

Advanced Post-Irradiation Examination Methods (2)

- Focus on a few examples

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(with the collaboration of B. Marini for RPV part

Ch. Poussard for RIA part

Ph. Guedeney for microanalyses part)

What is a hot laboratory used for?

- Fuel R&D => Surveillance programme
 - Cladding
 - Fuel
- RPV Irradiation surveillance programme
- Material development (GenIV, ODS, SiC, fusion,...)
- Reprocessing R&D - Chemistry
- Radioisotope production

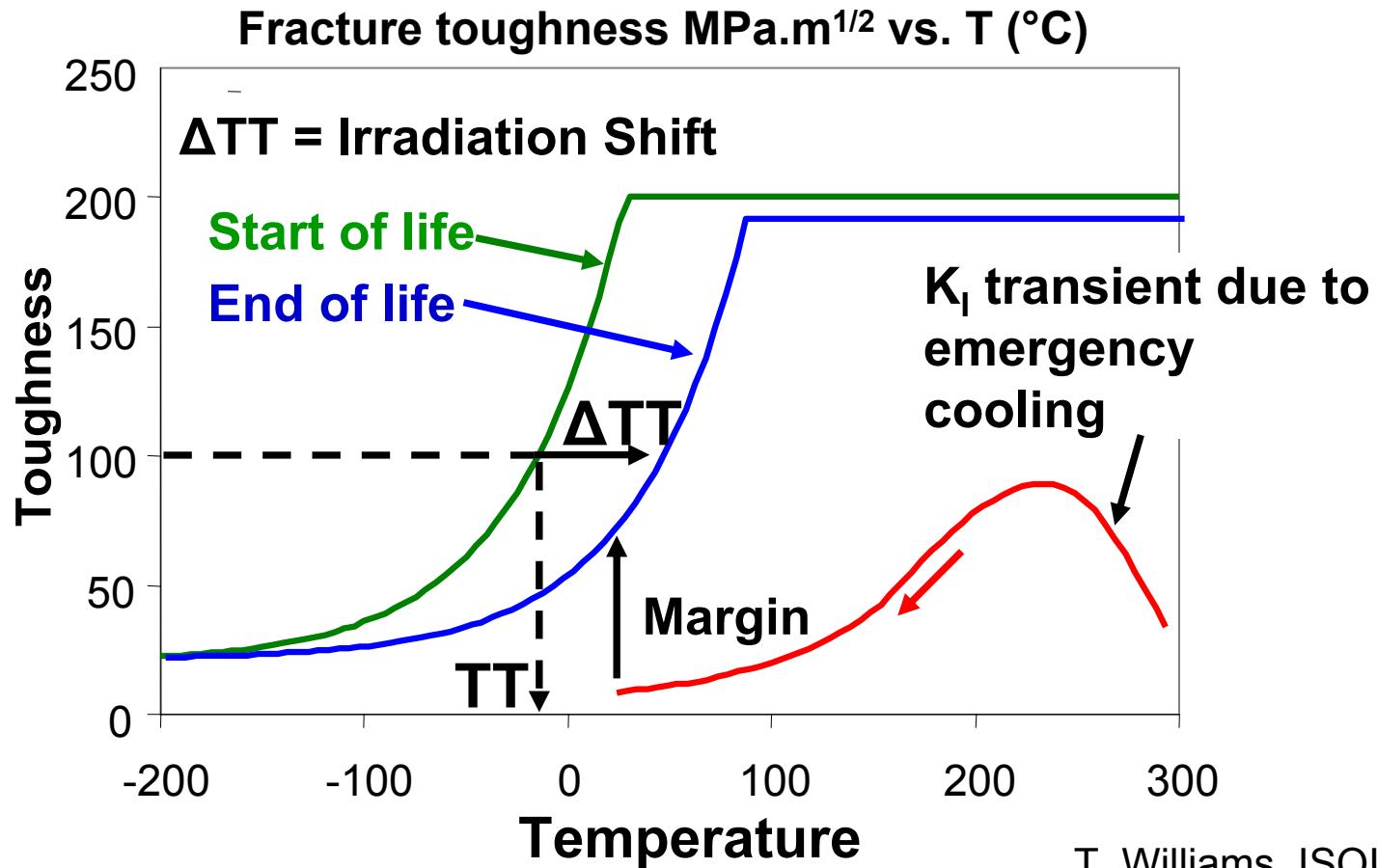
Zoom on a few examples:

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- RPV examinations
 - RPV irradiation surveillance programme
 - MTR irradiations on steels
- Safety tests:
 - RIA mechanical testing
 - Severe accidents scenario: fission gas release
- Fuel examination

1 - Reactor pressure vessel PIE

- Objective: Life extension of power plants = avoid brittle failure of RPV.



Reactor pressure vessel PIE: Hot labs are used in two ways:

- 1) RPV surveillance programme (in France, in EDF Chinon hot laboratory)

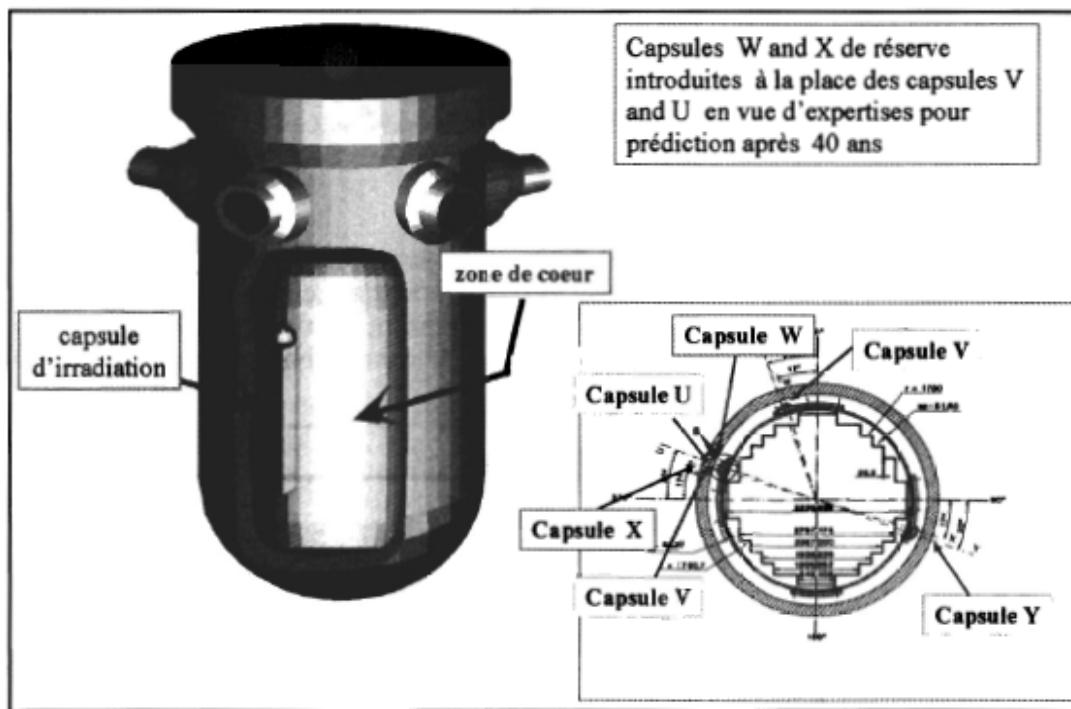


Fig. 6 - Positions des capsules d'irradiation

(doc RGN 2007 n°6)

- 2) After irradiation inside a MTR.

RPV surveillance programme capsule:

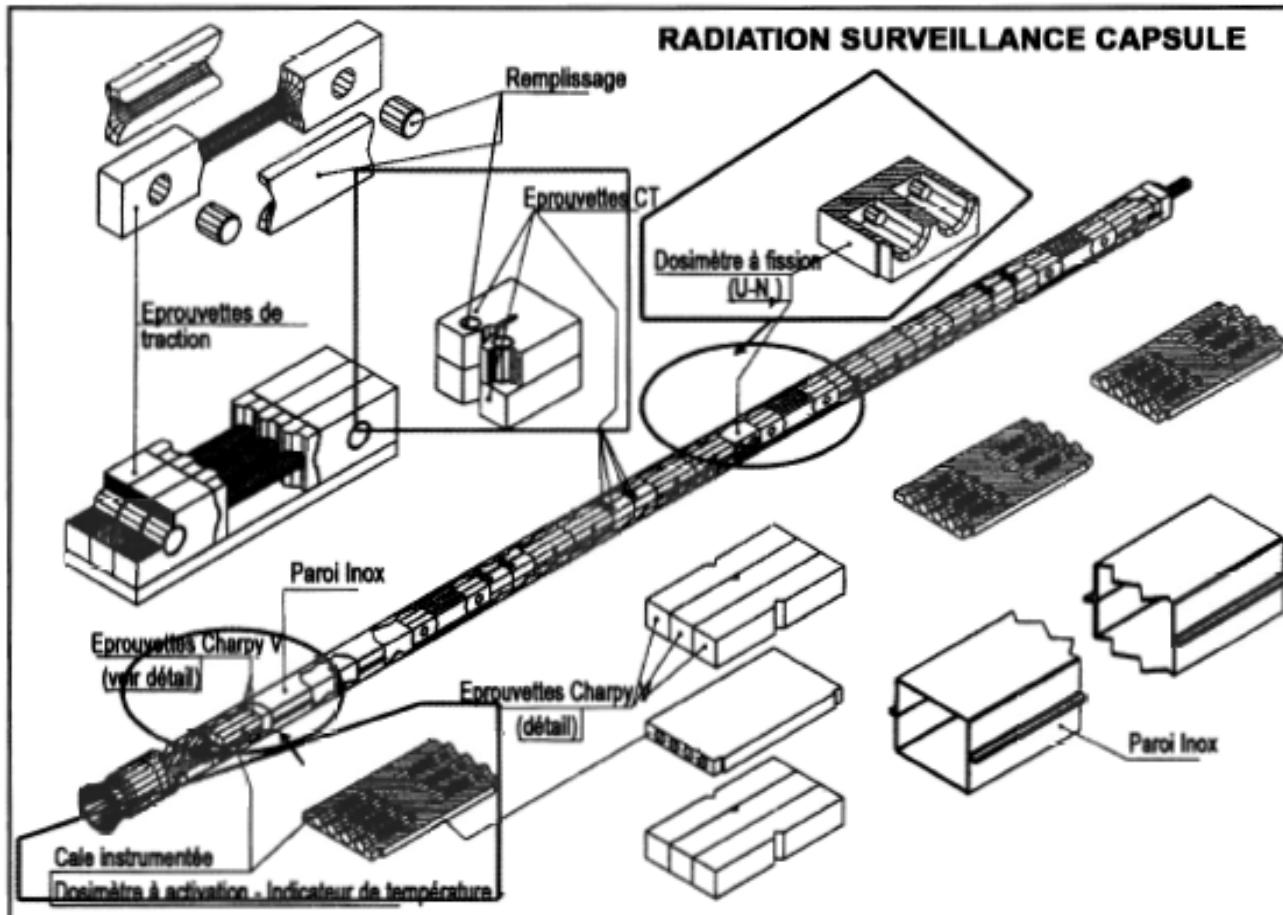
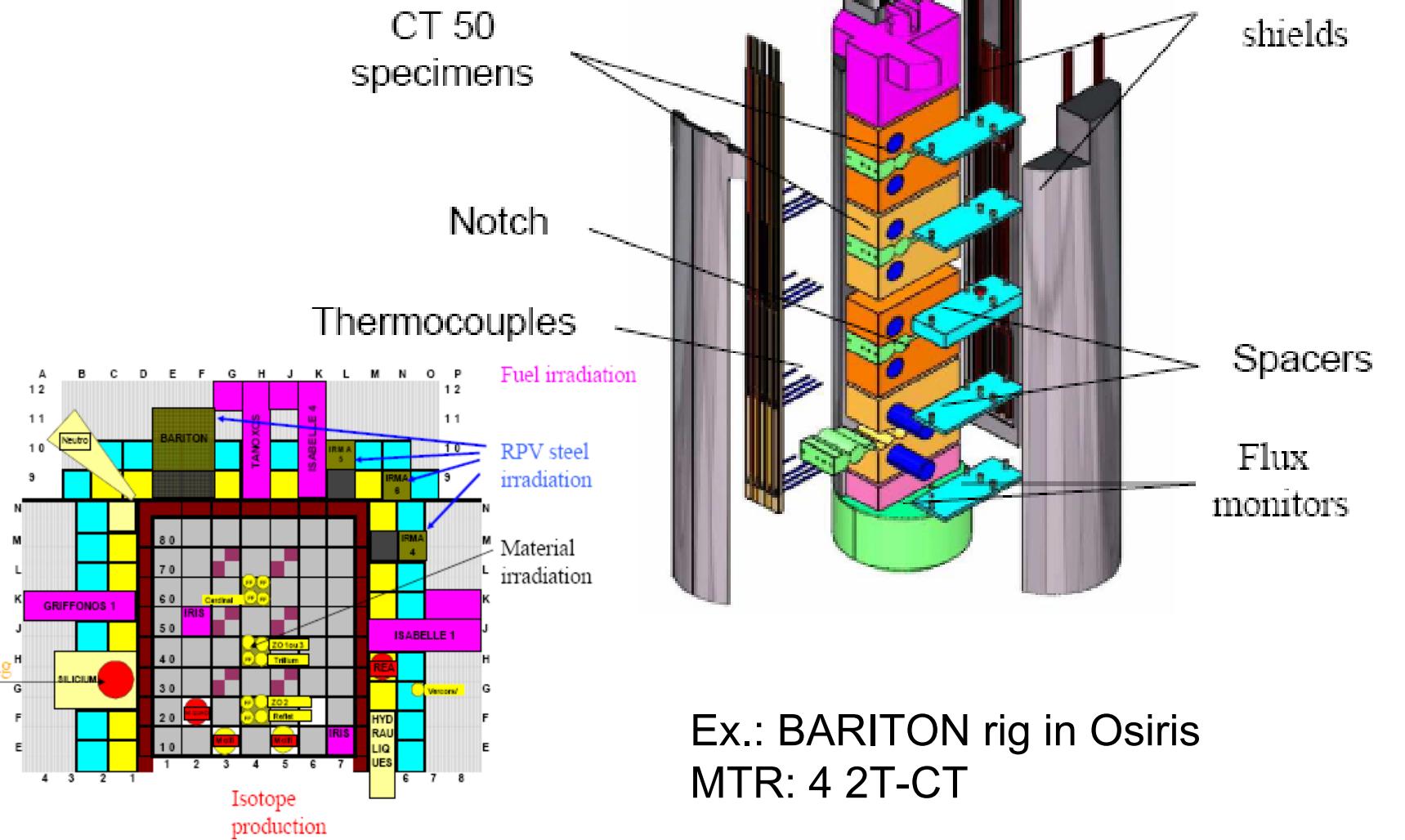


