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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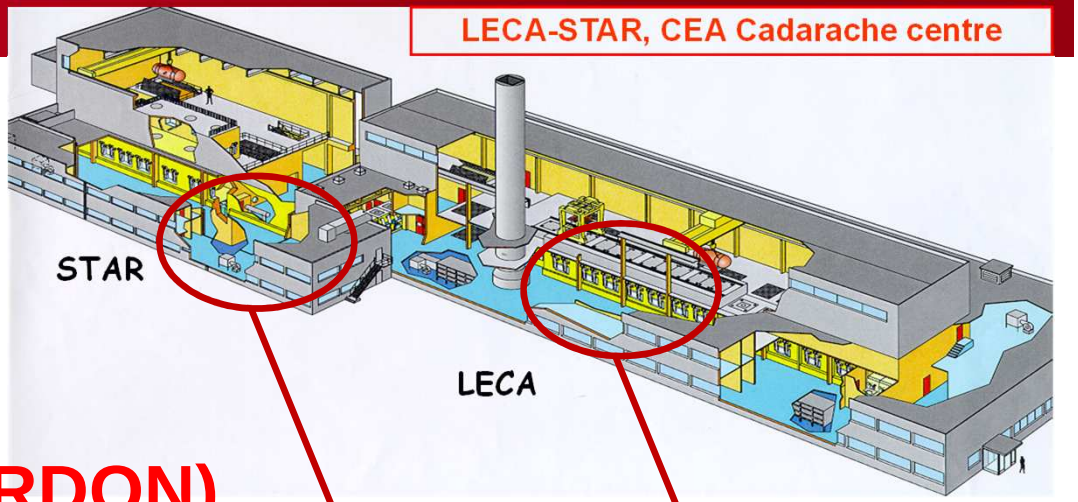
TopFuel, Fuel Reactor Perfomance Meeting

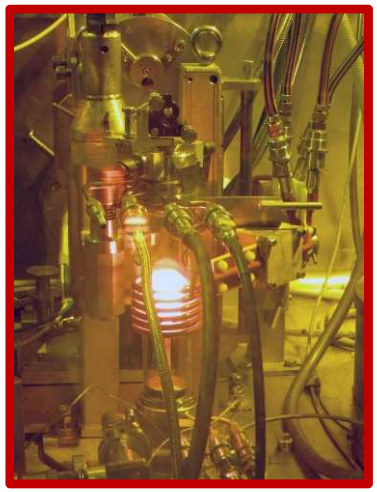
September 30th – October 4th, 2018

Outline



- **Context**
- **MERARG vs VERCORS(VERDON)**
- **Results:**
  - ***FGR comparison***
  - ***Some new insights from the VERCORS tests regarding FP***
- **Conclusion and perspectives**

