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## **New Insight on Volatile Fission Products (I and Cs) release from high burnup UO<sub>2</sub> fuel under LOCA type conditions**

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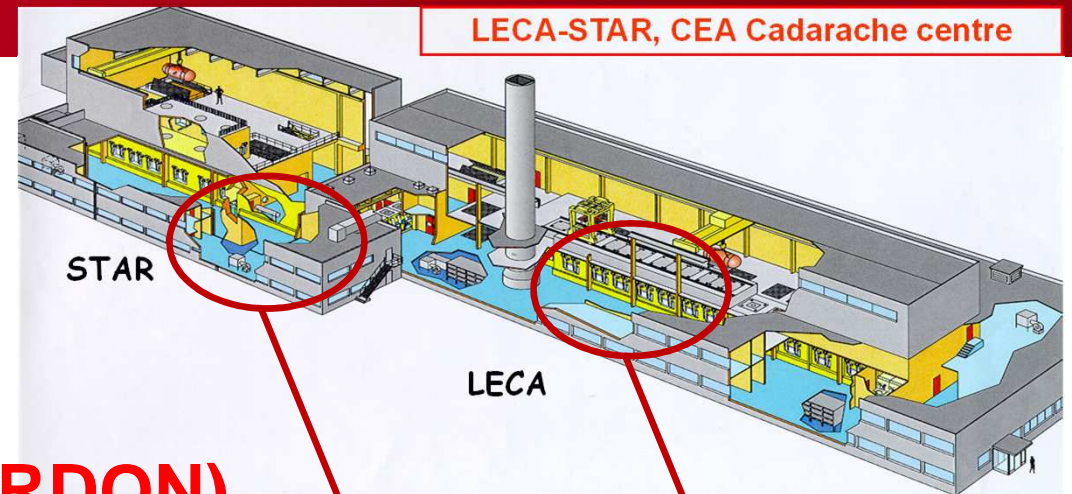
**NEW INSIGHT ON VOLATILE FISSION PRODUCTS  
(I AND Cs) RELEASE FROM HIGH BURNUP  $UO_2$   
FUEL UNDER LOCA TYPE CONDITIONS**

**Y. Pontillon, I. Moysan, S. Bernard, M. Ledieu**

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France.**

*TOPFUEL, FUEL REACTOR PERFORMANCE MEETING*

September 30<sup>th</sup> - October 4<sup>th</sup>, 2018



## ■ Context

## ■ MERARG vs VERCORS(VERDON)

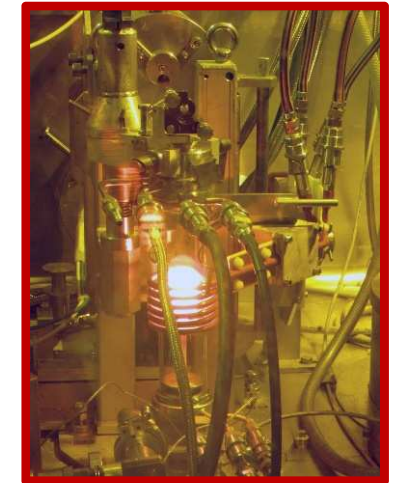
## ■ Results:

- ◆ *FGR comparison*
- ◆ *Some new insights from the VERCORS tests regarding FP*

## ■ Conclusion and perspectives

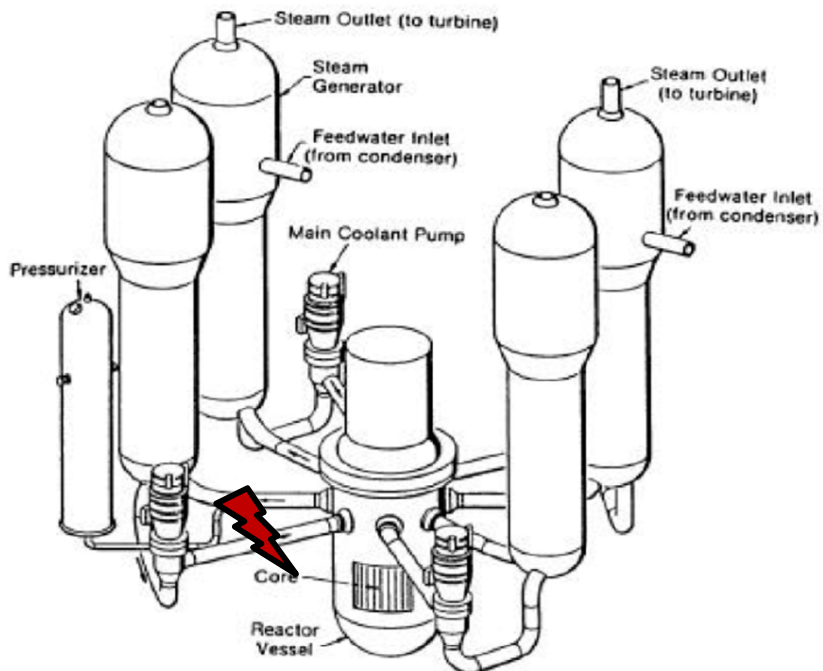


**VERDON**

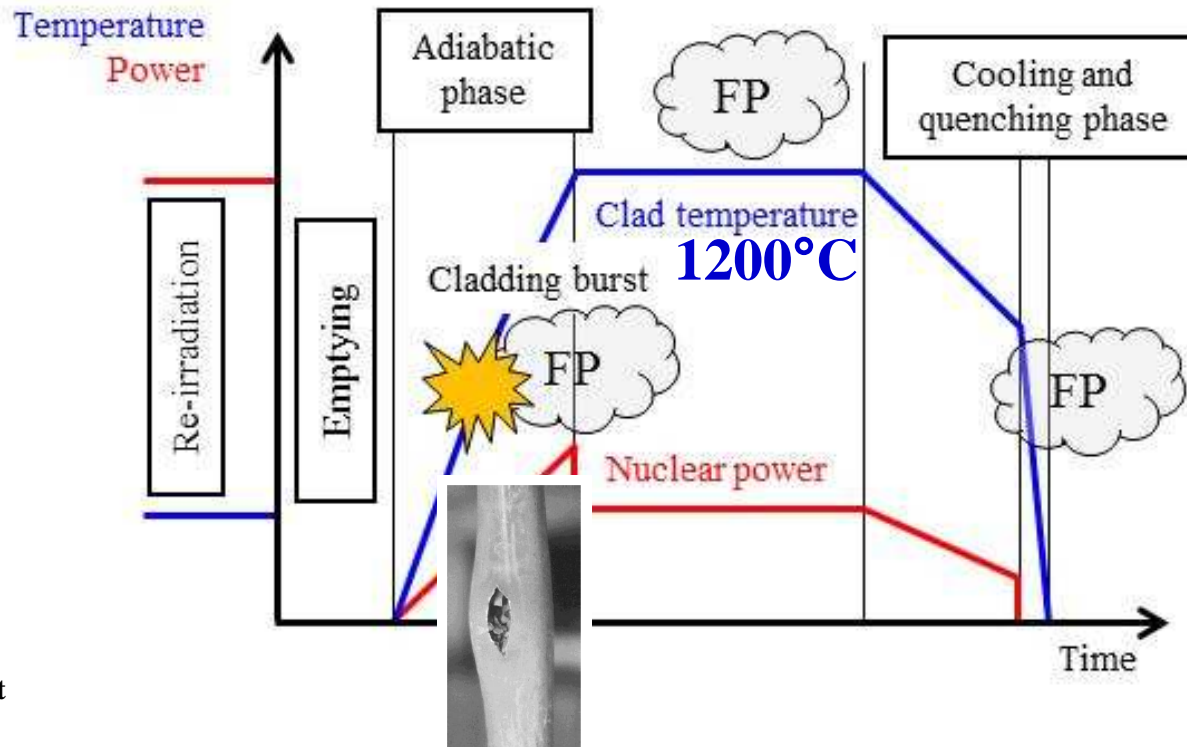


**MERARG**

## A hypothetical LOCA type transient in a light water reactor



**Large break**



NEA, OECD, Nuclear Fuel Behaviour in Loss-of-coolant Accident (LOCA) Conditions, State-of-the-art Report n°6846, 2009

The knowledge of the **amount of radioactivity released from the core to the environment, the determination of the “source term”**, is of prime and crucial importance