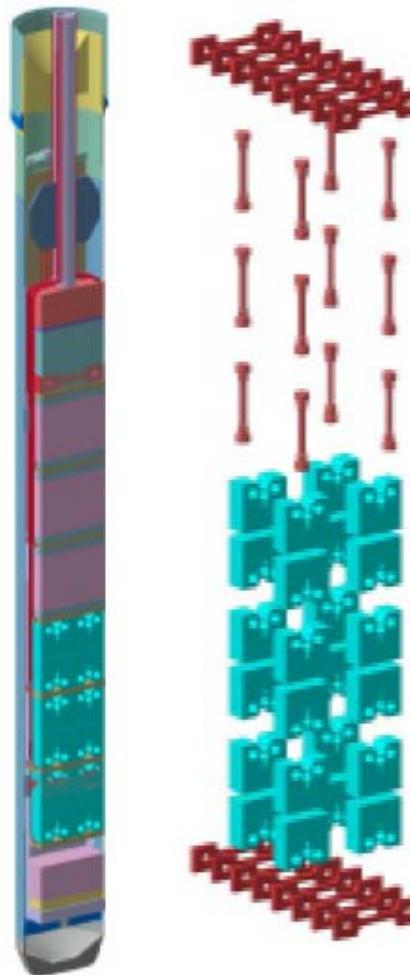
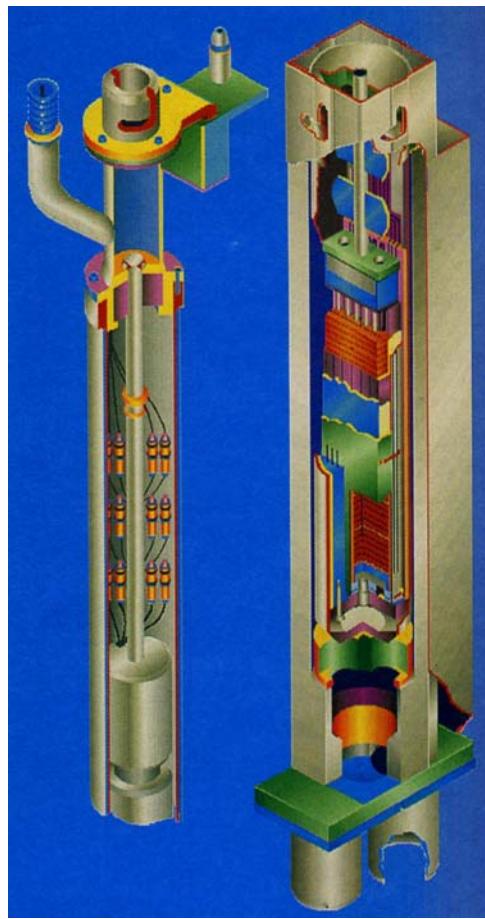
Fig.7 - Capsule d'irradiation du programme de surveillance comprenant les éprouvettes (CHARPY- ténacité - traction) ainsi que les dosimètres à fission et à activation

(doc RGN 2007 n°6)

2nd possibility: MTR irradiation



2nd possibility: MTR irradiation



Ex.: IRMA rig in Osiris MTR

Samples can be:

- toughness samples,
- tensile samples,
- Charpy,
- Auger.

Topics of interest:

- T° and dose effects on mechanical properties,
- Toughness in the HAZ,
- Effect of neutron spectrum on embrittlement,
- Influence of a thermal treatment on the brittle-ductile transition.

- T° range: 230°C – 320°C,
- $2-4 \times 10^{12}$ neutrons/cm²/s
- Inert atmosphere

Charpy tests in hot cells

Temperature range : -150°C to +600°C.

Automatic specimen feeding and positioning pneumatic system.

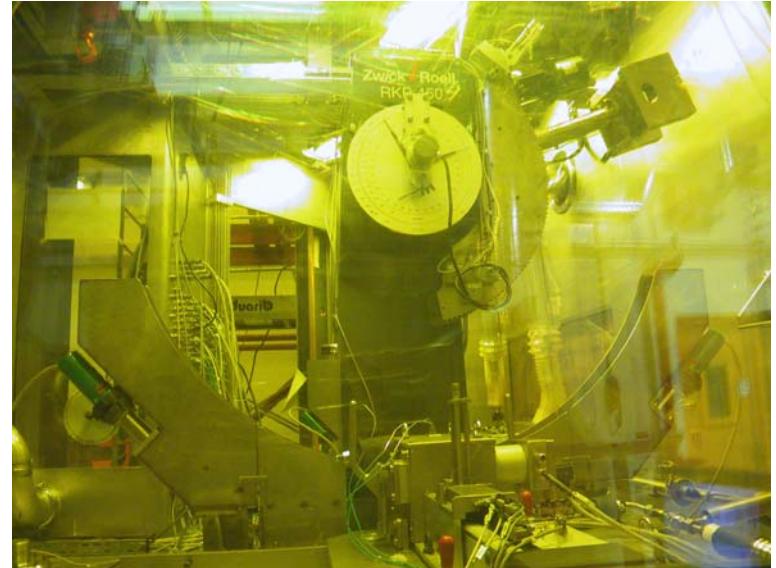
Fully instrumented pendulum system : Load, displacement and angle during the impact

⇒ **50 Joules Pendulum :**

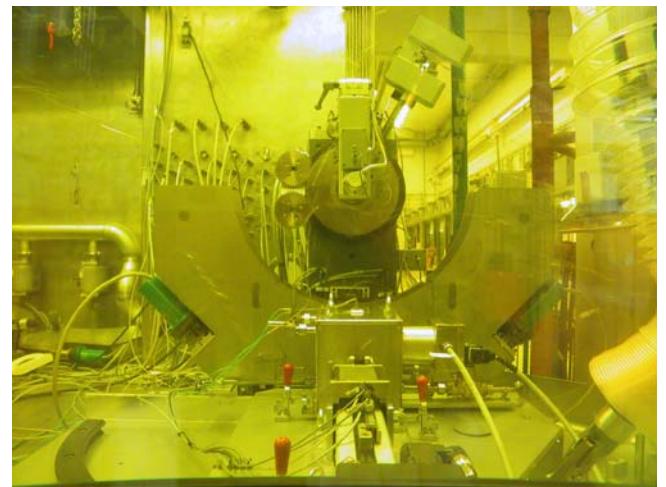
Specimen Types : Sub-Size Charpy-V of 3 x 4 x 27 mm or 3.3 x 3.3 x 24 mm

⇒ **300 Joules Pendulum:**

Specimen Types : Charpy-V or U of 10 x 10 x 55 mm or reduced to half thickness.



300 J (5.12 m/s) impact pendulum in hot cell



50 J (3.7 m/s) impact pendulum in hot cell

Fracture toughness measurements in hot cells

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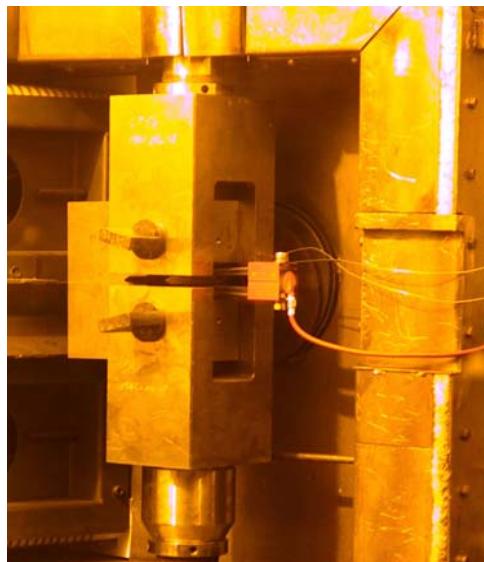
INSTRON Servo-hydraulic machines

Load range: 10 kN et 250 kN,

Temperature range: -160°C / 1000°C

Air or Argon

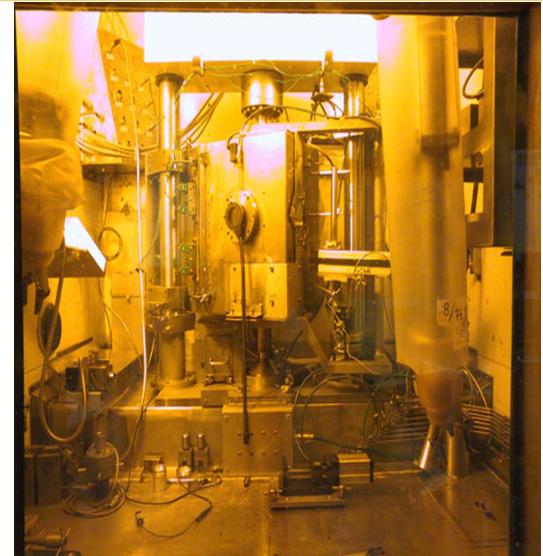
Different type of clip gages and extensometers



