



New Insight on Volatile Fission Products (I and Cs) release from high burnup UO₂ fuel under LOCA type conditions

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DE LA RECHERCHE À L'INDUSTRIE



**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 30th - October 4th, 2018

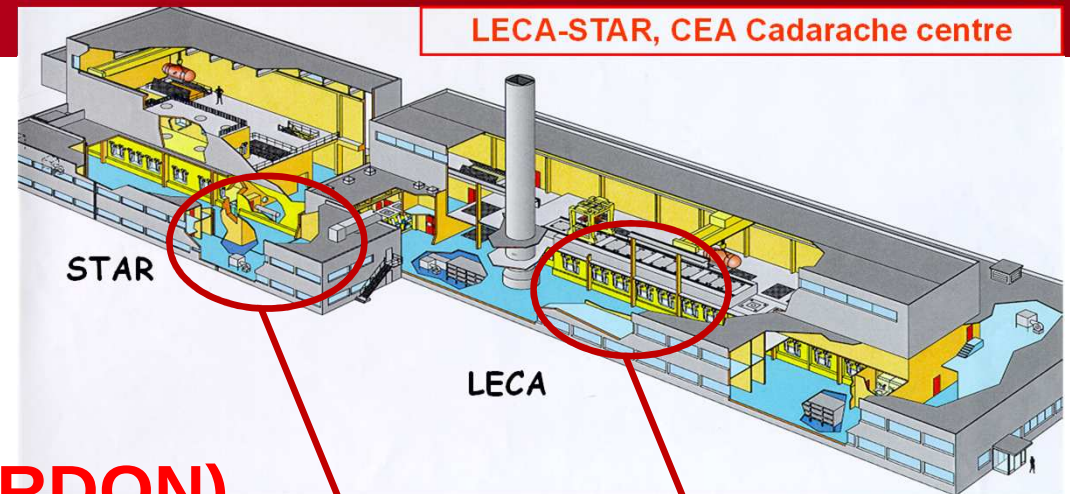
■ Context

■ MERARG vs VERCORS(VERDON)

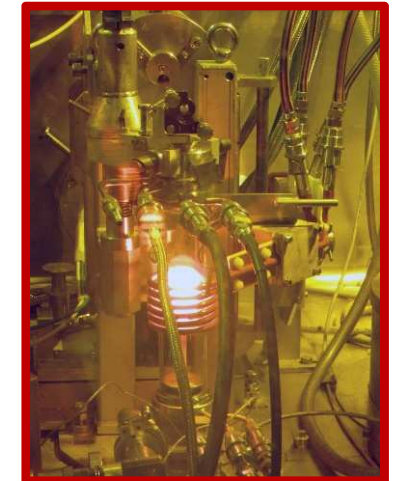
■ Results:

