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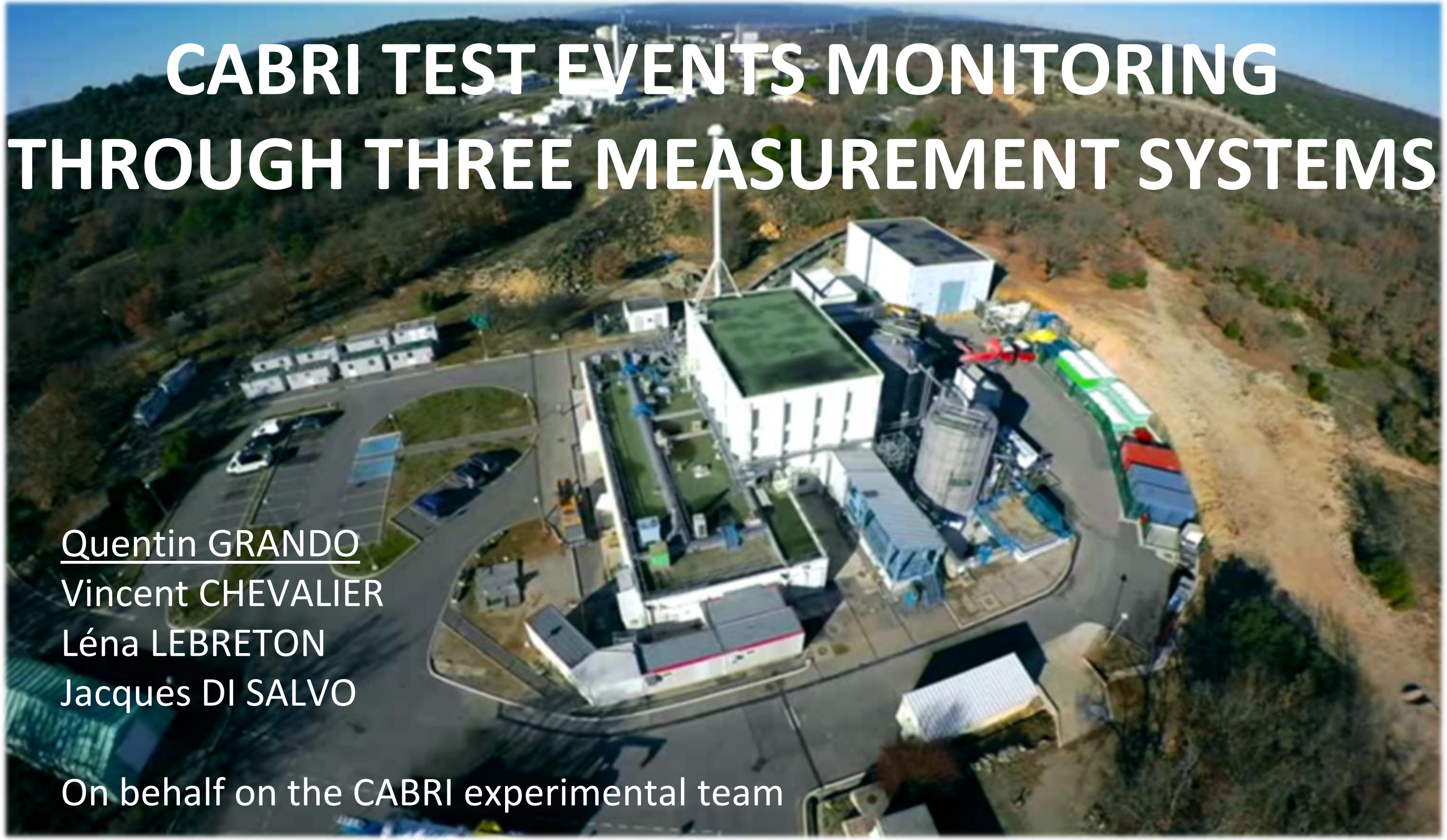

CABRI TEST EVENTS MONITORING THROUGH THREE MEASUREMENT SYSTEMS

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On behalf on the CABRI experimental team

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MEMBRE DE ETSON

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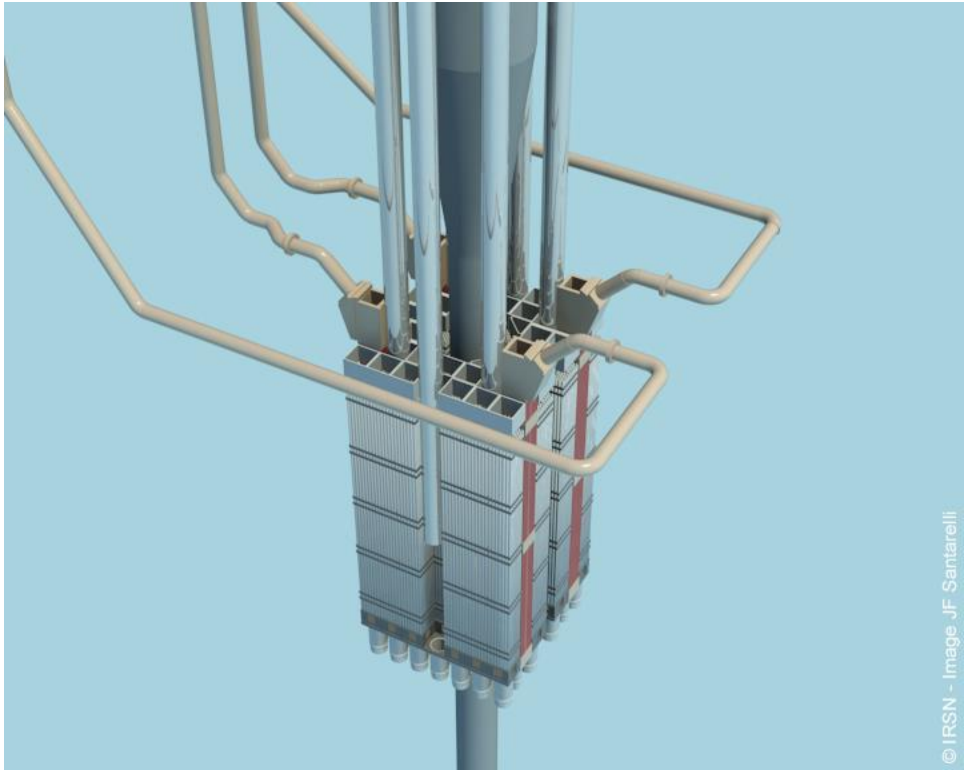
I. Introduction: the CABRI reactor

