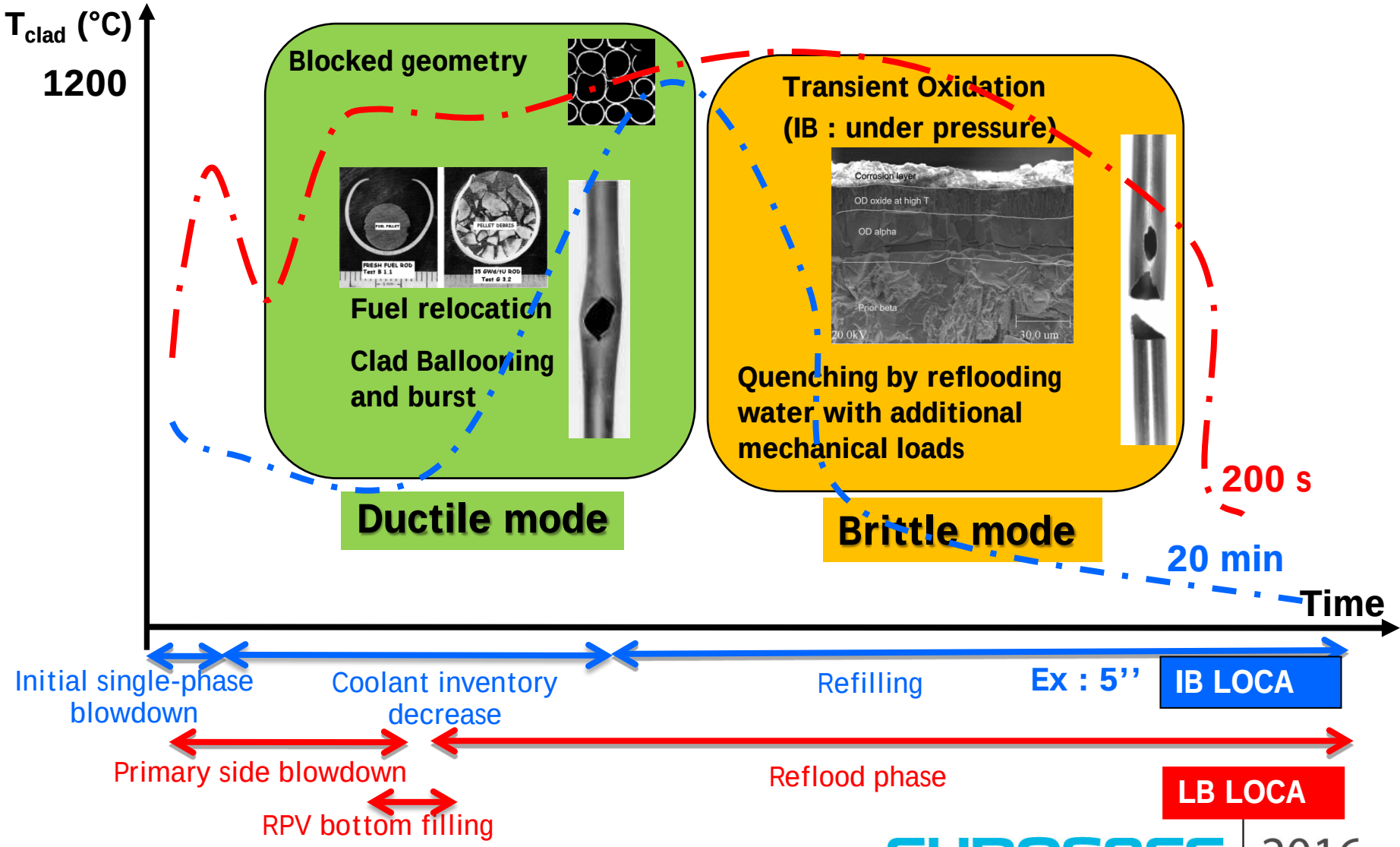


4 - How to Model Fuel Behaviour During LOCA

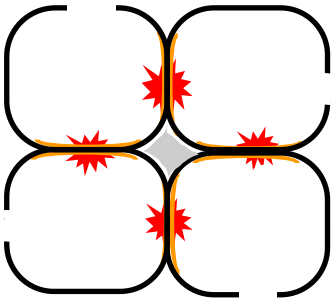
- **Phenomenology under IB and LB LOCA**



4 - How to Model Fuel Behaviour During LOCA

- **New French regulation**

  – **EDF calculation approach** before 2014 based on the CATHARE software associated with **1D fuel behaviour modelling** is not able to take into account **contacts between neighbouring rods** and **relocation of irradiated fuel in clad balloons**