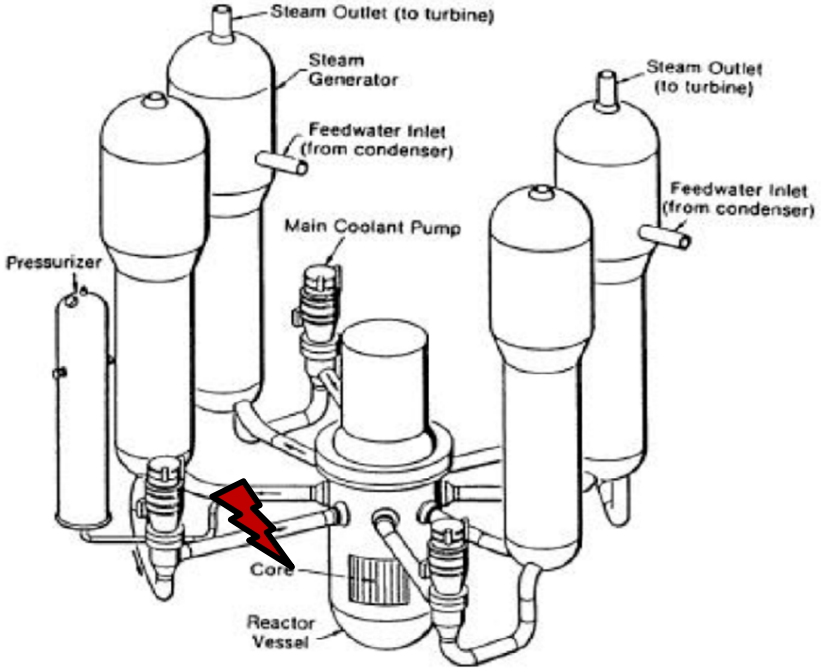
VERDON



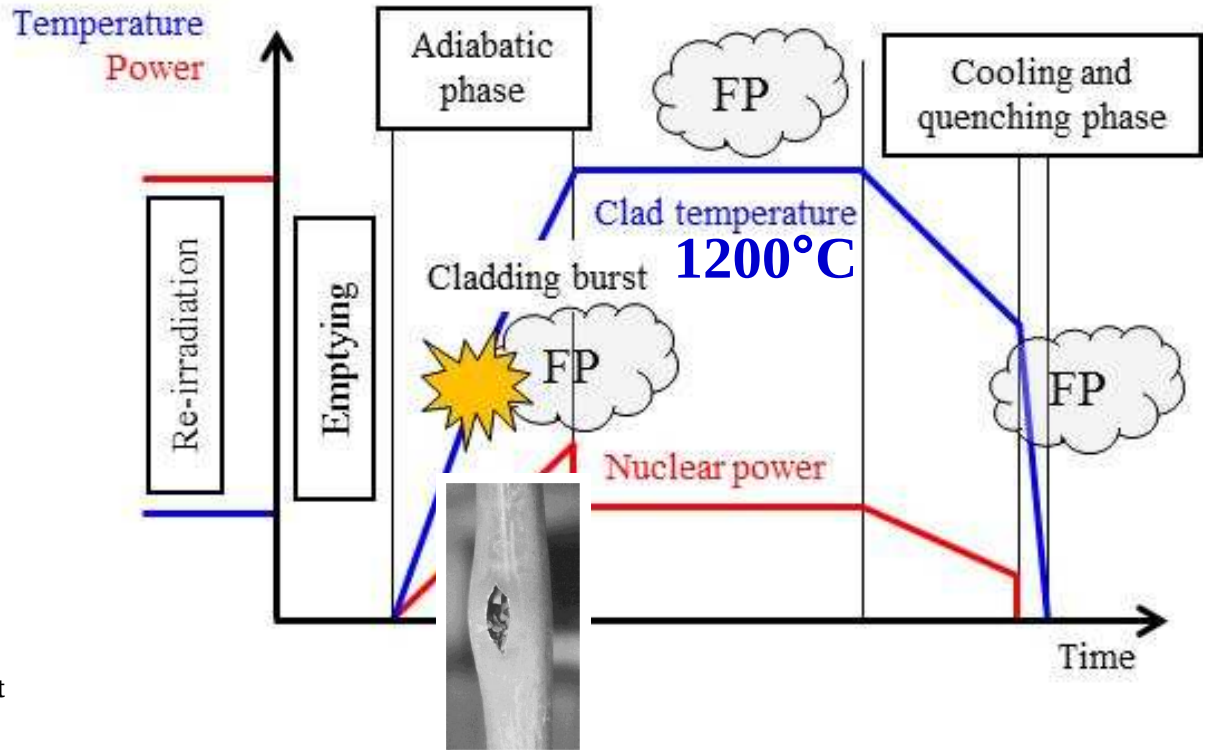
MERARG

Context: Generalities (1/2)

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 ?

Context: Generalities (2/2)