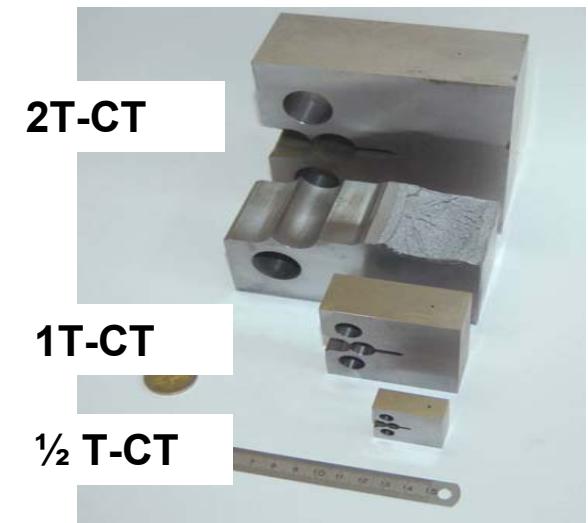
specimen on tensile
machine with clip gage



specimen on tensile machine
after test

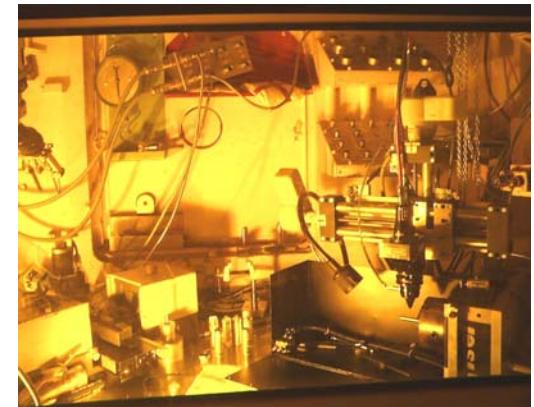


250 kN hydraulic tensile machine
equipped with thermal chamber



Sample preparation:

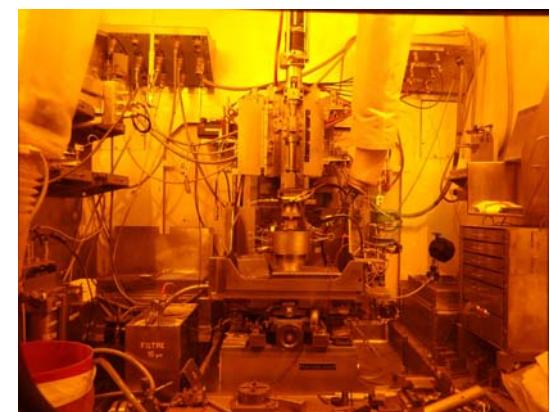
- ⇒ Machining: conventional (milling machine, lathe) and spark erosion machine with deionised water
- ⇒ Welding (TIG and Laser)
- ⇒ Subsize specimens



Laser welding

Observations:

- ⇒ Optical microscopy and Image Analysis
- ⇒ Hardness and microhardness
- ⇒ Preparation of microprobe specimens and fine foils for TEM
- ⇒ SEM
- ⇒ TEM
- ⇒ EPMA

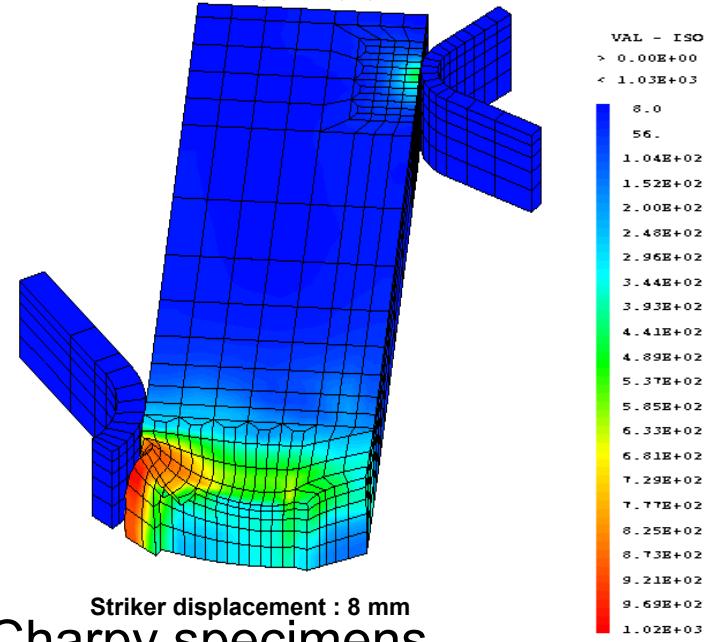
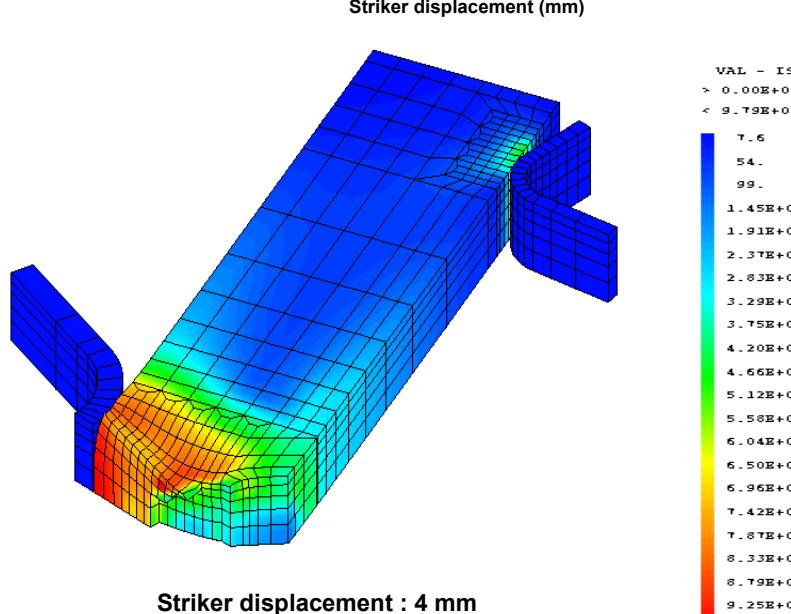
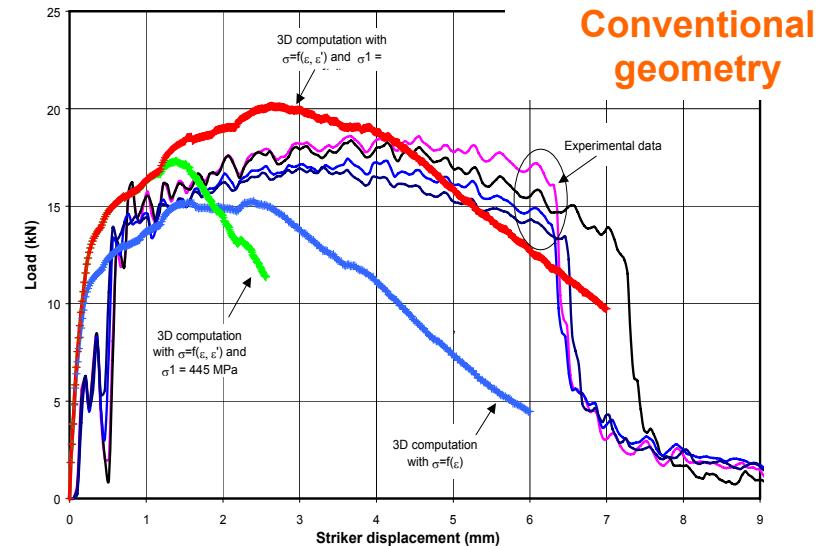
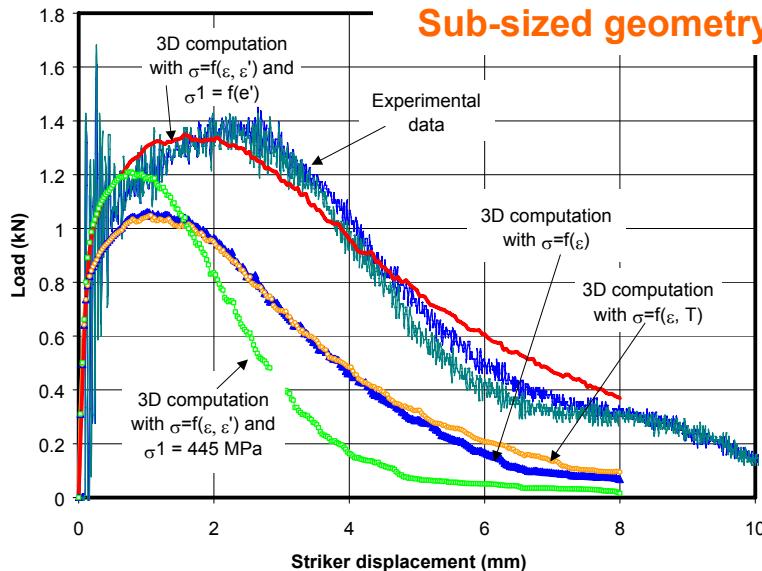


Spark erosion machining

Corrosion:

Autoclaves
(360°C, 200 bar),

Corrosion loop with circulating water and 3 autoclaves



Finite element modeling of Charpy specimens

Summary for RPV:

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RPV steel hardening or embrittlement can be characterized with conventional and sub-size specimens.

Most tests are preformed on Charpy samples, and completed by fracture toughness samples.

Surveillance programmes are completed by irradiation studies in MTR using irradiation rigs and hot cell examinations.

A good neutron dosimetry and a refined Finite Element analysis are necessary to analyse the tests.

Microscopic examinations are also needed (TEM, ...).

Beyond RPV steels, investigations are also performed on :

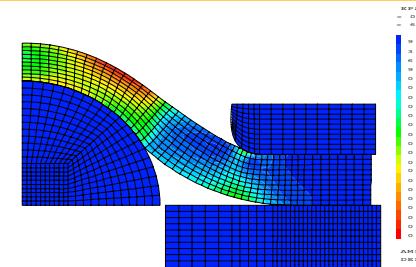
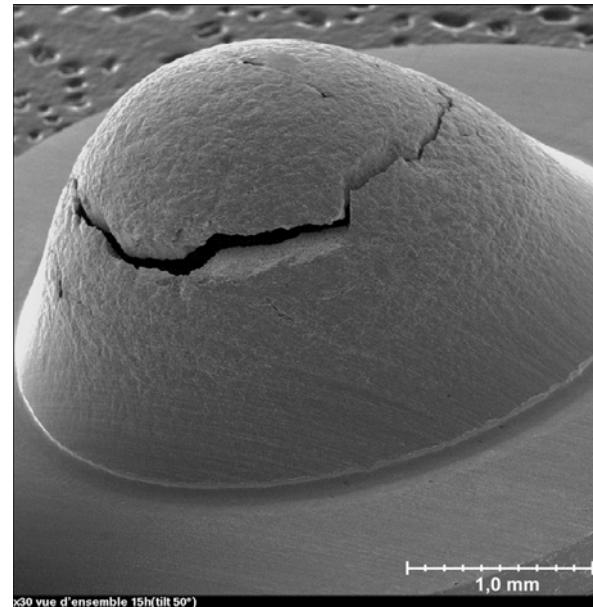
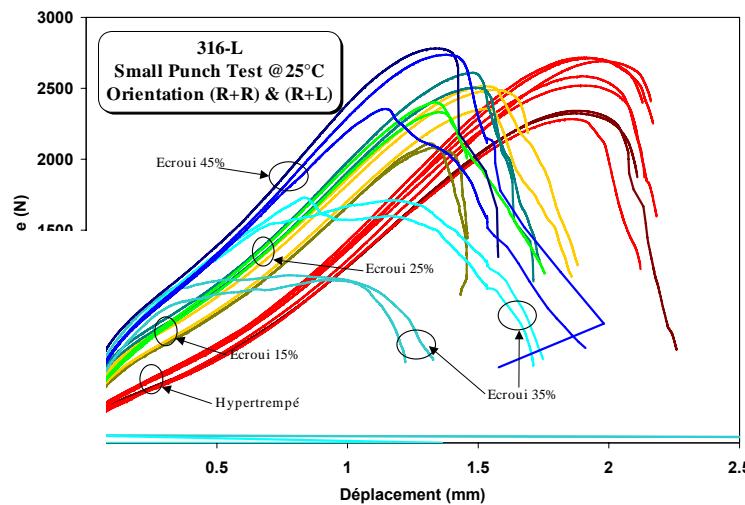
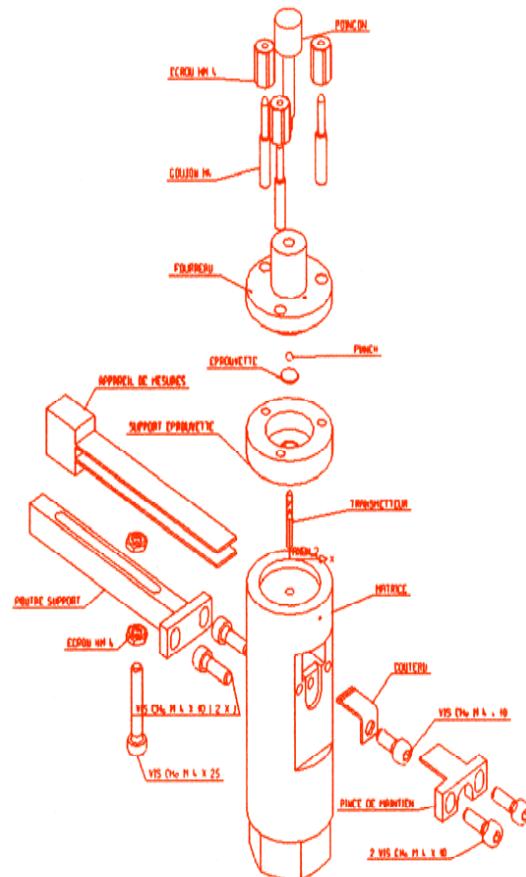
- Coolant circuit cast duplex stainless steel components (thermal aging),
- Internal structures of PWR such as baffle bolts, baffle plates.

