Plutonium management, minor actinides partitioning and transmutation R and D in France

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Waste Management Research Program Direction

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Presentation lay out

- **Introduction**
- **Plutonium management**
  - The french plutonium strategy
  - Pu inventory ; scenarios and cycle performances
- **High Level Long Lived Waste management**
  - Partitioning
  - Transmutation
- **Conclusion**

Introduction (1)

Multiple recycling of plutonium in PWR for minimising long-lived radioactive waste and proliferation risks

Two main objectives :

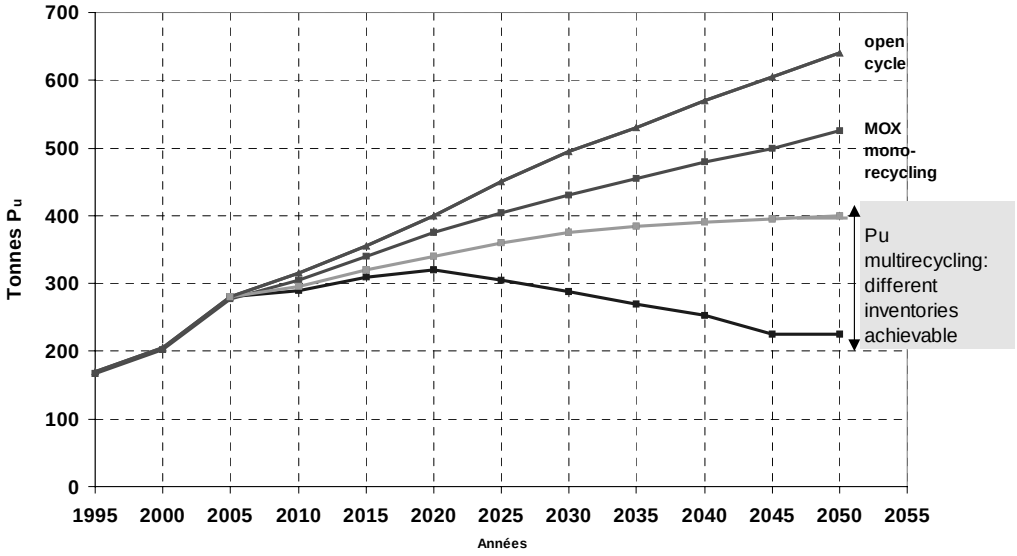
Control of plutonium stocks generated by operating french PWRs

- ✓ Pu consumption and waste minimisation

➔ Recycling of actinides (Plutonium, Minor Actinides)

Introduction (2)

Control of Plutonium stocks in today's french PWRs (400 TWh/yr)



Introduction (3)

The R&D needs for multiple recycling of plutonium in PWRs :

➔ Development of fuels

- at acceptable economic conditions
- with the possibility of simultaneous recycling of Minor Actinides

➔ Advanced fuels and appropriate fuel fabrication and reprocessing technologies

Introduction (4)

1991 : A french law on HLLL* radioactive waste

- The rights of future generations are recognised
- A 15 years moratorium on any geological disposal until a new law is issued
- A research programme is launched :
  - Geological disposal
  - Conditioning and long term storage
  - Radiotoxicity reduction by Partitioning and Transmutation
- Public consultation must be implemented

* High level long lived

The French plutonium strategy (1)

- Initially, plutonium extracted from irradiated fuel in PWR was meant for LMFBRs.

