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CHALLENGES RELATED TO MINOR ACTINIDE BEARING FUELS

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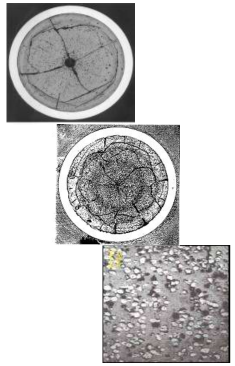
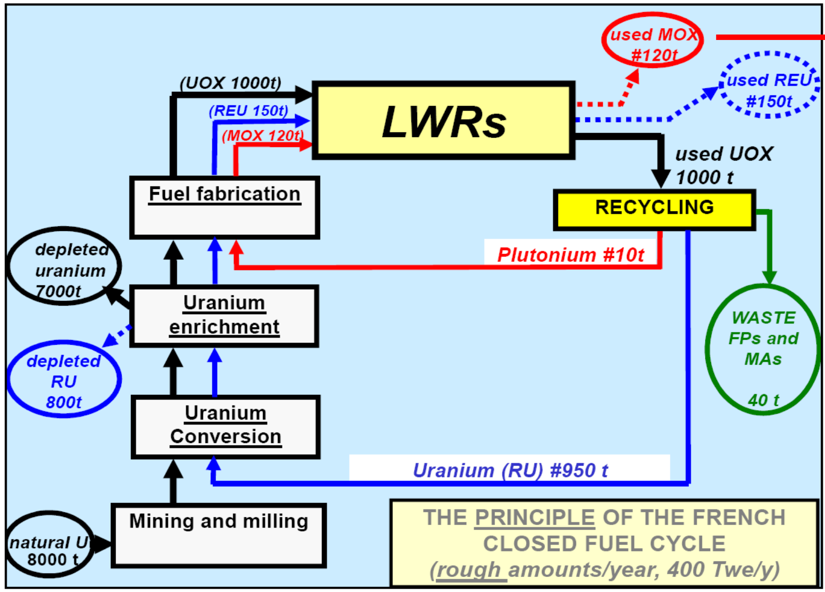
OUTLINE OF THE PRESENTATION

- The context for transmutation
- **The specifities** of MA bearing fuels
- Knowledge from irradiation experiments
  - Fast reactor : **homogeneous** transmutation mode
  - Fast reactor : **heterogeneous** transmutation mode
  - **Oxide** / metal, carbide or nitride
- **Fabrication** of MA bearing fuels
- **Modeling of** MA bearing fuels
- Conclusion



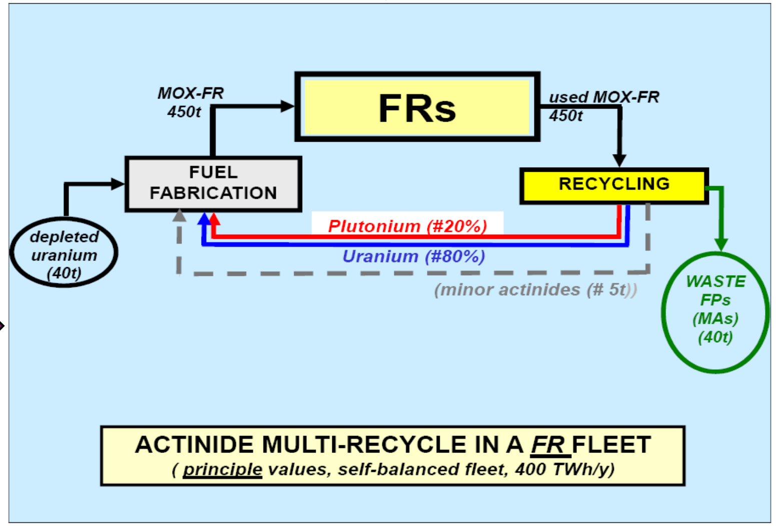
FROM LWR RECYCLING TO FR RECYCLING



1. **Pu stored in MOX LWR spent fuel recycled** in MOX SFR to start the SFRs deployment
2. **MA recycled in SFR**