↗ T_{clad}

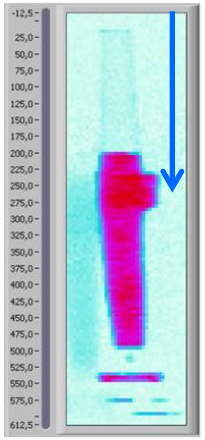


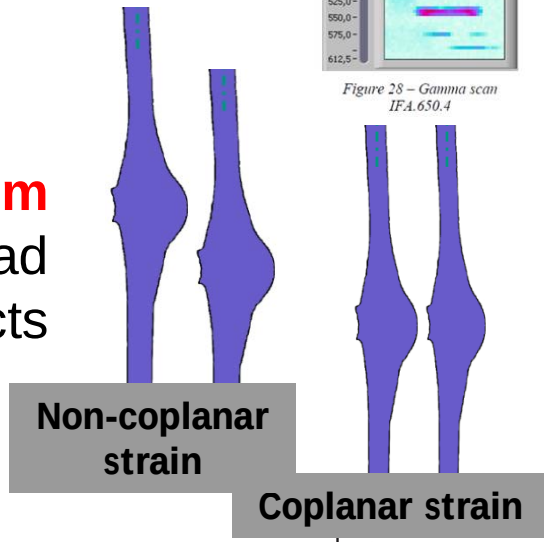
Figure 28 – Gamma scan IFA.650.4

➲ **Cladding temperature is thus underestimated…**

DUCTILE MODE

– **CathSBI new method** takes into account

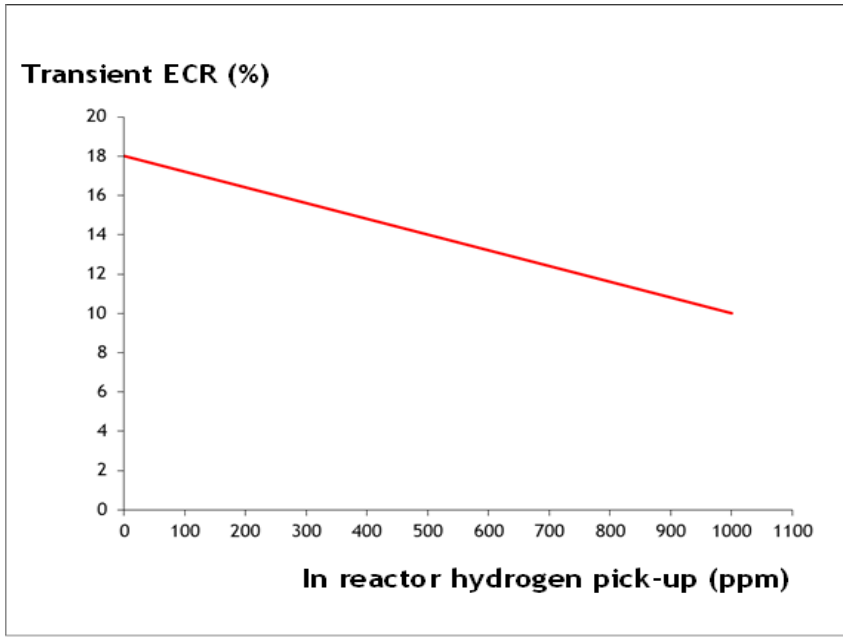
- **Negative effects on heat transfer from cladding to primary coolant** of clad ballooning and burst, blockage and contacts between rods
- Impact of **fuel relocation**

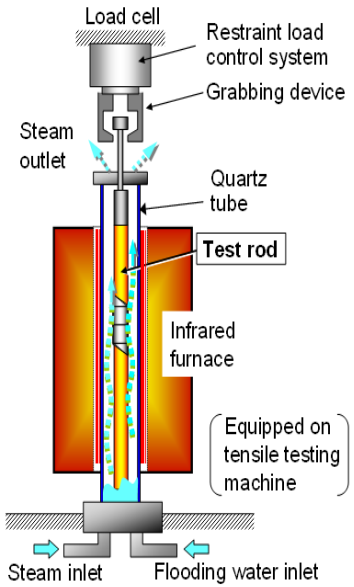


4 - How to Model Fuel Behaviour During LOCA

- **New French regulation**
  - New safety requirement in 2010 based on **strength-based approach** including an **additional axial loading** during the **quench**
  - A new French **ECR criterion**, expressed as a function of **in-reactor hydrogen pick-up** and combined with the **historical 1204°C**, was accepted by ASN in 2014

