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Progress in Transmutation Technology with Oxide-fuelled FR Cycle

J.M. Bonnerot, S. Bejaoui, N. Chauvin, F. Delage (CEA)

E. D'Agata, J. Somers, M. Rini (EC-JRC)

F. Klaassen, R. Hania (NRG)

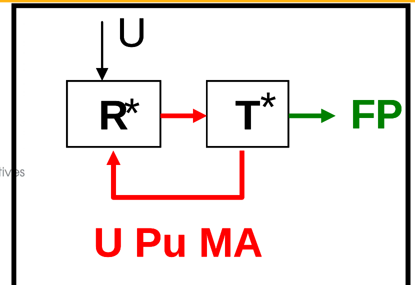
T. Mizuno (JAEA)

J. Carmack (INL)

Contents:

- Fuel cycle strategies
- Fuel behaviour under irradiation
- MA bearing fuel fabrication
- Summary

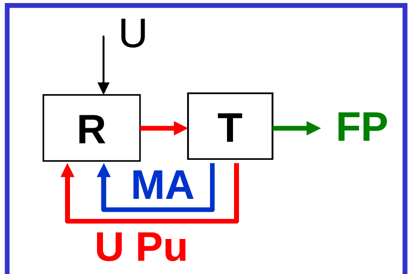
Fuel cycle strategies



MA Homogeneous ***Recycling***

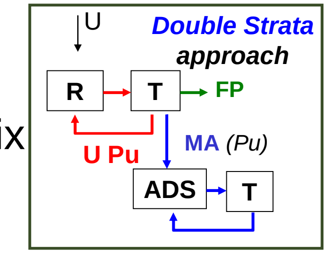
- **MA homogeneous recycling:**
  - MA bearing driver fuels (U,Pu,MA)O_{2-x}
  - MA < 5%
  - from moderate to significant impact on SFR core safety parameters and fuel cycle facilities

(: R for Reactor / T for Treatment)*



MA Heterogeneous ***Recycling***

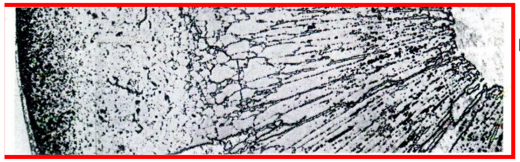
- **MA heterogeneous recycling:**
  - *Dedicated S/As in SFR core*:
    - Inert Matrix Fuels: MA oxides + Inert Matrix or MA Bearing Blankets: MA ox. + UO_2 in outer core
    - MA ~10-20%
    - limited impact on core operating & safety parameters and dedicated MA bearing fuel cycle facilities
  - *Accelerator Driven System case*:
    - driver fuels: (MA,Pu)O_{2-x} + Inert Matrix
    - MA~20-25%; Pu~20-25%



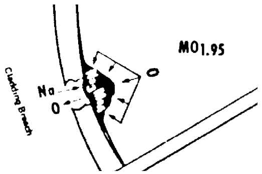
Development of MA bearing fuels is much more challenging compared to conventional fuels (additional elements, modified properties, He, remote fabrication,…)

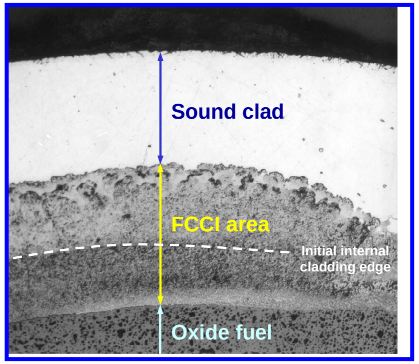
Homogeneous recycling – Fuel irradiation behaviour (1/4)

- MA impact:
  - Lower thermal conductivity & melting point:
    - ⇨ Higher central temperature & thermal gradient at Beginning Of Life
      - ⇨ Decreased margins to fuel melting
      - ⇨ Faster restructuration and thermal-migration of U, Pu, Am, O & volatile Fission Products + enlarged restructured area

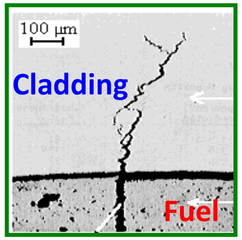


  - Oxygen Potential increase
    - ⇨ Thermal changes & increased volatile FPs migration from restructured area to periphery
      - ⇨ Earlier Fuel -Cladding Chemical Interaction ?
      - ⇨ Increased fuel-sodium reaction?



