Preliminary Results of the MARIOS Experiment on Minor Actinide Bearing Blanket Concept.

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Synopsis

- The objective of the experiment
- A description of the MARIOS experiment
- The startup
- The preliminary results
- About “Post Irradiation Examination”
- Conclusion and outlook
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The objectives of MARIOS

- The objective of the experiment is to obtain information on the temperature dependence of fuel swelling and helium release.

- The MABB concept consists in transmutation of minor actinide on a fertile support (UO$_2$) in a sodium cooled fast reactor (SFR) with a heterogeneous recycling mode.

- The experiment is complementary with another irradiation test (DIAMINO) in order to collect data on irradiated MABB fuel at different temperatures and different porosities.
He release and swelling

- Low He swelling (He atoms isolated in small size defects)
  
  \[ T < T_1 \]
  
  500 to 700°C
  
  *He Implantation and annealing test*

- Potentially significant He swelling.
  
  \[ T_1 < T < T_2 \]

- Low He swelling because of significant release
  
  \[ T_2 < T \]
  
  1100 to 1400°C
  
  *He Implantation and annealing MOX annealing SUPERFACT*

- MABB thermal conditions
Pu, Np, Am recycling in fast reactors:
- Reduction of lifetime and volume of high-level waste from fuels

2 options studied in EU context:
- MA-bearing driver fuel (MOX incl. <5% MA)
- Separate recycling in blankets (UO₂ incl. <20% MA)
  - Leave the driver fuel fabrication untouched
  - Lower (negative) effect on core neutronic
  - Separate reprocessing of MA-bearing targets

Material issues on \( ^{241} \text{Am} \)
- \( \alpha \) auto-irradiation \( \rightarrow \) damage and swelling
- In-pile formation of Cm-242 \( \rightarrow \) even more \( \alpha \) damage and swelling
A description of MARIOS

<table>
<thead>
<tr>
<th>Pin Nr.</th>
<th>Composition</th>
<th>Isotopic composition</th>
<th>Fuel Density [g cm(^{-3})]</th>
<th>(^{241})Am contents [g]</th>
<th>(^{235})U contents [g]</th>
<th>(^{238})U contents [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(U,Am)O(_2)</td>
<td>Natural U + (^{241})Am</td>
<td>10.2</td>
<td>0.195</td>
<td>7.78E-3</td>
<td>1.088</td>
</tr>
<tr>
<td>2</td>
<td>(U,Am)O(_2)</td>
<td>Natural U + (^{241})Am</td>
<td>10.2</td>
<td>0.195</td>
<td>7.78E-3</td>
<td>1.088</td>
</tr>
<tr>
<td>3</td>
<td>(U,Am)O(_2)</td>
<td>Natural U + (^{241})Am</td>
<td>9.71</td>
<td>0.186</td>
<td>7.41E-3</td>
<td>1.036</td>
</tr>
<tr>
<td>4</td>
<td>(U,Am)O(_2)</td>
<td>Natural U + (^{241})Am</td>
<td>9.71</td>
<td>0.186</td>
<td>7.41E-3</td>
<td>1.036</td>
</tr>
</tbody>
</table>

Chemical composition: Am\(_{0.15}\) U\(_{0.85}\) O\(_{1.94}\)
The main characteristics of the HFR core are:

- 33 fuel elements
- 6 control rods
- 23 beryllium reflector elements
- 19 in-core irradiation positions
- 22 irradiation positions in pool-side facility
- 12 horizontal beam tubes.
A description of MARIOS

The Pins containing the fuel

- TZM
- Niobium
- Inconel 718
- Zirconia
- Pellet
A description of MARIOS

A schematic view of MARIOS

- **Pin 1**: 92.5% density fuel, 1000°C
- **Pin 2**: 88% density fuel, 1200°C
- **Pin 3**: 1200°C
- **Pin 4**: 1000°C

Gas: He+Ne
1st Containment

Gas: He+Ne
2nd Containment

Gas: He inside the fuel pins

TZM Tray

Nuclear fuel pellets

Inconel 718 fuel pins

AISI 321 Sample holder

TRIO-131 channel

Titanium Shroud

Pin 1

Pin 2

Pin 3

Pin 4
A description of MARIOS

The average power per pellet:

![Graph showing the average power per pellet over irradiation time. The graph has a total power axis on the y-axis and an irradiation time axis on the x-axis. There are four lines representing different pellets: Pellet Pin 1, Pellet Pin 2, Pellet Pin 3, and Pellet Pin 4. The graph illustrates how the power increases with irradiation time.]
A description of MARIOS

The assembly of the Pins:
A description of MARIOS

The assembly of the Sample Holder:
A description of MARIOS

The Radiographic check:
The startup

The temperature was too high, the experiment has been turned from north to south

There was a strong gradient in nuclear heating from north to south position.
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**The preliminary results**

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The measured temperatures

The internal temperature (close to fuel temperature).

MARIOS All cycles - Pins 1 - 4

MARIOS All cycles - Pins 1 - 4

Number of irradiation days

Temperature [°C]

Pin 1
Pin 2
Pin 3
Pin 4
Cycle1 Cycle2 Cycle3 Cycle4 Cycle5 Cycle6 Cycle7 Cycle8 Cycle9 Cycle10 Cycle11

Research Centre
The VDU movements

The Vertical Displacement Unit is continuously adjusted in order to balance the temperature in the fuels:

MARIOS all together - VDU

Number of irradiation days
VDU position mm from the bottom

Cycle1 Cycle2 Cycle3 Cycle4 Cycle5 Cycle6 Cycle7 Cycle8 Cycle9 Cycle10 Cycle11

Joint Centre
The Control Rod “follow” the Vertical Displacement Unit (of course is the opposite).

MARIOS all cycles - HFR Ctrl-rods position
Americium and Helium contents estimation

The Americium content after 304 FPD is:
- Pin 1 = $2.05 \times 10^{21}$ atom/cm$^3$
- Pin 2 = $1.65 \times 10^{21}$ atom/cm$^3$
- Pin 3 = $1.50 \times 10^{21}$ atom/cm$^3$
- Pin 4 = $1.85 \times 10^{21}$ atom/cm$^3$

The Helium production after 304 FPD is:
- Pin 1 = $4.8 \times 10^{20}$ atom/cm$^3$
- Pin 2 = $6.5 \times 10^{20}$ atom/cm$^3$
- Pin 3 = $6.5 \times 10^{20}$ atom/cm$^3$
- Pin 4 = $5.3 \times 10^{20}$ atom/cm$^3$
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Neutron-radiography

Pins 4 and 3. Picture taken at 0°

Pins 4 and 3. Picture taken at 90°
Neutron-radiography

Pins 2 and 1. Picture taken at $0^\circ$

Pins 2 and 1. Picture taken at $90^\circ$
Neutron-radiography

Are these cracks through the centers of two pellets?

Pin 3

Pin 2
Dismantling

Pin 1

Pin 2
Dismantling of capsule 2

5 out of 6 pellets broken
Metallic surfaces remain clean
Results:

- ~100% helium release for all capsules (not counting He production after irradiation)
- Strong temperature dependence of fission gas release
- Xe and Kr vectors conform calculation

4 capsules punctured for gas analysis:
- Pressure by expansion into known volume
- Composition by mass spectrometry
- Release % by comparison to calibrated BU calculations
Conclusion & Outlook

**MARIOS irradiation:**
- The MARIOS irradiation performed well and finished after 304.72 Equivalent Full Power Days.
- Helium release in oxide matrix $\sim$100% at $T > 980 \, ^{\circ}\text{C}$.
- Release of Xe, Kr increases from $\sim$12% at $980 \, ^{\circ}\text{C}$ to $\sim$80% at $1360 \, ^{\circ}\text{C}$.
- Cs release follows trend Xe, Kr.
- Most pellets in capsule 2 broken from temperature stress.

**‘Ongoing’:**
- MARIOS destructive exams at CEA (Cadarache):
  - swelling, microstructure / damage, experimental burn-up determination
- DIAMINO irradiation at CEA (Cadarache):
  - Helium release at lower temperatures, production rate dependence
- MARINE irradiation at NRG/JRC (Petten):
  - semi-integral irradiation of blanket material
Thank you for your Attention!