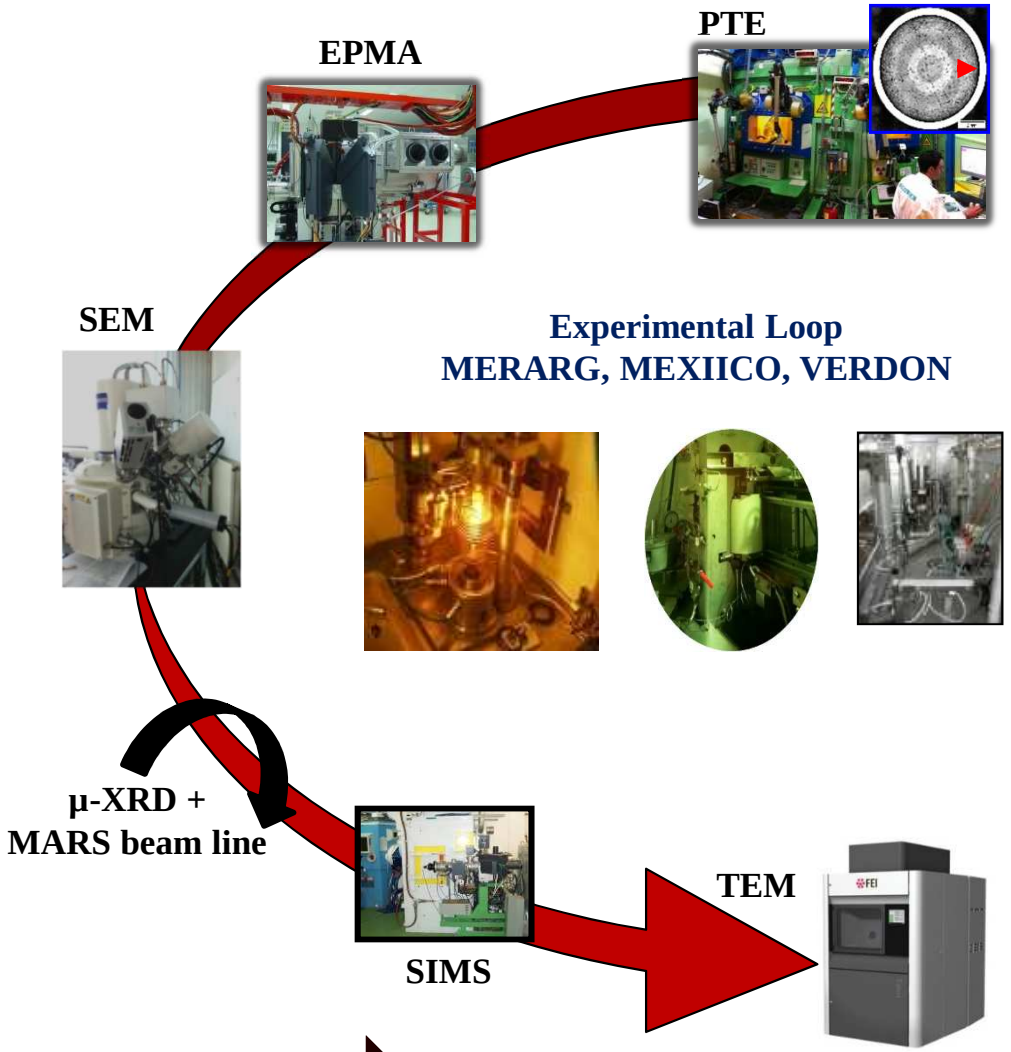
- **One of the most useful way: Separate effect Tests**

- **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, …)