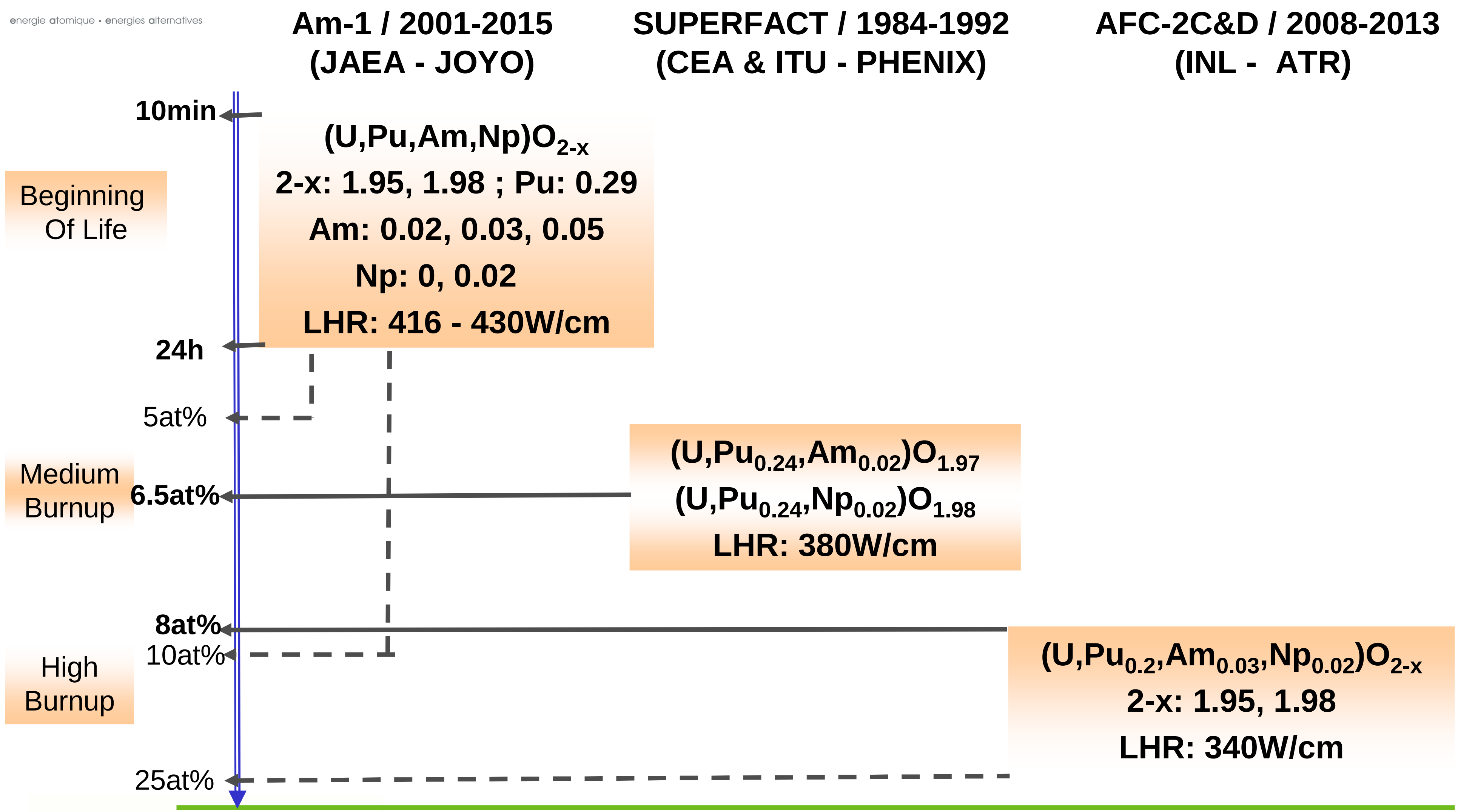


  - Higher Helium amount production
    - ⇨ Higher release rate of fission gas?
    - ⇨ Enhanced gaseous swelling ?
      - ⇨ Occurrence of Fuel - Cladding Mechanical Interaction ?