**R&D analytical programs ?**

## ■ One of the most useful way: Separate effect Tests

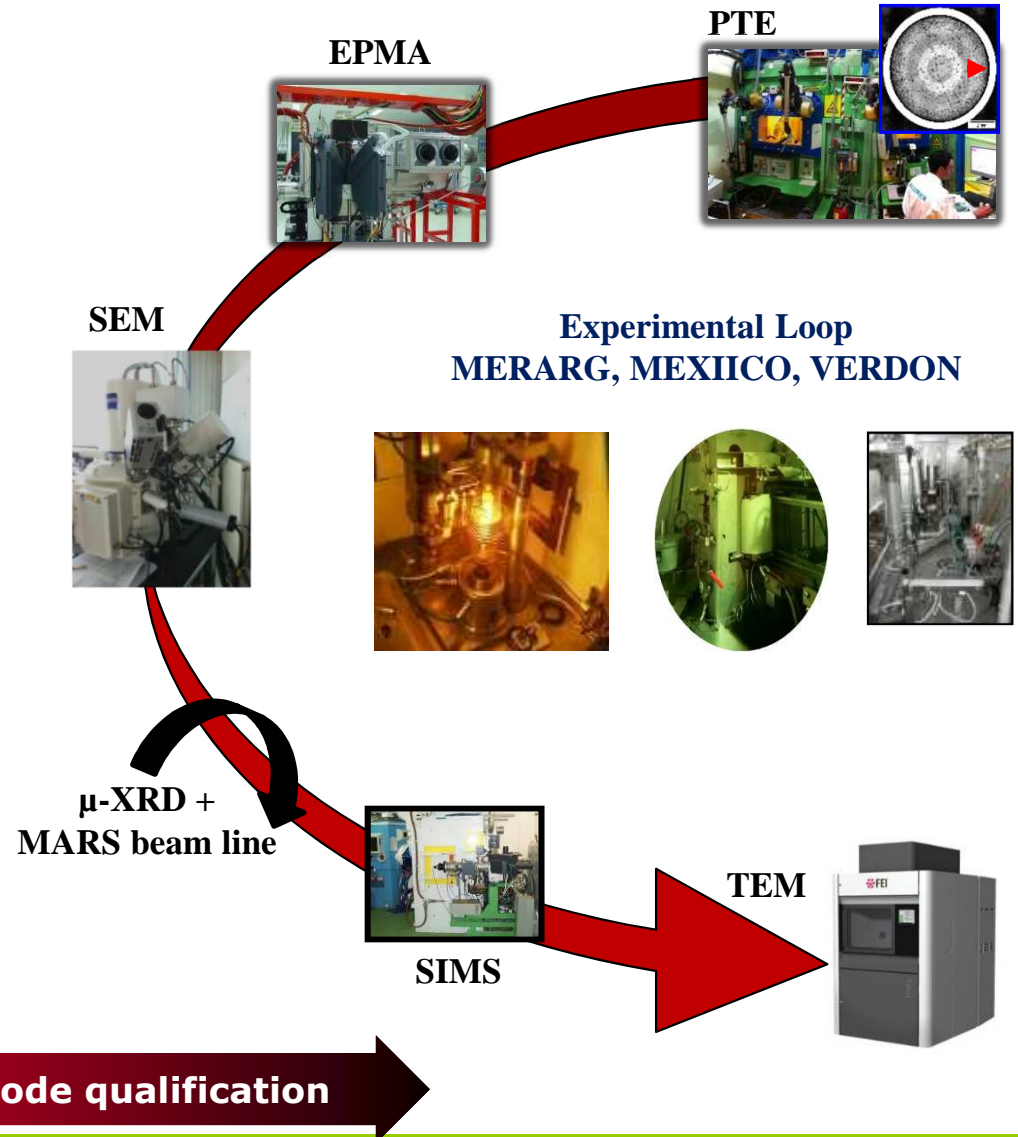
### ■ Annealing test coupled to (on line) measurements:

- ST quantification (FP kinetics)
- Temperature
- Pressure, ...