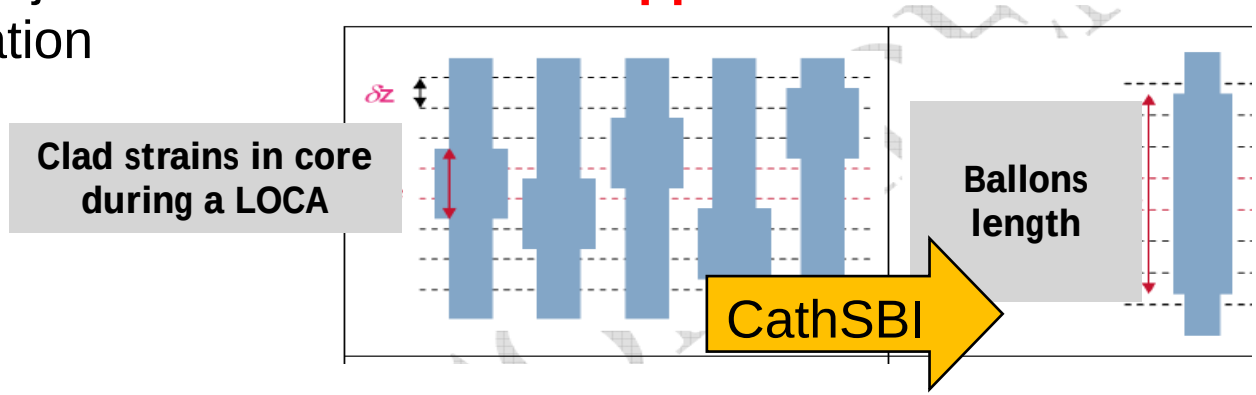
BRITTLE MODE





4 - How to Model Fuel Behaviour During LOCA

- **Fuel new modelling is improved and more accurate by taking into account more physical phenomena that were up to now either mis-modelled or non-modelled**
  - **Clad ballooning and burst**: Modelling is underway by EDF to improve the rupture criterion and to cover the IB heating rates
  - **Blockage of fuel channels hydraulics**: Enhancement of the new method consists in taking into account the **balloons length** - Subjected to a **statistical approach** based on a range of variation



  - **Thermal exchanges** between fuel rods and primary coolant taking into account **the reduction of the exchange surface** due to the contacts between the rods

4 - How to Model Fuel Behaviour During LOCA

- **Fuel new modelling is improved and more accurate by taking into account more physical phenomena that were up to now either mis-modelled or non-modelled**
  - **Fuel relocation phenomenon** (possible accumulation of fuel fragments in the ballooned section of the fuel rods) - various models developed to take into account **relocation consequences on clad temperature**
    - Thermal conductivity of pellet fragments
    - Gap between the pellet fragments and the clad
    - Linear power of the relocated fuel
  - Some parameters of these models are subjected to a **statistical approach based on a range of variation**
- IRSN analysis focused on the statistical approach and fuel modelling qualification - **main IRSN issues**
  - **Lack** of justification for **some uncertainties**