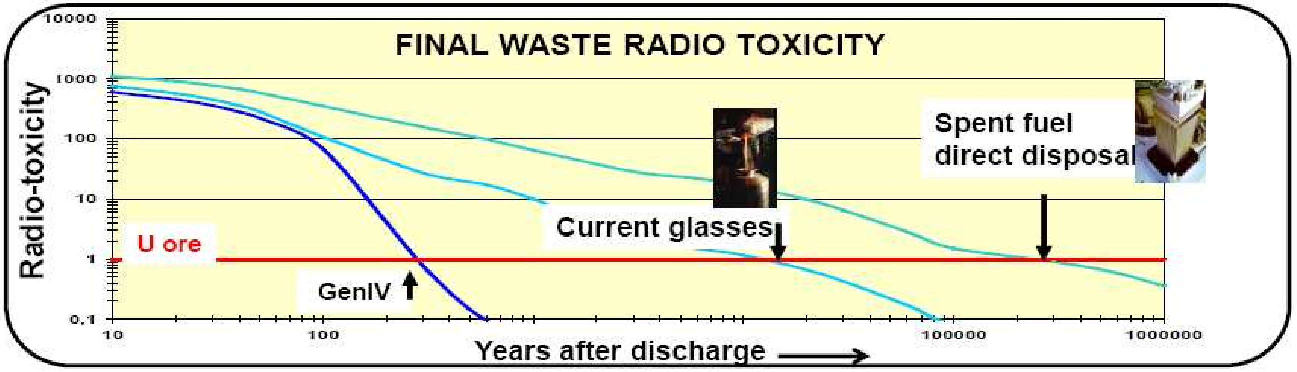
- **Scenarios have to be flexible**

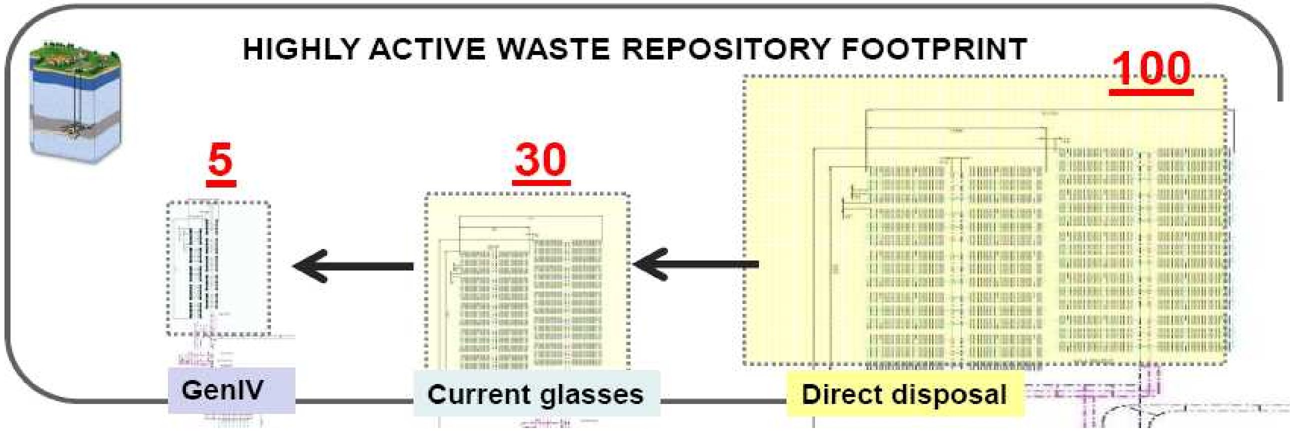
Both systems can coexist during a transition phase