Zoom on a few examples:

- RPV examinations
 - RPV irradiation surveillance programme
 - MTR irradiations on steels
- Safety tests:
 - RIA mechanical testing => see C. Poussard doc
 - Small punch test.
 - Fission gas release in a severe accident scenario.
- Fuel examination

DEN/DSOE

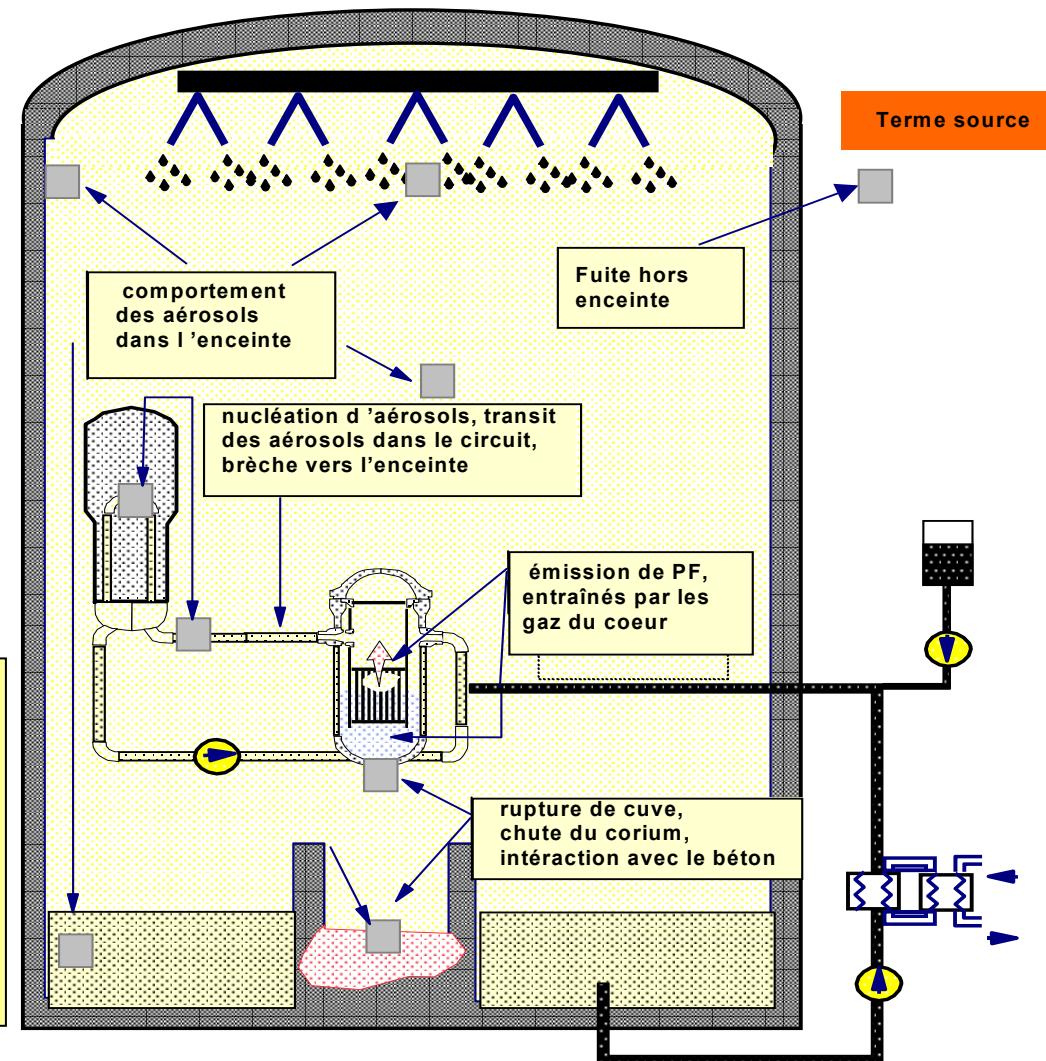
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A new facility: VERDON in CEA Cadarache

To study & understand physical and chemical phenomena of **fission product release** from the core in the hypothetical event of **a severe accident**.

- ⇒ Better determination of **Source Term**
- ⇒ Reduction of uncertainties in **PWR safety studies**
- ⇒ Validation / Qualification of **models and codes**



A new facility: VERDON in CEA Cadarache



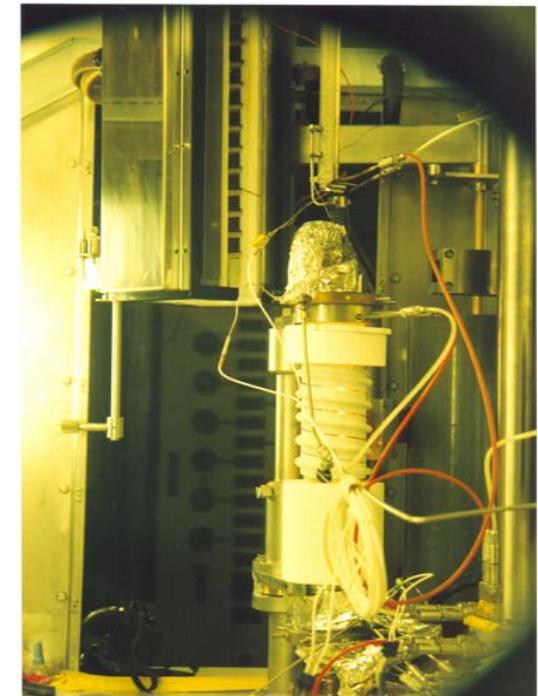
Between 1983 and 2002, 25 tests were performed in the VERCORS facility in Grenoble with EDF and IRSN:

- To gather experimental data on volatile and non-volatile FP,
 - To observe the delocalisation of the fuel
- ⇒ To improve models for safety codes.

New fuels (higher burn-up, MOX)

= new tests

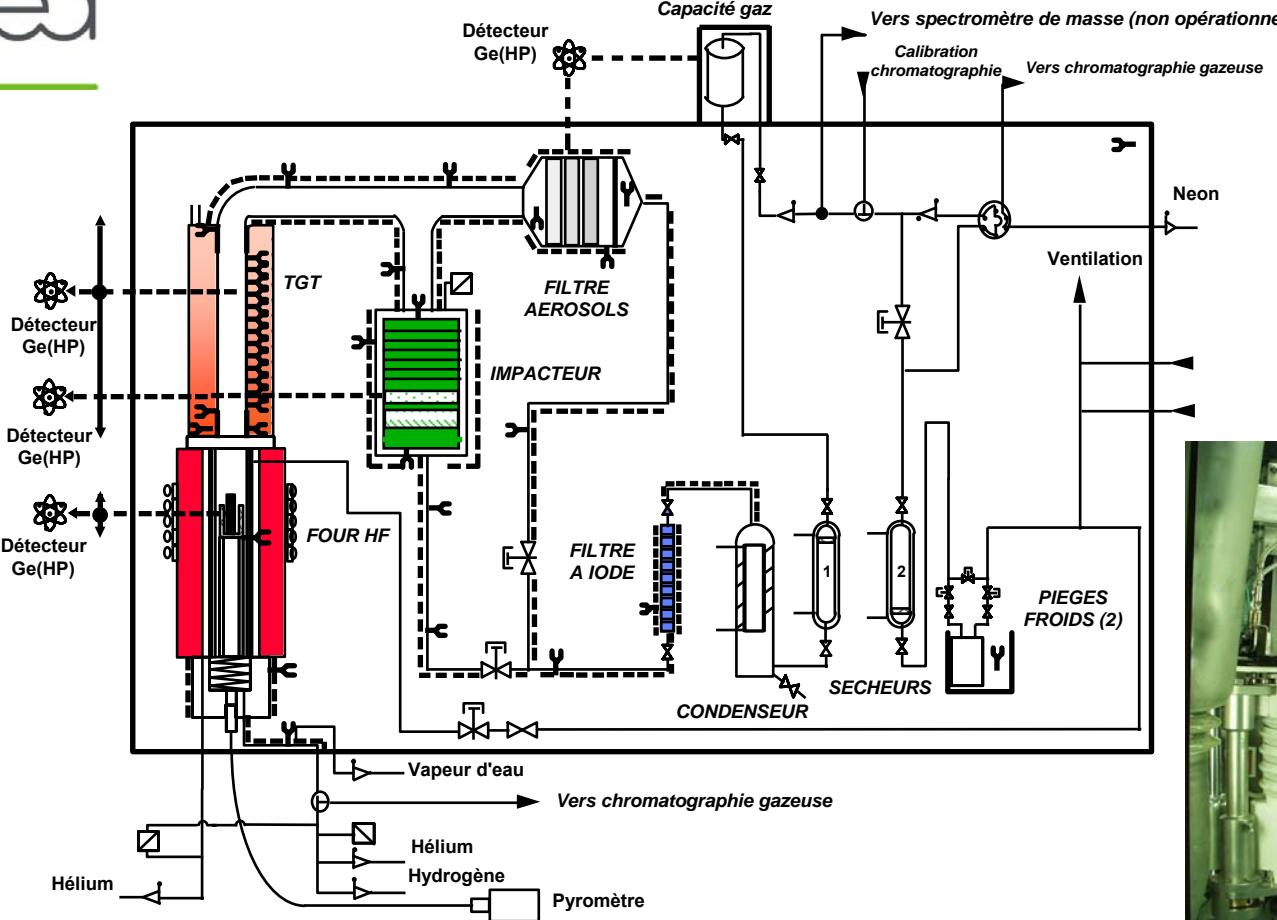
=> Needs for a new facility.



