Oxide fuels and targets for transmutation

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Introduction

- Direction 1 of the Act dated 30 December 1991 on the management of High Level, Long-Lived radioactive waste
- ➢ Explore solution to separate and transmute them into stable elements or elements with much shorter half-life
- Main radioactive elements
  - ✓ Fission Products: Caesium, iodine and technetium
  - ✓ Minor Actinides: Americium, Neptunium, Curium
- CEA launched a vast programme to demonstrate the scientific and technical feasibility of minor actinide transmutation:
  - In MOX fuels (homogeneous method) in PWR and Sodium-cooled fast reactor
  - On Inert Matrix support (heterogeneous method)
  - In Sub-Critical reactor dedicated to transmutation

Evaluation of Homogeneous Transmutation in a PWR

• Simulations made in 2002 :

	MOX	MOX-UE
Pu/ML (%)	9,026	8
U5/U (%)	0,25	4,3
AM/ML (%)	0	1,13
Burn up	60 GWd/tHM	
Xe+Kr produced (mm^3/g ox)	1250	1400
He produced (mm^3/g ox)	110	510
Internal Pressure (bar)	105	213

Above 100 mm^3/g, He is fully released

⇨ **<u>Internal pressure incompatible with the current design of EPR rods</u>**

(but there is no experimental data on gas release for MA fuels in PWR)

⇨ **Possible solutions**

- ✓ Reduce the americium content (around 0.5 %)
- ✓ Reduce the initial internal He pressure into the rod (efficiency against He release ?)
- ✓ Reduce the height of the fuel column (5 % : Impact on the reactor functioning to be evaluated)

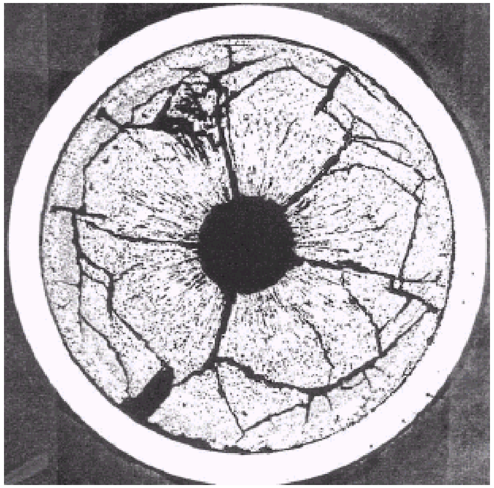
Evaluation of Homogeneous Transmutation in a FNR

- Nacre
  - A SuperPhénix S/A including Np (2%) in the fuel has been successfully manufactured
- Trabant (CEA, ITU, FZK)
  - Irradiation in HFR (Pu = 40 % and Np = 5 % ; BU = 9.3 at%)

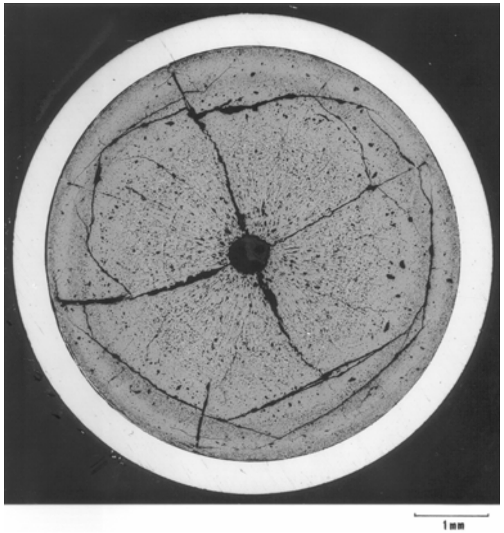
⇨ **Fuels containing neptunium behave as satisfactorily as the standard SFR fuel**

- SUPERFACT 1 (CEA, ITU)
  - Irradiation in PHENIX (Am = 2% and Np = 2 % ; BU = 6.5 at% ; Transmutation rate for MA = 30 %)

⇨ **First pin scale demonstration of the technical feasibility of the homogeneous-mode transmutation of the minor actinides in FNR**