### ■ $\mu$ -structural examinations before and after test:

- Evolution during the test

**What is needed ?**  
**FP release (gases, volatiles, ...)**

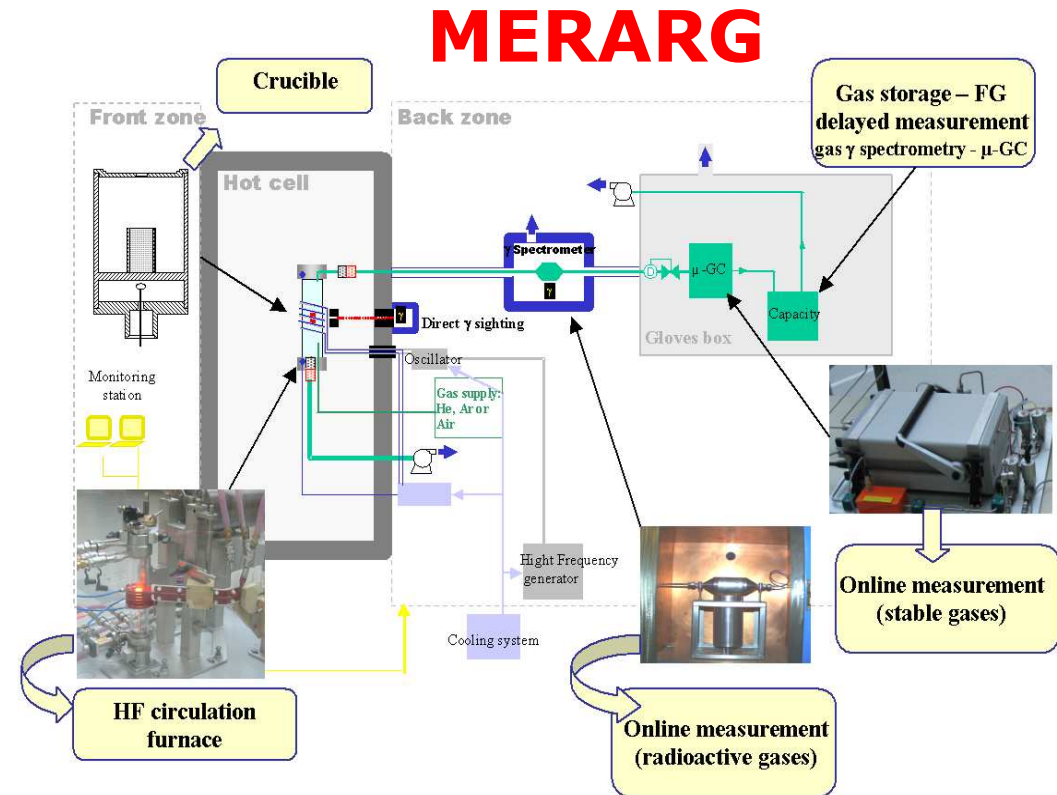


## Most of the analytical programs focusses:

### On gas behavior (LOCA type sequences): GASPARD program

### CEA - MERARG loop:

- Accurate ST quantification (FGR kinetics by gamma spectrometry)
- Accurate Temperature measurements (typically up to **1200°C**)
- Main part of the experiments: no access to FP behavior



Y. Pontillon, et al., J. Nucl. Mater. vol 385, issue 1, 2009, 137

Noirot, J., Pontillon Y., J. Nucl. Mater., 446(1-3), 163-171, 2014

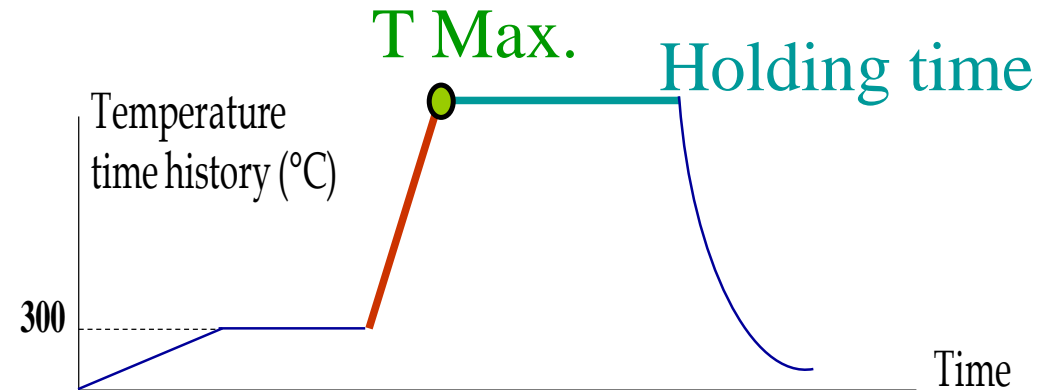
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- Accurate Temperature measurements (typically up to **1200°C**)
- Main part of the experiments: no access to FP behavior

## Typical GASPARD thermal sequence



- **TMAX between 1000°C and 1200°C,**
- **Holding time between 0 and 15 minutes.**