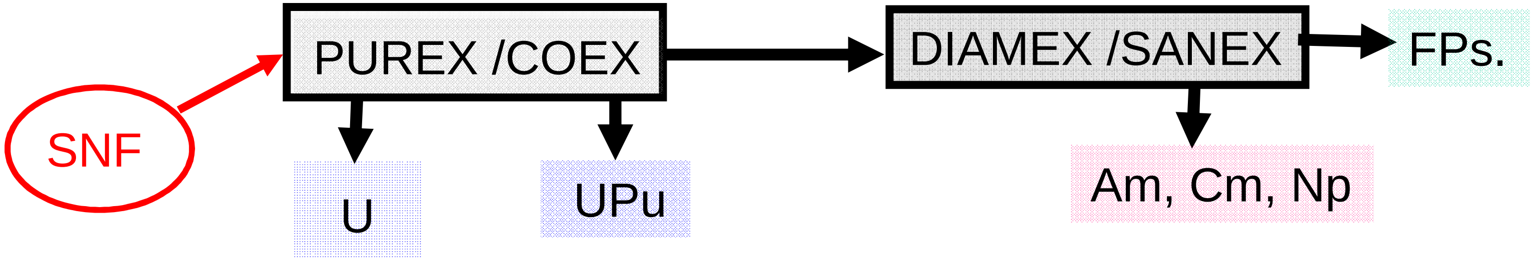
GENERATION IV SYSTEMS WASTES

Transmutation with GEN IV Fast Reactor systems will allow to avoid MAs in the waste repository : significantly lower radio-toxicity life time and lower footprint





MA PARTITIONING AND TRANSMUTATION



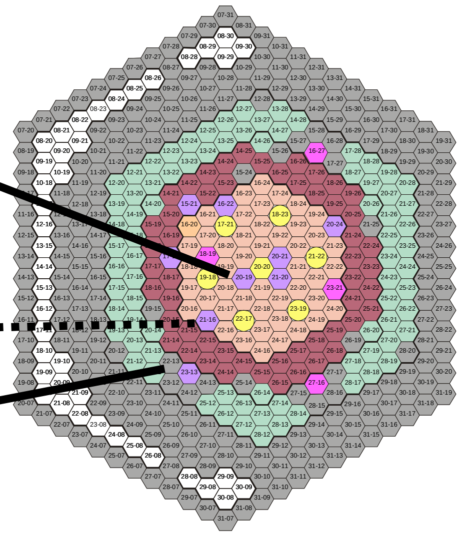
Innovative partitioning processes based on the design of new extractants

MA recovery processes have been successfully experimented, (kgs-scale, genuine spent fuel)

HOMOGENEOUS **# 2% MA diluted in the fuel**

HETEROGENEOUS:

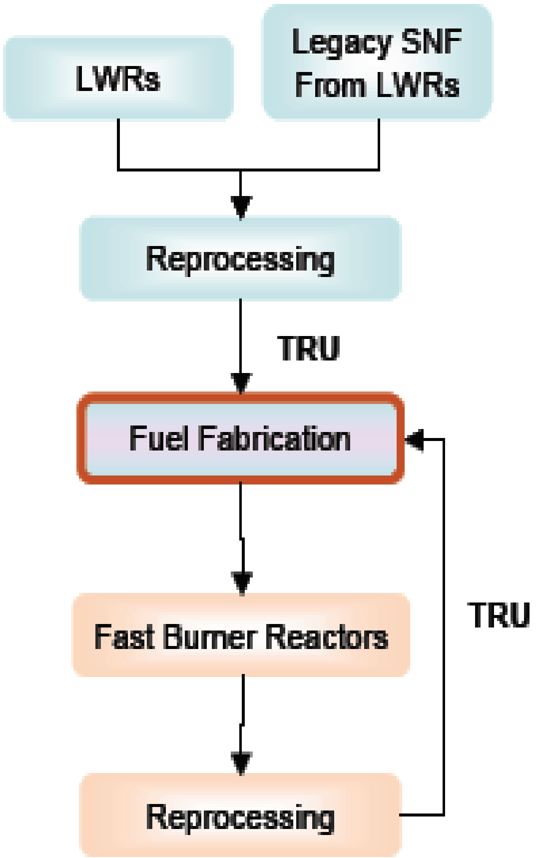
- **« once through targets » (inert matrix)**
- **multi-recycled «MA bearing blankets » (# 10-20% MA on UO_2)**