  A fast neutron spectrum was and still is, indeed, the most efficient option for:

  – Economics of neutrons
  – Use of natural resources
  – Reduce the quantity of actinides in final waste

The French plutonium strategy (4)

- In the long term, to achieve a sustainable energy development

  – Safe
  – Competitive
  – Non proliferating
  – Making best use of natural resources
  – And minimizing the ultimate waste

  (mass, volume, decay heat and radio toxicity as a function of time)

- CEA is developing a new technological range based on gas cooled reactors and the associated fuel cycle

The French plutonium strategy (5)

- The main periods:
  - Before 1975: the “heroic” period
  - 1975 – 1985: toward an industrial recycling
  - 1985 – 2000: confirming the first options
  - 2000 – 2015: improving the single recycling
  - After 2015: toward a multi recycling **CORAIL**
  - After 2025: improving plutonium cycle **APA**

Conclusion on Pu management

- ➔ Pu multirecycling in PWR with advanced fuels has multiple advantages
  - ➢ Optimisation of use of natural resources and energy extracted
  - ➢ Control of Plutonium inventory
    - ➢ Almost no Plutonium out of cycle
    - ➢ Concentration of Plutonium in a limited quantities of fuel rods (APA)
- ➔ The CEA, in very close cooperation with the concerned industries (Framatome-ANP, EdF, COGEMA), is carrying out active R & D to improve cycle management performances through
  - ➔ continuation of existing technologies (**CORAIL**)
  - ➔ the use of more innovative solutions (**APA**)
- ➔ Isotopic degradation of Plutonium – and increased production of MA – due to multirecycling limit risks of proliferation
- ➔ If needed, MA could also be recycled in PWR as well as Pu, in order to minimise radiotoxicity impact and also proliferation risk

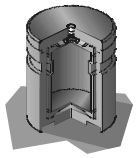
High Level Long Lived Waste management (1)
Existing radioactive waste in France

Short-lived low and medium activity ~ 1 million m³
For the current nuclear power plant park

~ 90 % of the total volume of waste produced in France,
<1% of the radioactivity.

Are subject to final disposal under current regulations

Intermediate level long lived waste ~ 50 000 m³ in 2020
< 10 % of the total volume of waste,
<10% of radioactivity



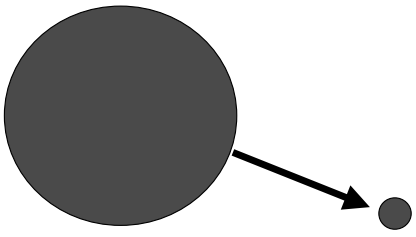
High level long lived waste ~ 5 000 m³ in 2020
~ 1 % of the volume of waste,
>90% of the radioactivity

Partitioning and transmutation (1)
Two strategies for managing toxic products

=> Two criteria for risk assessment

Confinement and careful storage

Effective risk

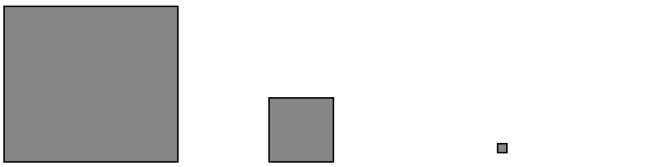


Reduce inventory

Potential toxicity
= danger

Partitioning and transmutation (2)
Reducing quantity (radiotoxicity)

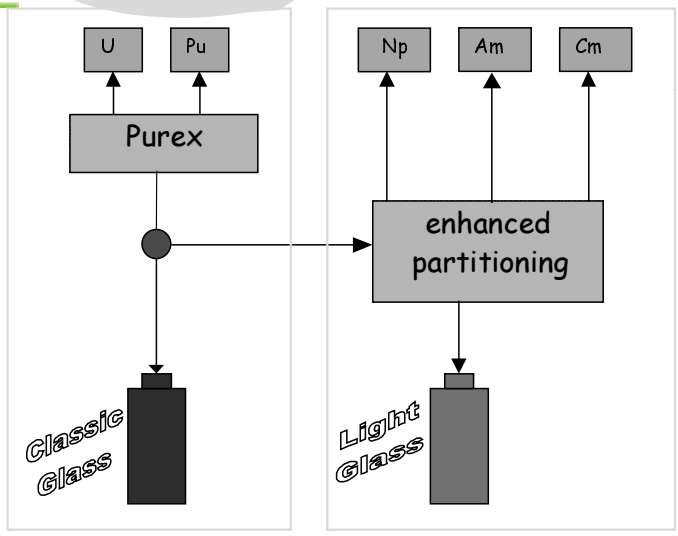
Potential radiotoxicity after 1000 years