- CABRI is an experimental pool-type reactor located in Cadarache nuclear research center
- It is devoted to study fuel behavior under Reactivity Initiated Accident (RIA)
- It was used to study this kind of accident in sodium fast reactors
- CABRI International Program, managed by IRSN in collaboration with CEA, under OECD/NEA agreement
- Huge renovation conducted: a water loop built to reproduce the thermohydraulic conditions of a Pressurized Water Reactor (PWR) => conditions of a RIA in a PWR

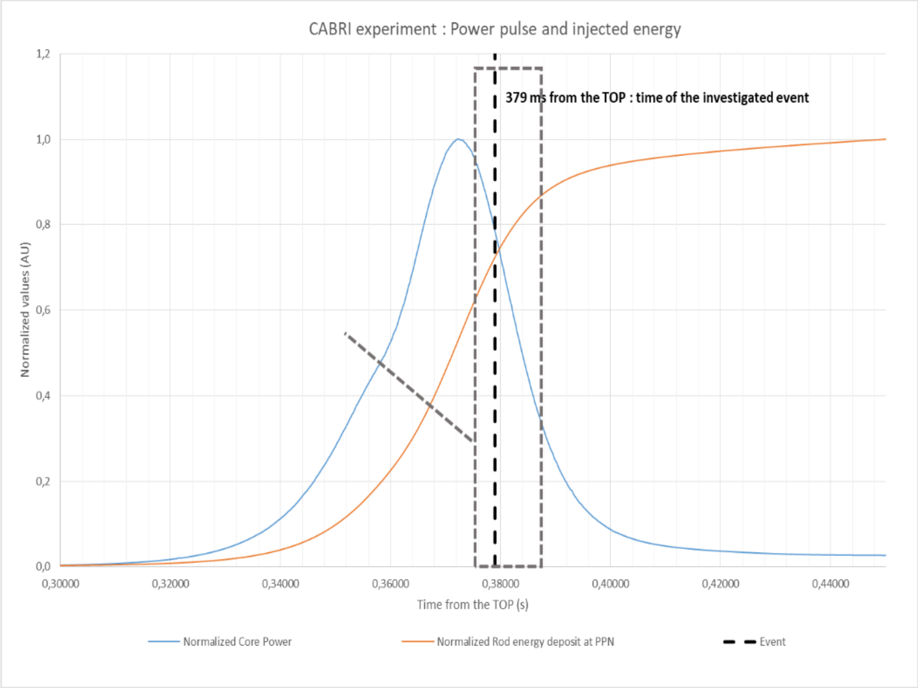
I. Introduction: the CABRI reactor



- Test rod is inside a cavity of the new water loop in the center of the driver core
- Insertion reactivity is still created by depressurizing ^3He

I. Introduction: RIA transient

- Experimental detectors follow the excursion of power from few MW to 20 GW
- Pulses widths from 10 ms to few dozens of ms
- For this pulse, focus on an event detected at TOP_{ONSET} + 379 ms (Transient Over Power ONSET, noted t0). Signal will be carefully studied in the time interval [t0 + 375 ms ; t0 + 392 ms]

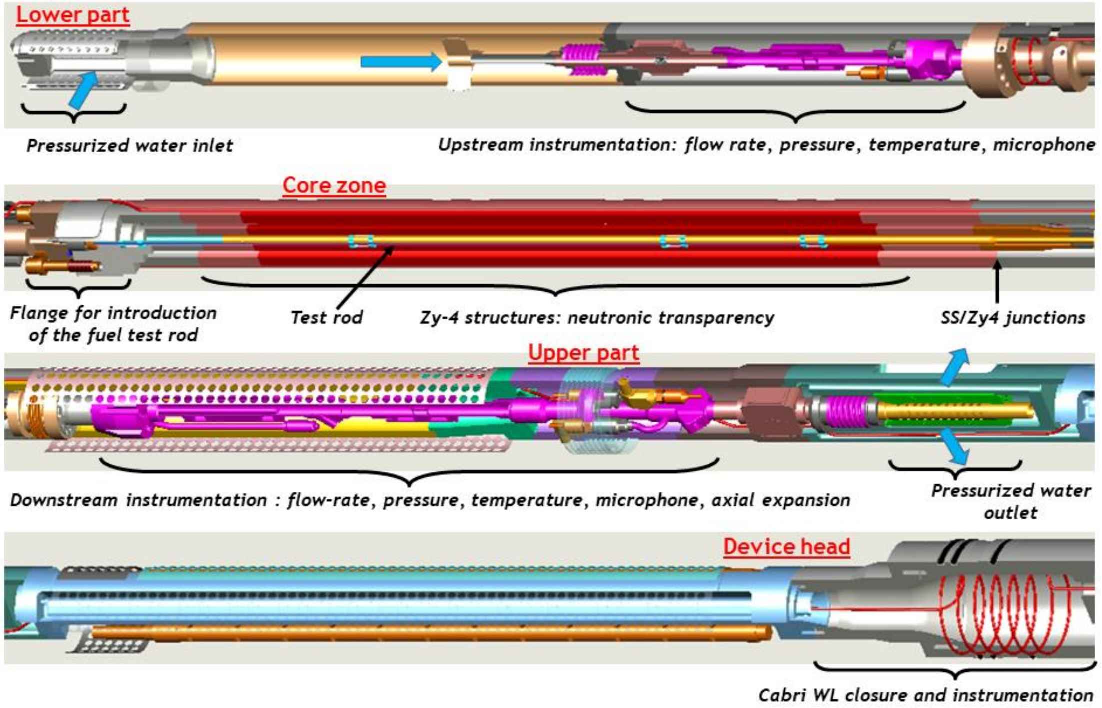


II. ANALYSIS Performed

II.1 ANALYSIS Performed : from the test device point of view

II.1 Schematic view of the test device

- CABRI test device : instrumented test rod holder
  - Initial conditions: PWR conditions (155 bar, 280 °C)
  - Test rod held in the central part
  - Heaviliy instrumented upstream and downstream parts
  - Around 50 sensors
  - Focus :
    - **Rod elongation sensor**
    - **Transient flowmeters**
    - **Pressure sensors**
    - **Acoustic events detectors**