Trabant



SUPERFACT

Transmutation in Heterogeneous mode

Inert Matrix: Introduction

- Dilution of MA into Inert Material = Target
  - ⇨MA content : 1.5 to 2.5 $g.cm^{-3}$
  - ⇨Main issues to be studied
    - ✓Materials : actinides compound and inert matrix
    - ✓Damages due to FP recoil
    - ✓Excessive swelling due to He production
- Materials for inert matrix
  - ✓High Thermal conductivity after material damaging
  - ✓Low swelling induced by neutrons and FP damaging
  - ✓High melting point
  - ✓**No chemical interaction** with actinide compounds, clad and coolant

⇨ **First selection** (Bibliography, out of pile measurements):

MgO, ZrN, TiN, Cr, V, Mo, Al_2O_3, $MgAl_2O_4$, $Y_3Al_5O_{12}$, St-ZrO_2, CeO_2

Compatible with Sodium — Compatible with Water

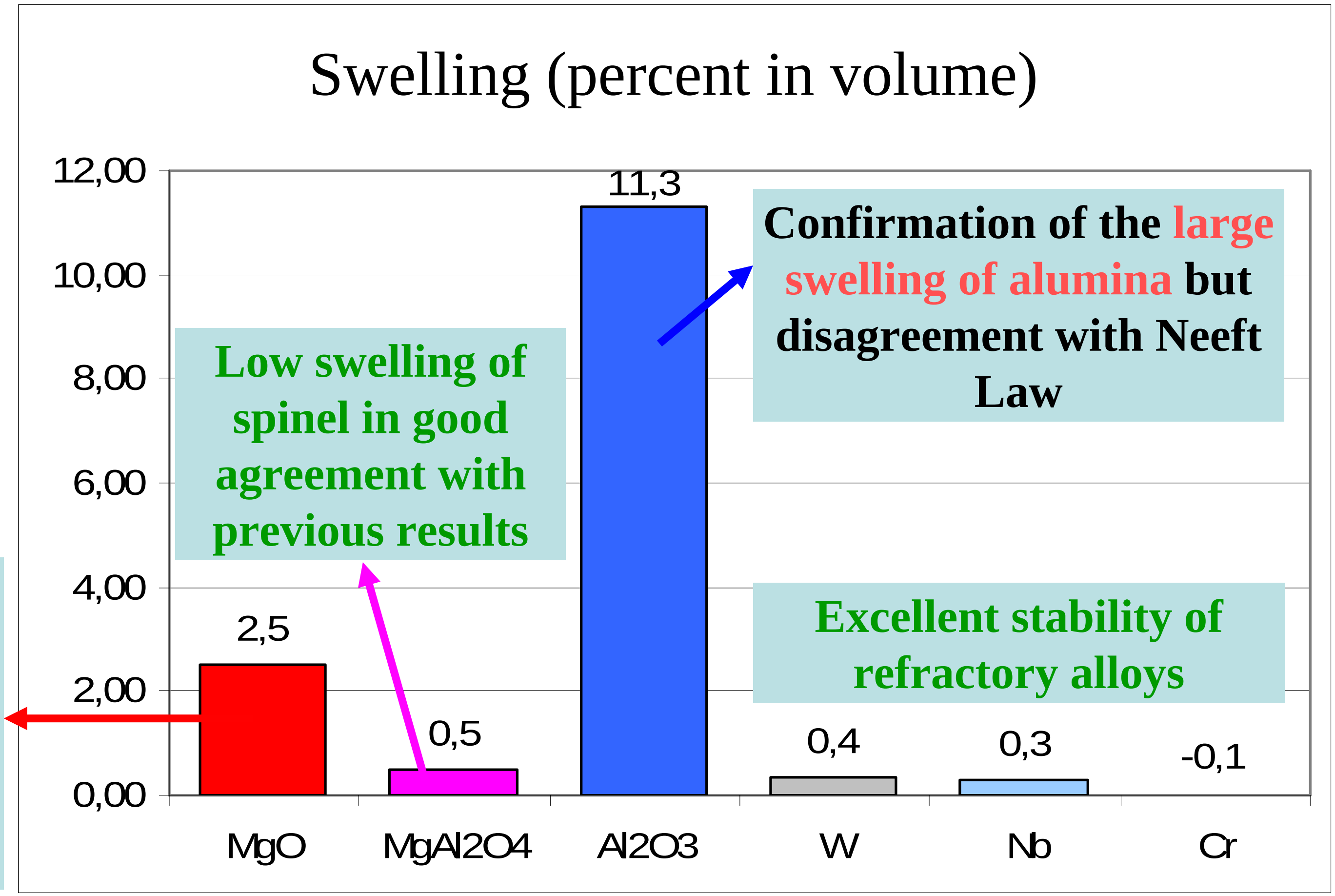
⇨ **Irradiations**

✓Inert Matrices alone (neutron damaging): T2bis, SANTENAY, MATINA 1A

✓Inert Matrices with Fissile Compound (FP damaging): T3, THERMET, MATINA 1A

Synthesis of first MATINA 1A results:

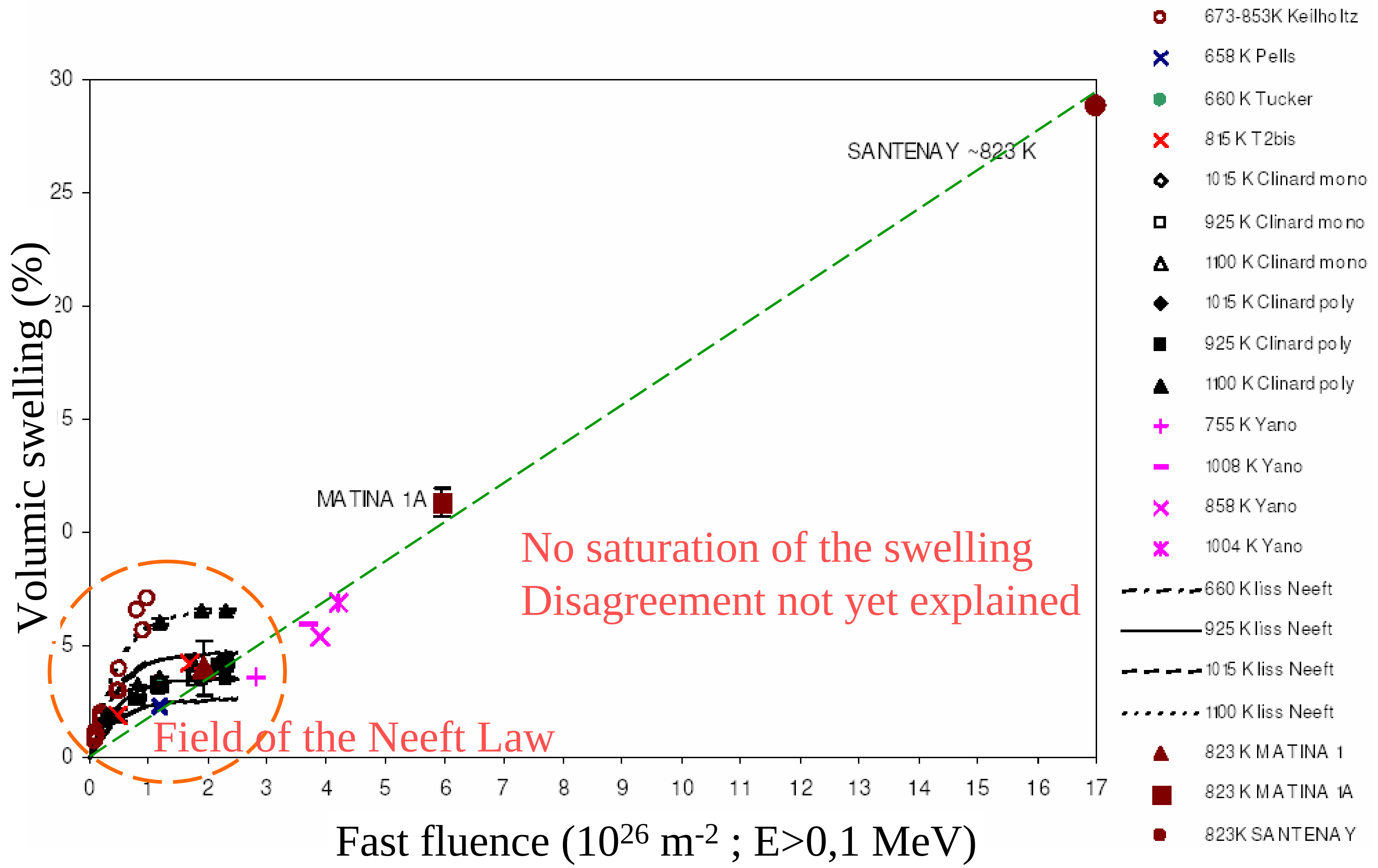
Swelling of inert matrices due to a fast fluence = 6.10^{26} neutrons.m^{-2}