Y. Pontillon et al., 2004 Water Reactor Fuel Performance Meeting, ORLANDO, FLORIDE, September 2004

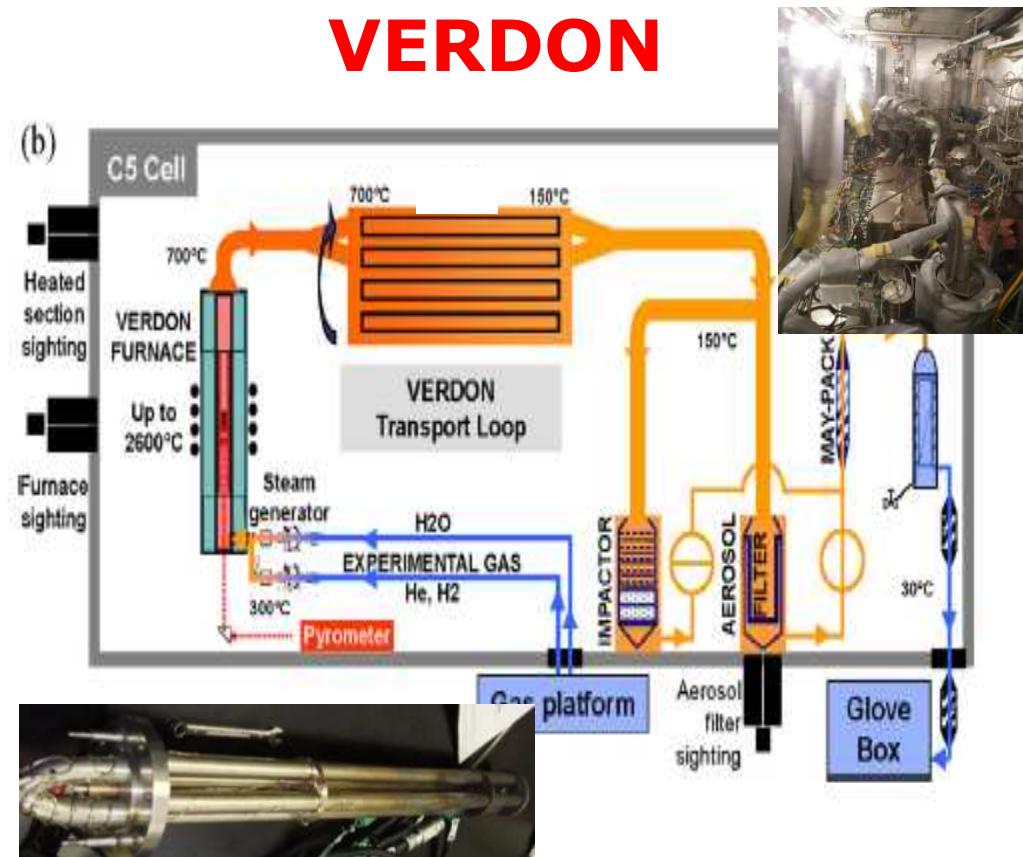
## Most of the analytical programs focusses:

- On all FP behavior (Severe accident type sequences), VERCORS/VERDON programs

## CEA – VERCORS/VERDON loops:

- Accurate ST quantification (**FGR** and **FPR** kinetics by gamma spectrometry)
- Accurate Temperature measurements
- All the FP behavior available, but very high temperature (**up to fuel relocation**)

## VERDON



Pontillon, Y. et al., NUCLEAR ENGINEERING AND DESIGN, 2010, 240,1843

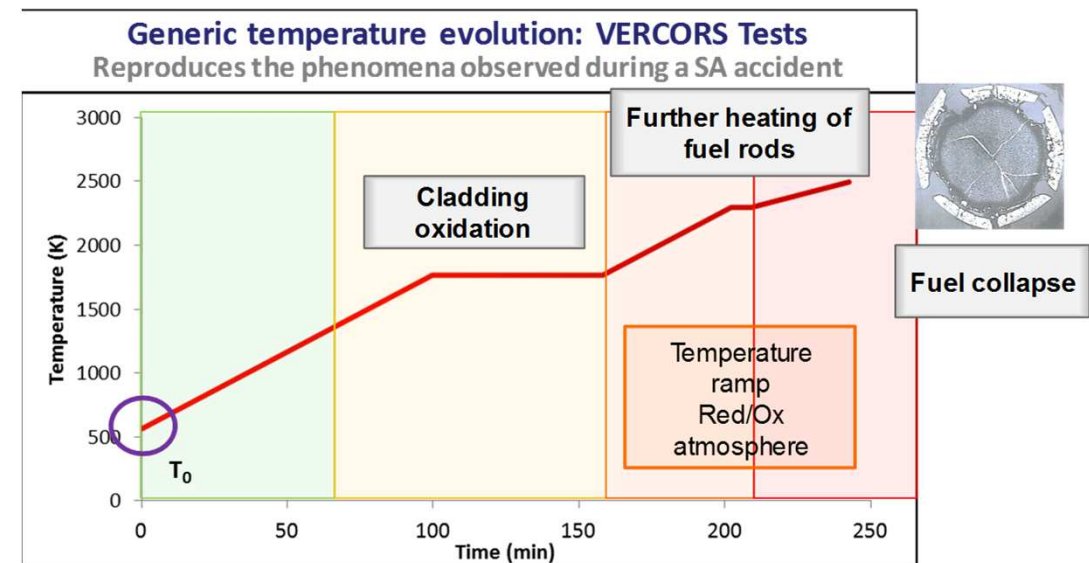
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## Typical VERCORS/VERDON thermal sequence



G. Ducros, et al., *Nuclear Engineering and Design*, vol. 208, no. 2, pp. 191–203, 2001.

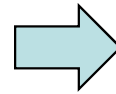
## ■ FP behavior (I and Cs) in LOCA type thermal scenario ?