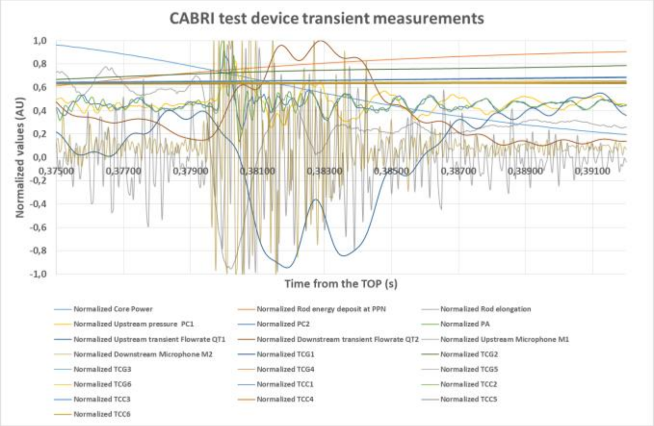


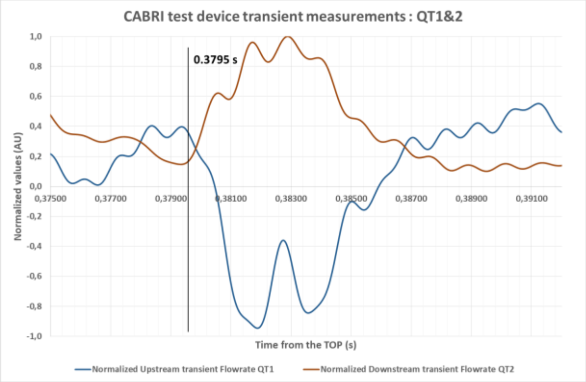
II.1 Analysis of the signal measured by the test device sensors during the transient

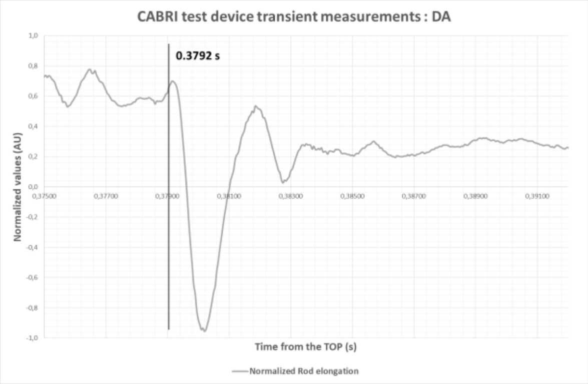
- All the sensors focused on are responsive to the event

- Elongation sensor first
  - Fast signal decrease
  - Then back to an average value

- Then the transient flowmeters
  - Each one in the opposite direction, sign of steam burst and water ejection



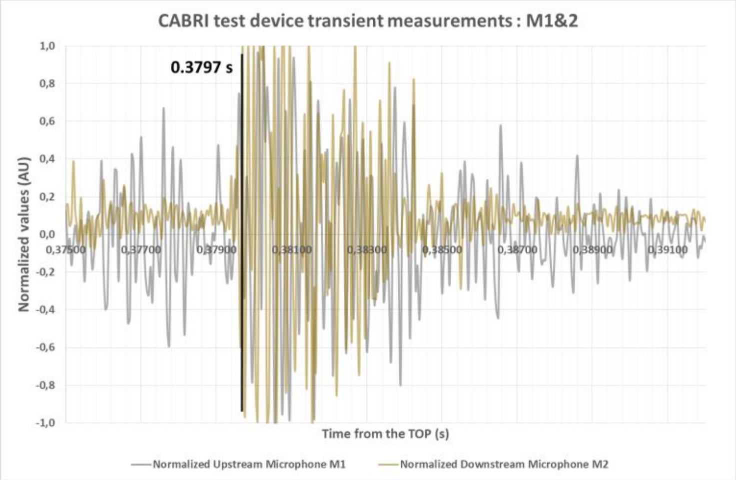


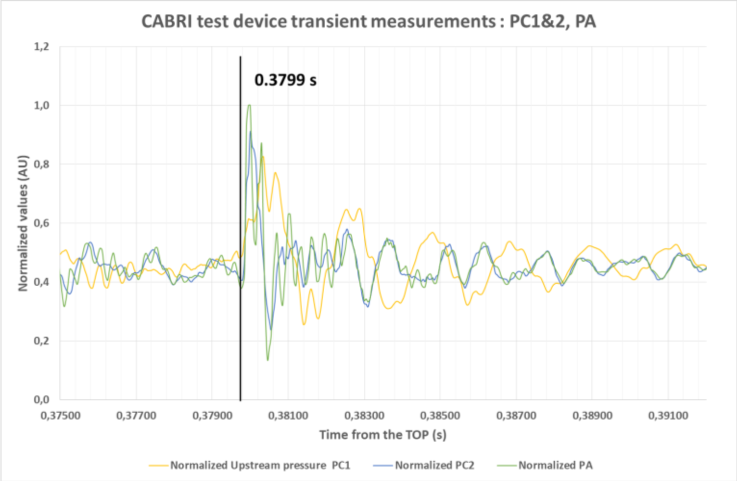


II.1 Analysis of the signal measured by the test device sensors during the transient

- Acoustic sensors
  - See the phenomenon but with very limited accuracy

- Pressure sensors
  - They indicate a pressure peak
  - More violent downstream than upstream
  - Last sensors to react