First result on magnesia at such a neutron fluence ($6\ 10^{26}$ m^{-2} against $2\ 10^{26}$)

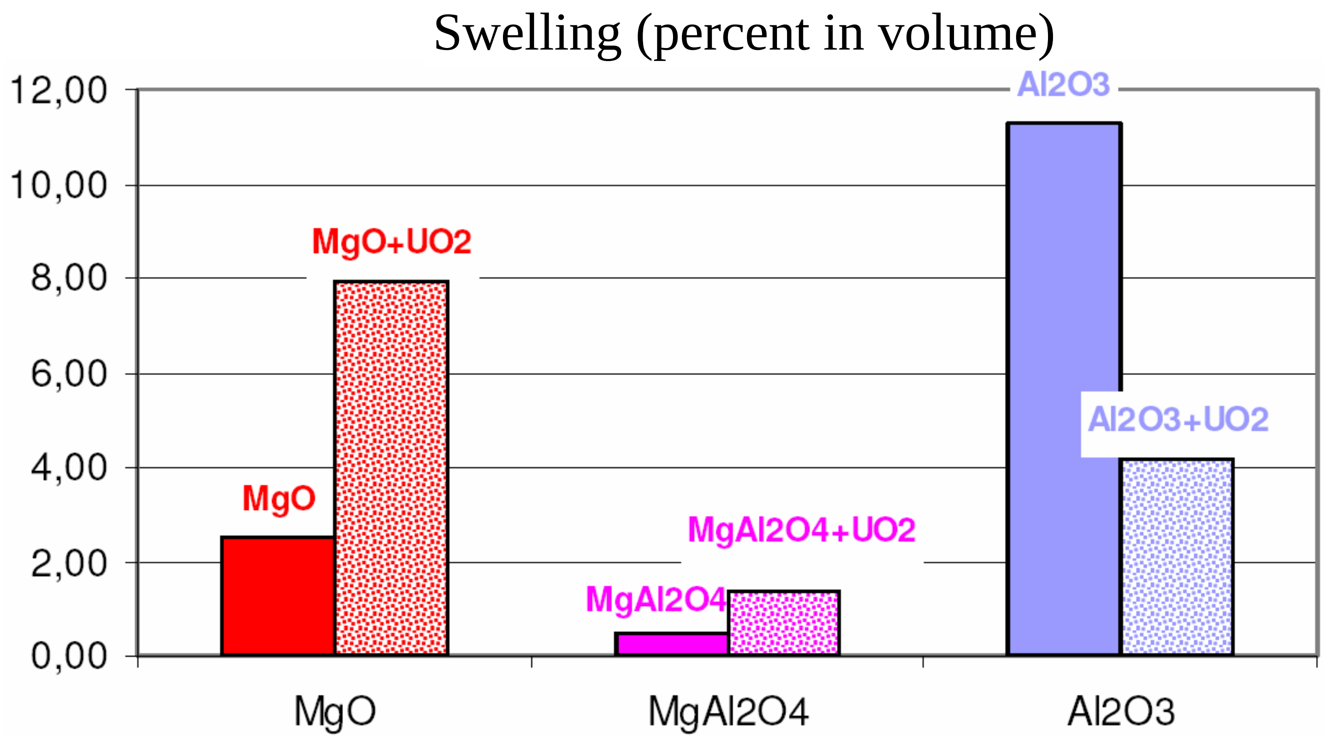
Transmutation in Heterogeneous mode

Swelling of **alumina** under fast neutron flux : synthesis



Synthesis of first MATINA 1A results:

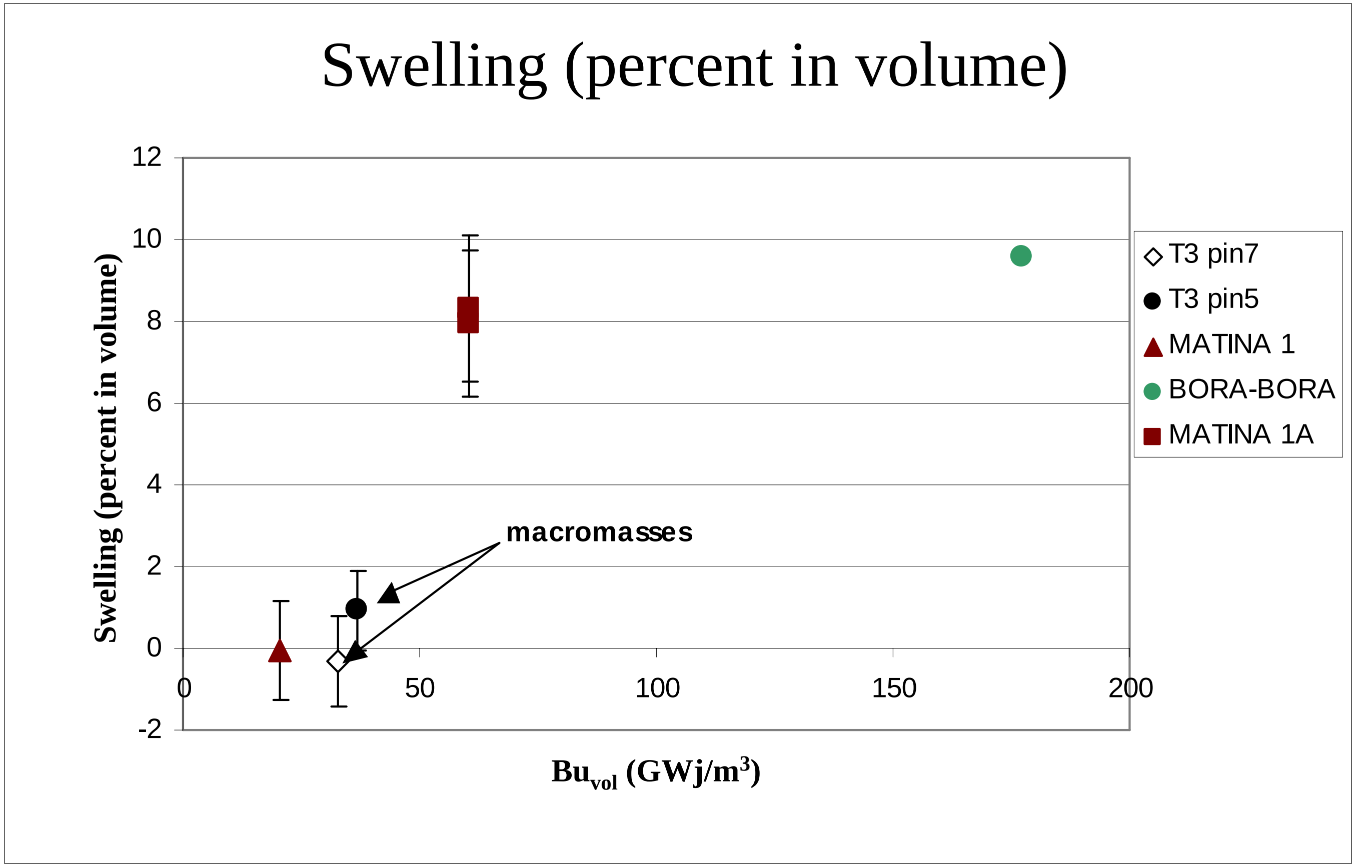
Swelling due to neutron flux and **Fission Products damages**



- Fission Products Damaging process is different from a matrix to another
- It seems
  - ✓ MgO : Sensitive to FP damaging
  - ✓ $MgAl_2O_4$: Good stability **at high temperature**
  - ✓ Al_2O_3 : Positive effect of the temperature (1400 °C with UO_2 against 550 °C without UO_2) : Damage annihilation ?