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

■ Conclusion and perspectives

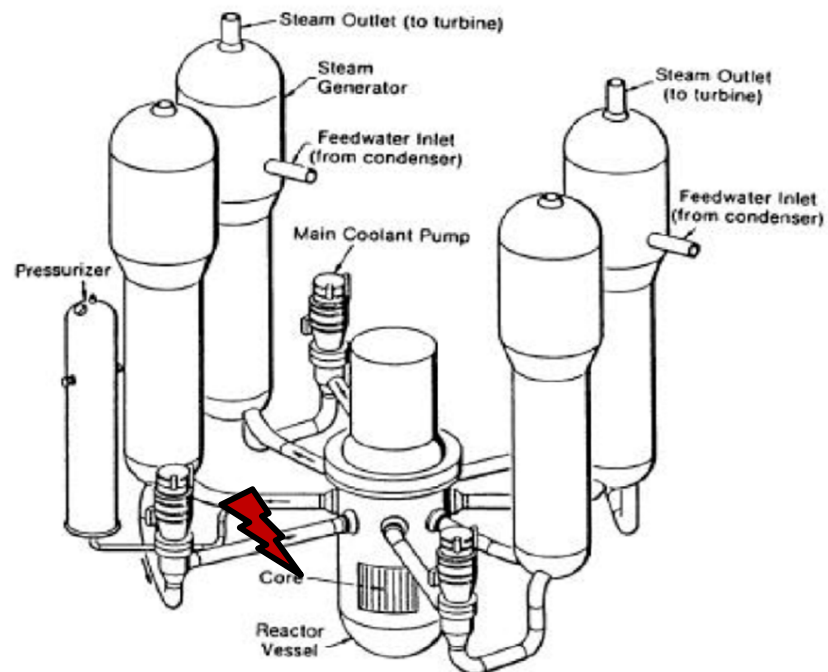


VERDON



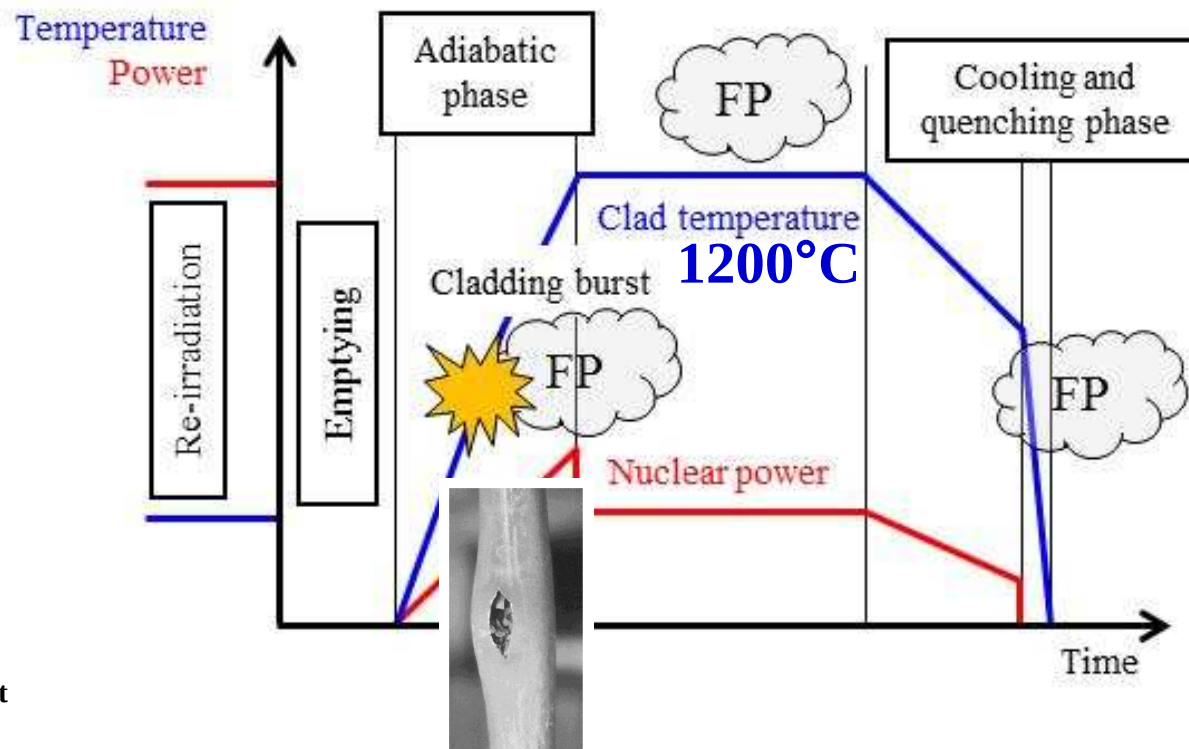
MERARG

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:

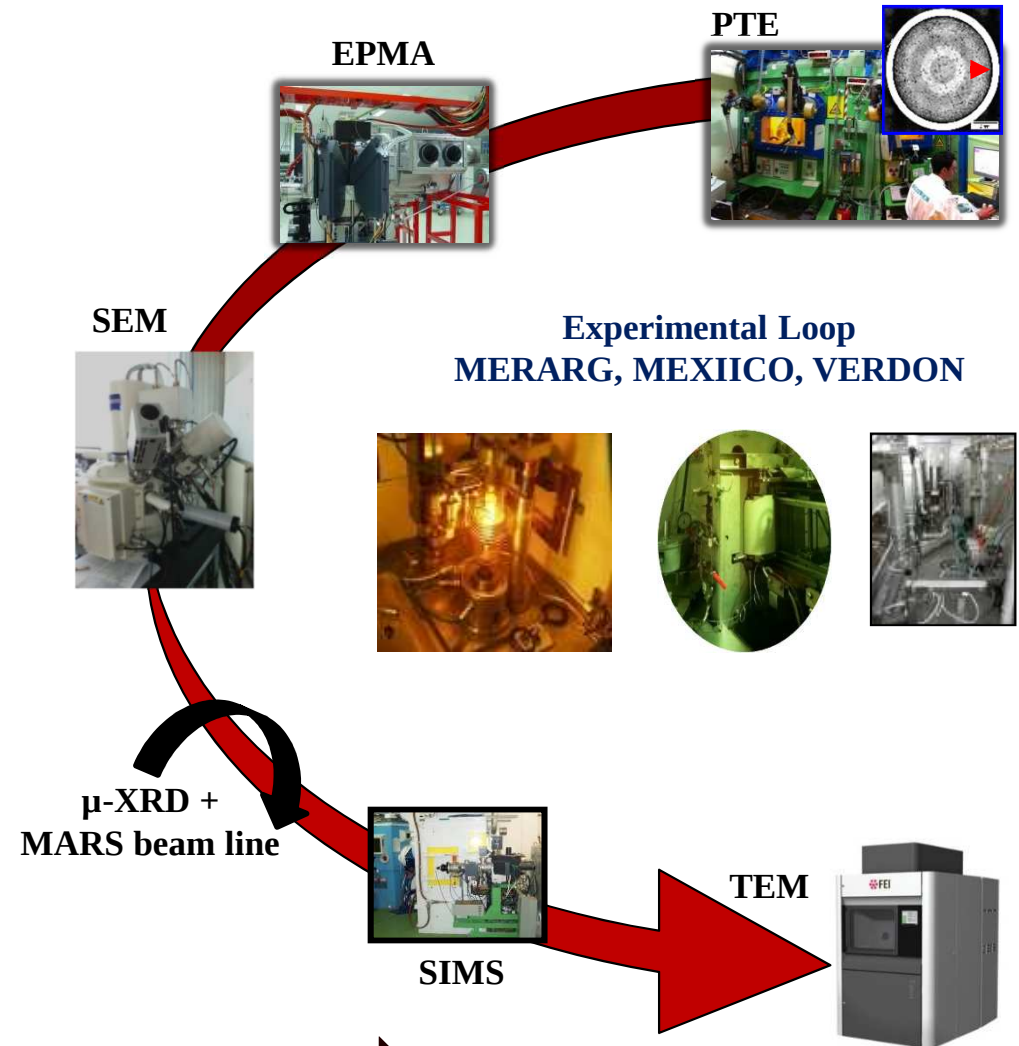
- ST quantification (FP kinetics)
- Temperature
- Pressure, ...

■ μ -structural examinations before and after test:

- Evolution during the test

What is needed ?

FP release (gases, volatiles, ...)