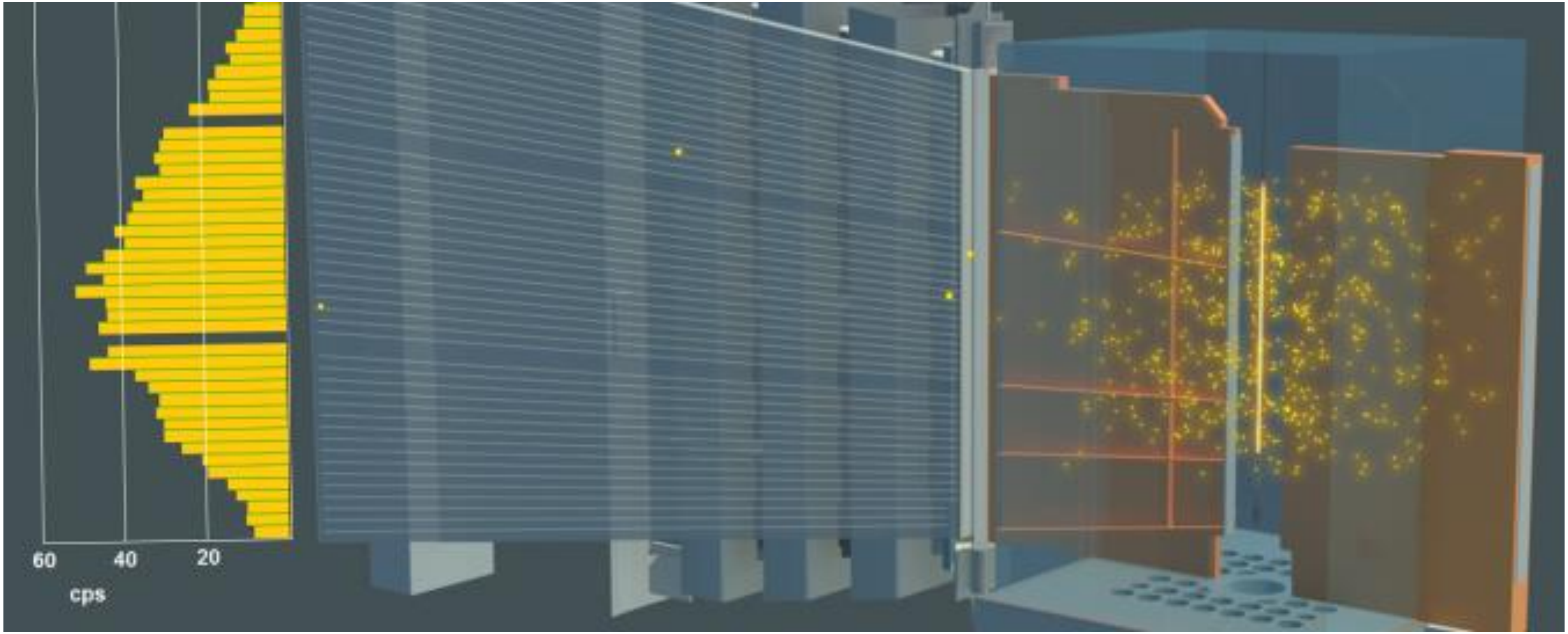


II.1 Analysis of the signal measured by the test device sensors during the transient

- Sensors reacted to an event in the test channel
- Most of them indicate a fuel coolant interaction (flow inversion + pressure peak)
- The slight timing difference between upstream and downstream sensors tends to indicate it happened in the upper part of the rod
- …but very difficult to time or located exactly : certainly a two phases mixture

II.2 ANALYSIS Performed : from the hodoscope point of view

II.2 Analysis of the signal measured by the hodoscope system

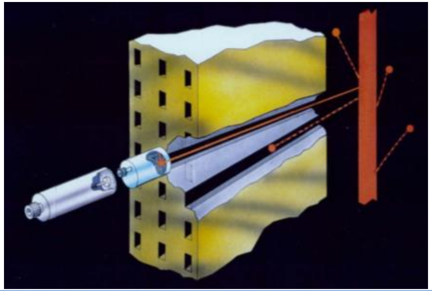


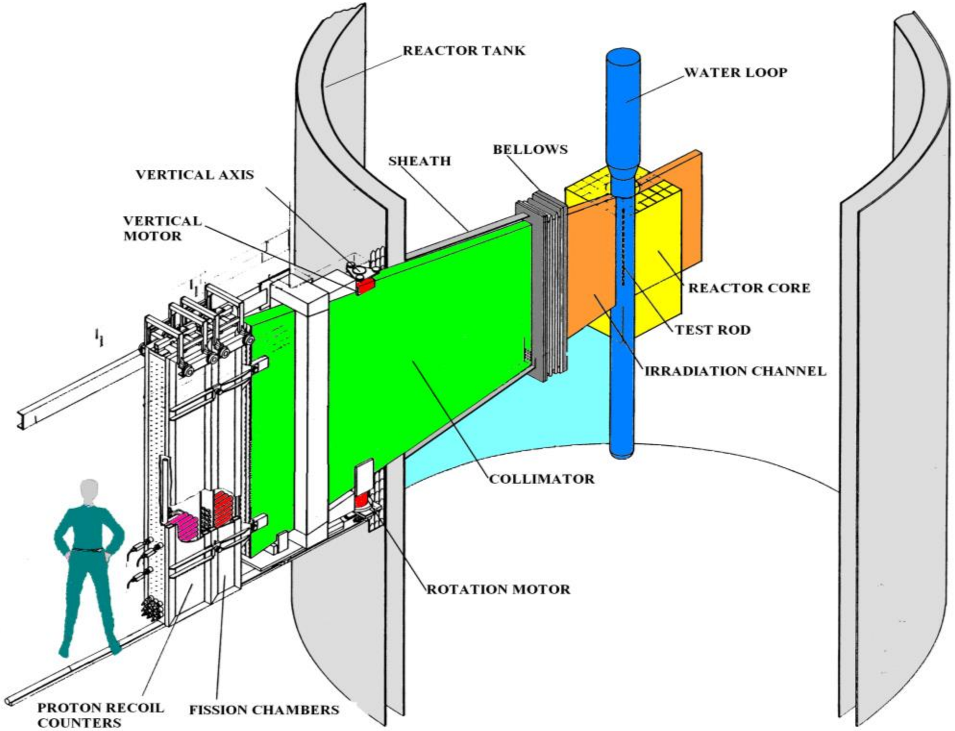
II.2 Schematic view of the hodoscope equipment

- The hodoscope measures on line the fuel motion deduced from the detection of the fast neutrons emitted by the test rod during the transient.