Swelling of **magnesia** due to neutron flux and Fission Product damages : synthesis

- **MATINA 1A and BORA-BORA** are results obtained by the CEA in 2005
- New **BORA-BORA** results expected in 2006 (BU_{vol} = 300 $GWj.m^{-3}$)
  - ⇨ Confirmation of the swelling "saturation" ?



Transmutation in Heterogeneous mode
Technical feasibility : ECRIX

Demonstration of the technical feasibility

⇨ Irradiation in representative conditions (coolant, neutron spectrum, …)

⇨ ECRIX Irradiation

✓ In Phénix, from March 2003 to March 2006

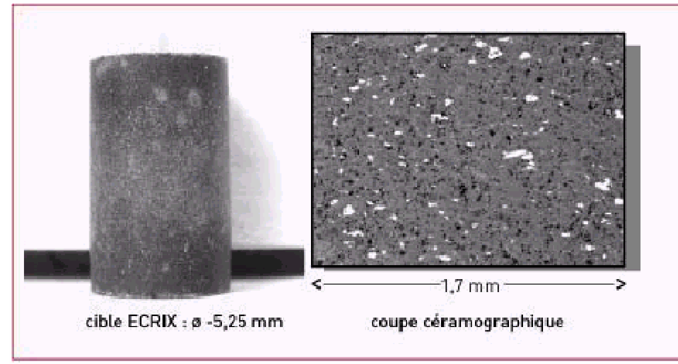
✓ $AmO_{1.6}$ micro dispersed into MgO

✓ Am = 0.7 $g.cm^{-3}$ (2.75 g of Am in 200 mm height column)

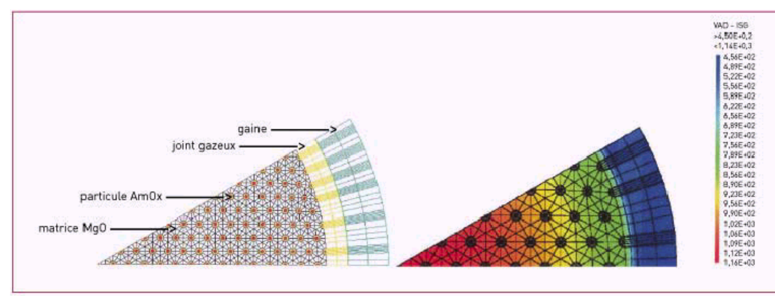
✓ Objective Fission Rate = 30 at% (≈ 90 % Transmutation Rate) → 35 at% have probably been reached

⇨ PIE results will probably allow to increase the performance of magnesia targets: Am amount and fission and transmutation rates