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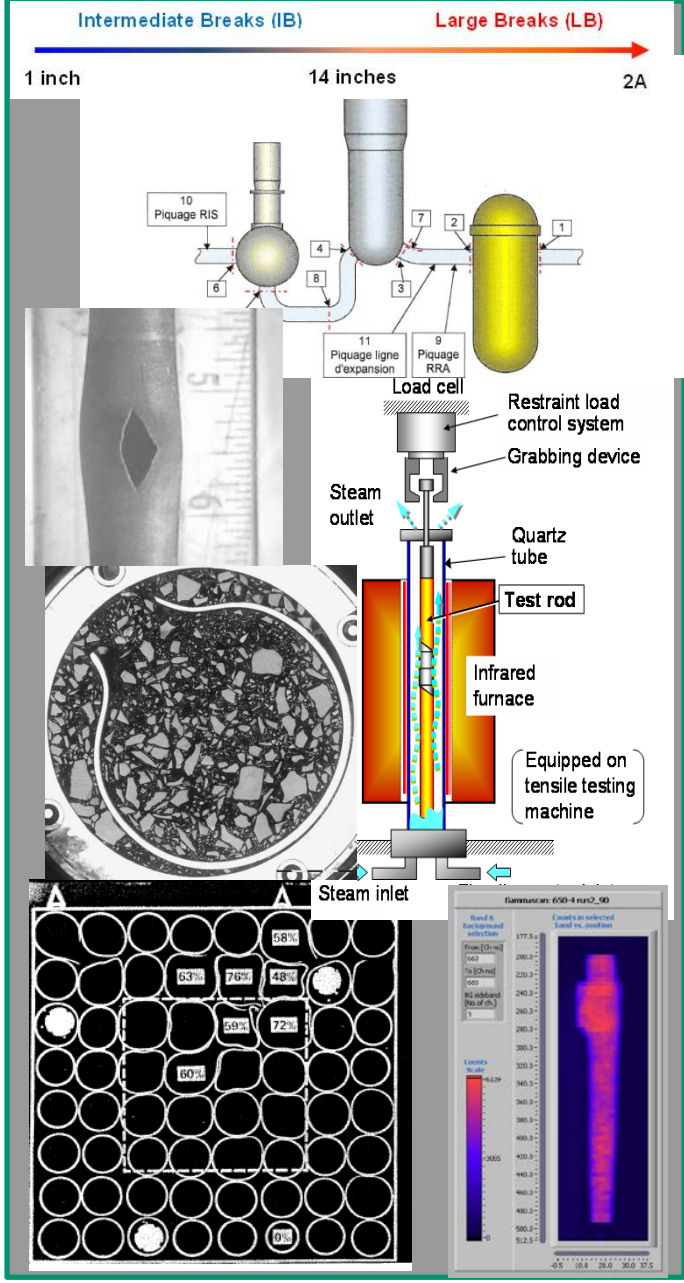
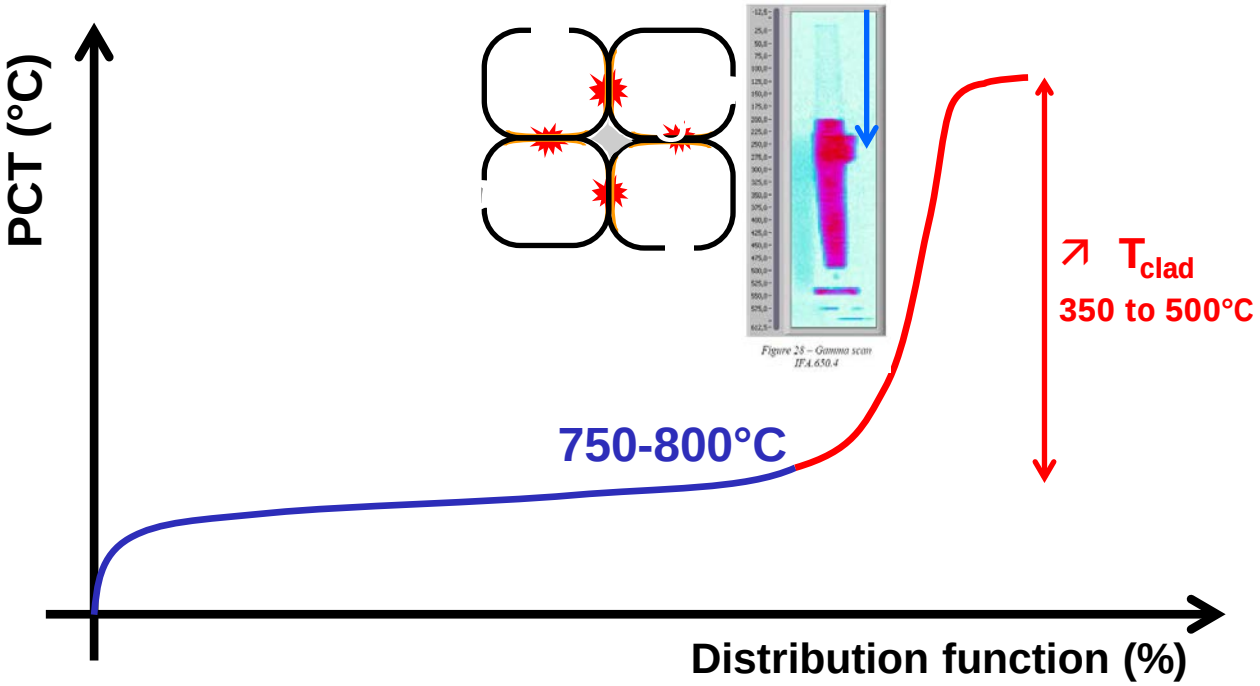


5 - Pending Questions

- PCT and ECR calculated without taking into account all the fuel physical phenomena may be **underestimated**: the first results obtained with CathSBI show a **significant sensitivity** of the **clad temperature** to the input parameters



High sensitivity linked to the fuel rod phenomena activation if

difference between clad internal and external pressures high enough + clad temperature above 750 – 800 °C

➲ **Ensuring the robustness of LOCA safety studies is still a challenge for EDF**

Thank you for your attention