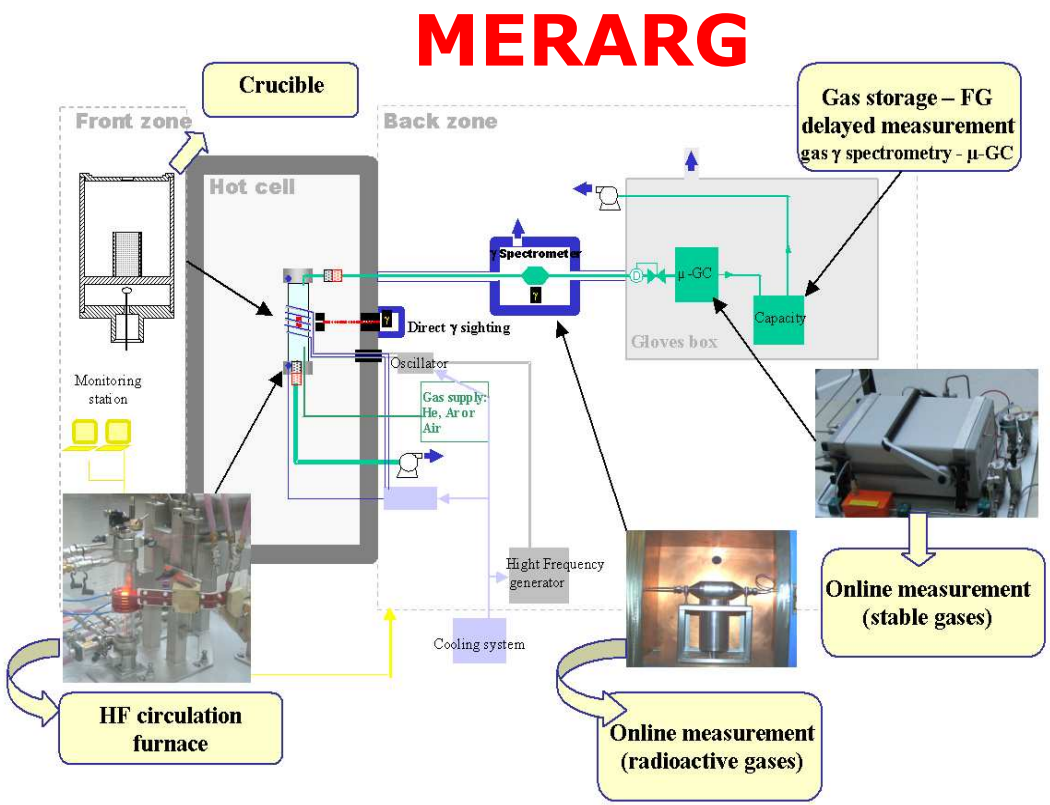
Model validation / Code qualification

MERARG vs VERCORS (1/3)

- **Most of the analytical programs focusses:**

- **On gas behavior (<u>LOCA type sequences</u>): 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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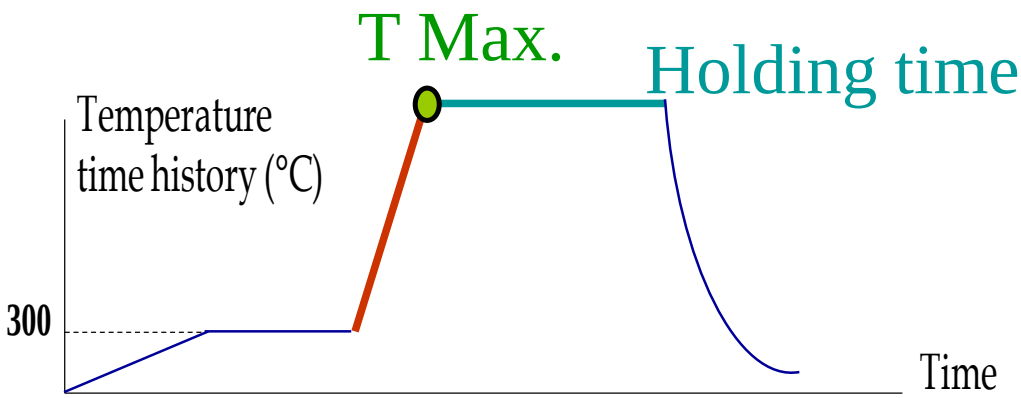
Typical GASPARD thermal sequence



