# Irradiated Fuel Behaviour under Thermal Transient: An Overview of the capabilities at the LECA-STAR hot Laboratory

45th annual meeting
"Hot Laboratories and Remote Handling"
Working group, Kendal, UK
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**Pontillon Y*, Clement S, Capdevilla H, Malgouyres PP**

**CEA, DEN, DEC, SA3C, F-13108 Saint-Paul-lez-Durance, France**

# Outline

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- MERARG II facility:
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  - *Experimental loop*
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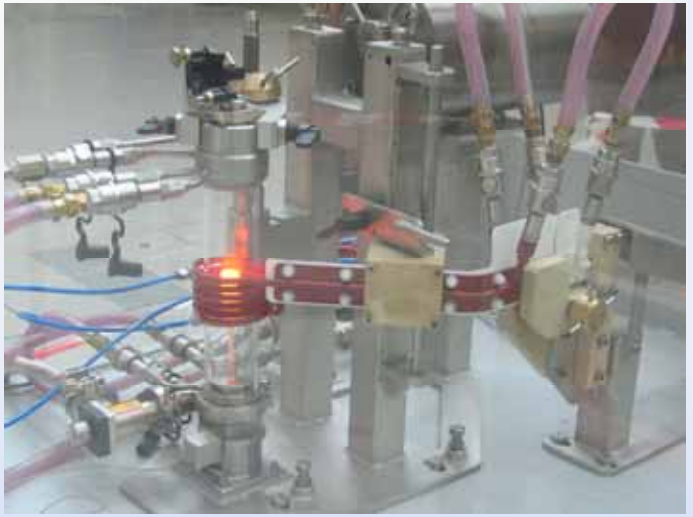
- Conclusion



# Introduction (1/2)

**He and Fission Gas Release (FGR) from nuclear fuels are an important operating and safety issue :**

**Release**

✓ Rod over-pressure due to the large inventory of fission gases in the free volumes :
- **Limitation on burn-up extension**
- **Storage,** …

✓ Source Term :
- **Off normal conditions …**


**Retention**

✓ Swelling :
- **PCI**

✓ HBS - formation :
- **specific behaviour …**

# Introduction (2/2)

**Correct evaluation of He and FGR remain a significant and important challenge**

One of the most useful ways to achieve this

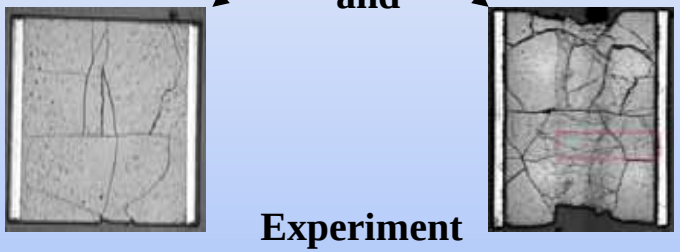
Annealing experiments
With or Without Pressure

+

Sample examinations :