Vercors furnace

Vercors design:

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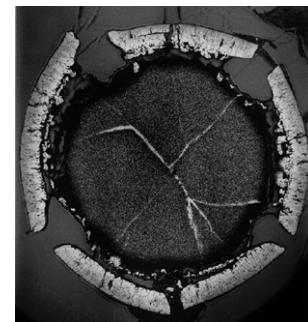
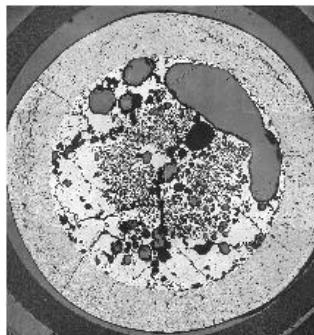


Vercors instrumentation:

- On-line γ spectrometers
- Impactor,
- Filter,
- Thermal Gradient Tube
- Gas sampling
- Metallography, etc

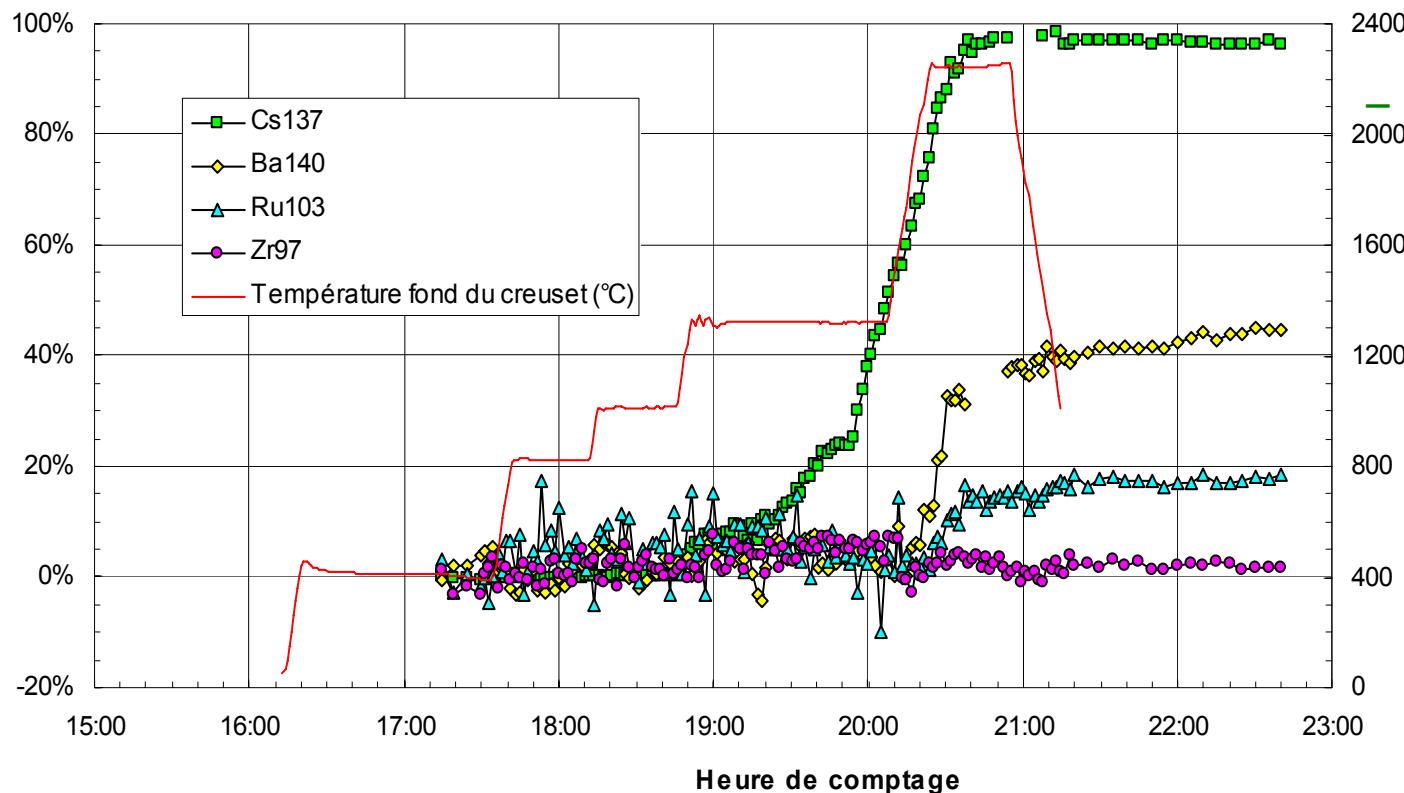


On-line gamma spectrometers (ex. on the fuel ↓)



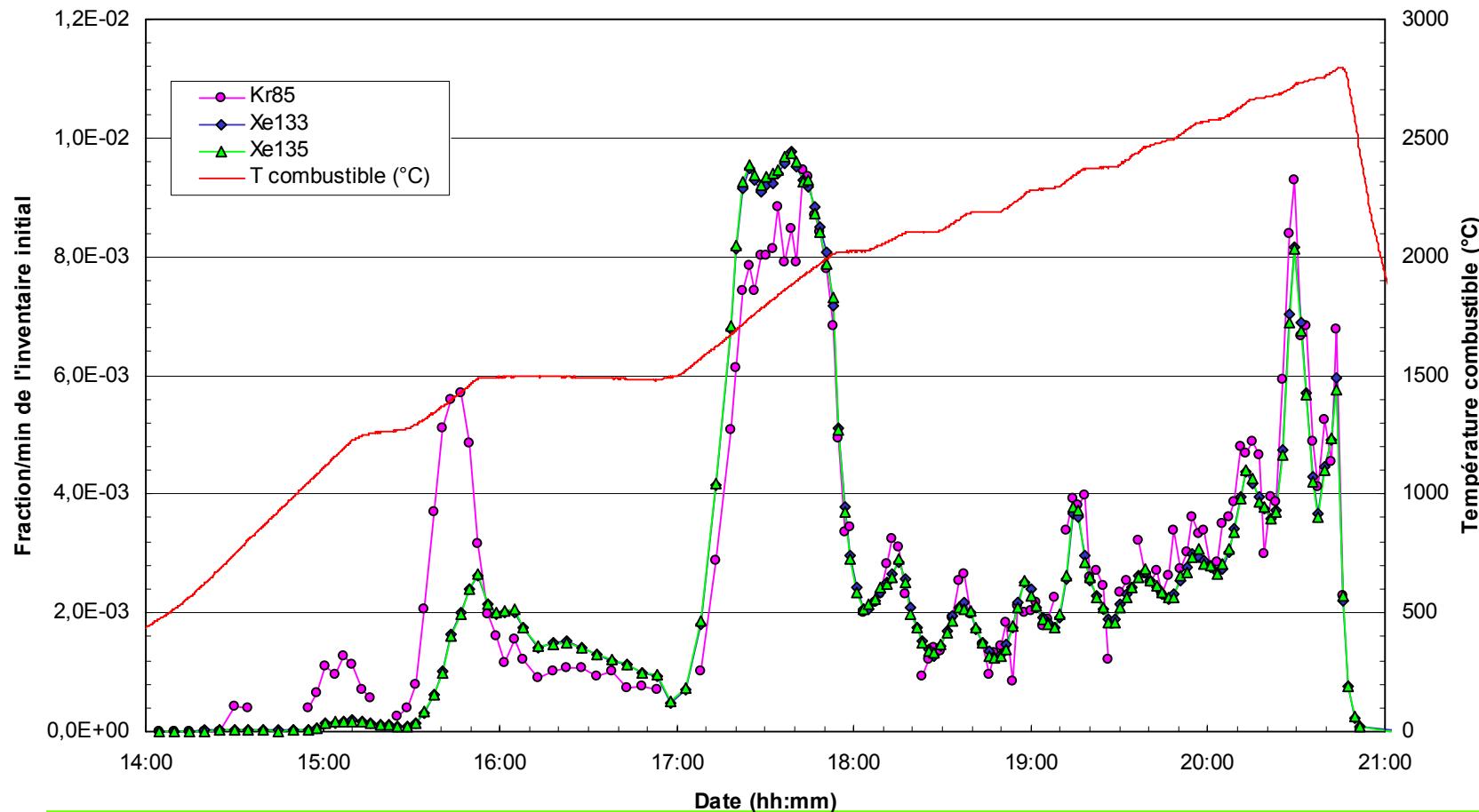
• 4 classes of volatility

- **Volatile**: Xe, Kr, I, Cs, Te, Sb, Rb, Ag, Cd
- **Semi-volatile**: Mo, Ba, Rh, Pd, Tc
- **Low volatile**: Sr, Y, Nb, Ru, La, Ce, Eu
- **Non volatile**: Zr & Nd



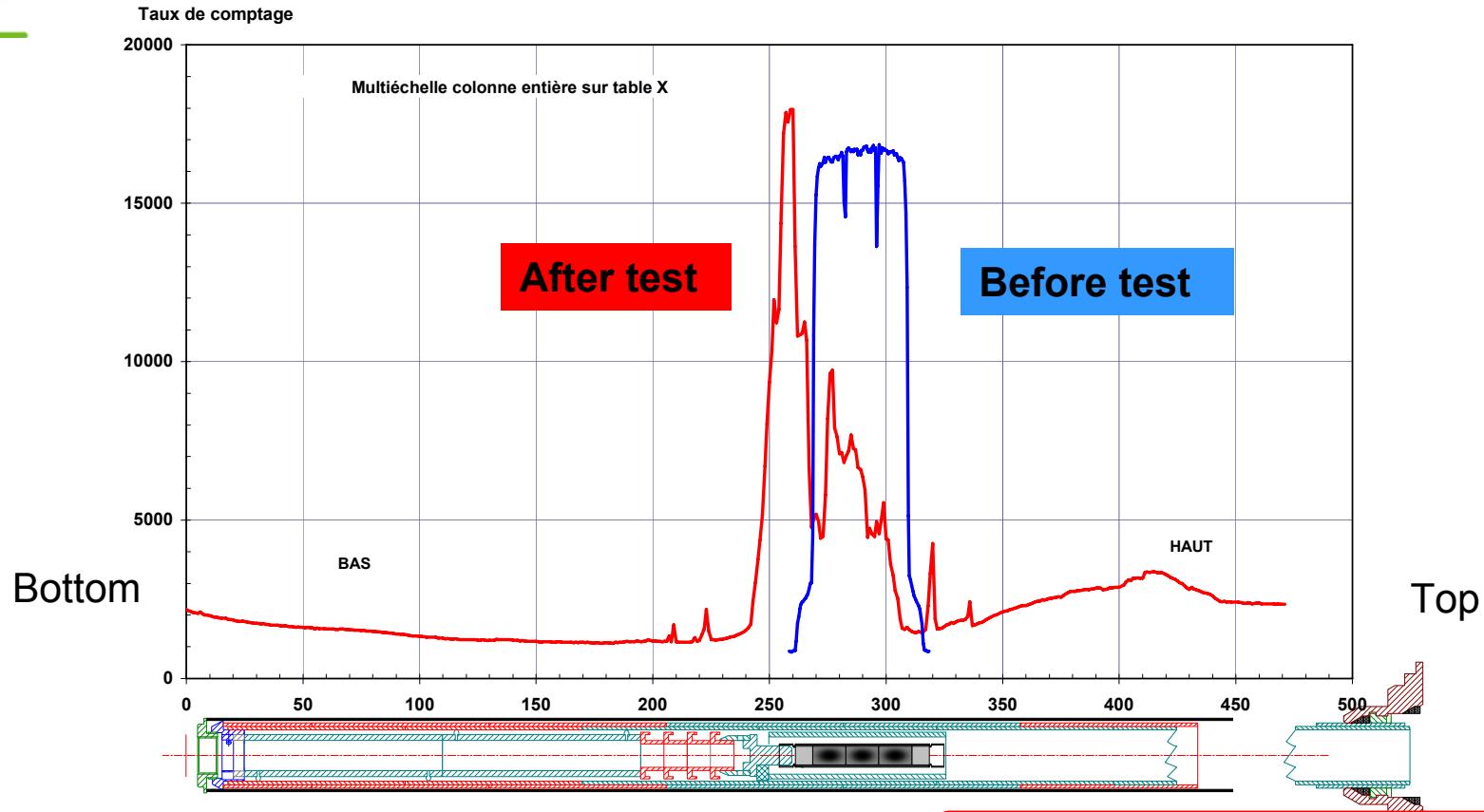
Vercors instrumentation:

-On-line gamma spectrometers on a gas sampler ↓



Vercors results:

- Fuel relocation.