- **Partitioning**
- **Transmutation** *or* **specific conditioning**

Partitioning and transmutation (3)

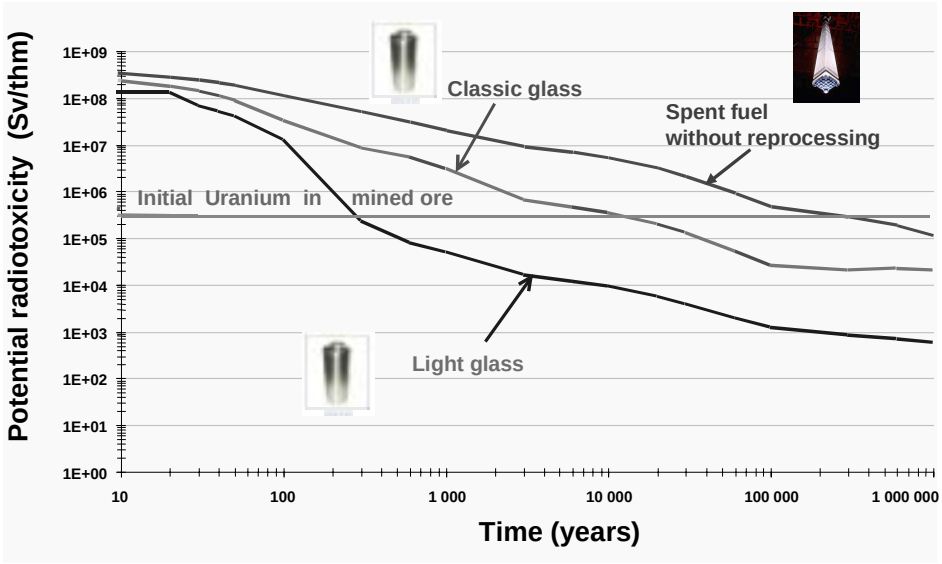
La Hague today



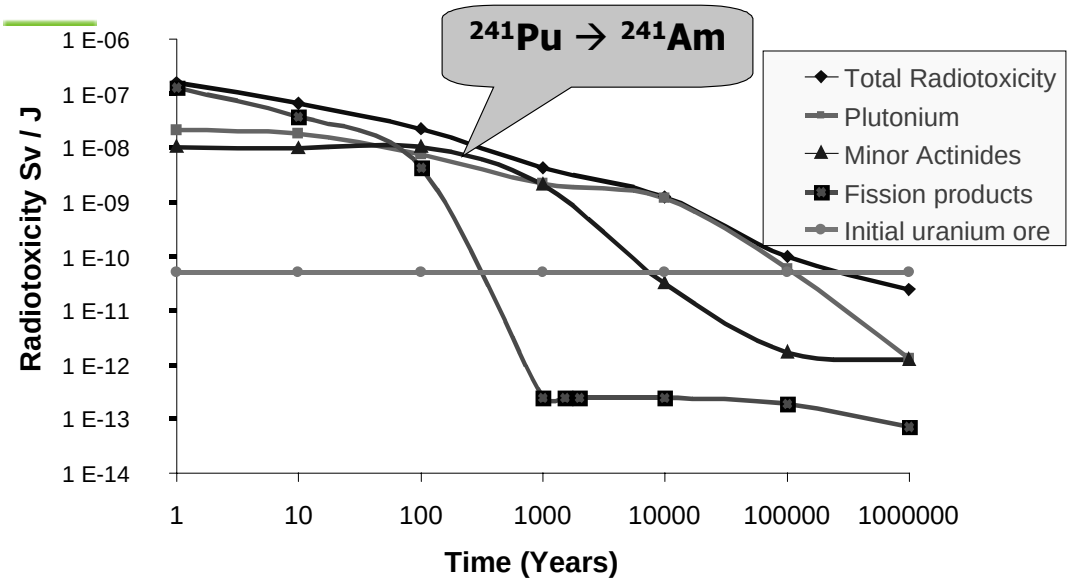
New possibilities

ATALANTE

Partitioning and transmutation (4)
Potential radiotoxicity (as if incorporated)