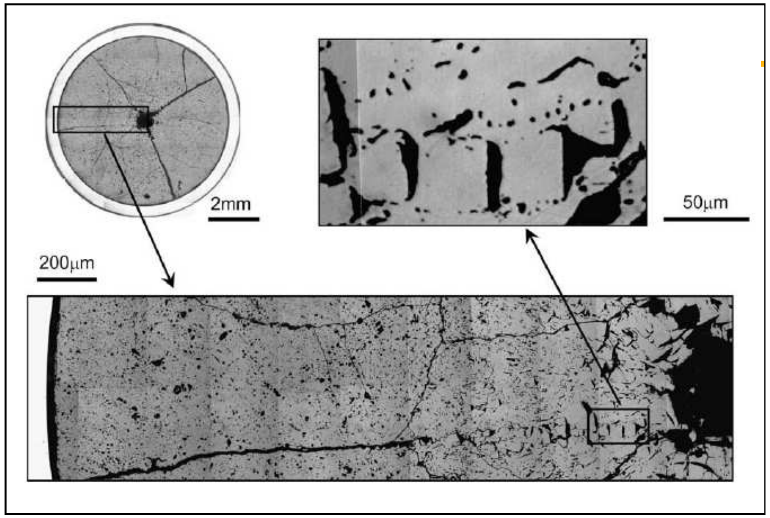
Homogeneous recycling (2/4)

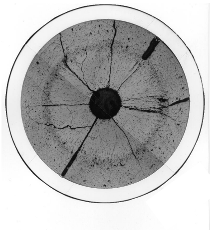
- Characteristics of irradiation tests achieved or already in pile:



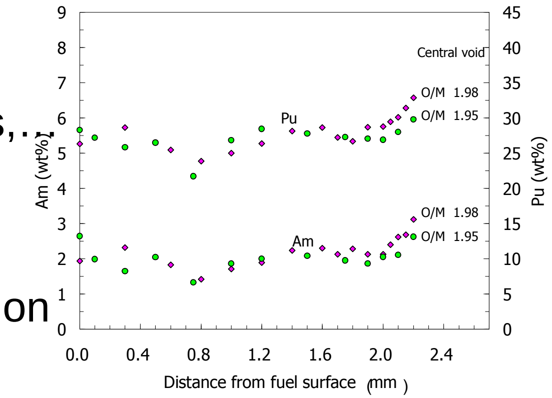
Homogeneous recycling (3/4)

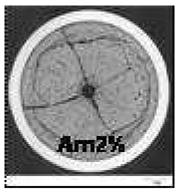
- PIE - main results:
  - 10 min (Am-1): No sign of fuel melting
    First structural changes:
    - cracks, central void & lenticular pores
    - no significant actinide redistribution



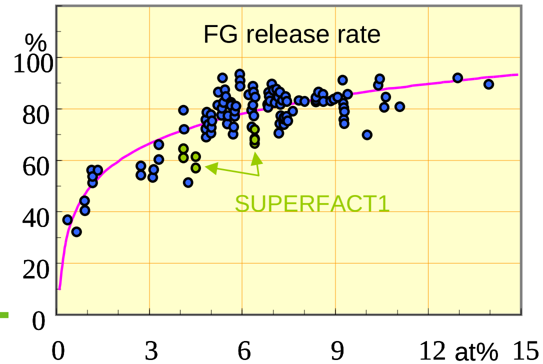


  - 24h (Am-1): Significant central hole, columnar grains,...
    No Np radial redistribution
    Similar Am & Pu radial profiles
    Slightly O/M effect on Am, Pu redistribution





  - 6.5at% (SUPERFACT): No sign of inner corrosion
    Helium totally released during irradiation
    Restructuring and Xe+Kr behaviour quite similar to standard fuel (~LHR)
    Similar MA & Pu radial profiles



Burnup

Homogeneous recycling (4/4)

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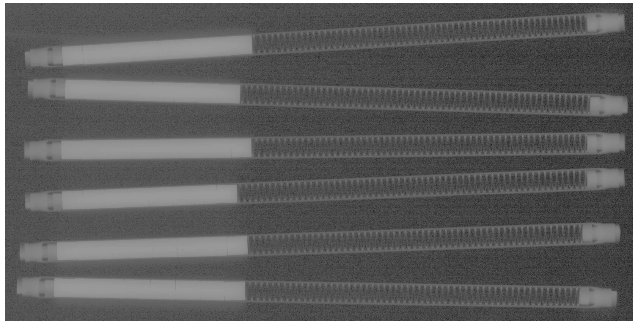
- Next steps:



  – End of irradiation tests & PIE :
    - Am-1: 5-10at%
    - AFC-2C &2D: 8-25at%

  – SPHERE test in HFR within the European project FAIRFUELS (2009-2013):
    - Comparison of irradiation performance of $U_{0.78}Pu_{0.18}Am_{0.04}O_{2-x}$ fuel stacks made of pellets and beads (dust free fabrication route).