THE SPECIFICITIES OF MA BEARING FUELS

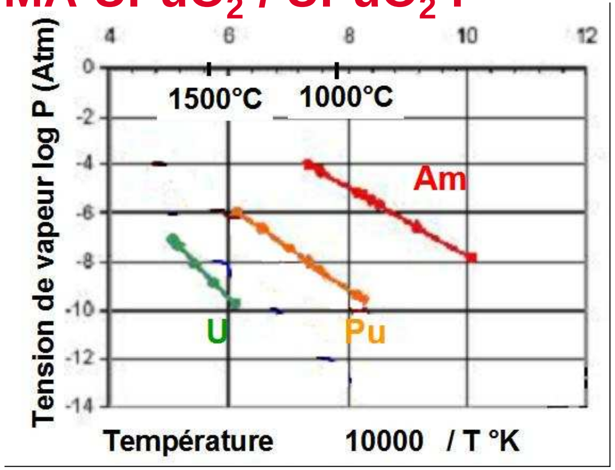
Transmutation fuel development is considerably more challenging than for conventional fuels :

- Multiple elements in the fuel
  - U, Pu, Np, Am, Cm
- Varying thermodynamic properties
  - e.g. High vapor pressure of Am
- Impurities from separation process
  - e.g. High lanthanide carryover
- High burnup requirements
- High helium production during irradiation
- Remote fabrication & quality control
- Fuel must be qualified for a variable range of composition
  - Age and burnup of LWR SNF
  - Changes through multiple passes in FR
  - Variable conversion ratio for FR



THE SPECIFICITIES OF MA BEARING FUELS

- **Thermal, physics and chemistry properties of MA-$UPuO_2$ / $UPuO_2$:**
  - **Melting temperature : lower**
  - **Thermal conductivity : lower**
  - **Volatility : higher**
  - **Oxygen potential : higher**



- **Thermal and radio toxicity conditions :**
  - **Thermal power : higher :**

    Pth MA target = ~10 x Pth LWR-MOX
  - **Neutron emissivity : higher : MA target = ~2000 x LWR-MOX**