Time dependence → He FGR ← Absolute level

Before and After Experiment

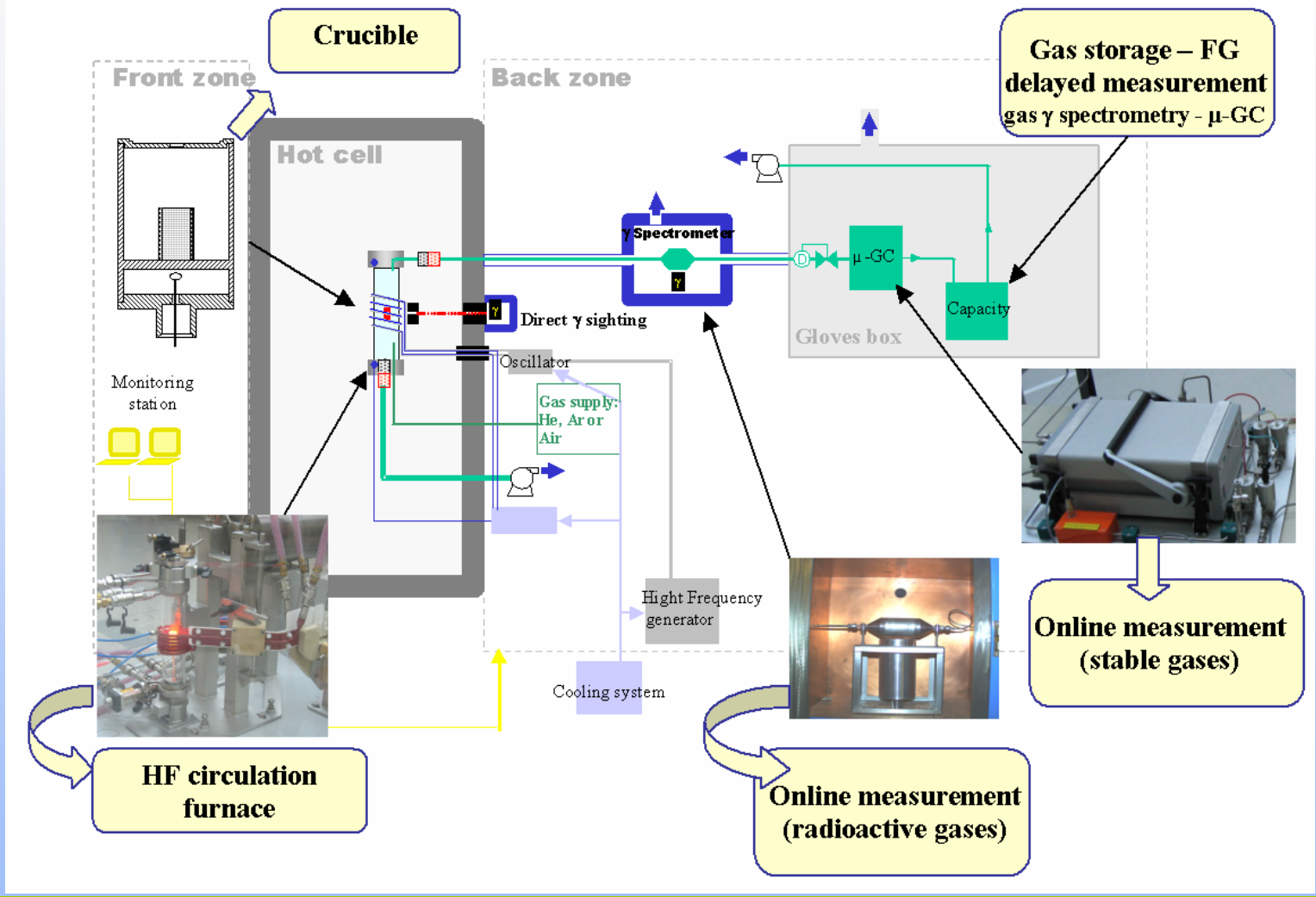


**MERARG II and MEXIICO facilities**

**Fuel Performance Code validation**

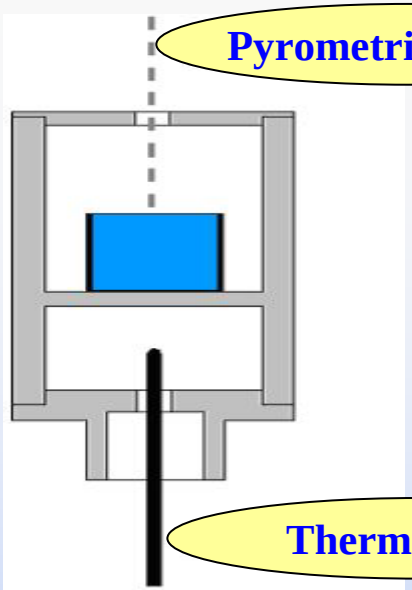
# MERARG II: General presentation (1/1)

**The main objectives of MERARG II facility** ➡ **extract all or part of the gaseous inventory from an irradiated fuel sample (one pellet) by annealing**



# MERARG II: Experimental Loop (1/6) - Crucible

Crucible Characteristics




Y. Pontillon, J. Bonnin et al., "Fission Gas Release Under Normal and off-Normal Conditions : New Analytical Device Implemented at CEA-Cadarache", European Working Group, "Hot Laboratories and Remote Handling", Plenary Meeting, Petten, the Netherlands, May 23rd – 25th, 2005

## Three different configurations:

**Mo** crucible, T° up to 2200°C

**W/W-Re** Thermocouple

**Inert** atmosphere: He, Ar

**Pt** crucible, T° up to 1400°C

**Pt/Pt-Rh** Thermocouple

**Oxidant or Inert** atmospheres: Air, He, Ar

**W** crucible, T° up to 2800°C

**W/W-Re** Thermocouple

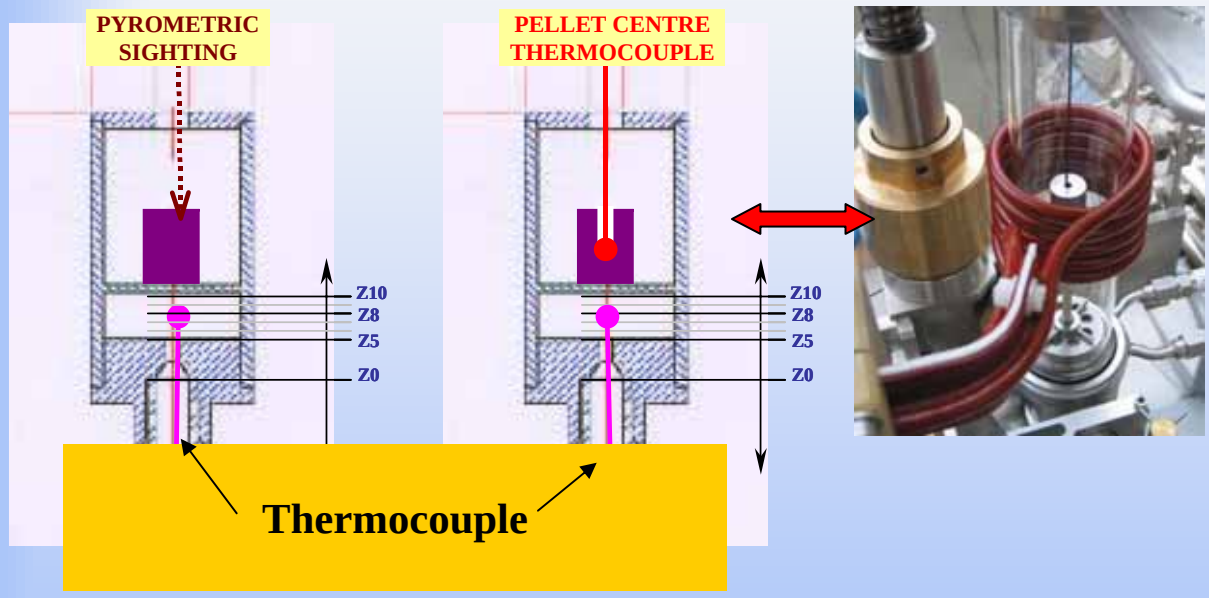
**Inert** atmosphere: He, Ar

# MERARG II: Experimental Loop (2/6) – Thermal Calibration

## Crucible Instrumentation

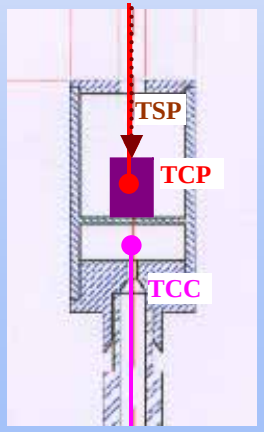
**« standard » instrumentation**

**« specific » instrumentation**




~140 tests were performed: 70 identical tests in both cases of instrumentation and for the three MERARG configurations. In each test, the experimental team focused on the:

- Surface pellet temperature **TSP** (standard instrumentation case),
- Central pellet temperature **TCP** (specific instrumentation case),
- Crucible lower chamber temperature **TCC** (both standard and specific instrumentation cases).