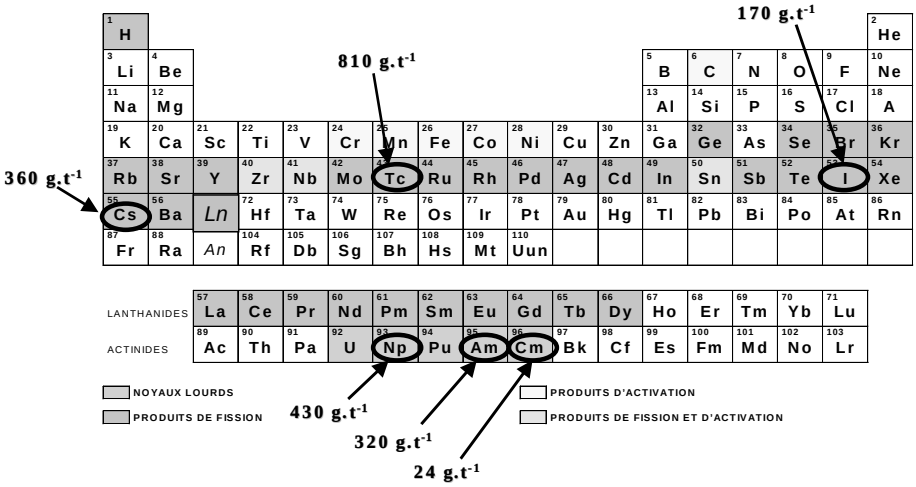
Partitioning and transmutation (5)
Evolution of the radiotoxic content of spent fuel



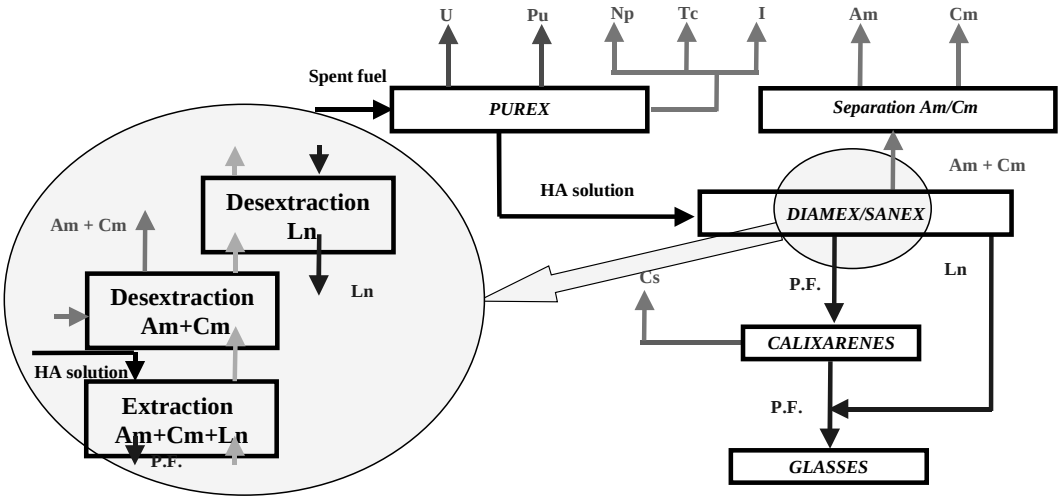
Partitioning and transmutation (6)
Spent fuel content