  – GACID project (2007-2025) within the CEA-DOE-JAEA collaboration under the GIF umbrella:

    1/ Irradiation of a $(U,Pu,Am,Np)O_{2-x}$ fuel pin (fast flux, High Burnup)

    2/ Irradiation of a (U,Pu,Am,Np,Cm)O_{2-x} fuel pin (fast flux, High Burnup)

    3/ Irradiation of a pin bundle or sub-assembly of $(U,Pu,Am,Np,Cm)O_{2-x}$ fuel in MONJU

Heterogeneous recycling – IMF irradiation behaviour (1/2)

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- Investigation approach:

  – Step 1: Inert Matrix **preliminary selection** on past experience & basic knowledge on material & fuel science,…

  – Step 2: Effect of neutron fluxes and temperatures on IM candidates

  Neutron impact

  HFR

  BOR-60

  PHENIX

  SILOE

  MATINA 1

  – Step 3: Irradiation testing of IMF surrogates: UO_2+IM, PuO_2+IM

  Neutron + Fission Product impact

  THERMHET

  BORA-BORA

  MATINA 1A

  – Step 4: Irradiation testing of AmO_{2-x} bearing IMF

  Neutron + Fission Products + helium impact

  ECRIX B and H

  EFFTRA T4 & T4bis

  – Step 5: Irradiation testing in FR representative conditions of optimised IMF microstructures

  Impact of open porosity, particle size, temperature

PIE underway

HELIOS

MATINA 2-3 , CAMIX, COCHIX

Heterogeneous recycling – IMF irradiation behaviour (2/2)

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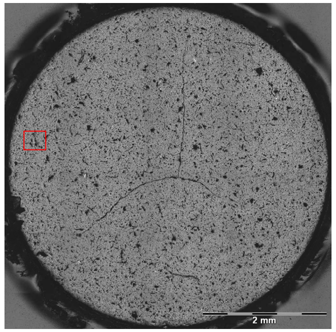
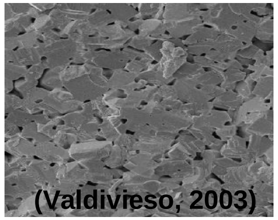
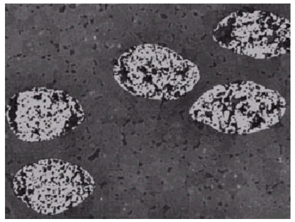
- Major outcomes:
  - MgO, Y-ZrO_2, Mo selected from MATINA 1 & 1A, THERMET, BORA-BORA, EFFTRA T4 & T4bis tests
  - ECRIX-H PIE on MgO - 16.5%$AmO_{1.62}$: good behaviour
    - Transmutation and fission rates: 94.3 and 24.9 at% (154 GWd/m^3)
    - 23% Helium release
    - Moderate swelling: 6.7 vol% for significant He production (5.8 mg/cm^3) and burnup
    - Maximum temperatures in IMF pellets between 700 and 800°C
    - Satisfactory microstructure after irradiation



- Next steps: PIE achievement to assess effects of
  - Tailored open porosity to promote He release (HELIOS pin 1: MgO-CERCER)
  - Large fissile particles to prevent FP damage in IM (MATINA 2-3, COCHIX)
  - High temperature operating conditions (>1100°C) to promote He thermally driven release and IM radiation damage recovery (MATINA 2-3, CAMIX, HELIOS pin 3: $(Pu,Am,Zr,Y)O_{2-x}$, HELIOS pin 5: Mo-CERMET)


(Valdivieso, 2003)