- **High He production : alpha decay of 242Cm**

  , coming from beta decay of 241Am

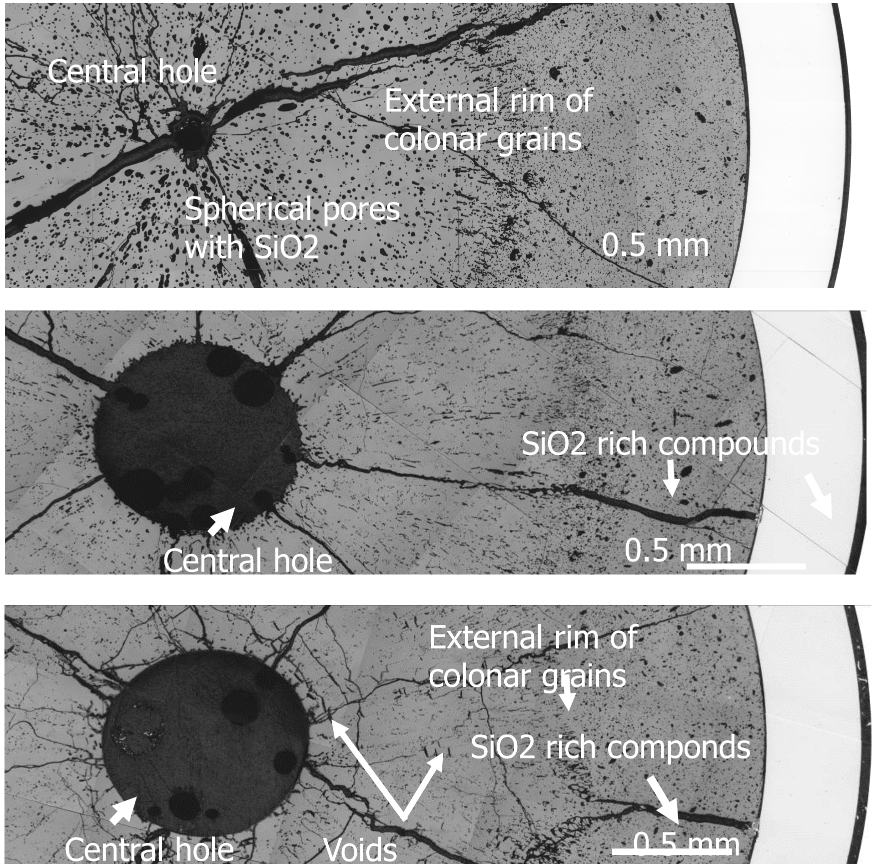
⇒ **MAs recycling has impacts on :**

- Fabrication, handling, transport, control,… conditions

- In pile behavior

MA BEARING FUEL FOR HOMOGENEOUS RECYCLING : IN FR PILE BEHAVIOR

- **Am1 in JOYO :**
  - $U_{0.67}Pu_{0.29}Am_{0.02}Np_{0.02}\ O_{1.98}$
  - P_{LIN} = 416 to 430 W/cm
  - Irradiation : 10 minutes, and 24h



O/M 1.98

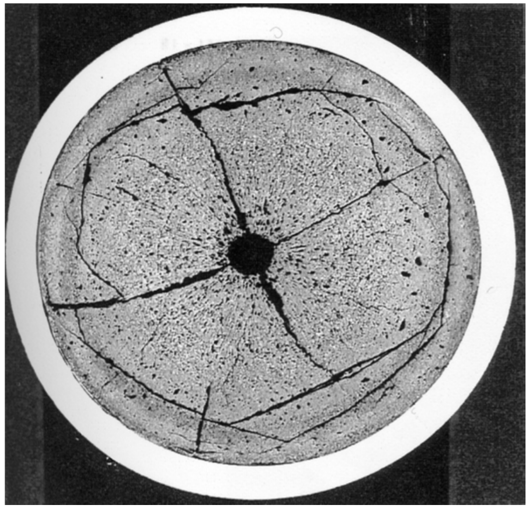
O/M 1.95

First test, 10 min
- SiO_2-MOX precipitates (around the central hole)
- Formation of spherical pores, moving to the center

Second test, 24 h
- SiO_2 rich compounds, next to the cracks
- Formation of holes, moving to the center
- Large central hole is formed

MA BEARING FUEL FOR HOMOGENEOUS RECYCLING : IN FR PILE BEHAVIOR

- **SUPERFACT homogeneous** transmutation mode in SFR Phénix :
  - $U_{0.74}Pu_{0.24}Am_{0.02}O_2$ and $U_{0.74}Pu_{0.24}Np_{0.02}O_2$
  - 382 efpd, P_{LIN} = 380 to 325 W/cm
  - Burn up = 6.7 at%



- **Transmutation rate** at mid plan **:**
  28% for 241Am, and 30% for 237Np

- U, Pu, Am and Np radial concentration profiles are very flat : **no specific redistribution of MAs**