Delocalisation / Fusion of the
fuel sample

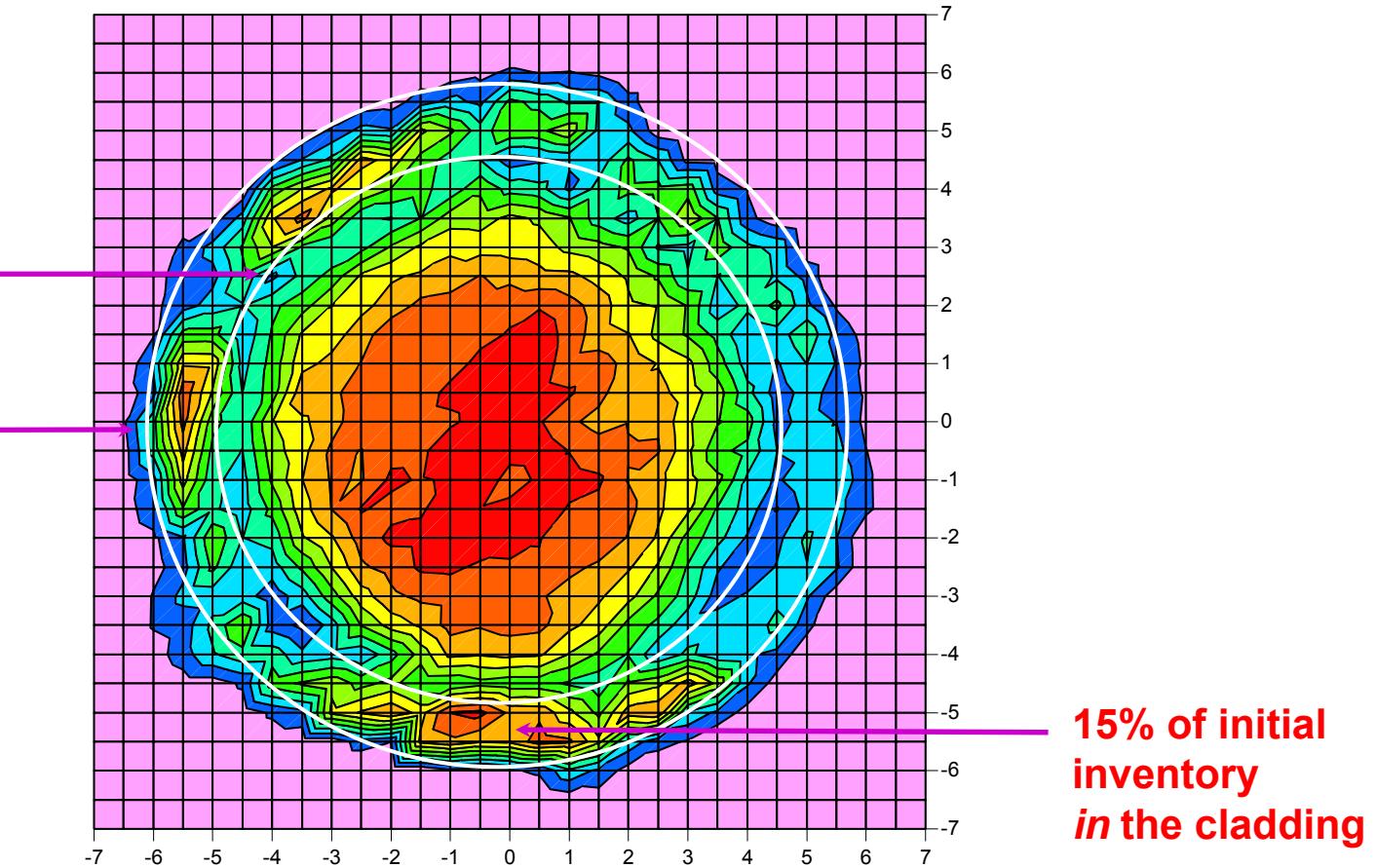


Relocalisation in the lower part of
the melting pot (two gamma peaks)

Vercors results: Gamma emission tomography on fuel pellet after a test (^{140}Ba)

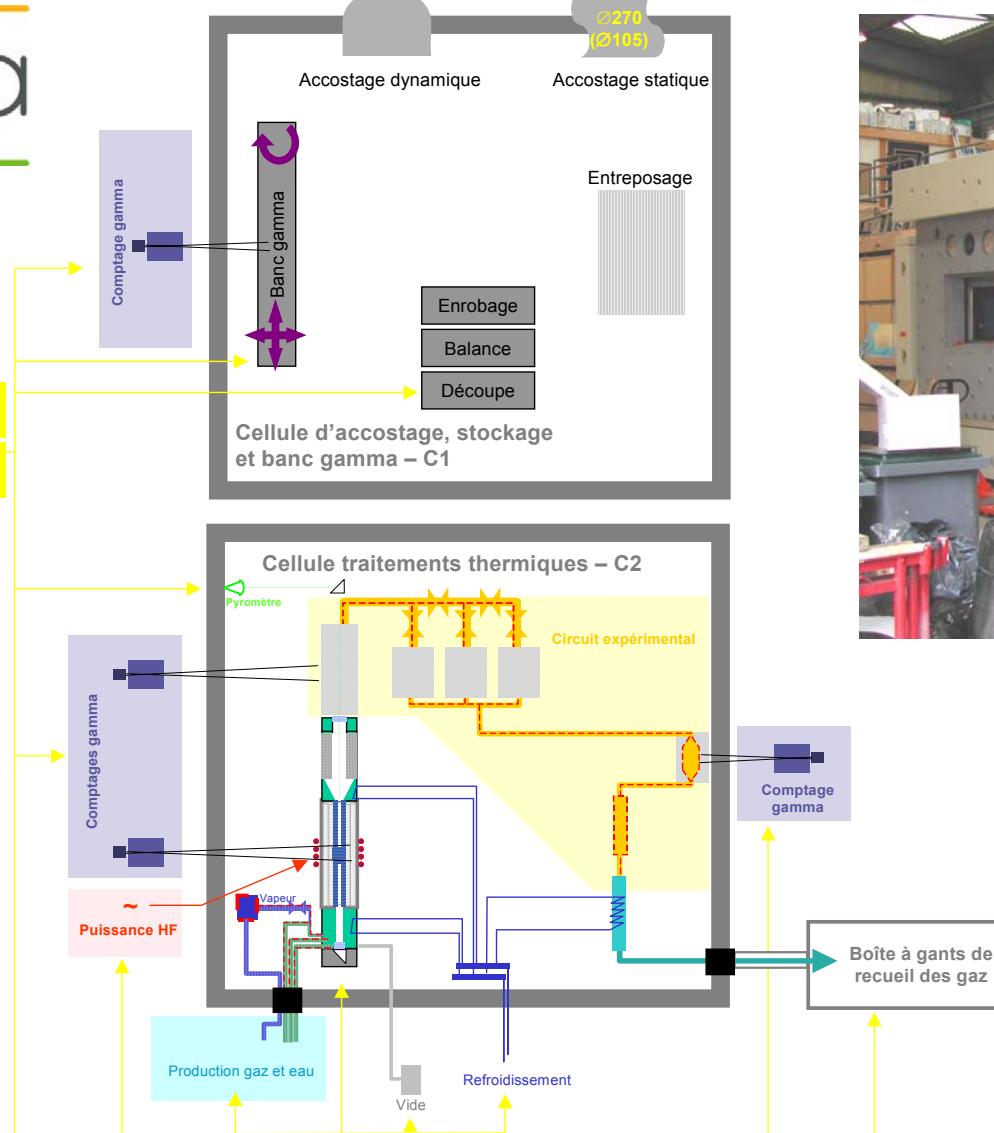
Cladding
inner side

Cladding
outer side



A new facility under construction: VERDON

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Zoom on a few examples:

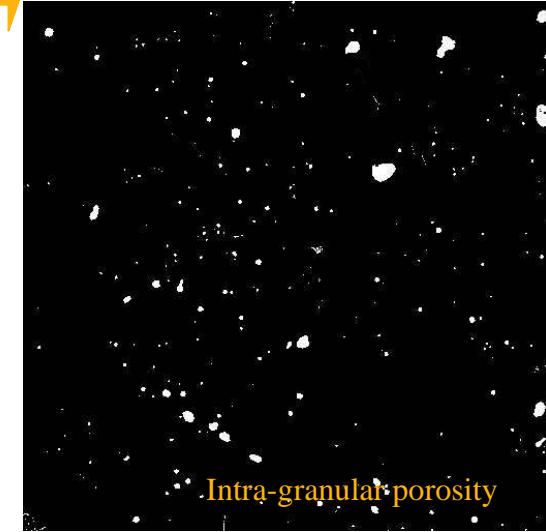
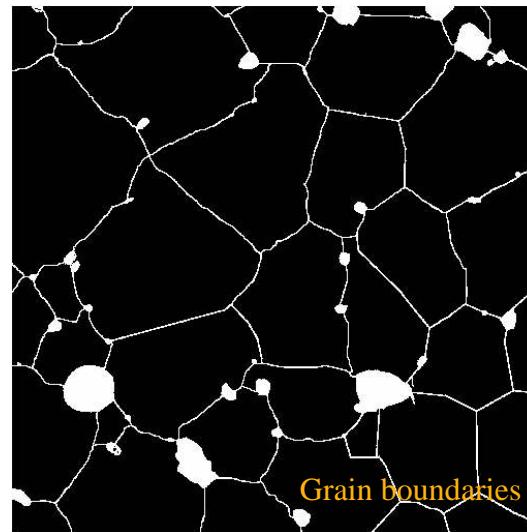
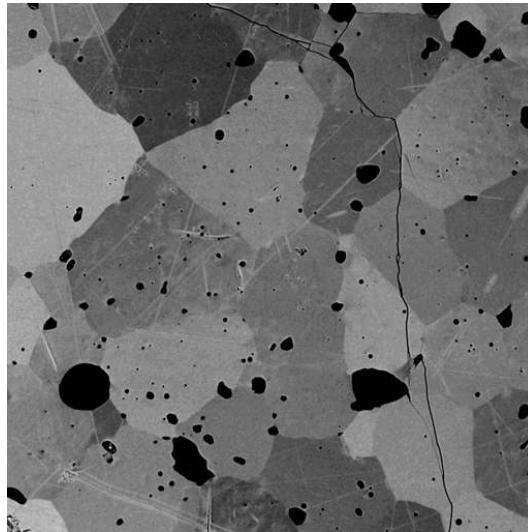
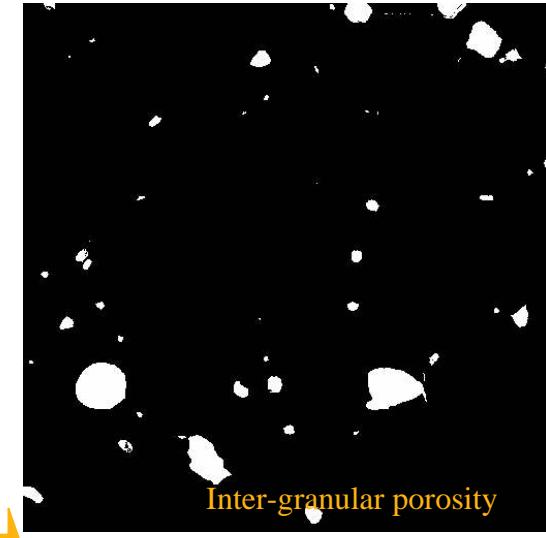
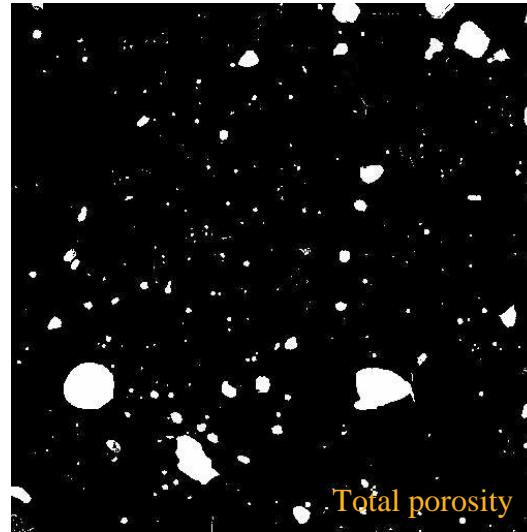
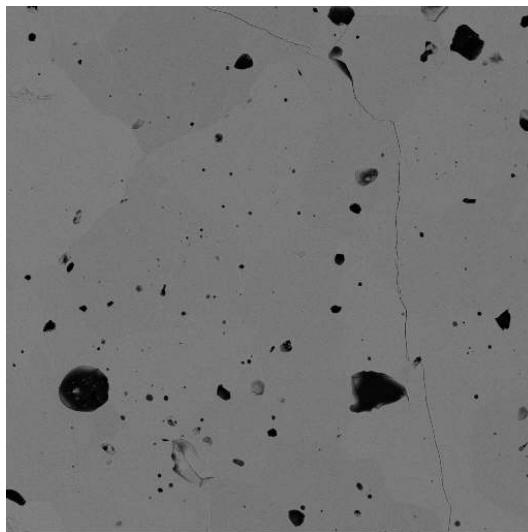
- RPV examinations
 - RPV irradiation surveillance programme
 - MTR irradiations on steels