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- Progress status:
  - Feedback + synergy / IMF developments
  - European Projects: FUTURE -> EUROTRANS -> FAIRFUELS (on-going)
  - Reference candidates : CERCER ↔ (Pu, MA)O_{2-x} + MgO
    CERMET ↔ (Pu, MA)O_{2-x} + ^{enr}Mo
    (Pu,MA,Zr)O_2 solid-solution as an alternative
  - 2 irradiation tests achieved on Am-bearing fuels :
    - HELIOS (HFR)
    - FUTURIX-FTA (PHENIX)
      - Collaboration CEA-DOE-EURATOM-JAEA
      - Comparison of oxide, nitride and metallic fuel behaviour in ADS representative conditions

Pin	composition	Am (g/cm3)	TRU (g/cm3)	LHR (W/cm)	Burnup (at%)
5	$Pu_{0.8}Am_{0.2}O_{2-x}$ + 86%vol Mo	0.3	1.3	130	18
6	$Pu_{0.23}Am_{0.25}Zr_{0.52}O_{2-x}$ + 60%vol Mo	1.0	1.8	130	13
7	$Pu_{0.5}Am_{0.5}O_{2-x}$ + 80%vol MgO	1.0	2.0	100	9
8	$Pu_{0.2}Am_{0.8}O_{2-x}$ + 75%vol MgO	1.9	2.5	90	6

-> PIE on oxide fuels underway within the project FAIRFUELS (2009-2013)

Heterogeneous recycling – MABB irradiation behaviour

- **Major issue / (MA,U)O2 fuels:**

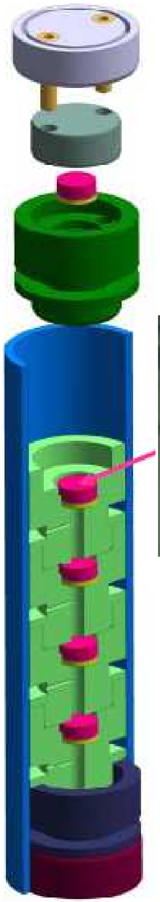
  Fuel Cladding Mechanical Interaction risk to prevent, related to high He production (up to 7mg He/cm^3) & moderate irradiation temperature (700-1100℃) under normal operating conditions

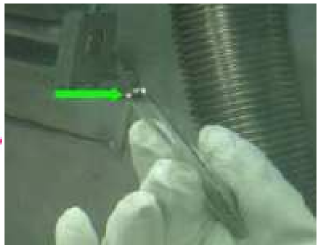
- **Phase 1 / experimental program:**

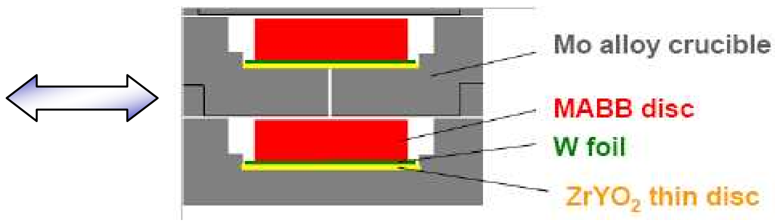
  Separate-effect irradiation tests to investigate He release and $(Am,U)O_{2-x}$ pellet swelling versus: Am content (7.5-15%), pellet microstructure (high and low density) and temperature (600-1200℃)

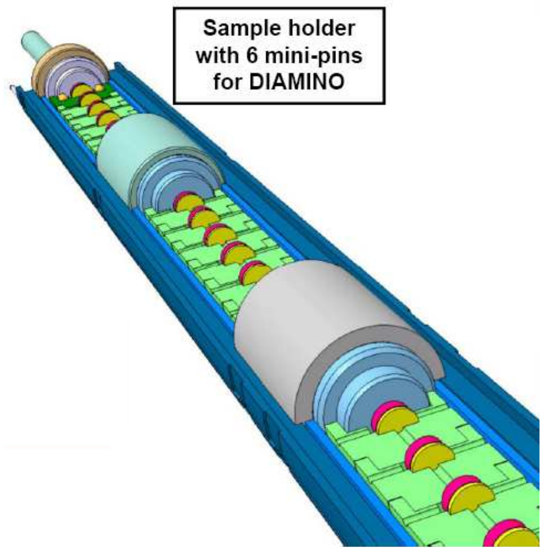
-> MARIOS within FAIRFUELS: in pile in HFR since March 2011 for 310 EFPD

-> DIAMINO: under preparation for irradiation in OSIRIS









Fabrication of MA-bearing fuels (within the project FAIRFUELS)

- 2 examples:

