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

*Nuclear Energy Division, CEA*  
*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)

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

Two main objectives :

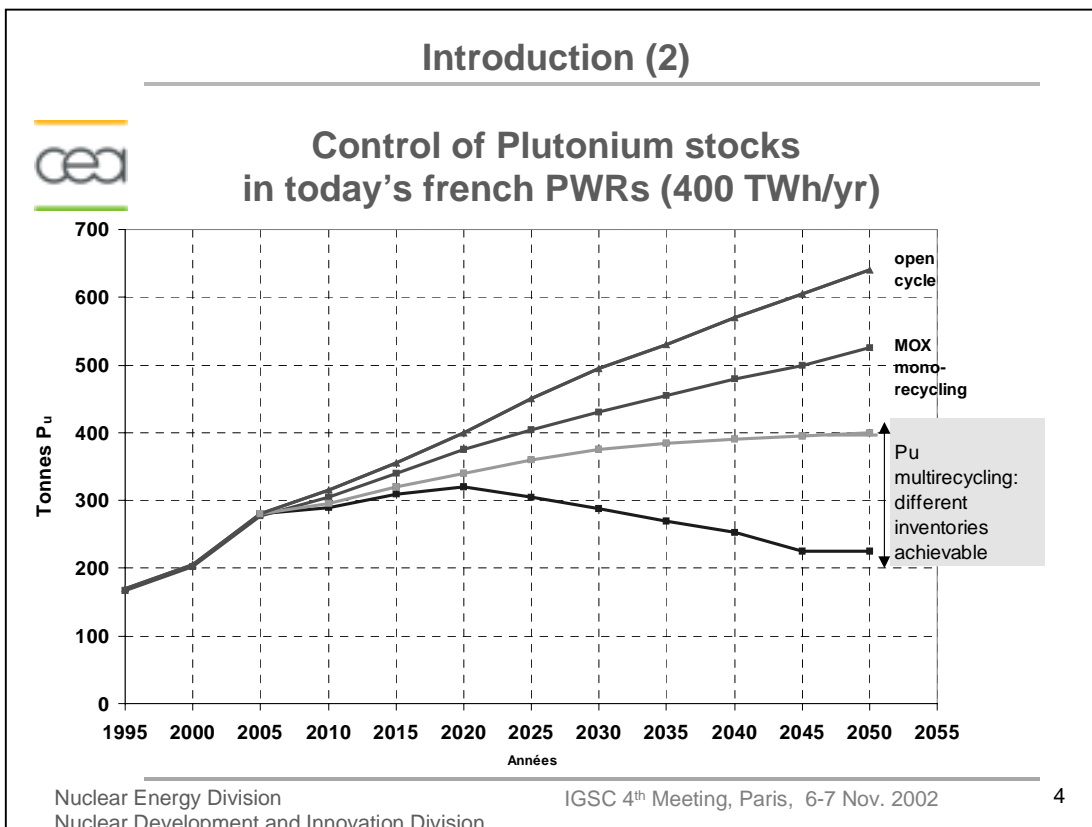
Control of plutonium stocks generated by operating french PWRs

- ✓ Pu consumption and waste minimisation

➔ Recycling of actinides (Plutonium, Minor Actinides)

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### Introduction (3)

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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)

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#### 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


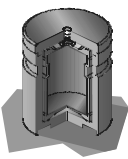



- Pu multirecycling in PWR with advanced fuels has multiple advantages
  - Optimisation of use of natural resources and energy extracted
  - Control of Plutonium inventory
    - Almost no Plutonium out of cycle
    - Concentration of Plutonium in a limited quantities of fuel rods (APA)
- The CEA, in 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




<p><b>Short-lived low and medium activity</b>      ~ 1 million m<sup>3</sup></p> <p style="text-align: right; font-size: small;">For the current nuclear power plant park</p> <p>~ 90 % of the total volume of waste produced in France, &lt;1% of the radioactivity.</p> <p style="text-align: center;">Are subject to final disposal under current regulations</p>	
<p><b>Intermediate level long lived waste</b>      ~ 50 000 m<sup>3</sup> in 2020</p> <p>&lt; 10 % of the total volume of waste, &lt;10% of radioactivity</p>	
<p><b>High level long lived waste</b>      ~ 5 000 m<sup>3</sup> in 2020</p> <p>~ 1 % of the volume of waste, &gt;90% of the radioactivity</p>	