- **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

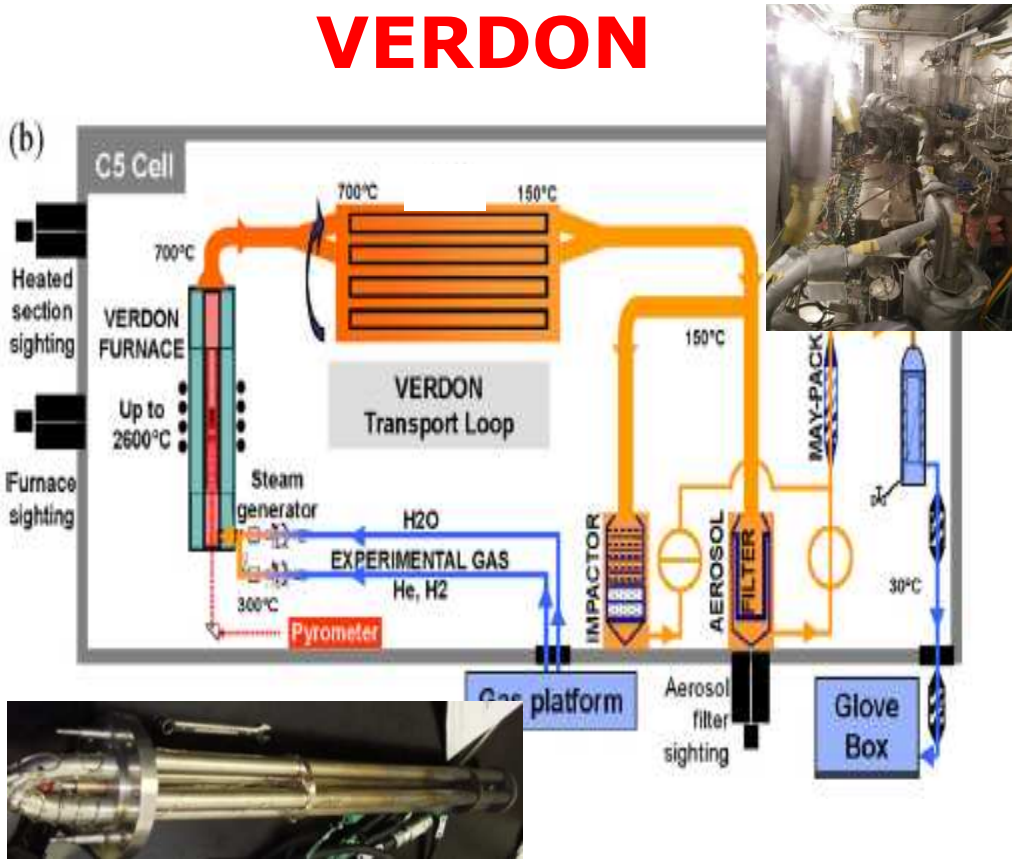
MERARG vs VERCORS (2/3)

- **Most of the analytical programs focusses:**

- **On all FP behavior (<u>Severe accident type sequences</u>), 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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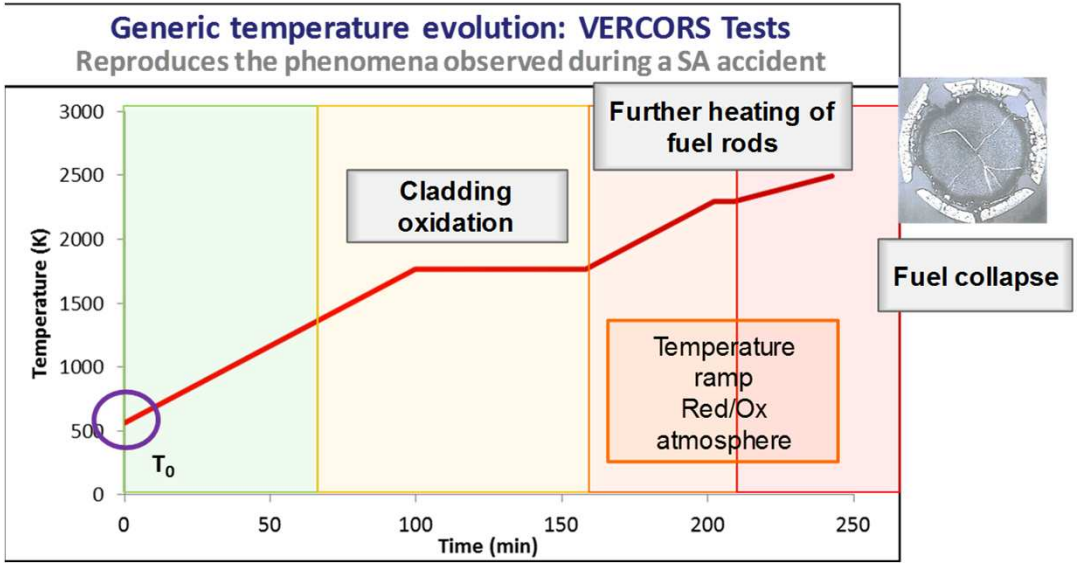


G. Ducros, et al., *Nuclear Engineering and Design*, vol. 208, no. 2, pp. 191–203, 2001.

MERARG vs VERCORS (3/3)