- Proton counters (CH_4):
  - For low power : ~ 10 kW to 50 MW
  - Energy threshold: 400 keV

- Fission Chambers (^{237}Np):
  - For high power: ~ 1 MW to 25 GW
  - Energy threshold: ~ 650 keV





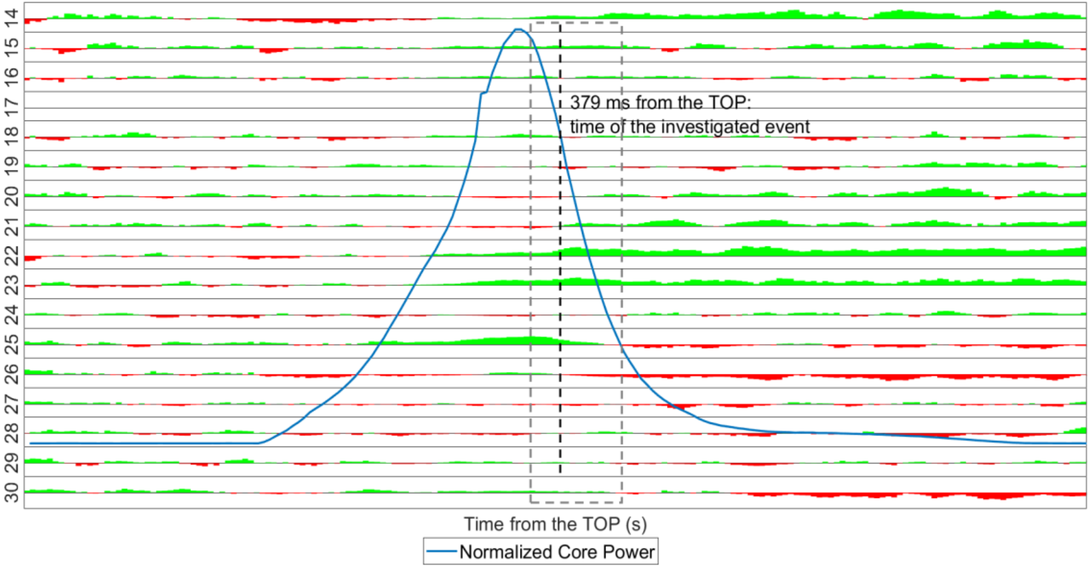
II.2 Hodoscope measurements

- Evolution of the axial fuel distribution during the transient: plot of the SNR(t)/SNR(BT) indicator for each row of the upper part of the fuel, with a variable time range and up to 1 ms during the transient

- Green/Red: Fuel accumulation/lack of fuel

- Blue: normalized power peak measured by fission chambers

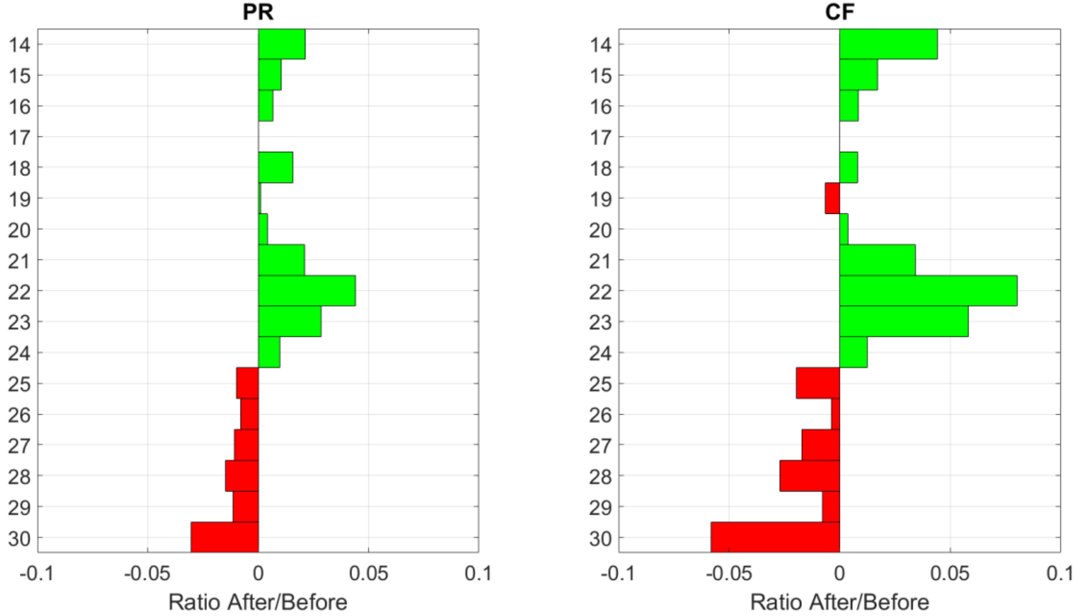
- From t0+375 to t0+392 ms: focus on the interval of time for the investigated event



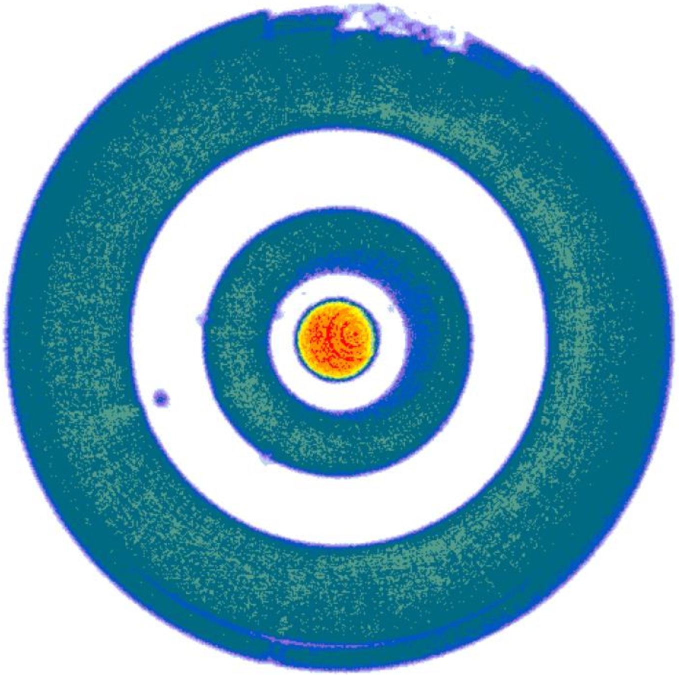
II.2 Hodoscope measurements

- Final state measured during a power plateau at 100 kW: for each row of the upper part of the fuel, with Proton Recoils and Fission Chambers detectors