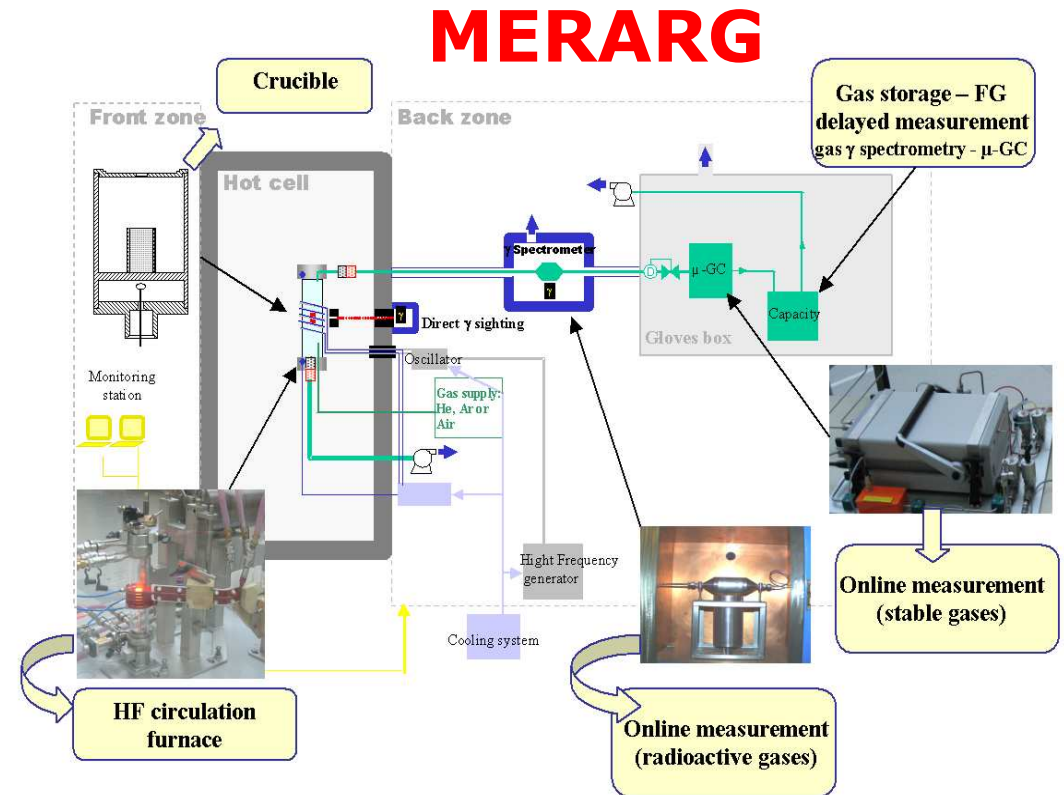


■ Most of the analytical programs focusses:

■ 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

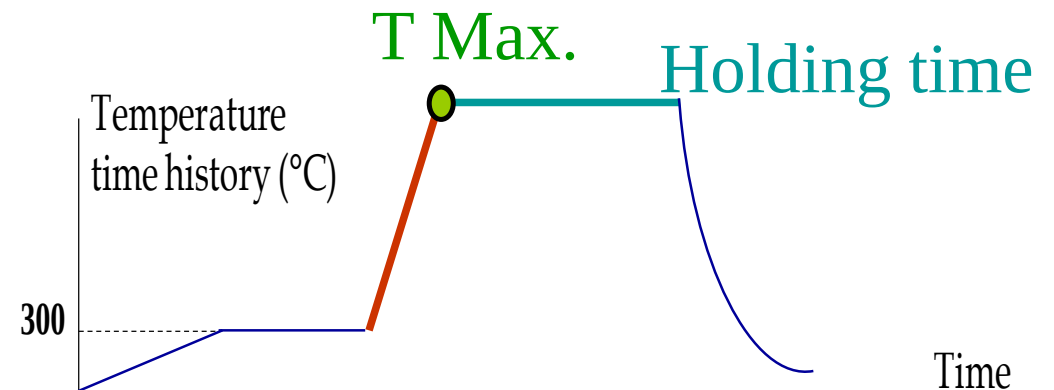
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Typical GASPARD thermal sequence



- **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

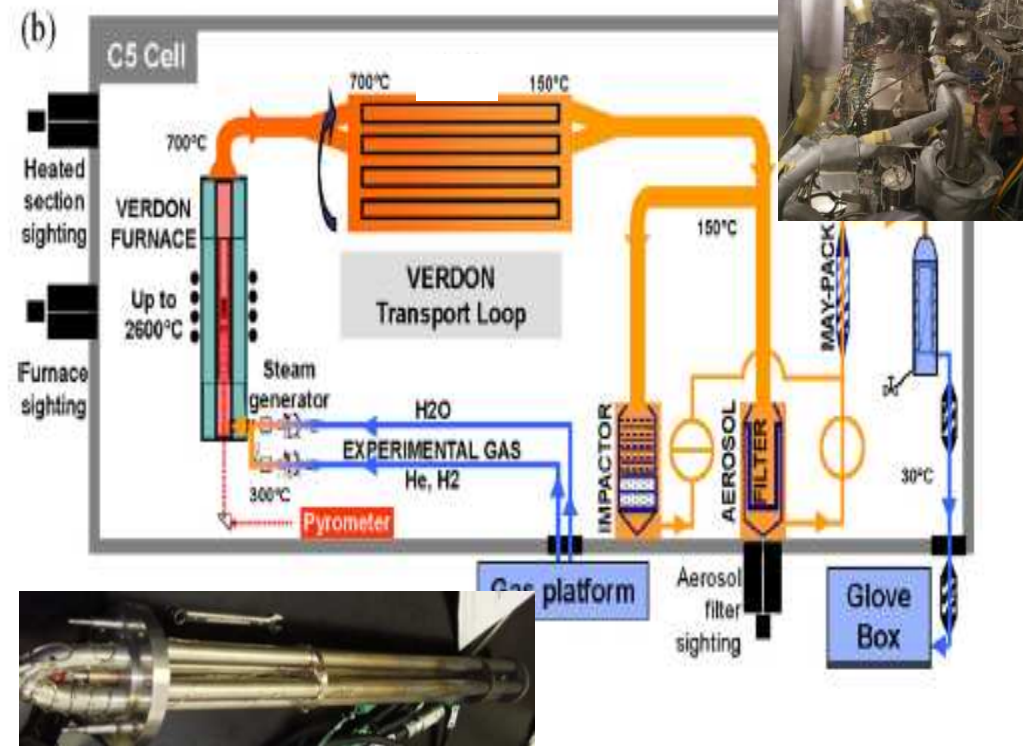
■ Most of the analytical programs focusses:

- 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

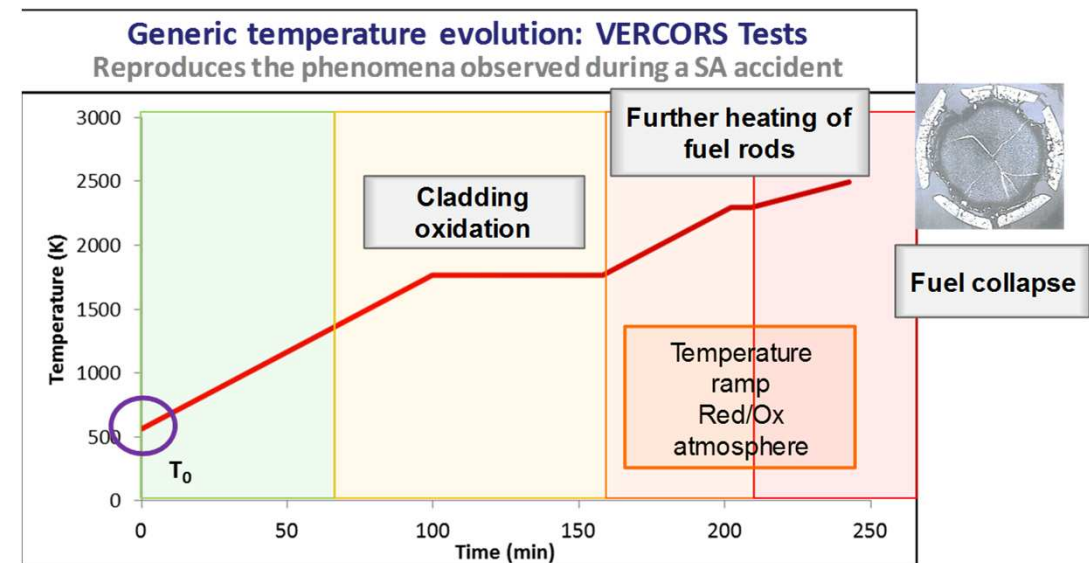
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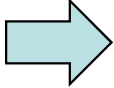
Typical VERCORS/VERDON thermal sequence



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

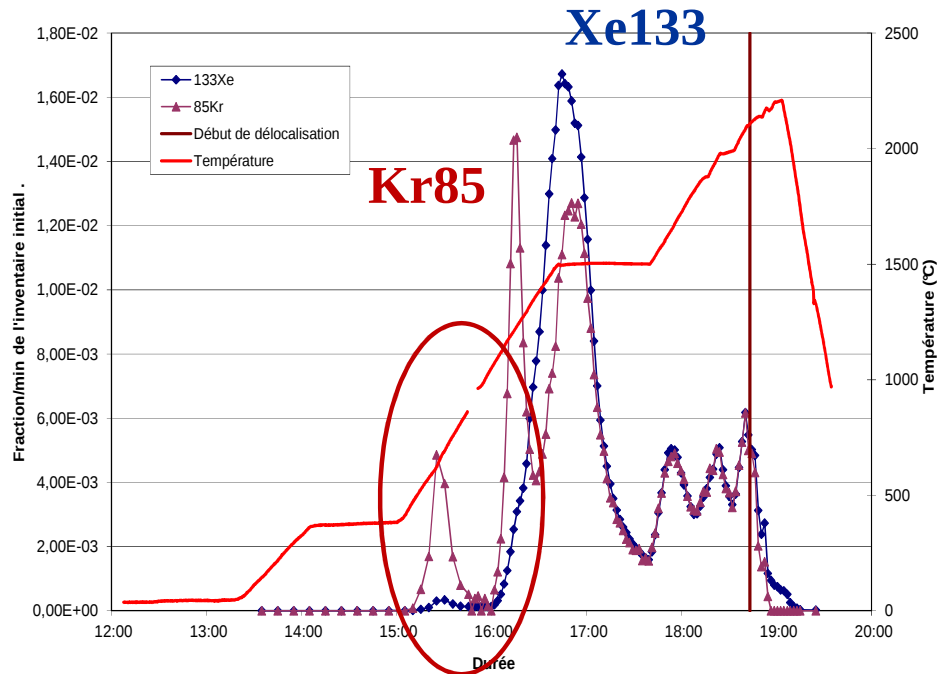
■ FP behavior (I and Cs) in LOCA type thermal scenario ?