- **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**

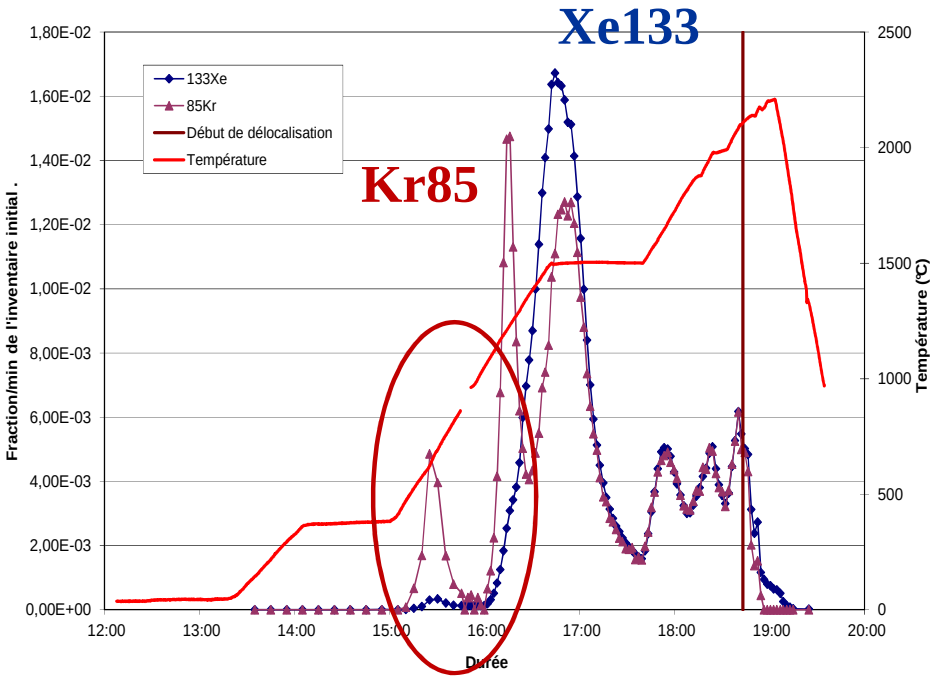
- **This determination is made easier because a direct comparison can be done:**

- The same fuel rod has been tested in the two programs (6 cycles UO_2 at 72 GWd/t)

Results (1/3)

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

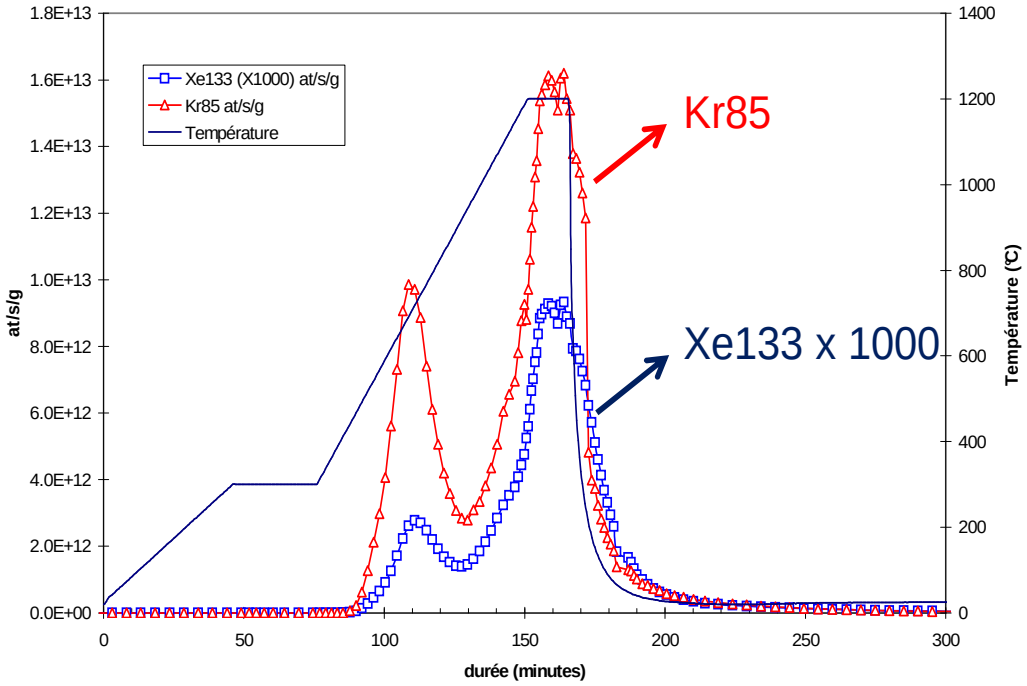
VERCORS:



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

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

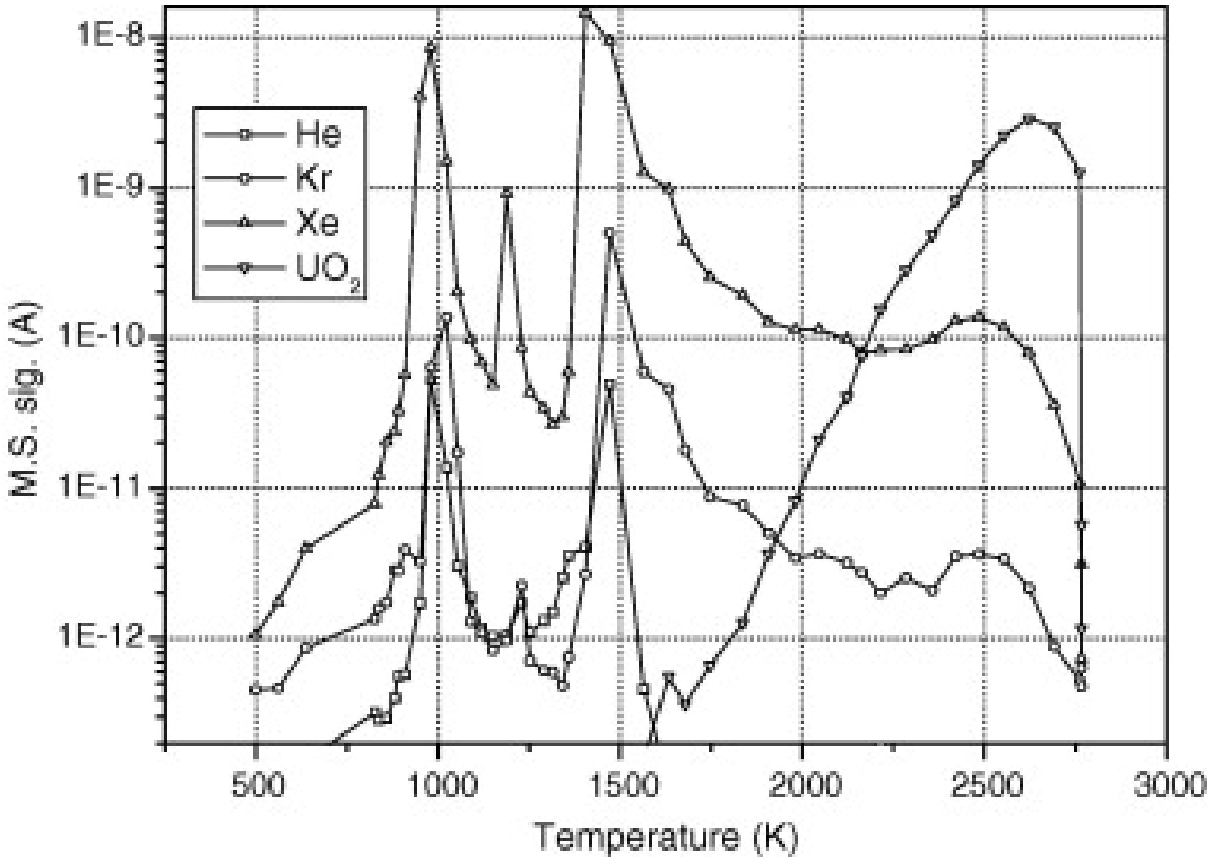
GASPARD:



Exactly the same behavior

Results (1/3)

- **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

Results (2/3)

- **FG behavior up to 1200°C (released fraction),** UO_2 at 72 GWd/t

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

Very good consistency between the results obtained thanks the two programs

Results (3/3)

- **FG and FP behavior up to 1200°C (released fraction),** UO_2 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

Results (3/3)

- **FG and FP behavior up to 1200°C (released fraction),** UO_2 at 72 GWd/t

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	(end of the test, 2200°C) **RT6**	~100	~100	100	100
other UO2 fuel	(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 %)

Results (3/3)

- **FG and FP behavior up to 1200°C (released fraction),** UO_2 at 72 GWd/t

	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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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]

Conclusion/Perspectives

- 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 ?