- **Microstructure evolution is similar to UPuO2**

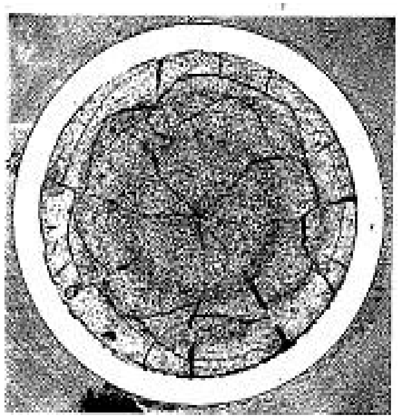
For still limited power and burn up, **no influence of the MAs concentration on in-pile behavior, except for the He gas release (4 times higher / UPuO2)**

MA BEARING FUEL FOR HETEROGENEOUS RECYCLING : IN FR PILE BEHAVIOR

- **SUPERFACT heterogeneous transmutation mode in SFR Phénix :**
  - $U_{0.6}Am_{0.20}Np_{0.20}O_2$, 4 g MA/cm^3
  - 382 efpd, P_{LIN} = 174 to 273 W/cm
  - Burn up = 4.1 at%

- **Limited restructuration of the fuel :**
  - Limited fuel-cladding interaction
  - "Cold" fuel : no formation of central hole
  - **High He production and retention**

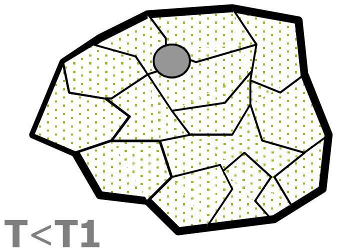
No formation of central hole



mm^3/g fuel	Xe Kr	He
Standard $UPuO_2$,6at%	1220	40
$UAmNpO_2$, 4at%	764	2970

- In a "cold" fuel, **the He behavior in the UO_2 matrix has to be carefully studied** (potential clad failure under operation)

MA BEARING FUEL FOR HETEROGENEOUS RECYCLING : IN FR PILE BEHAVIOR

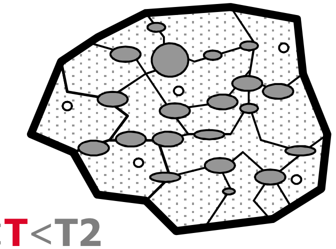


T<T1

500 to 700°C

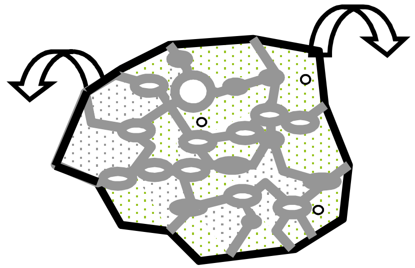
- **Low matrix swelling** : He atoms isolated and no mobile

MA bearing blanket



T1<**T**<T2

- **Potential significant swelling**
- ***Fuel–clad interaction risk***



T2<T

1100 to 1400°C

- Moderated swelling due to high He release

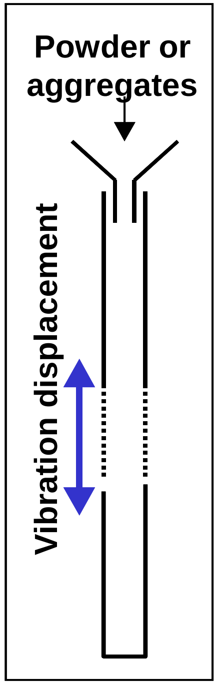
- Conditions of **swelling-release** has to be known quantitatively , in **order to design an heterogeneous MA transmutation pin** :
  - On going experimental program (in the HFR and Osiris MTRs, with UO_2 matrix + Am concentrations, **open/closed porosity**) in order to obtain **experimental data in support of fuel design**
  - Second experimental phase : **for optimizing the microstructure**
  - Third phase : **high burn up experiments of representative fuel** elements under operating and qualifying conditions

POSSIBLE TRANSMUTATION FUEL

- Mixed (U,Pu): Oxide (SFR, GFR, LFR…) versus
  Carbide (GFR, …), Nitride (SFR), Metal (SFR, …)

- Two different technologies:
  - Hydrometallurgy: powders to pellets in fuel pin
  - Pyrochemistry:
    - well adapted to metal fuel
    - aggregates by Vibropack in fuel pin
    - metal fuel casting

U-29PU-4AM-2NP-30ZR METAL FUEL CASTING
4.9 MM DIAMETER CAST



OXIDE VERSUS METAL, CARBIDE OR NITRIDE ?