Target

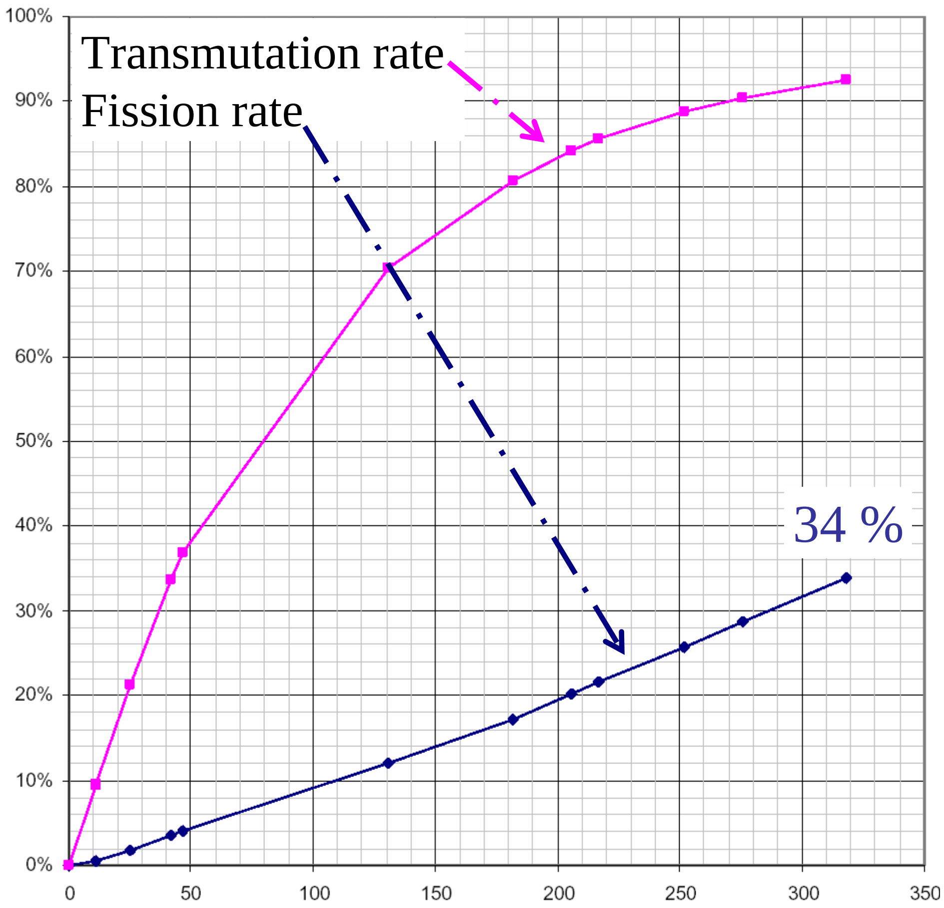


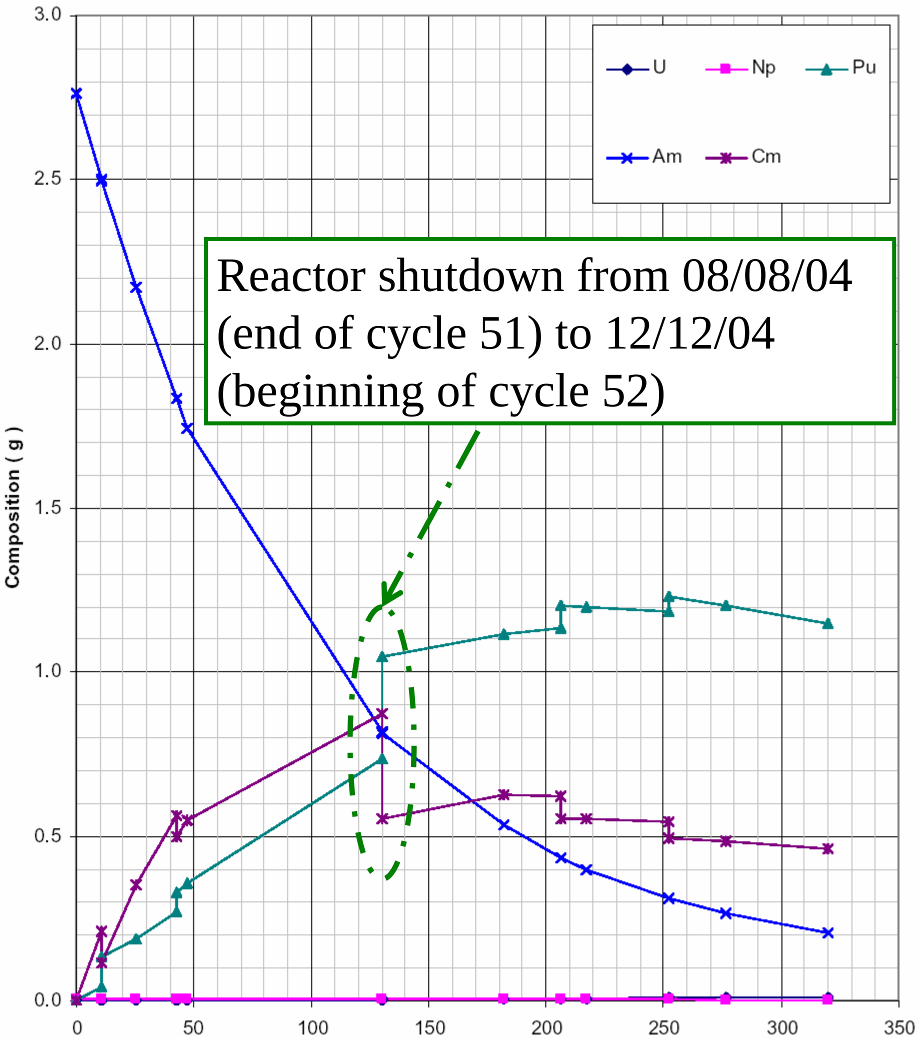
Thermo mechanical Model



Transmutation in Heterogeneous mode

ECRIX : Irradiation historic





Transmutation in Heterogeneous mode

Inert Matrix : Main achievements

- Selection of the most promising materials
  - ✓ MgO for FR
  - ✓ $(Zr,Y)O_2$ for PWR, FR…
  - ✓ $MgAl_2O_4$ discarded at low or intermediate temperature (amorphization)
- FP damaging: Possible solutions
  - ✓ High temperatures (1000 – 1200 °C): allow damage annealing
  - ✓ Macrodispersion: Actinide compounds dispersed under the form of 100 µm particles could limit the damaging of inert matrix
- He retention and swelling
  - ✓ After results from T4 and T4bis experiments (high swelling due to He bubbles accumulation in spinel)
    - ➔Results from ECRIX (34 % of Am transmutation rate in MgO)
    - ➔Development of porous target (HELIOS irradiation in HFR)
    - ➔Target operating at high temperature (T > 1000°C)

Transmutation in dedicated mode

➢ Fuel Design Criteria

- ✓ Multi-recycling : Average BU = 20-30 at%
- ✓ High MA content : > 3 g TRU/cm^3 & degraded Pu
- ✓ Inert matrix volume fraction > 50 vol%
  - To make easier the manufacturing
  - To keep the benefit of the inert matrix properties

➢ BORA-BORA

- ✓ Irradiation in BOR60 : 60 % PuN/ZrN ; 40 % PuO_2/MgO ; B.U. = 11 at%
- ⇨ **PIE results** : Good behaviour of the fuel element (pellet and cladding)