The analysis of the results of these tests consisted in combining the $T_{CC}$, $T_{CP}$ and $T_{SP}$ measurements for each thermal sequence programmed on the HF generator regulation device.

# MERARG II: Experimental Loop (3/6)

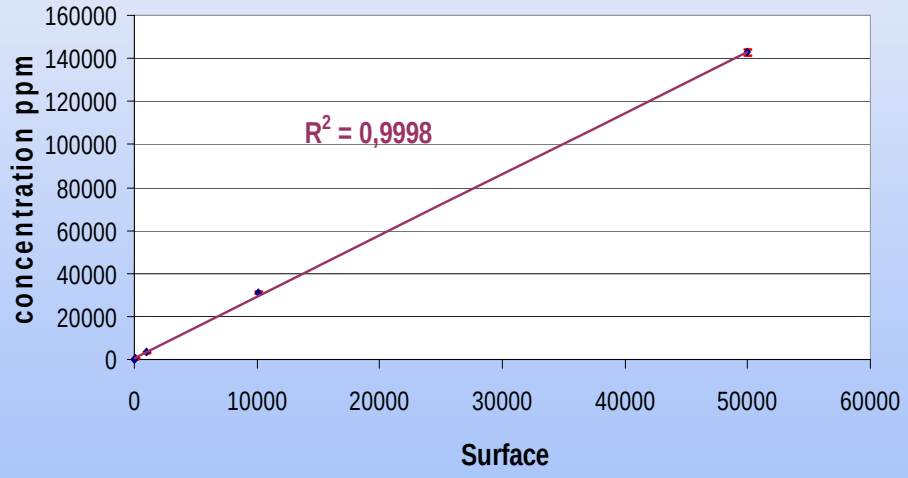
**Allows to analyse stable gases**

µ-gas chromatography :

Example (Kr)

| Pic Area | Standard value | Experimental error |
|---|---|---|
| 326 | 104 ppm | ± 10 |
| 3259 | 1003 ppm | ±50 |
| 31050 | 10100 ppm | ±341 |
| 142740 | 50 000 ppm | ±1708 |

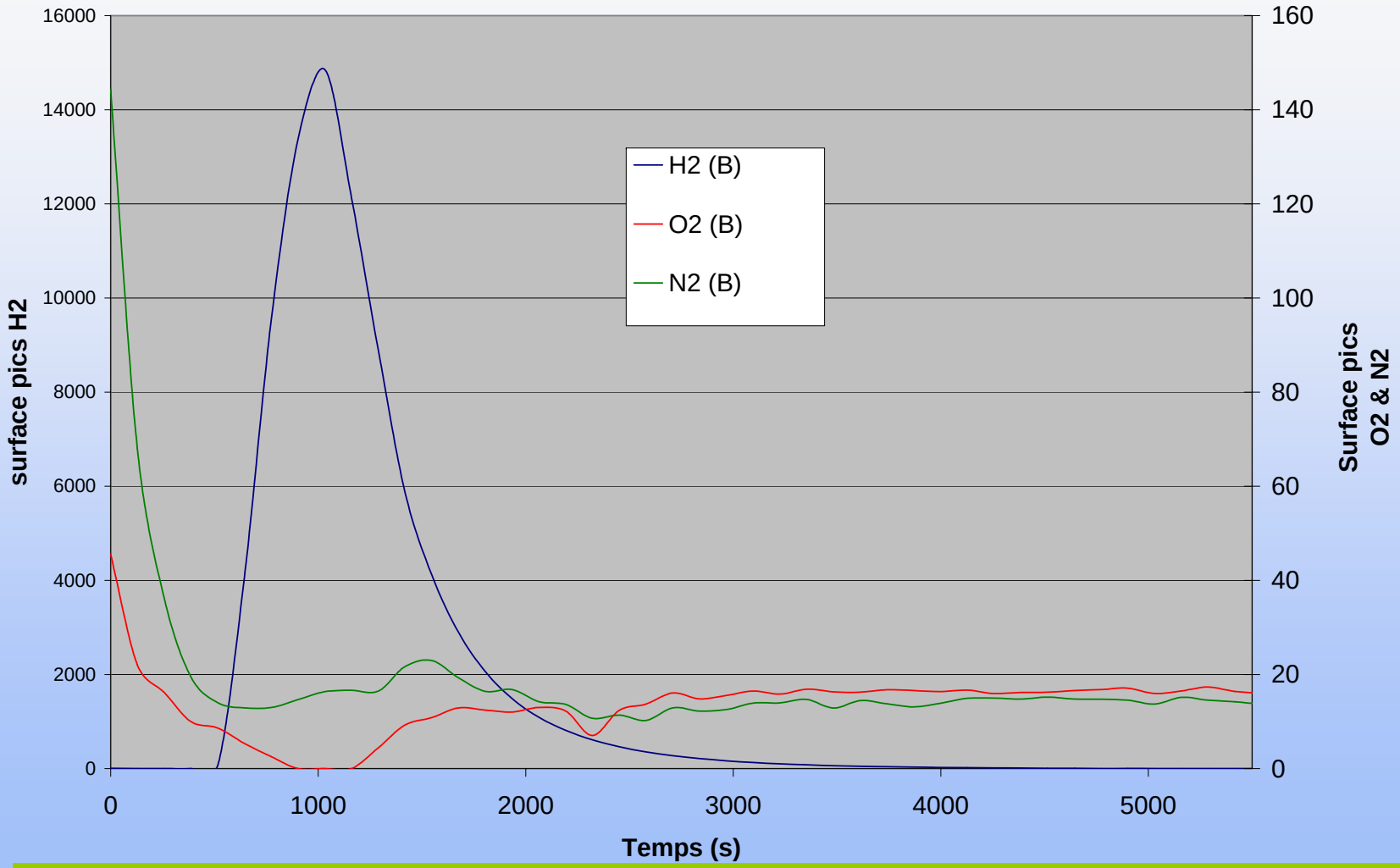
| Element | Detection limit | Linearity |
|---|---|---|
| Kr | 0,6 ppm | 5 decades |
| Xe | 0,3 ppm | 5 decades |
| He | 3 ppm | 5 decades |
| $N_2$, $O_2$, … | ~ 1 ppm | 5 decades |