U ~ 950 kg/t

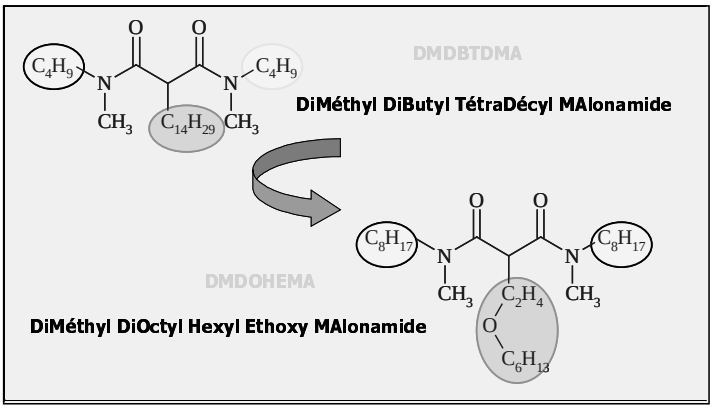
Pu ~ 10 kg/t

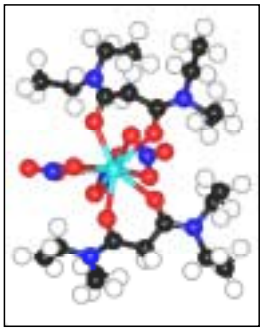


Partitioning (1)
Hydrometallurgy general flowsheet



Partitioning (2)
Diamex extracting molecule





Partitioning (3)
Enhanced separation : main hot tests recent results

ATALANTE facility, genuine fuels, laboratory scale :
scientific feasibility is achieved

- DIAMEX (1999 and 2000) : > 99.9% An+Ln
  Reference molecule : DMDOHEMA
- SANEX (2000 and 2001) : up to > 99.9% An
  Ln : from 0.01% to 0.1%
  3 distinct routes explored ; nPrBTP
- CCCEX (2001) : > 99.9% Cs
  1, 3 alternate calixcrown

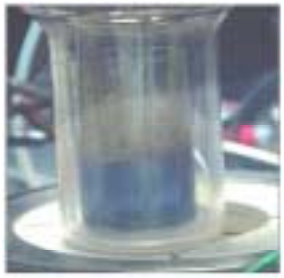
Partitioning (4)
Criteria and main milestones from now

- **Criteria :**
  - selective recovery efficiency
  - stability (medium effects)
  - industrialisation, secondary waste minimisation
- **Milestones from now by 2004 :**
  - processes and technologies optimisation
  - “representative” hot runs (a few kg of spent fuel)
  - global evaluation processes

➔ technical feasibility

Partitioning (5)
Alternative process by pyrochemistry

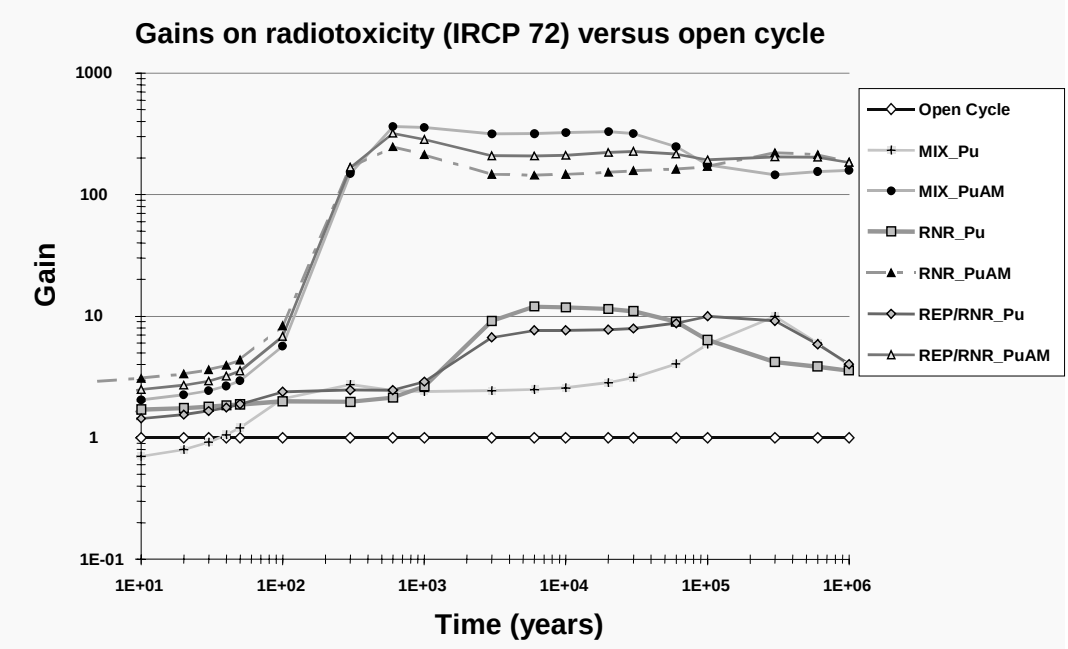
- One step process
- Can be integrated on reactor sites