- ✓ Irradiation extension : 18.8 at% BU ⇨ PIE in progress

➢ FUTURIX/FTA (CEA-DOE-ITU-JAERI)

- ✓ Irradiation in Phénix from 2007 to 2008
- ✓ 8 types of fuel irradiated in the same conditions :
  - ✓ 2 Metallic with sodium bond (up to 1.2 $g.cm^{-3}$ of Am)
  - ✓ 2 Nitride with sodium bond (up to 2.7 $g.cm^{-3}$ of Am)
  - ✓ 2 Oxide CER-CER (MgO) Composite (up to 2.0 $g.cm^{-3}$ of Am)
  - ✓ 2 Oxide CER-MET (Mo) Composite (up to 1.0 $g.cm^{-3}$ of Am)

Conclusion

- Transmutation in Homogeneous mode : SUPERFACT 1 is a first pin scale demonstration of technical feasibility
- Transmutation in Heterogeneous mode :
  - ➢ Today
    - – MgO confirmed at the reference matrix, ZrO_2 (and Mo^{92}) is an alternative
    - – $MgAl_2O_4$ is discarded: not stable enough under irradiation at low Temp.
    - – ECRIX (Irradiation including Am): NDE are underway
    - ⇨ Demonstration of the pin scale technical feasibility
  - ➢ From 2008 to 2010 : Last Phenix Irradiations and PIE
    - ➔ Performance of the microdispersed concept: ECRIX
    - ➔ Influence of the target microstructure on FP damaging: MATINA 2-3 and COCHIX
    - ➔ Performances of the zirconia matrix: MATINA 2-3 and CAMIX
    - ➔ Influence of high temperatures on damage annihilation: MATINA 2-3
- Transmutation in sub-critical dedicated reactor → FUTURIX/FTA
  - – Irradiation: from 2007 to 2008
  - – PIE: from 2009 to 2010