B. Meunier, Y. Pontillon et al., , European Working Group, "Hot Laboratories and Remote Handling", Plenary Meeting, Bucharest, Romania September 20 – 21, 2007

# MERARG II: Experimental Loop (4/6)

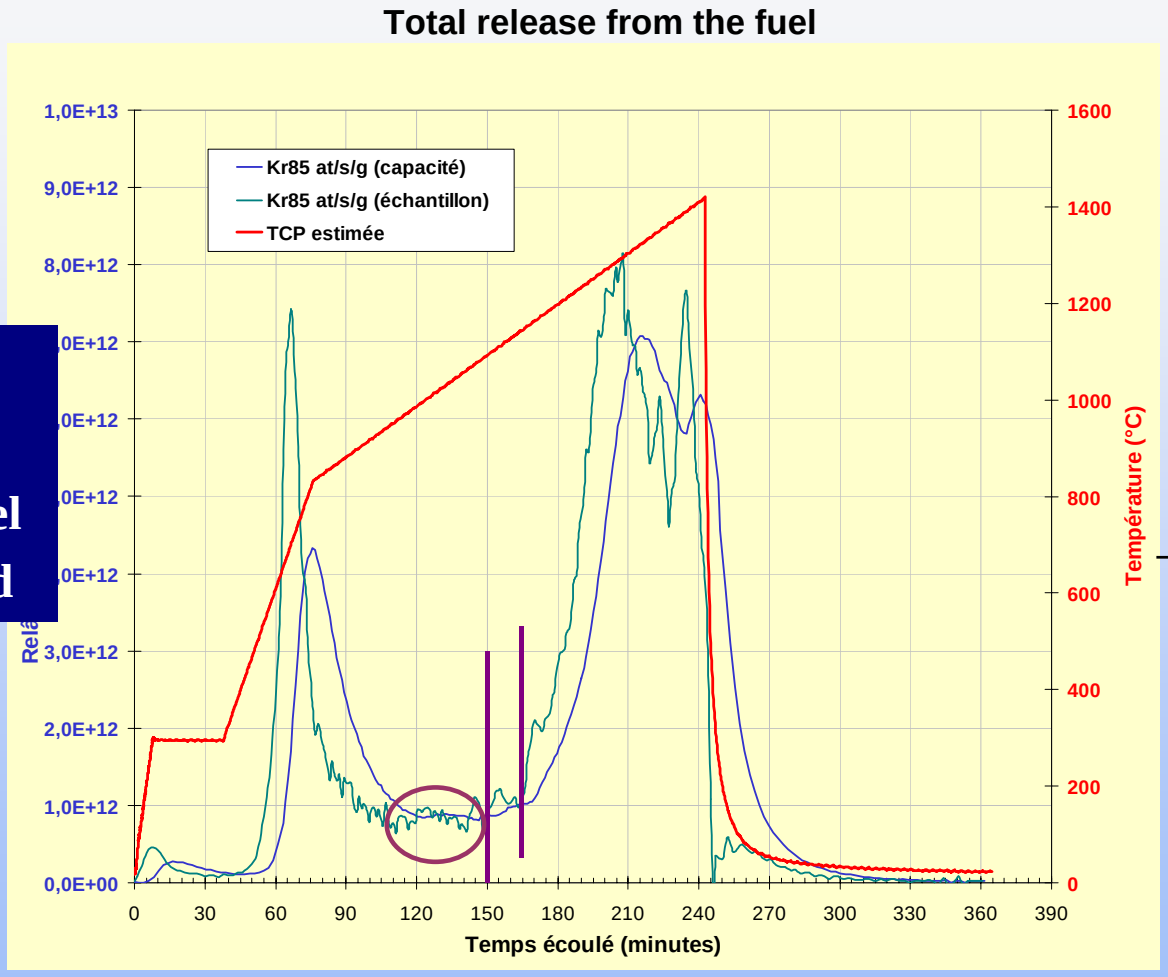
µ-gas chromatography :