Transmutation (1)
Scenarios based on reactor core physics

- Plutonium , MA (Am, Cm, Np) and optional LLFP (Tc, I, Cs) management scenarios established for :
  - homogeneous recycling Pu/MA in PWR and FR
  - homogeneous recycling Pu/Np + heterogeneous Am/Cm in FR
- Scenarios to be established for :
  - PWR (Pu) + dedicated system (MA)
  - PWR then HTR-GCFR (Pu+AM) + dedicated systems ?
- Reduction of long term radiotoxicity :
  - a factor 3 to 5 for Pu recycling scenarios
  - up to a few hundreds for (Pu+MA) recycling scenarios

Transmutation (2)
Possible gains in radiotoxicity



Transmutation (3)

Transmutation with present technology

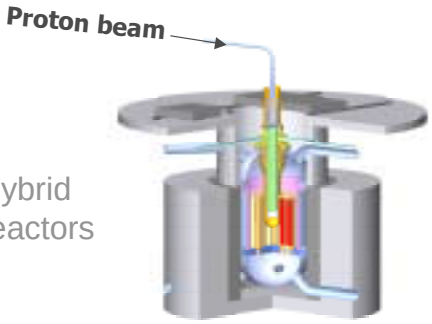
Fast neutrons reactors

Light water reactors

New perspectives……

Advanced gas cooled reactors

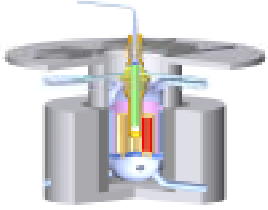
Hybrid reactors



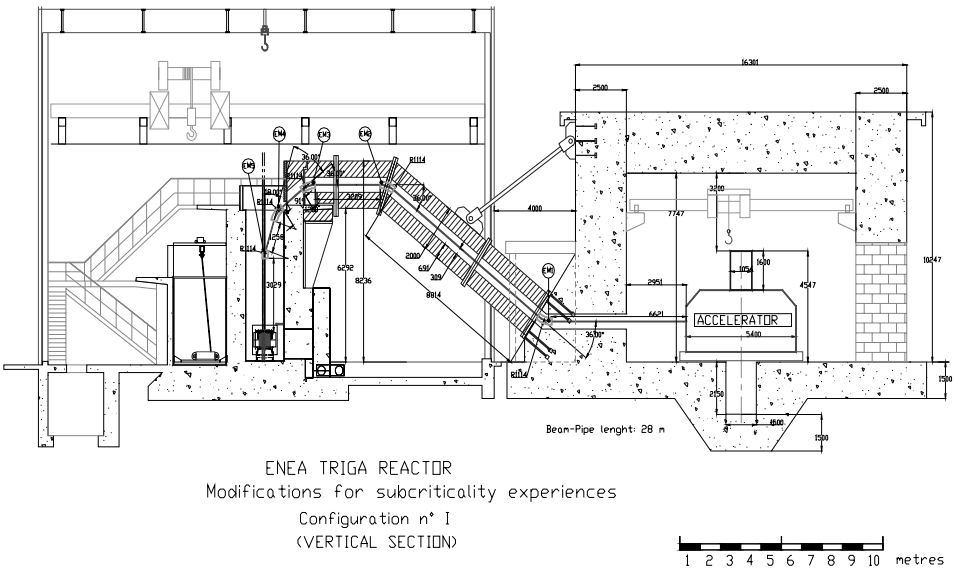
Transmutation (4)