Safety tests:

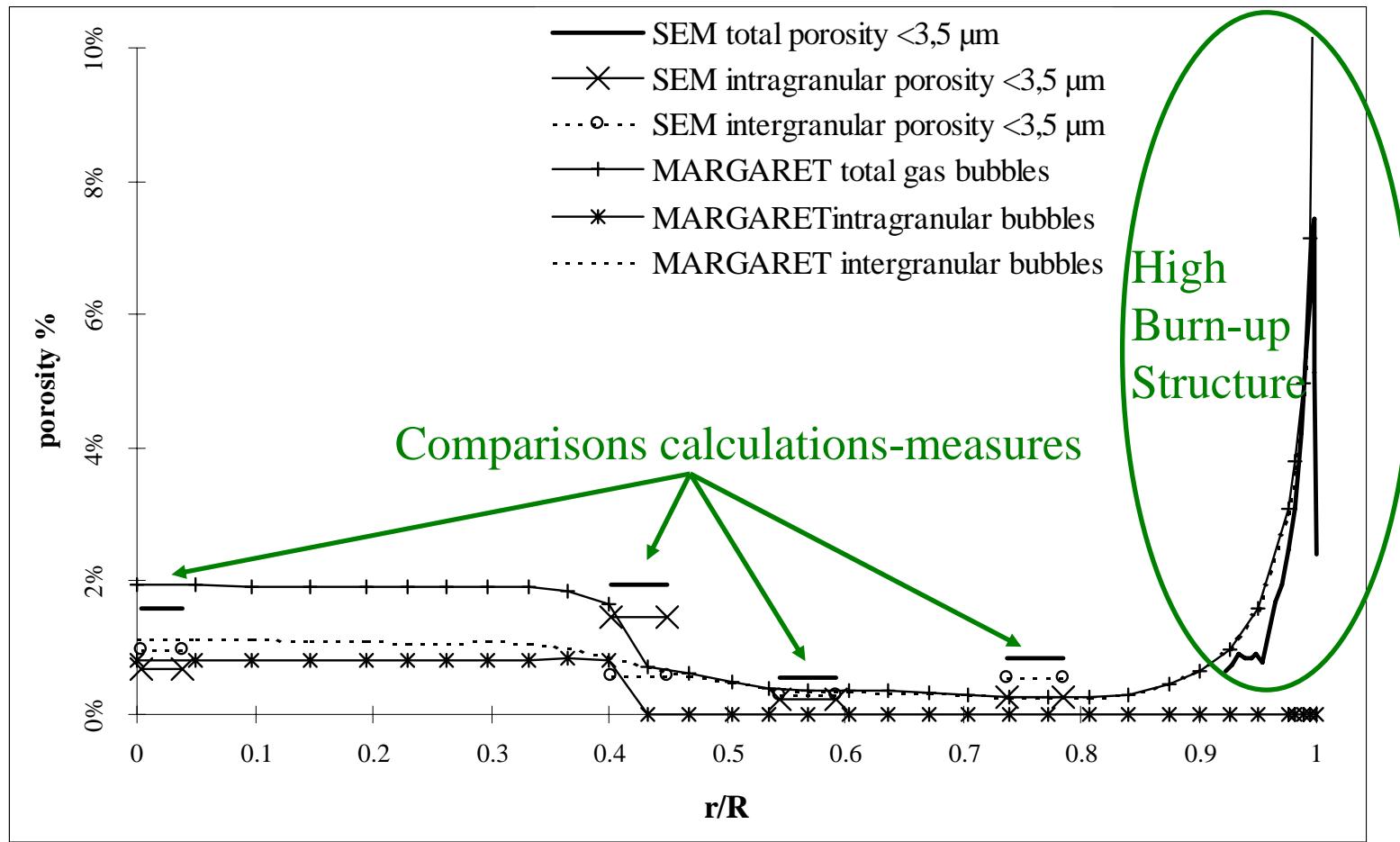
- RIA mechanical testing => see C. Poussard doc
- Small punch test.
- Fission gas release in a severe accident scenario.
- Fuel examination
 - Importance of microstructure examinations

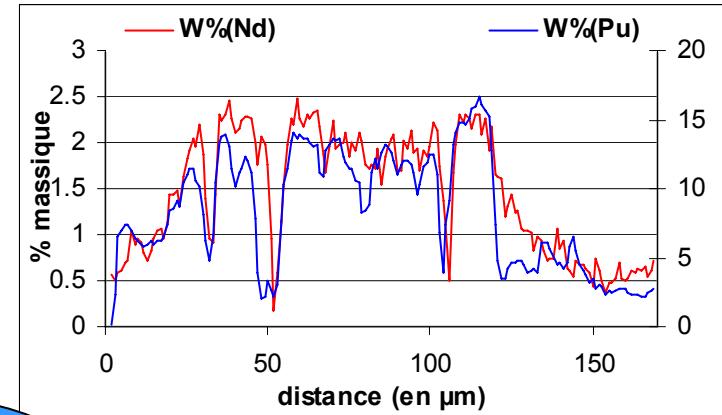
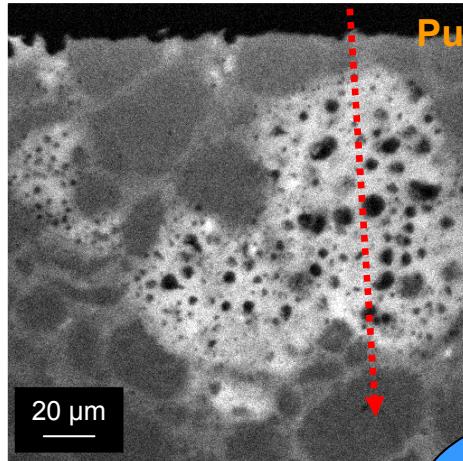
Identification of inter & intra-granular porosities

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Qualification of a mechanist model for fission gas release: MARGARET

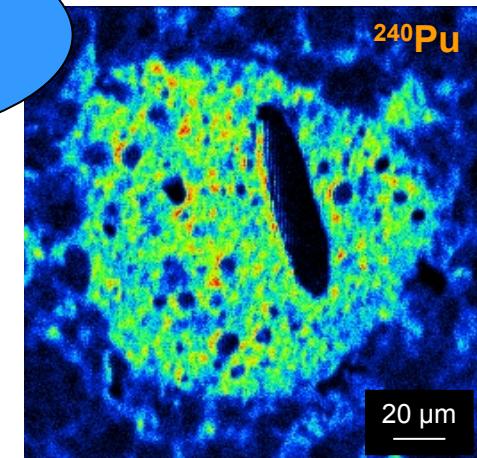
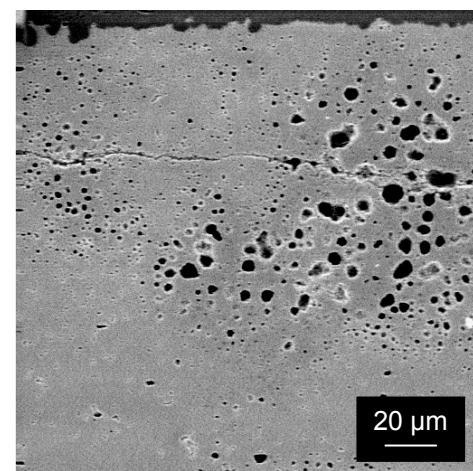




EPMA
Elementary Analyses
and mapping

SEM
Microstructure and
image analysis

SIMS
• Isotopic analyses
• Trace elements
• Gas inventory

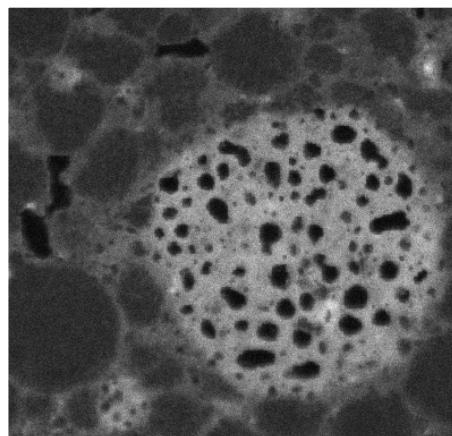
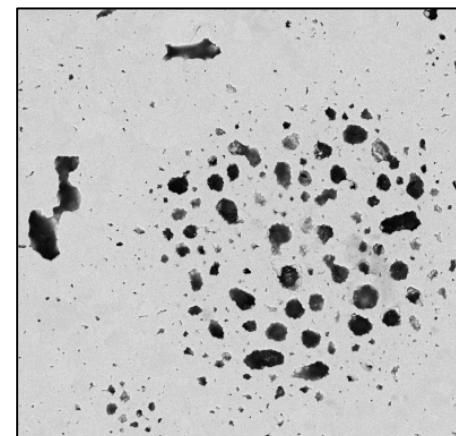
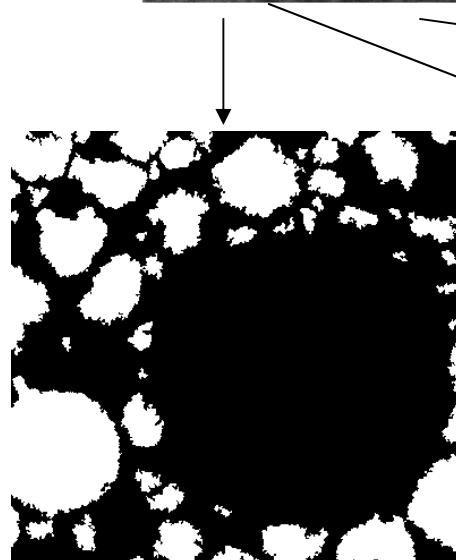
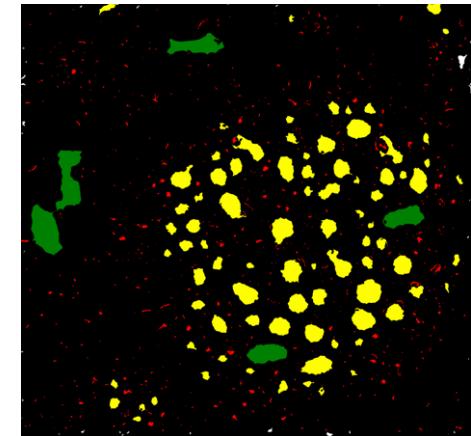