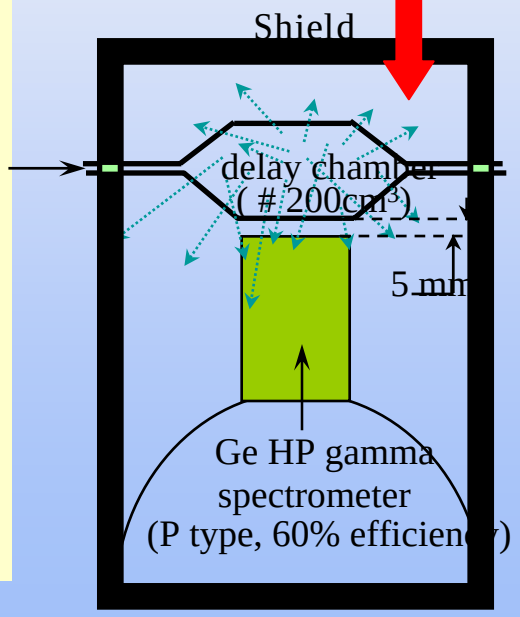


# MERARG II: Experimental Loop (5/6)

On-line gamma spectrometry: gas measurement

**Allows the fission gases leaving the fuel to be recorded**

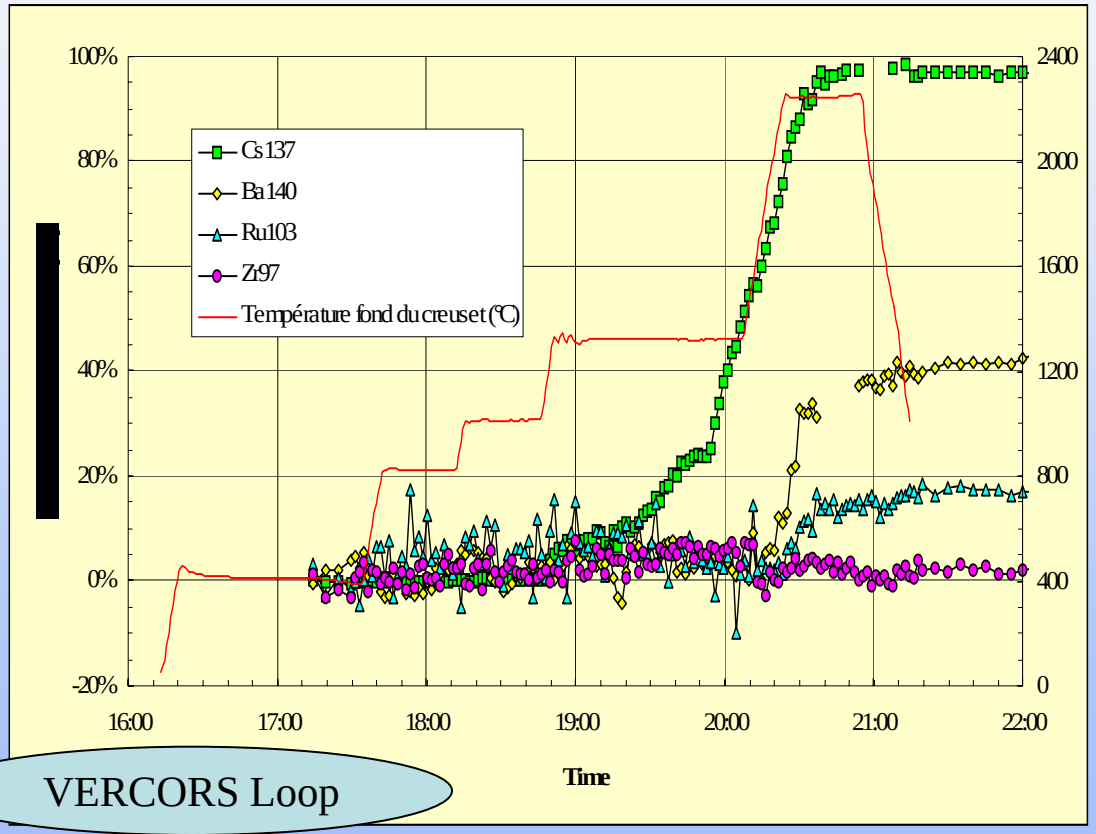


# MERARG II: Experimental Loop (6/6)

On-line gamma spectrometry: fuel sight

**Total release from the fuel**
**(differential measurement : low sensitivity)**



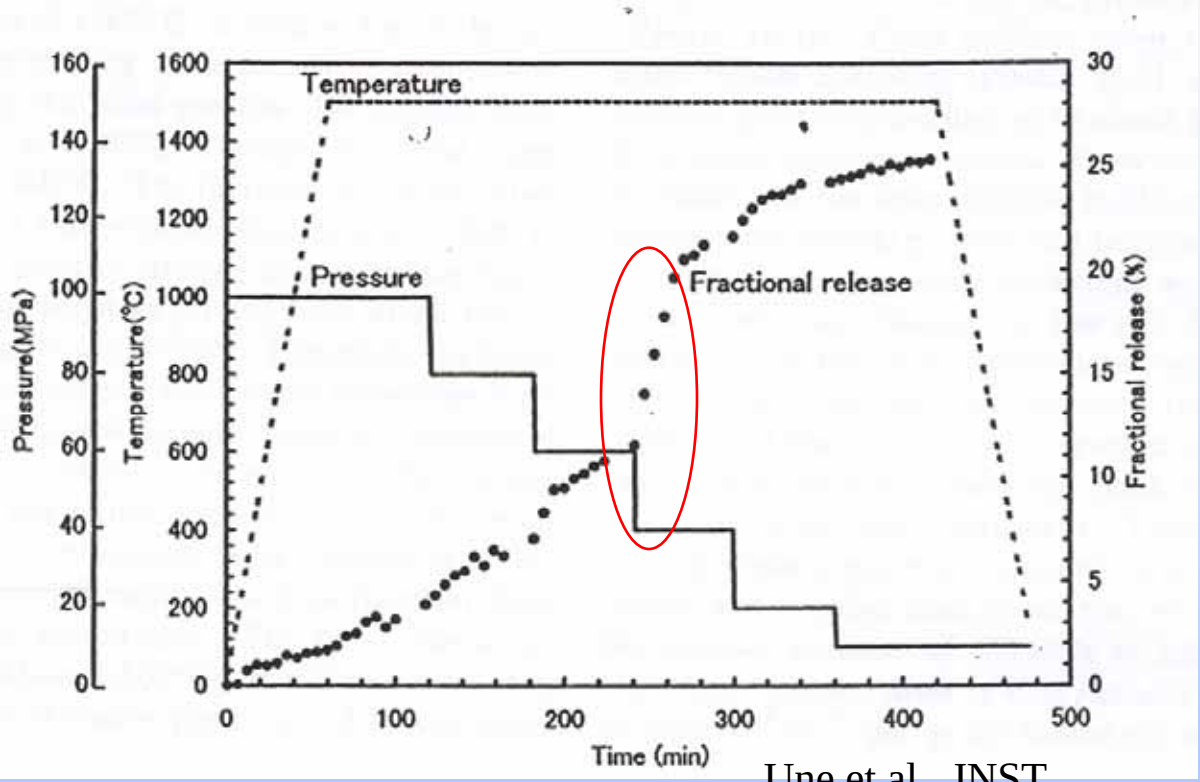

**Allows the FP leaving the fuel to be recorded**

VERCORS Loop