- **Metal :**
  - A satisfactory option for SFR, good knowledge in USA
  - Large on going experiment program in US Labs, using Idaho-ATR (UPuAmZr) and SFR Phénix (PuAmZr)

- **Carbide :**
  - An option for SFR, “almost” reference for Gas cooled GFR
  - UPuC knowledge in Europe (limited) and in India (large)
  - No irradiation tests so far of MA-UPuC
  - Pyro phoricity of divided carbide materials

- **Nitride :**
  - An option for SFR, UPuN knowledge in Japan, Europe and USA
  - Complexity of fabrication process (carbothermic reduction, N15 enrichment ?)
  - MA-nitride stability as a function of temperature
  - PuAmZrN and PuAmN irradiated in SFR Phénix

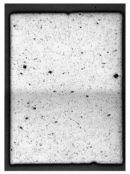
Laboratory scale process

- **Synthesis of MA compound powders**, starting from separated MA nitric solution (interface co-conversion)
- A promising process : **the oxalic co-precipitation**, calcination, then direct-powder or UO_2-diluted powder pelletizing

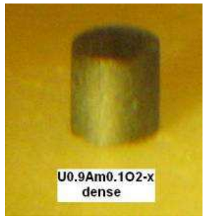
Pu

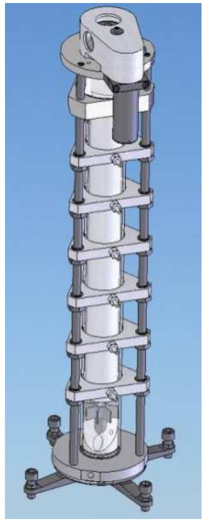
U and Pu

COPIX $(UPu)O_2$ irradiation test in Phenix, 2008-2009



U, Pu, Np, Am,..Cm





- **Characteristics of the powders** : physico-chemistry, purity, flowability, **sintering properties**,…
- **Technology :** continuous precipitation apparatus: vortex effect, pulsed column,...
- **Remote handling operations**