### ■ Methodology used:

■ First, one focuses on the results obtained up to 1200°C (VERCORS series) for **Fission Gases**

■ Then, one checks the consistencies with those of the GASPARD program (**Fission Gases**)

■ Finally, determine the corresponding volatile FPs source term

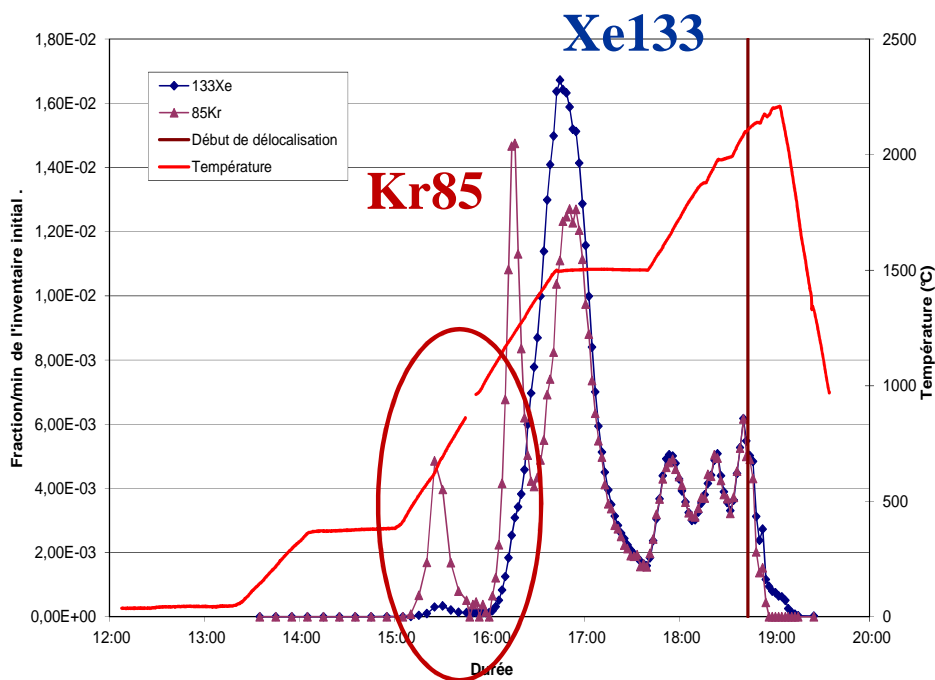


■ This determination is made easier because a direct comparison can be done:

■ The same fuel rod has been tested in the two programs (6 cycles UO<sub>2</sub> at 72 GWd/t)

## FG behavior up to 1200°C (Kinetics), UO<sub>2</sub> at 72 GWd/t

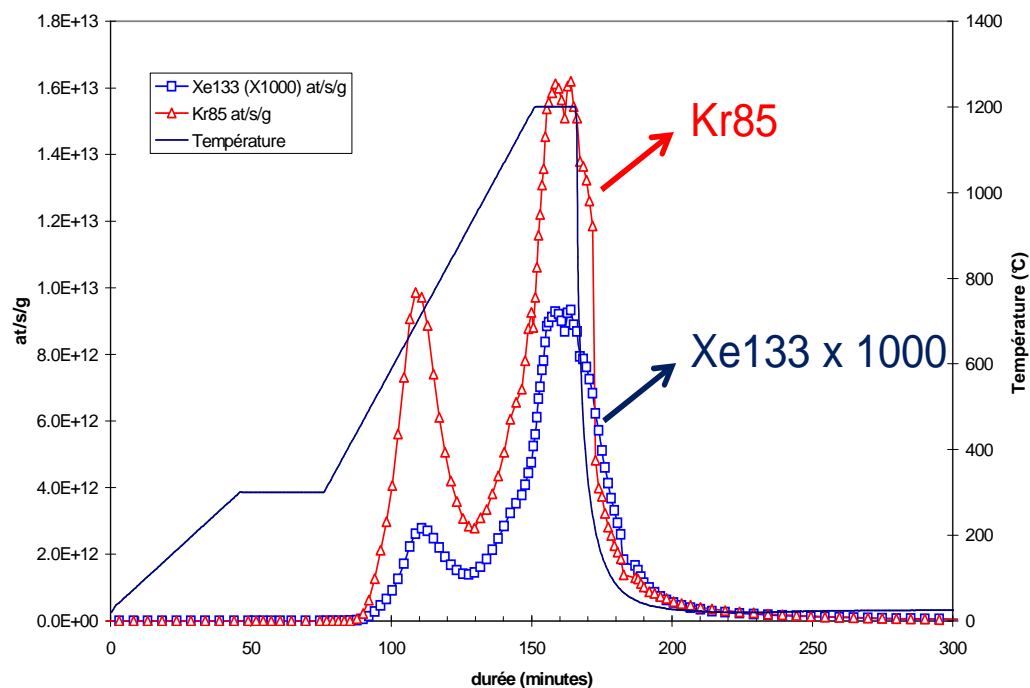
### VERCORS:



Start of gas releases at around 500-600°C, greater amplitude for <sup>85</sup>Kr than for <sup>133</sup>Xe at 700-800°C),

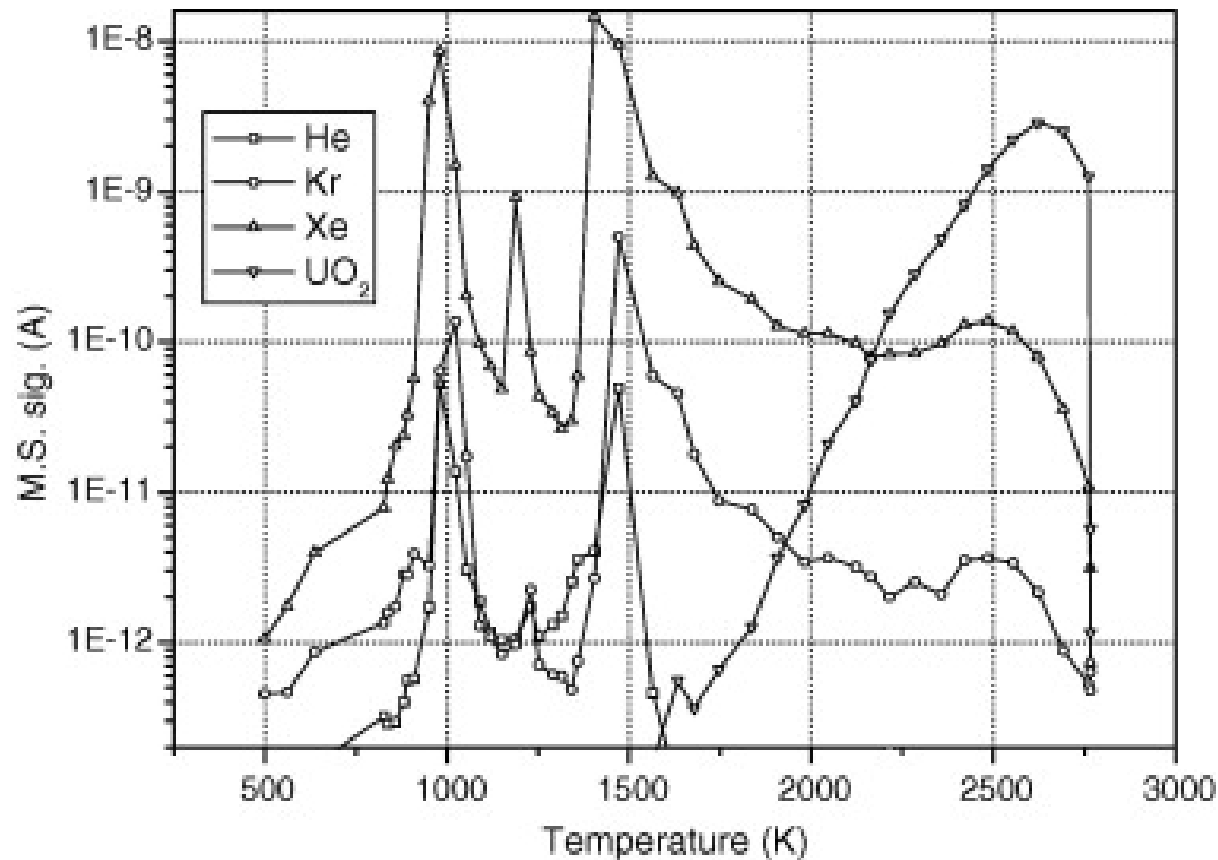
The second burst release around 1,100-1,200°C with significantly greater amplitude for the <sup>85</sup>Kr in relation to the <sup>133</sup>Xe,