Y. Pontillon G. Ducros, International VERCORS Seminar, October 15-16th, 2007 – Gréoux les Bains, France

# MEXIICO: Context

## Why ?

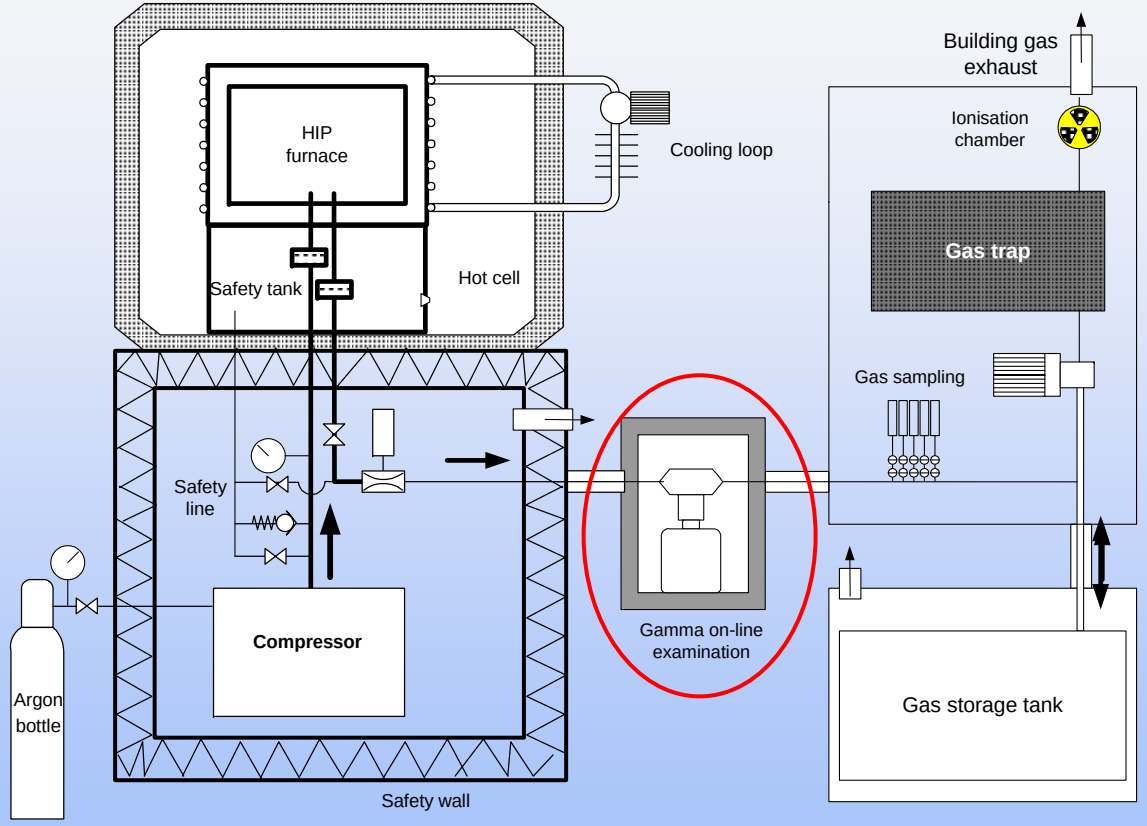



Une et al., JNST

In order to investigate the impact of stresses on FGR, decision was made to install a high pressure furnace in a hot cell

# MEXICO: Experimental loop

Maximum temperature / pressure : 1600°C / 160 MPa - Maximum heat up rate : 1K/s
Restraint state is simulated by mean of argon at high pressure
The standard fuel sample is a fuel pellet (few grams).