(TRANSMUTATION) FUEL MODELING

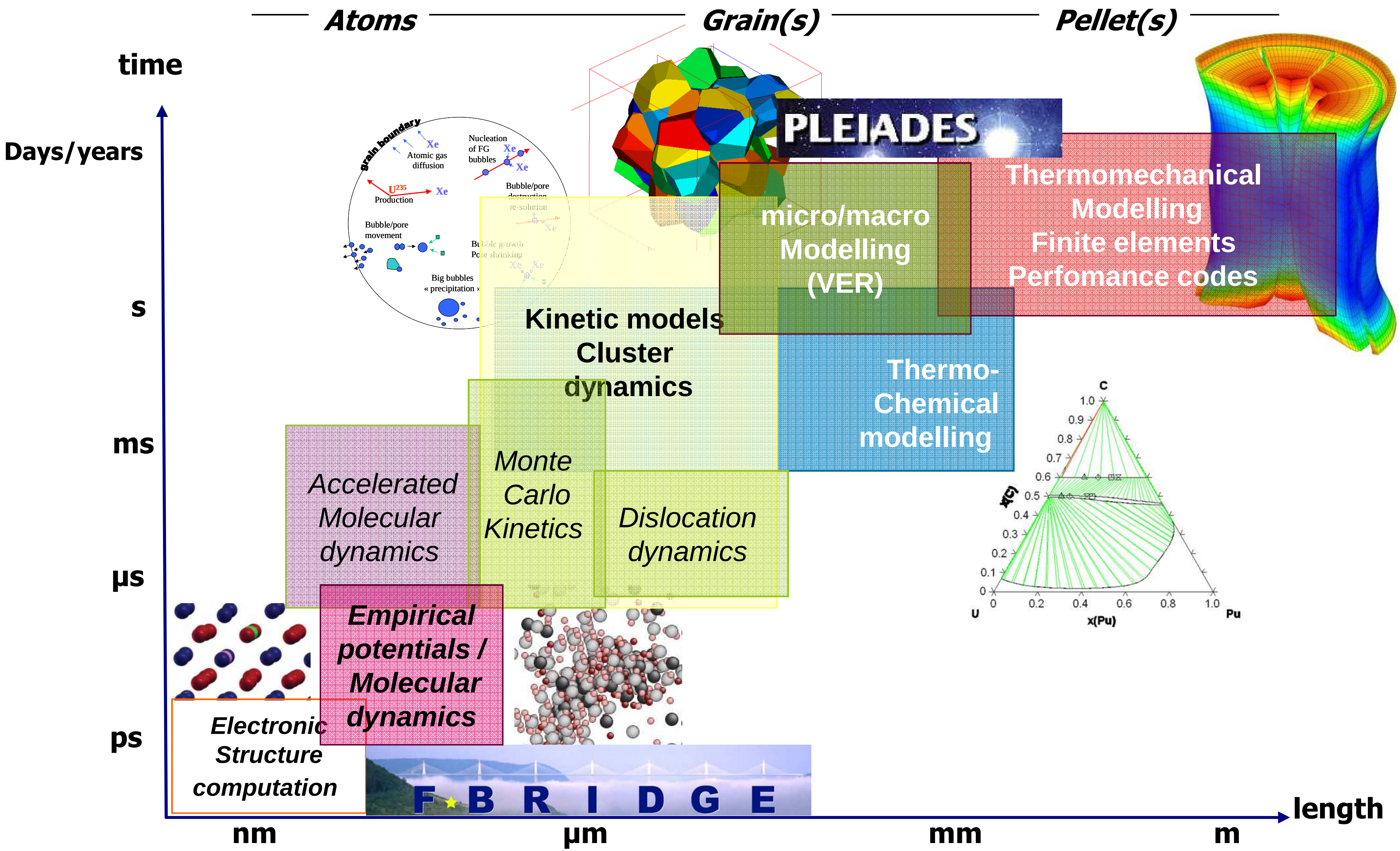
Fuel performance prediction requires understanding of multiple phenomena :

- Thermal conductivity
- Thermal expansion
- Specific heat
- Phase diagrams
- Fission gas formation, behavior and release
- Materials dimensional stability
  - Restructuring, densification, growth, creep and swelling
- Defect formation & migrations
- Diffusion of species
- Radial power distribution
- Fuel-clad gap conductance
- Fuel-clad chemical interactions
- Mechanical properties

Dynamic properties:
Changes with radiation effects, temperature, and time

Nonlinear effects
Initial condition dependence (fabrication route)

(TRANSMUTATION) FUEL MULTI-SCALE MODELING



CONCLUSION

- **Homogeneous** transmutation mode :
  - Satisfactory in pile behavior, "similar" to standard $UPuO_2$
  - Irradiation tests at high burn up still necessary (Monju, ASTRID,…)
  - **Towards the qualification**, at pin scale

- **Heterogeneous** transmutation mode :
  - In pile behavior still to be fully known
  - Concept to be optimized : microstructures, pin design, irradiation conditions,…
  - **In pile irradiations : data, feasibility** (HFR, Osiris, ATR, Joyo, RJH, Monju, ASTRID,…) ; **EC projects**

- Accuracy and validation of **nuclear data**

- **Fabrication operation : remote handling** operations at significant scale

- **Modeling** development

- **Curium issue ?**

Thank you for your attention

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Direction de l'Energie Nucléaire