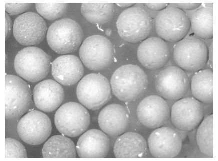
- SPHERE irradiation preparation (ITU):
  Fabrication of $(U,Pu,Am)O_{2-x}$ pellets
  from Am-infiltrated $(U,Pu)O_2$ beads

- MARIOS irradiation preparation (CEA):
  Fabrication of $(U,Am)O_{2-x}$ disks

PuO_2 Lab

$U_{dep.}$ nitrate solution+^{242}Pu nitrate solution

Conversion by gelation



Calcination → $(U,Pu)O_2$ beads

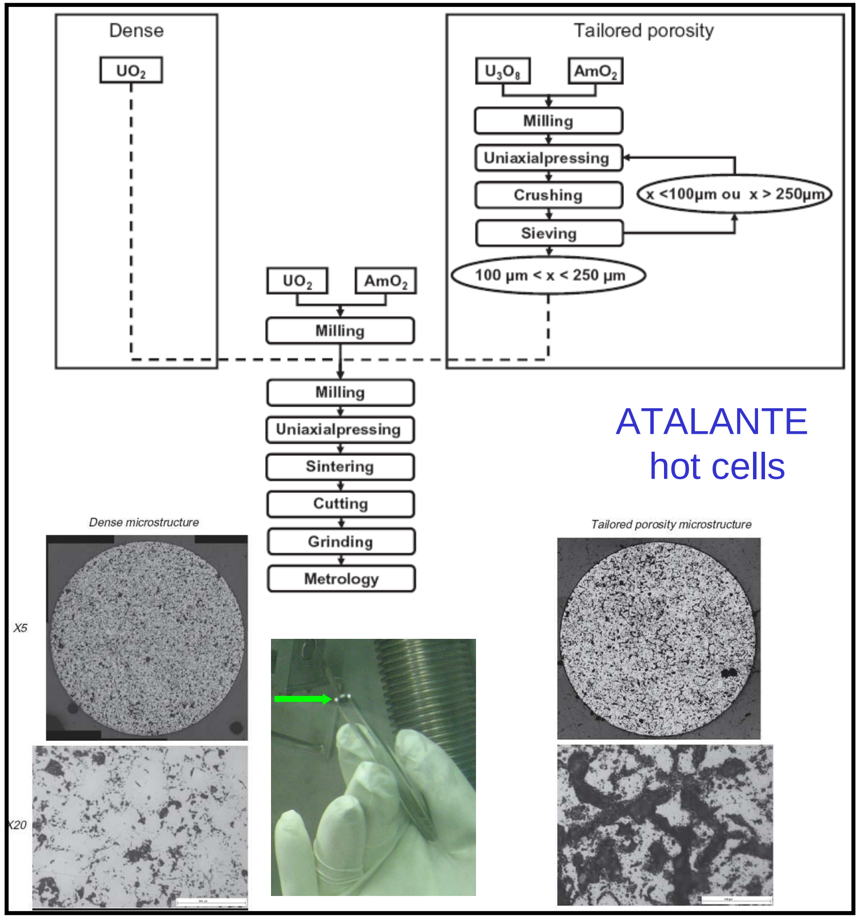
MA Lab

Infiltration ← Am nitrate solution

Calcination → $(U_{0.78},Pu_{0.18},Am_{0.04})O_{2-x}$ beads

Compaction

Sintering →



ATALANTE hot cells

Summary

- **Progress in Transmutation Technology with Oxide-fuelled FR Cycle**

  – Homogeneous recycle:
    - A technically sound approach reinforced by national and international programs
    - An appropriate readiness level to consider irradiation tests from pin to bundle scale within the GACID project under the GIF umbrella
    - A fuel qualification and demonstration last step in ASTRID?!

  – Heterogeneous recycle:
    - IMF: a comprehensive database thank to ~35 experiments in MTRs & PHENIX and promising results to be completed by Post-Irradiation Examinations on optimized microstructures
    - ADS fuels: a very informative feedback from IMF developments, completed by dedicated collaborative programs, including 2 major irradiations in the fuel performance assessment: HELIOS and FUTURIX-FTA
    - MABB: a first step in the fuel development long-term process, with MARIOS & DIAMINO tests in HFR and OSIRIS, before prototypic environmental experiments in MTR (ATR, HFR, JHR) and later in ASTRID.