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

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Outline

- Introduction
- MERARG II facility:
  - General presentation
  - Experimental loop
- MEXIICO facility
  - Context
  - Experimental loop
  - Scoping test
- Main programs (FGR)
- Conclusion
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 ...

- Source Term:
  - Off normal conditions ...

- Limitation on burn-up extension
- Storage, ...

- Specific behaviour ...
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:
Before and After Experiment

Time dependence

He FGR

Absolute level

MERARG II and MEXIICO facilities

Fuel Performance Code validation
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

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

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)**

**µ-gas chromatography:**

<table>
<thead>
<tr>
<th>Pic Area</th>
<th>Standard value</th>
<th>Experimental error</th>
</tr>
</thead>
<tbody>
<tr>
<td>326</td>
<td>104 ppm</td>
<td>± 10</td>
</tr>
<tr>
<td>3259</td>
<td>1003 ppm</td>
<td>±50</td>
</tr>
<tr>
<td>31050</td>
<td>10100 ppm</td>
<td>±341</td>
</tr>
<tr>
<td>142740</td>
<td>50 000 ppm</td>
<td>±1708</td>
</tr>
</tbody>
</table>

**Allows to analyse stable gases**

<table>
<thead>
<tr>
<th>Element</th>
<th>Detection limit</th>
<th>Linearity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kr</td>
<td>0,6 ppm</td>
<td>5 decades</td>
</tr>
<tr>
<td>Xe</td>
<td>0,3 ppm</td>
<td>5 decades</td>
</tr>
<tr>
<td>He</td>
<td>3 ppm</td>
<td>5 decades</td>
</tr>
<tr>
<td>N₂, O₂, …</td>
<td>~ 1 ppm</td>
<td>5 decades</td>
</tr>
</tbody>
</table>

R² = 0,9998


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HotLab, September 22-24, 2008

Y. Pontillon (CEA/DEN/DEC/SA3C)
MERARG II: Experimental Loop (4/6)

µ-gas chromatography:

![Graph showing gas chromatography data with lines for H2 (B), O2 (B), and N2 (B) over time.](image)
On-line gamma spectrometry: gas measurement

Total release from the fuel

- Kr$^{85}$ at/s/g (capacité)
- Kr$^{85}$ at/s/g (échantillon)
- TCP estimée

Allows the fission gases leaving the fuel to be recorded.
On-line gamma spectrometry: fuel sight

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

- Cs137
- Ba140
- Ru103
- Zr97
- Température fond du creuset (°C)

MERARG II: Experimental Loop (6/6)

Allows the FP leaving the fuel to be recorded

Y. Pontillon G. Ducros, International VERCORS Seminar, October 15-16th, 2007 – Gréoux les Bains, France
In order to investigate the impact of stresses on FGR, decision was made to install a high pressure furnace in a hot cell.

Une et al., JINST
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:
MEXIICO: Scoping test

"Inactive" qualification phase:
Fission Gas Release: Main Programs

- **GASPARD** (fuel behaviour under loca type conditions):

- **ADAGIO** (inter and intra-granular gas fraction):

- **Doped UO₂** fuels (TANOX, TANOXOS, CONCERTO)

- **GFR** (for instance NIMPHE samples, (U,Pu)N and (U,Pu)C), High Burn up Fuels, MOX, ...
FIRST PEAK (600-800°C)
Grain boundary cracking

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

85Kr release
UO₂, ~70 GWd/t

GASPARD PROGRAM
**ADAGIO PROGRAM**

**UO₂ samples**

- initial state: $^{85}$Kr (matrix + bubbles intra + grain boundaries)
- Re-irradiation: low T, He
- $^{133}$Xe from re-irradiation: intra-gran. gas tracer
- first thermal plateau: air, 380°C

1. **Re-irradiation**
   - low T, He
   - $^{133}$Xe from re-irradiation: intra-gran. gas tracer

2. **Opening of grain boundaries**
   - fraction of intergranular gas

3. **Release of complete gas inventory**
   - $\text{U}_4\text{O}_9$ beginning at grain boundaries
   - opening of grain boundaries
   - release of all inter-granular gas + fraction of intra-granular gas
   - quantification by $\gamma$ 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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45th annual meeting
“Hot Laboratories and Remote Handling”
Working group, Kendal, UK
September 22th – 24st, 2008

Thank you for your attention