- Green/red: fuel accumulation/lack of fuel

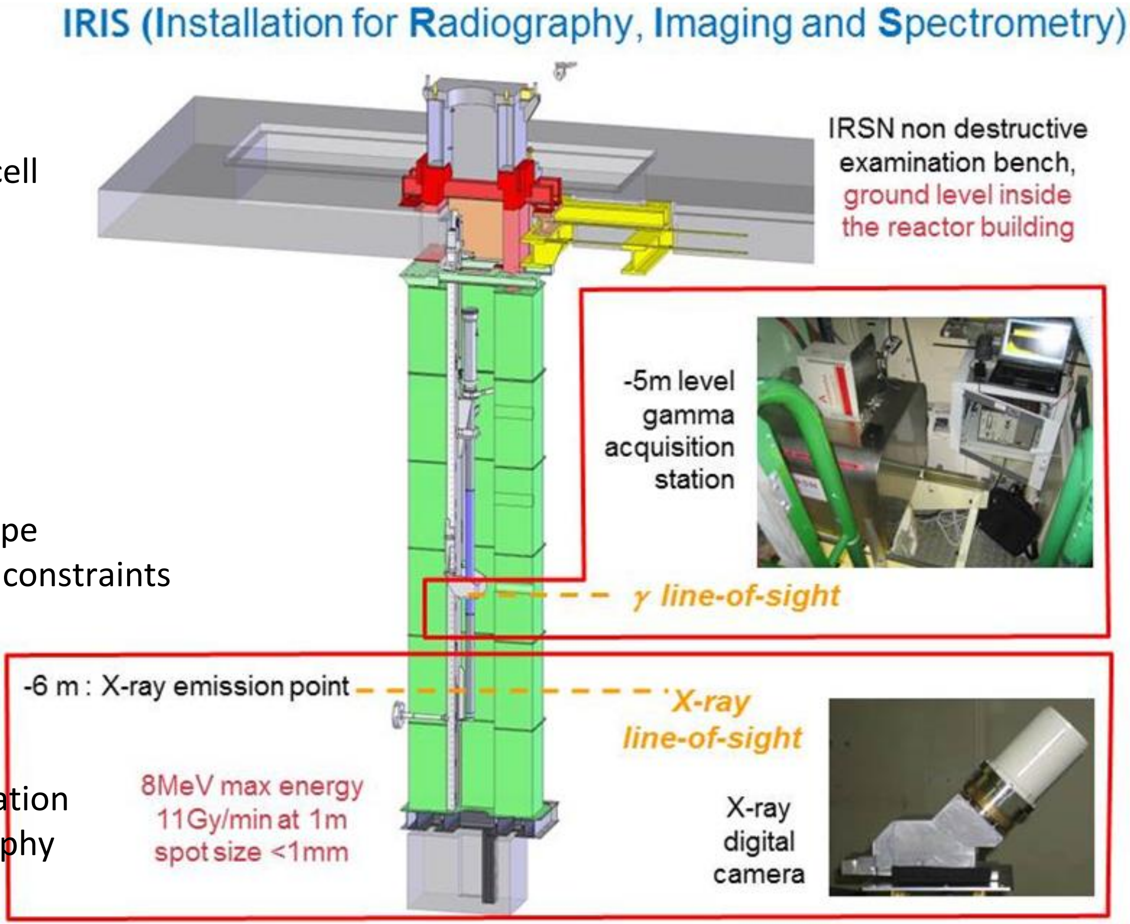


II.3 Analysis performed from the IRIS imagery and γ-spectrometry system point of view