■ 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 UO₂ at 72 GWd/t)

■ FG behavior up to 1200°C (**Kinetics**), UO₂ at 72 GWd/t

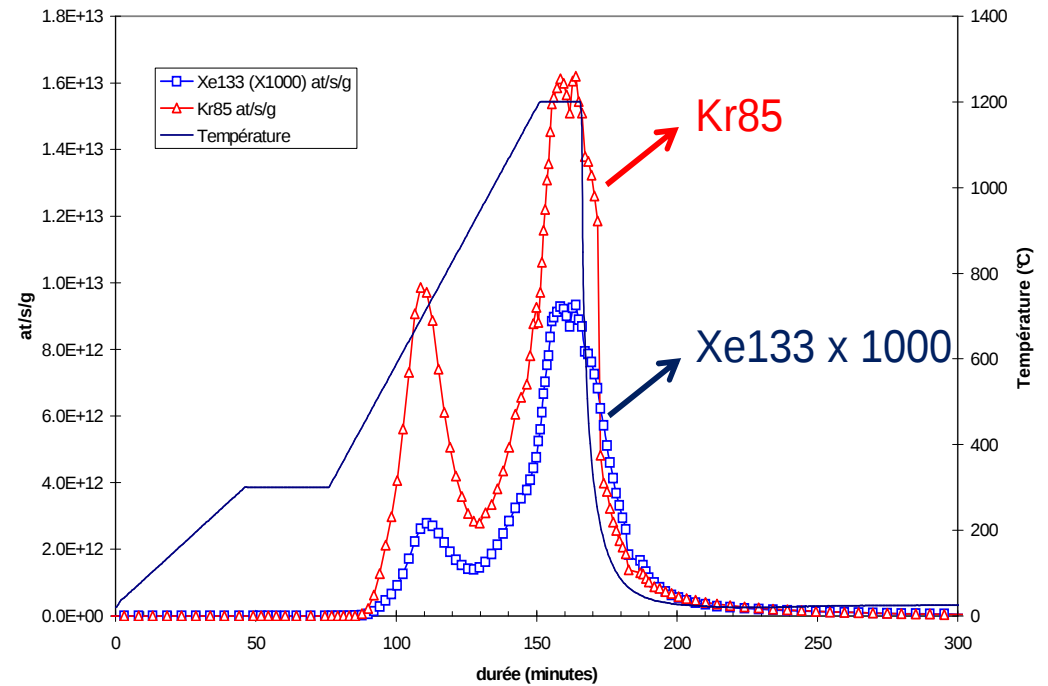
■ VERCORS:



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

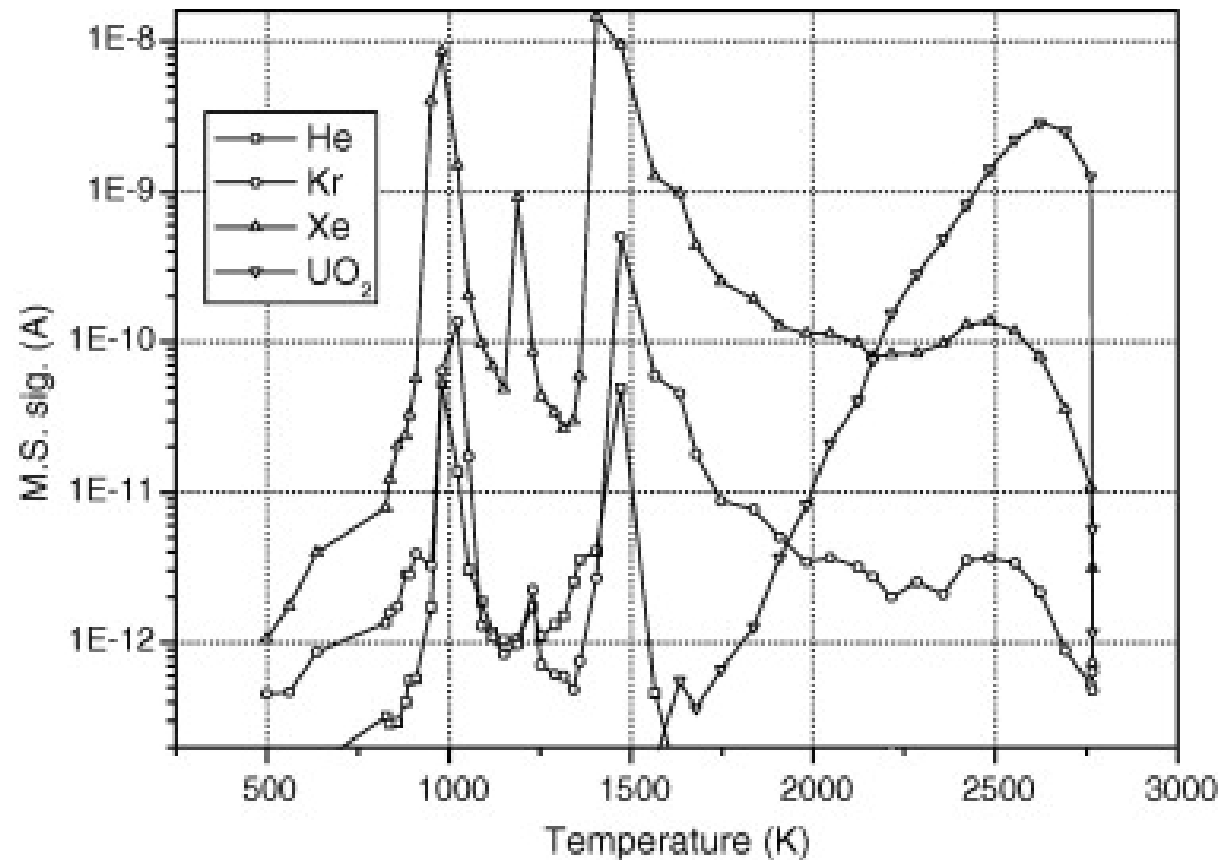
The second burst release around 1,100-1,200°C with significantly greater amplitude for the ⁸⁵Kr in relation to the ¹³³Xe,

■ GASPARD:



Exactly the same behavior

■ FG behavior up to 1200°C (**Kinetics**), UO_2 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**), UO₂ 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), UO₂ at 72 GWd/t**

Same UO₂ fuel used
in GASPARD

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

■ FG and FP behavior up to 1200°C (**released fraction**), UO₂ at 72 GWd/t

Same UO₂ fuel used
in GASPARD

other UO₂ fuel

VERCORS Tests	FGR (⁸⁵ Kr, 6 cycles specimen, %)	FGR (¹³³ Xe, 6 cycles specimen, %)	FPR (¹³⁷ Cs, 6 cycles specimen, %)	FPR (¹³¹ I, 6 cycles specimen, %)
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(0.2°C/s / 1200°C) RT6	12.7	1.8	0.47	0.56
(end of the test, 2200°C) RT6	~100	~100	100	100
(0,2°C/s / 1000°C) RT8	10.4	0.7	0.08	0.18
(0,2°C/s / 1200°C) RT8	11.5	1.0	0.45	0.35
(end of the test, 2200°C) RT8	~100	~100	100	100

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

■ FG and FP behavior up to 1200°C (**released fraction**), UO₂ at 72 GWd/t

Same UO₂ fuel used
in GASPARD

other UO₂ fuel

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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 ¹, the diffusion coefficient of gaseous and volatile species in nuclear ceramics ²

- This paper first focuses on the global characteristics of the GASPARD and VERCORS programs
- The VERCORS results regarding high burn up 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 ?