Complementary information are given by different tools

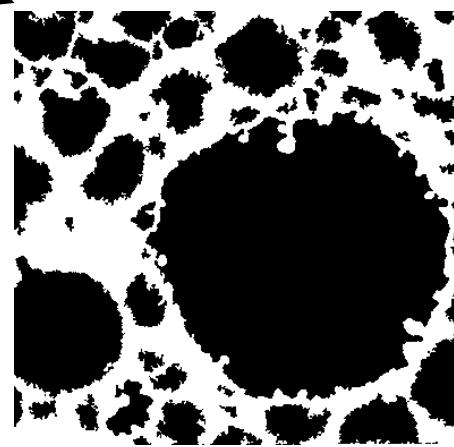
Example of MOX aggregate

20
μm

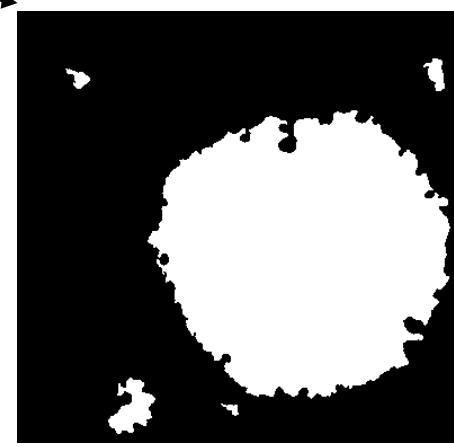
Pu mapping

BSE
imageDigital
image

U-rich phase



Embedding phase

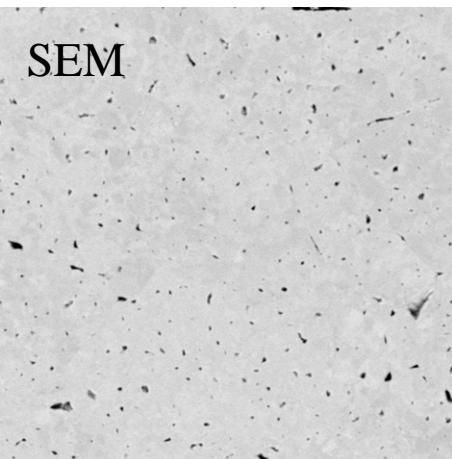
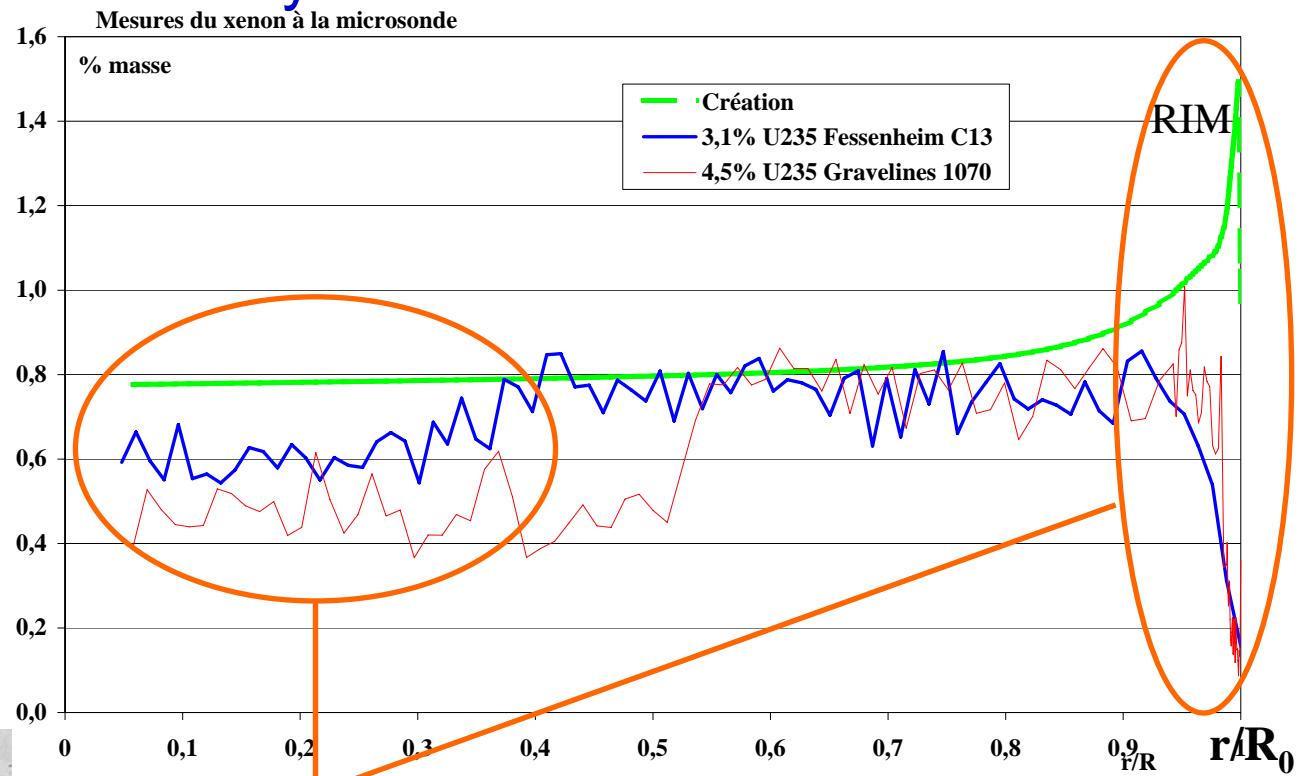


Pu-rich phase

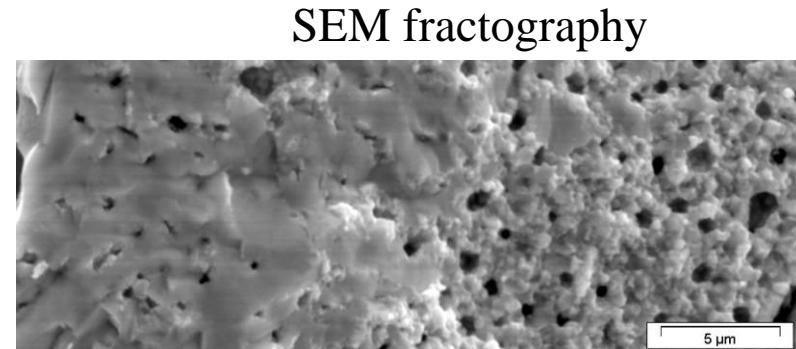
Measure of porosity distribution in
the 3 phases

Xenon determination by EPMA

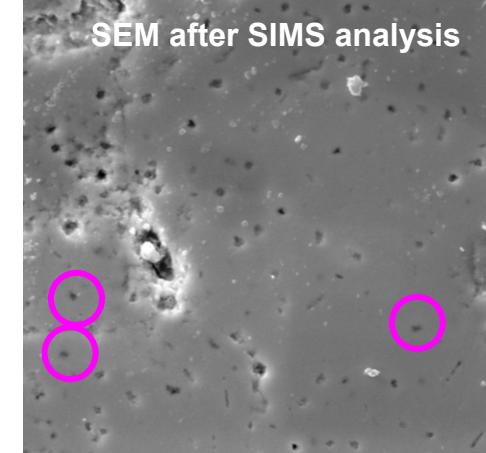
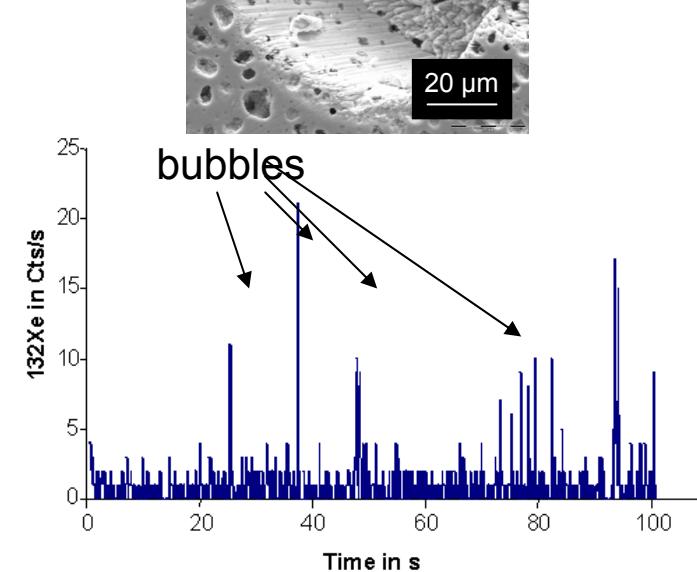
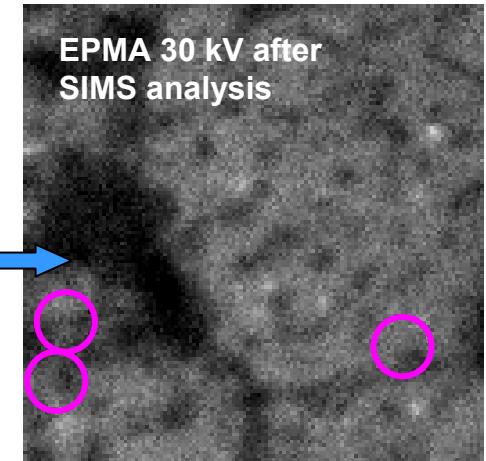
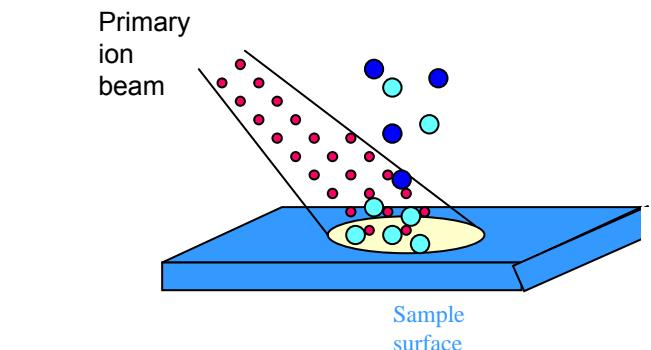
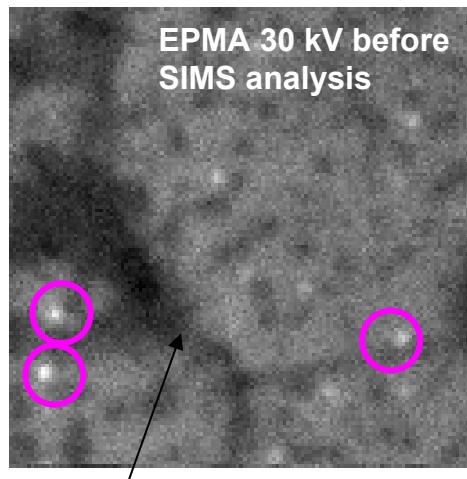
Xe content
Mass. %



- EPMA measures only dissolved Xenon and as nanometric bubbles
- "Loss" of fission gases = release
- Xenon precipitation as micro bubbles



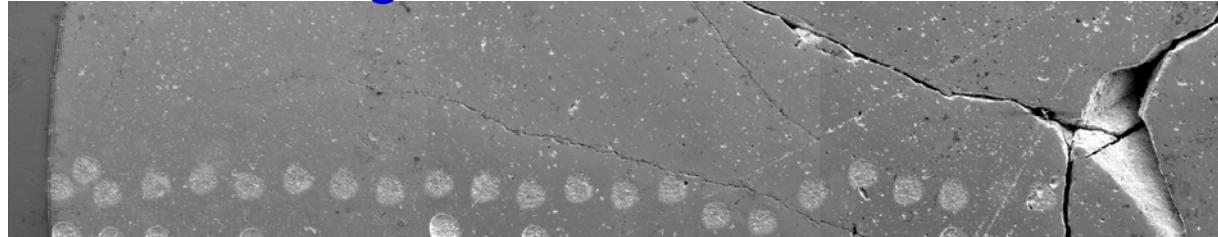
Xenon bubble characterization using SIMS



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Xenon distribution along a radius

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Precipitation in
the High Burn up
Structure area

- w%(Xe) moyenne 3 rayons µsonde
- w%(Xe) 10 pts µsonde
- ▲ w% (Xe) ldb SIMS
- w% (Xe) total SIMS
- création xenon

Fission gas release in the
central area

Dissolved Xenon
content:
•EPMA
•SIMS baseline