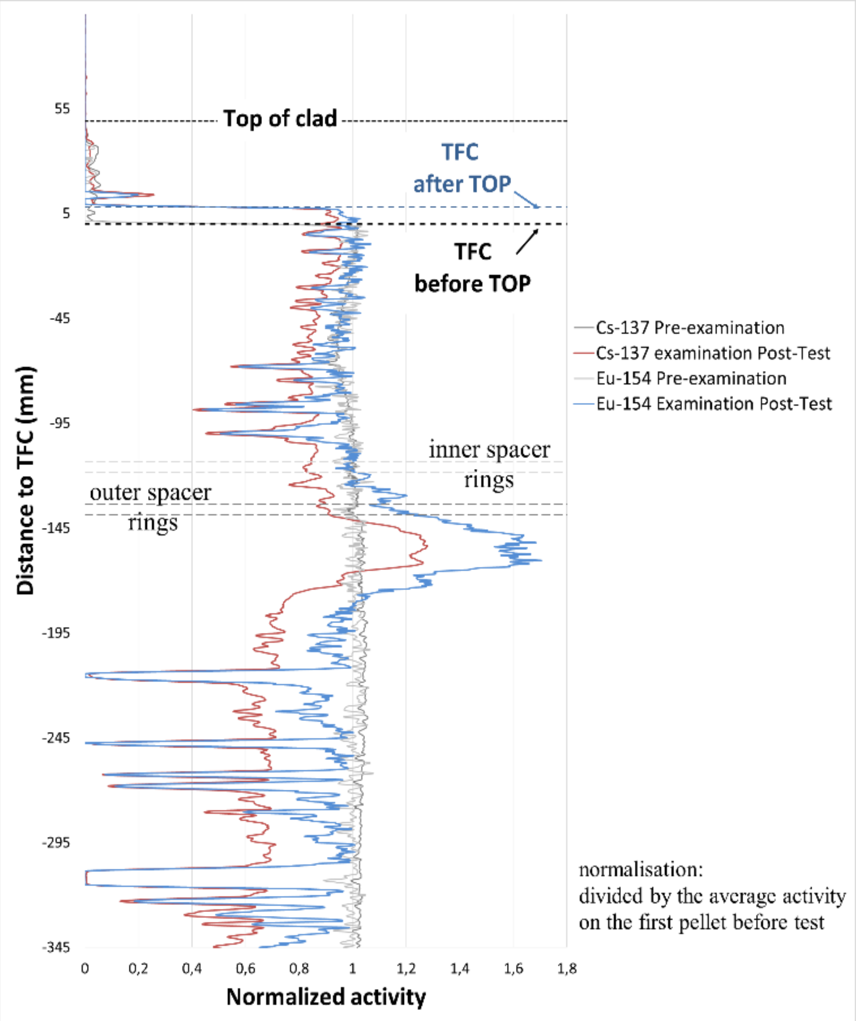
II.3 Schematic view of IRIS System

- Located near the CABRI reactor experimental cell
  - » Fast transfer in vertical position
- Quantitative gamma-scanning
  - » Germanium detector
  - » Vertical translation of the test device
- X-ray transmission radiography
  - » X-rays production by a compact prototype accelerator adapted to reactor building constraints
  - » Onedimension NMOS camera
  - » Vertical translation of the test device
- X-ray transmission tomography
  - » Radiography done each 0.4˚angular rotation
  - » Home treatment code to build tomography



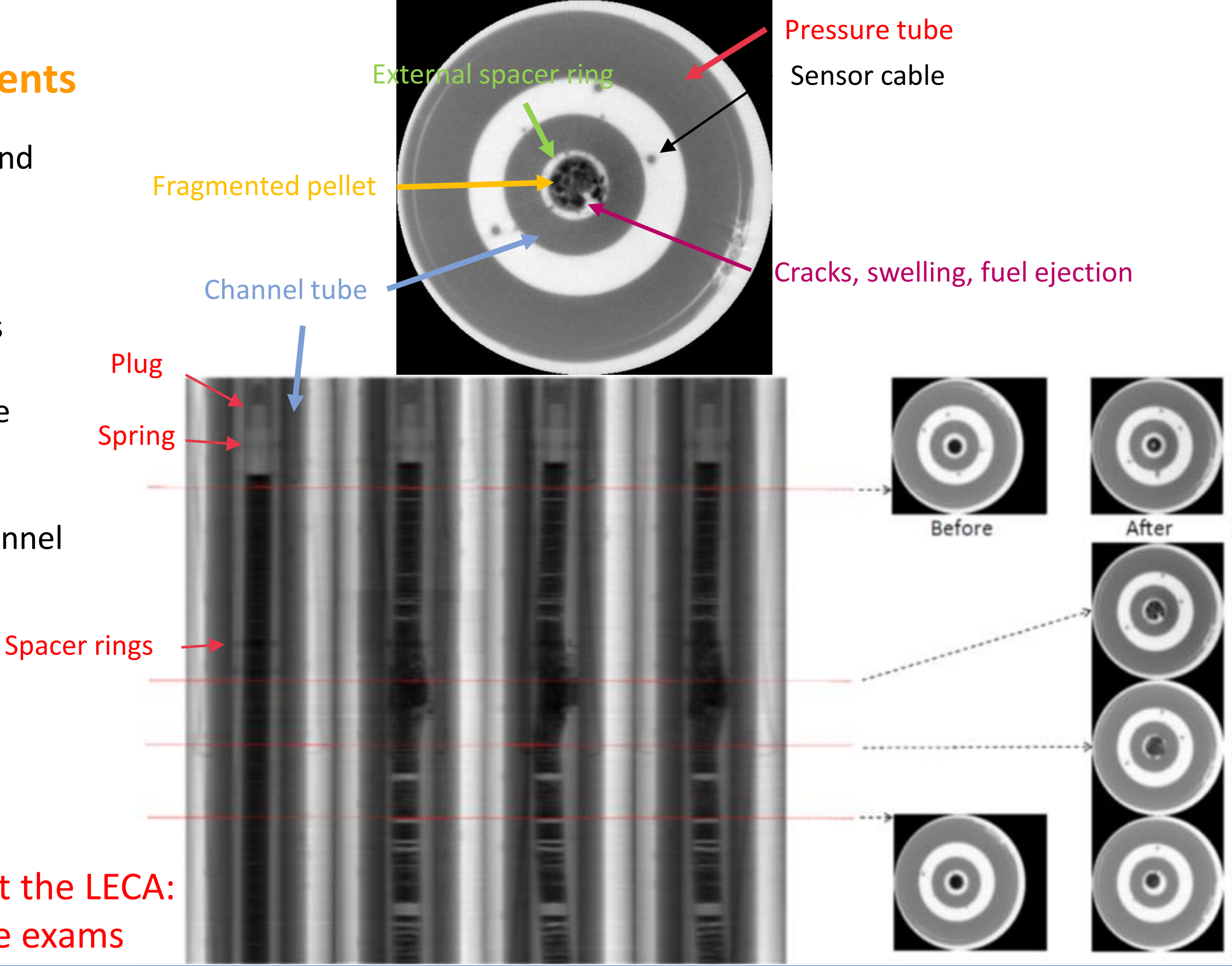
II.3 IRIS Gamma spectrometry measurements

- Activity profile as a function of the test device (vertical position)
- Comparison of the activitybefore and after the transient
- Before: ^{137}Cs, ^{154}Eu, ^{134}Cs
  - » Pellets, inter-pellets,
  - » BFC (Bottom of Fissile Column), TFC (Top of Fissile Column)
  - » Integrated activity
- After: same radio-isotopes + short live isotopes ($^{140}La/Ba$, $^{95}Zr/Nb$ …)
  - » Fuel movement: lack, accumulation
  - » BFC, TFC shift?
  - » Activity in plenums?
  - » Loss of integrated activity?