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## Partitioning and transmutation (1)

### Two strategies for managing toxic products

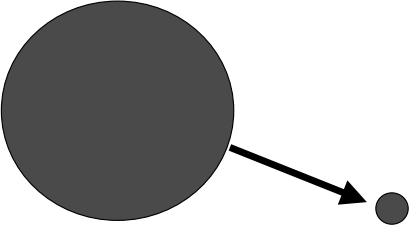


=> Two criteria for risk assessment



**Confinement and careful storage**

Effective risk




**Reduce inventory**

Potential toxicity = danger


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## Partitioning and transmutation (2)

### Reducing quantity (radiotoxicity)



Potential radiotoxicity after 1000 years




Material	Potential radiotoxicity after 1000 years
Plutonium	High
Minor actinides	Medium
Fission products	Low

- Partitioning
- Transmutation *or* specific conditioning

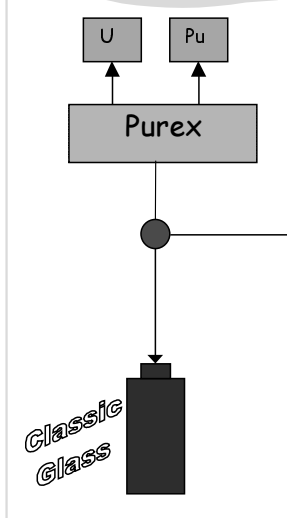
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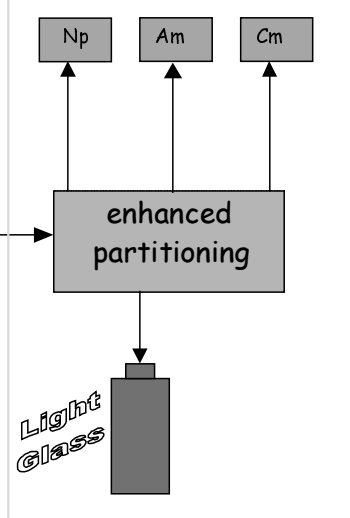
## Partitioning and transmutation (3)