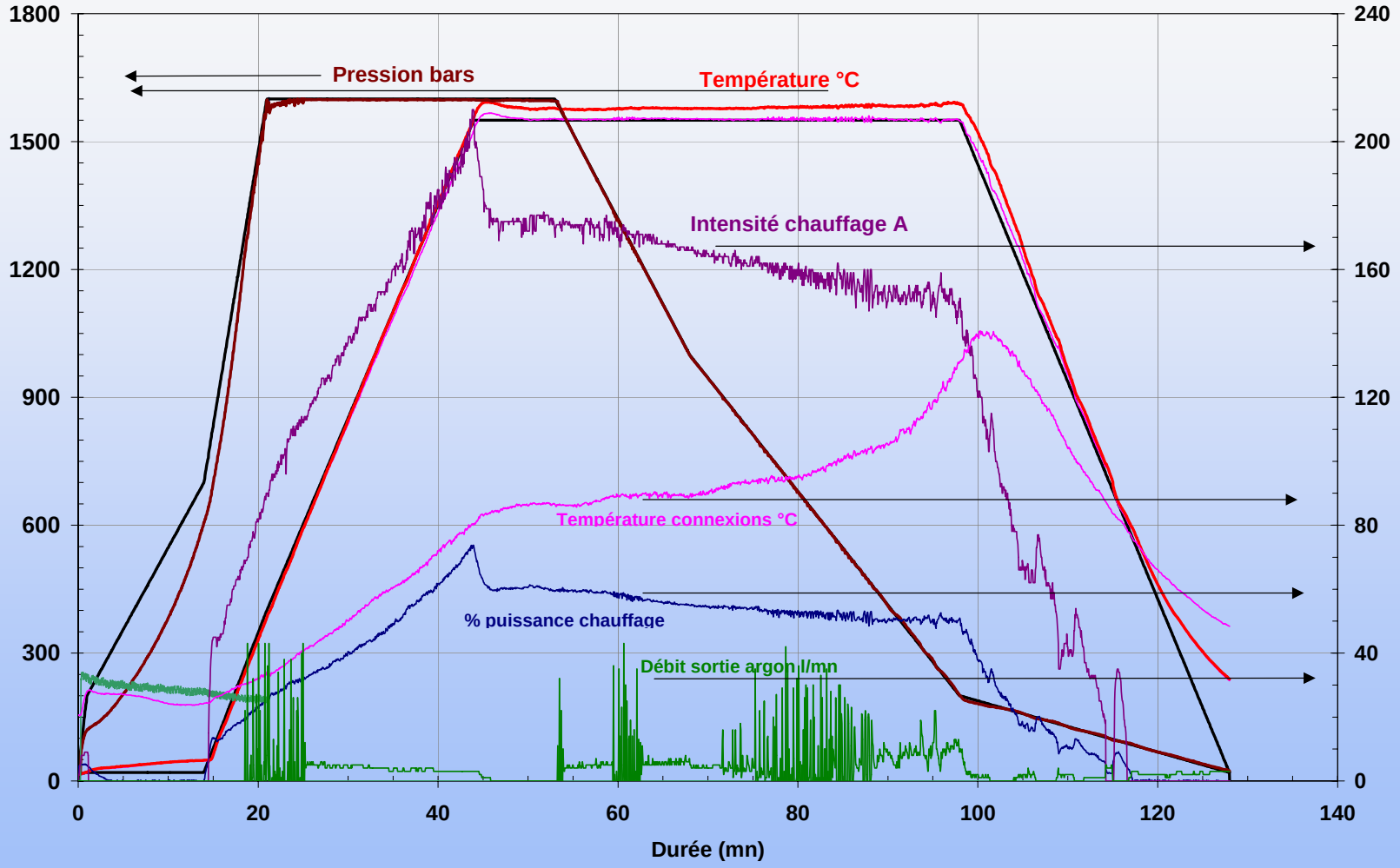

Y. Pontillon et al., "Fuel Performance under different PWR conditions : An overview of the annealing test facilities at the CEA Cadarache 2005 Water Reactor Fuel Performance Meeting , October 2-6, 2005 --Kyoto, Japan

# MEXICO: Experimental loop

"Inactive" qualification phase:

# MEXICO: Scoping test

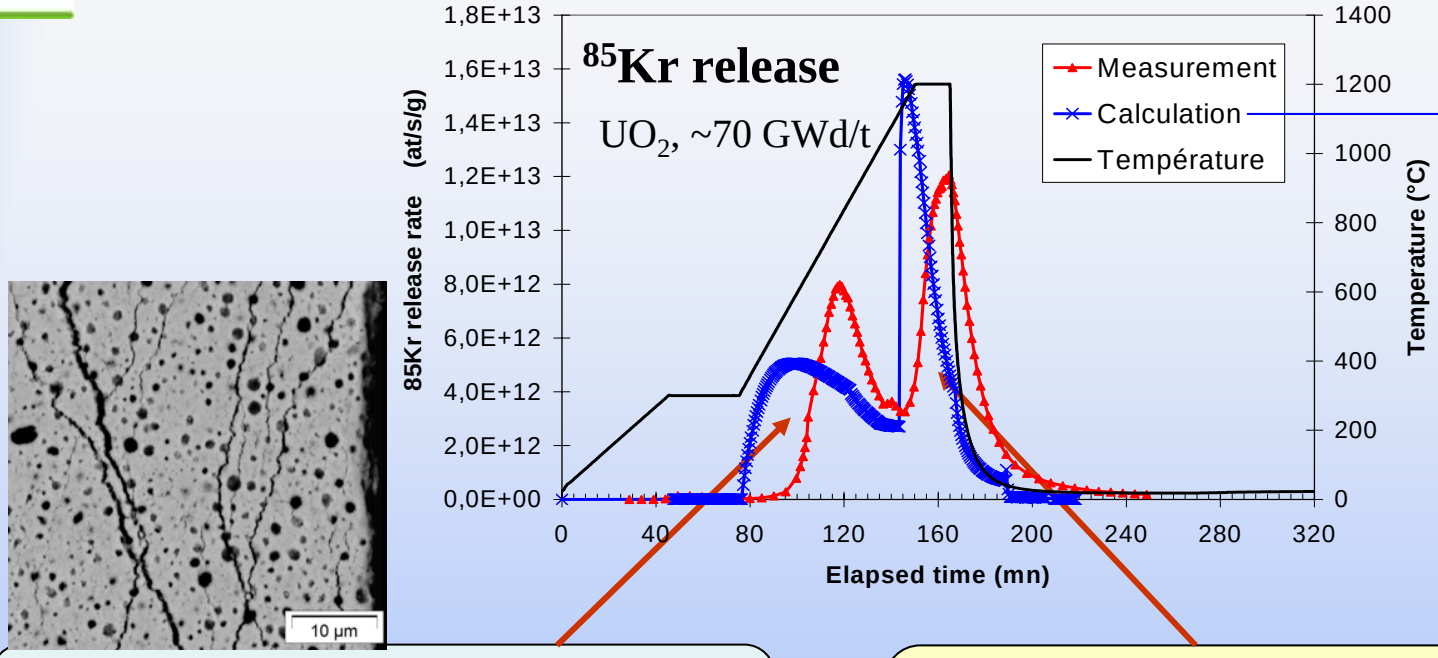
"Inactive" qualification phase:



# Fission Gas Release : Main Programs

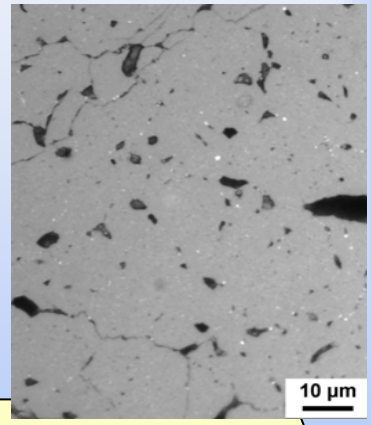
- GASPARD (fuel behaviour under loca type conditions) :
  - *Y. Pontillon, et al. "Experimental and Theoretical Investigation of Fission Gas Release from UO2 up to 70 GWd/t under Simulated LOCA Type Conditions: The GASPARD Program", Proc. of The 2004 Water Reactor Fuel Performance Meeting, September 19-24, 2004, Orlando, Floride, USA.*
- ADAGIO (inter and intra-granular gas fraction) :
  - *Y. Pontillon, et al. " Direct Experimental Evaluation of the Grain Boundaries Gas Content in PWR Fuels : New Insight and Perspective of the ADAGIO Technique", Proceedings of the 2007 International LWR Fuel Performance Meeting, San Francisco, California, September 30 – October 3, 2007*
- Doped $UO_2$ fuels (TANOX, TANOXOS, CONCERTO)
  - *L. Caillot, J. Noirot, Y. Pontillon, S. Vallin, « TANOXOS: an analytical irradiation program aiming at understanding the behaviour of various doped UO2 fuels », Proceedings of the 2006 International LWR Fuel Performance Meeting, Salamanque, October 2006, Spain*
- GFR (for instance NIMPHE samples, (U,Pu)N and (U,Pu)C), High Burn up Fuels, MOX, …

# GASPARD PROGRAM




METEOR



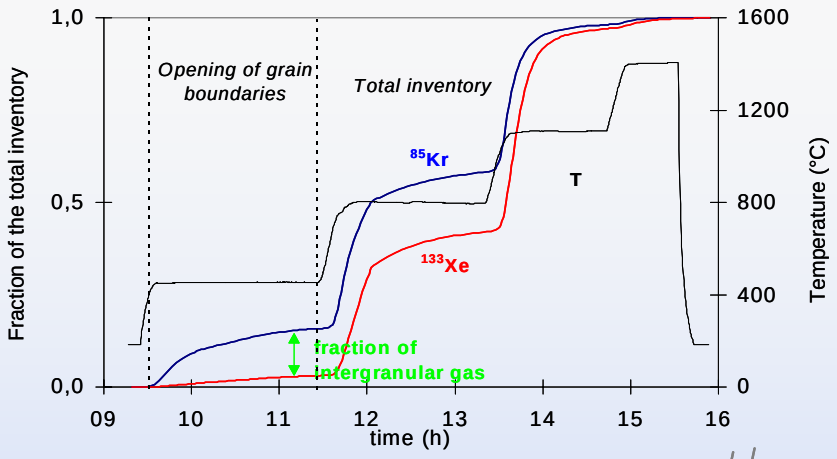




FIRST PEAK (600-800°C)
**Grain boundary cracking**

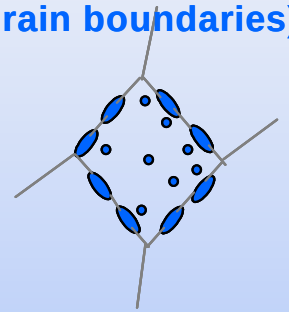
MAIN PEAK (T > 1000°C)
**Bubbles interconnection and release**

# ADAGIO PROGRAM

$UO_2$ samples



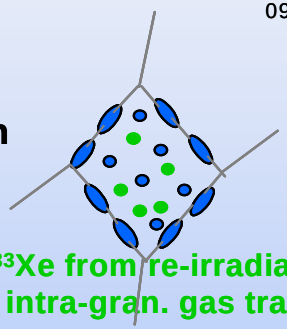

**initial state**
**$^{85}$Kr (matrix + bubbles intra + grain boundaries)**



1

**Re-irradiation**

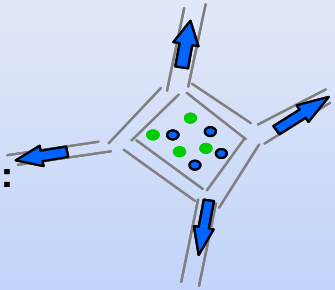
**low T, He**



**$^{133}$Xe from re-irradiation: intra-gran. gas tracer**

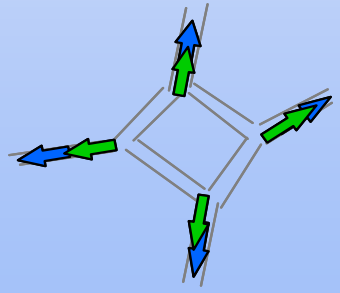
2

**first thermal plateau : air, 380°C**



3

**release of the complete gas inventory**



- $UO_2$ ⇨ $U_4O_9$ beginning at grain boundaries
- opening of grain boundaries
- release of all inter-granular gas + fraction of intra-granular gas
- quantification by γ spectrometry of $^{85}$Kr and $^{133}$Xe release

difference = amount of inter-granular gas

# Conclusion

**The MERARG II** facility offers **accurate results for the fission gas and He measurements** thanks to on-line gamma spectrometry and µ-GC

**The MEXIICO** facility will offer **accurate results for the fission gas measurements under high pressure** thanks to on-line gamma spectrometry.

**The complementary between these two facilities will provide very attractive results regarding the pressure effect on fission gas release from irradiated fuels**

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# Thank you for your attention