R & D on Accelerator Driven Systems

- Nuclear data, neutronics of coupling (MUSE in MASURCA)
- High intensity accelerator research (IPHI, *with CNRS*)
- Materials (window), technology (Pb/Bi), irradiation behaviour (MEGAPIE target project)
- Mid power (few hundreds kW) ADS demonstrator TRADE project
- Preliminary engineering design of experimental european ADS (PDS-XADS project)
- Europe, US, Japan collaborations



Transmutation (6)
Preliminary design of the TRADE project



Transmutation (7)
Targets and fuels for Transmutation

• Uranium-free fuels : solid solutions, ceramic inclusions in ceramic, ceramic inclusions in metal

• Specific requirements :

- strong interactions with neutrons, FP, alpha particles (large production >> usual one of FR)
- thermal / mechanical / chemical properties

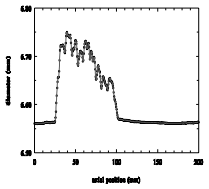
• Ongoing irradiations in experimental reactors

- Actinide compounds (MAO_X, $MAZrYO_x$,…)
- Matrices (Al_2O_3, $MgAl_2O_4$, MgO,…)
- Composites

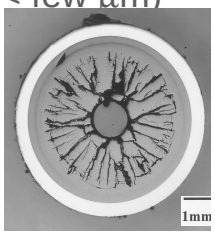
Transmutation (8)

First results on targets and fuels for Transmutation

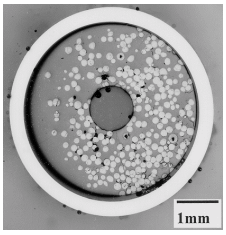
- **Matrices :**
  - Al_2O_3 : high swelling under irradiation
  - $MgAl_2O_4$: swelling, complex behaviour under irradiation
  - MgO : good behaviour under irradiation, present reference
- **Microstructures :**
  - Microdispersed fuel (fissile particles < few µm)
  - Macromasses (> 100 µm)



A : Diameter change of Efttra T4



B: Microdispersed fuel



C: Macromasses

Transmutation (9)

Planned irradiation tests in the fast Phénix reactor

Experiment	Time EFPD	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
			R&D - Conception - Fabrication					Irradiation			ND ExamS	D Exams D
ECRIX B	670											
ECRIX H	340											
METAPHIX 1-2	360											
METAPHIX 3	600											
PROFIL - R	240											
ANTICORP1	500											
PROFIL - M	240											
MATINA 2 - 3	360											
CAMIX COCHIX	340											
FUTURIX	240											

Full power PHENIX

Conclusion on HLLL waste management (1)

Solutions do exist, that could be implemented in a progressive manner.

Several scenarios might be considered and combined :

- Full Pu consumption
- Deep geological disposal of existing vitrified waste and “B” waste
- Long term storage of any waste (up to 300 y)
- Spent fuel direct disposal
- Partitioning and transmutation of Minor Actinides and LL Fission Products

Conclusion on HLLL waste management (2)

Partitioning and Transmutation :

- MA (and some LLFPs) could be efficiently recovered from PUREX HLLW
  - DIAMEX/SANEX/SESAME hot runs : up to 99.9% recovered
  - These results open the way to a possible specific management of LLRNs
- Advances in dedicated fuel development, but further work is needed

  (Phénix experiments planned from beginning of 2003)
- ADS appear well suited for high consumption of MA in dedicated strata ; CEA and CNRS contribute to the international work in this field

Conclusion on HLLL waste management (3)

- Future nuclear power production systems designed to minimise waste
- French law 1991-2006
  - Solutions will be available for presentation to the French government and the Parliament in 2006, for open debate and choice of options for the long-term management of HLLW in France
- International cooperation :

an essential need for the future !!