### GASPARD:



Exactly the same behavior

## ■ FG behavior up to 1200°C (**Kinetics**), UO<sub>2</sub> at 72 GWd/t



*J.-P. Hiernaut et al./Journal of Nuclear Materials 377 (2008) 313–324*

Consistent with other results

■ **FG behavior up to 1200°C (released fraction), UO<sub>2</sub> at 72 GWd/t**

	VERCORS		GASPARD	
Temperature	Kr(85), %	Xe(133), %	Kr(85), %	Xe(133), %
1000°C	7,4	0,8	6,2	0,6
1200°C	12,7	1,8	11,6-12,2	1,7-2,1

Very good consistency between the results obtained thanks the two programs

■ **FG and FP behavior up to 1200°C (released fraction), UO<sub>2</sub> at 72 GWd/t**

Same UO<sub>2</sub> fuel used  
in GASPARD

VERCORS Tests	FGR ( <sup>85</sup> Kr, 6 cycles specimen, %)	FGR ( <sup>133</sup> Xe, 6 cycles specimen, %)	FPR ( <sup>137</sup> Cs, 6 cycles specimen, %)	FPR ( <sup>131</sup> I, 6 cycles specimen, %)
(0,2°C/s / 1000°C) <b>RT6</b>	7.4	0.8	0.04	0.25
(0.2°C/s / 1200°C) <b>RT6</b>	12.7	1.8	0.47	0.56
(end of the test, 2200°C) <b>RT6</b>	~100	~100	100	100

■ **FG and FP behavior up to 1200°C (released fraction), UO<sub>2</sub> at 72 GWd/t**

Same UO<sub>2</sub> fuel used in GASPARD

other UO<sub>2</sub> fuel

VERCORS Tests	<b>FGR</b> ( <sup>85</sup> Kr, 6 cycles specimen, %)	<b>FGR</b> ( <sup>133</sup> Xe, 6 cycles specimen, %)	<b>FPR</b> ( <sup>137</sup> Cs, 6 cycles specimen, %)	<b>FPR</b> ( <sup>131</sup> I, 6 cycles specimen, %)
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(end of the test, 2200°C) <b>RT6</b>	~100	~100	100	100
(0,2°C/s / 1000°C) <b>RT8</b>	10.4	0.7	0.08	0.18
(0,2°C/s / 1200°C) <b>RT8</b>	11.5	1.0	0.45	0.35
(end of the test, 2200°C) <b>RT8</b>	~100	~100	100	100

Very low I and Cs releases (less than 0,6 %)

## ■ FG and FP behavior up to 1200°C (released fraction), UO<sub>2</sub> at 72 GWd/t

Same UO<sub>2</sub> fuel used in GASPARD

other UO<sub>2</sub> fuel

VERCORS Tests	FGR ( <sup>85</sup> Kr, 6 cycles specimen, %)	FGR ( <sup>133</sup> Xe, 6 cycles specimen, %)	FPR ( <sup>137</sup> Cs, 6 cycles specimen, %)	FPR ( <sup>131</sup> I, 6 cycles specimen, %)
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1) J-P Hiernaut et al., JNM 377 (2008) 313-324; C. Ronchi, High Temperature 2007, Vol 45, n°4, pp 552-571; I. Johnson et al., JNM 154 (1988) 67-73

2) J. A. Turnbull et al., JNM 1982 107 168-184; W. H. Hocking et al., JNM 294 2001 45-52; D. Roudil et al., Material research society symposium proceeding Vol 824; S. G. Prussin et al., JNM 154 1988 25-37; C. T. Walker et al., JNM 393 (2009) 212-213

In good consistency with what one can extract from literature: the temperature limit at which I and Cs can become mobile <sup>1</sup>, the diffusion coefficient of gaseous and volatile species in nuclear ceramics <sup>2</sup>

- **This paper first focuses on the global characteristics of the GASPARD and VERCORS programs**
- **The VERCORS results regarding high burn up  $\text{UO}_2$  fuel are discussed and compared to those of GASPARD**
- **Thanks to the quasi identical results obtained for FG between GASPARD and VERCORS, indications on volatile fission product releases are then given.**
- **The global released fraction is very low for I and Cs, i.e. less than 0.6% up to 1200°C**
- **Enlarge the FP data in LOCA type transient: all the VERCORS and VERDON tests.**

**Funding: EdF and Framatome (GASPARD), IRSN and EdF (VERCORS)**

**Thanks you,**

**Any questions ?**