II.3 IRIS X-rays measurements

- Visualisation of the test rod, before and after test, for comparison
- Before:
  - » Integrity of the fissile columns
  - » Pellets/interpellets; BFC/TFC, spring, elements of test device
  - » Dimensional measurement: diameter of pellet
  - » Rodlet well centred in the channel tube?
- After:
  - » Fuel movement
  - » BFC/TFC displacement
  - » Cracks, swelling, rodlet deformation

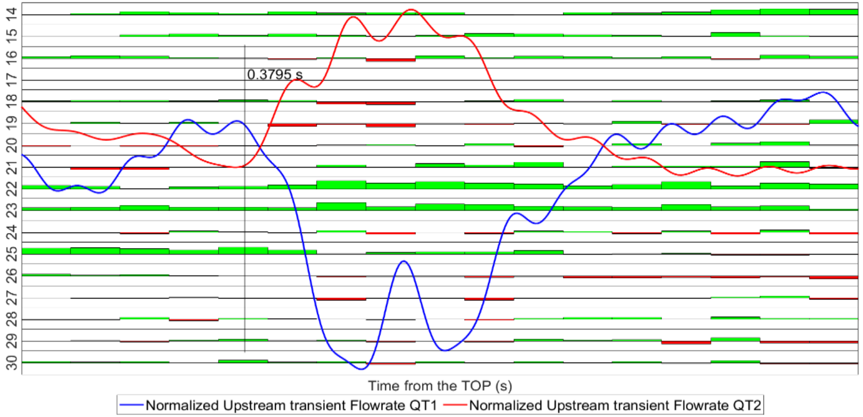


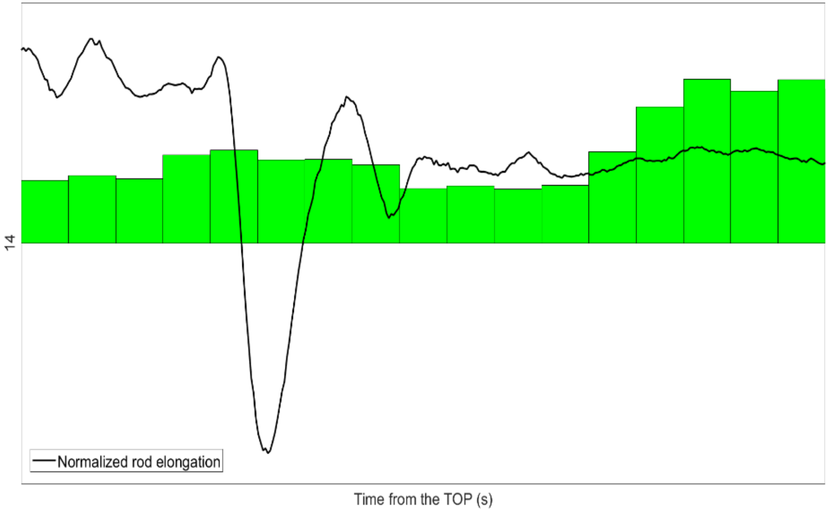
IRIS results guide measurements at the LECA: for non destructive and destructive exams

III. Combination of the analysis

- During the transient:
  - fuel motion detection (accumulation) for rows 14, 22, 23 simultaneously and/or after transient flowmeters indicates steam burst and water ejection (time step for hodoscope equal to 1 ms)
  - For row 14 (top of the fissile column), accumulation of fuel after the detection of the event by the axial rod elongation sensor

- Hodoscope results are coherent with test device sensors measurements: a clear effect on the fissile column can be detected consequently to the event, with a displacement of the top of the fissile column and several rows for which the quantity of fissile material decrease

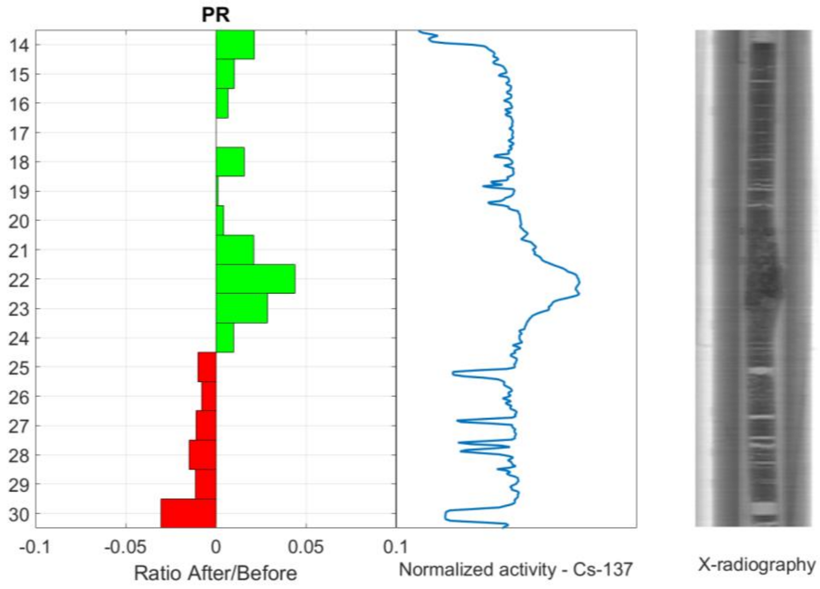




III. Combination of the analysis

- Final state of the fuel rod
  - For hodoscope measurements: comparison before/after the transient. Row 14 (TFC) is higher after the test / before
  - This can be compared to the X-radiography
  - Gamma emission, X-radiography and hodoscope both show:
    - ❑particular augmentation of the fissile material at the same axial position,
    - ❑important decrease of fissile material in a lower axial position

  - Quantitative results relative to the loss of mass of the fissile column can be accessed by hodoscope and gamma-spectrometry



IV. Main results

- RIA test in CABRI reactor are deeply instrumented with robust on-line instrumentation and Non Destructive Examinations performed quickly after the transient, directly in the CABRI facility

- Failure events can be detected and located with the sensors embedded in the test device, the subsequent movement of fuel are recorded during the transient thanks to the hodoscope system

- At the end, NDE performed with IRIS facility confirms the observations gathered with the hodoscope and provides the final state of the fuel rod, confirming and localizing more precisely the event

- The combination of all these systems makes CABRI experimentations almost unique and powerful for the RIA studies

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THANK YOU FOR YOUR ATTENTION

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