La Hague today



New possibilities

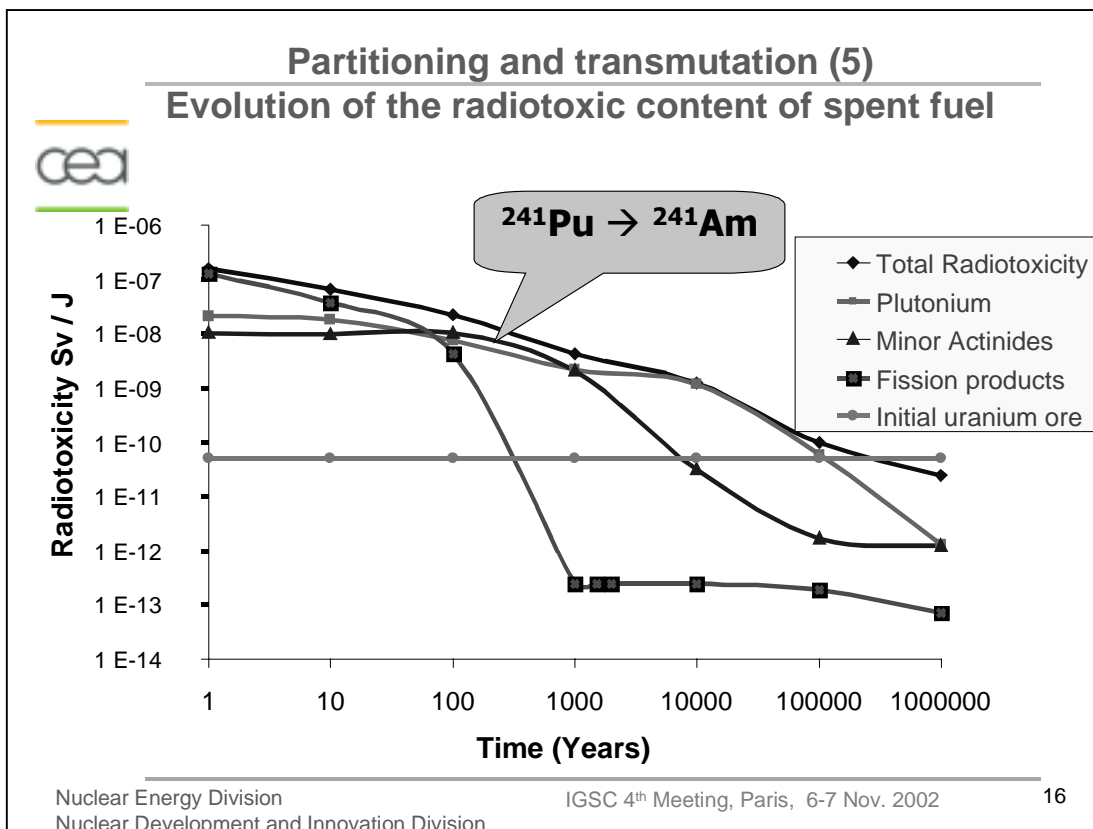
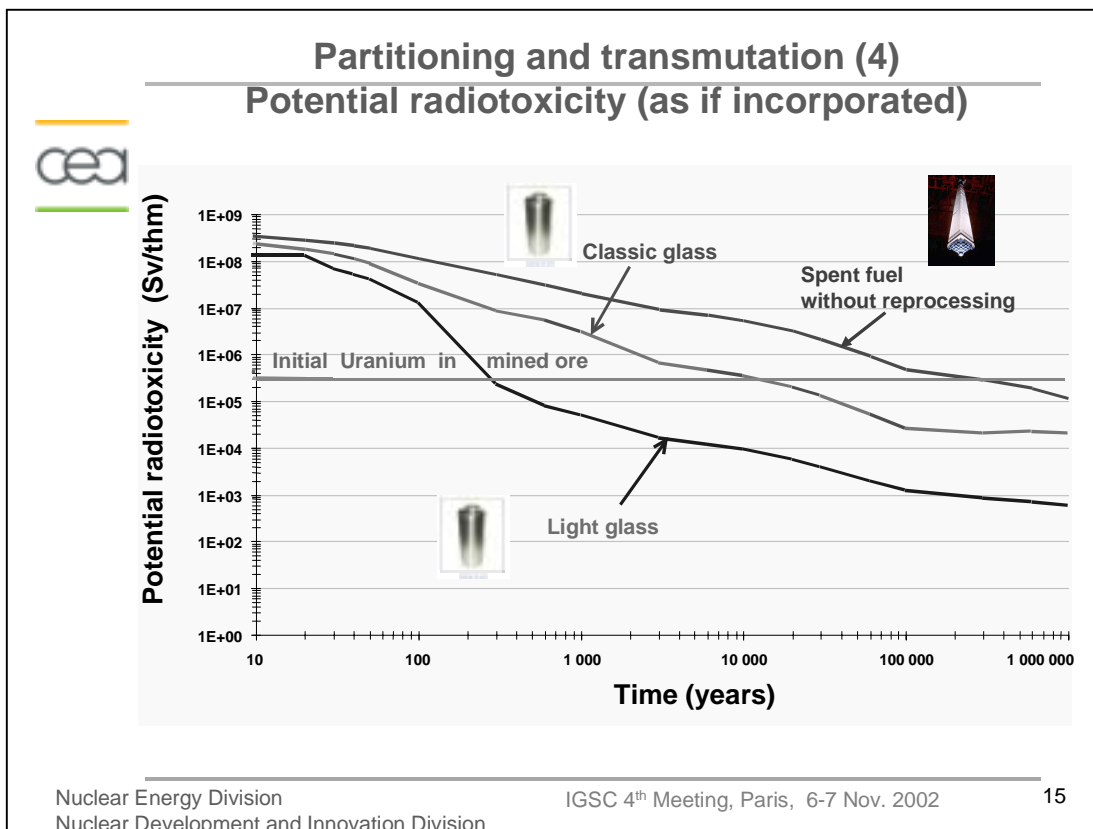




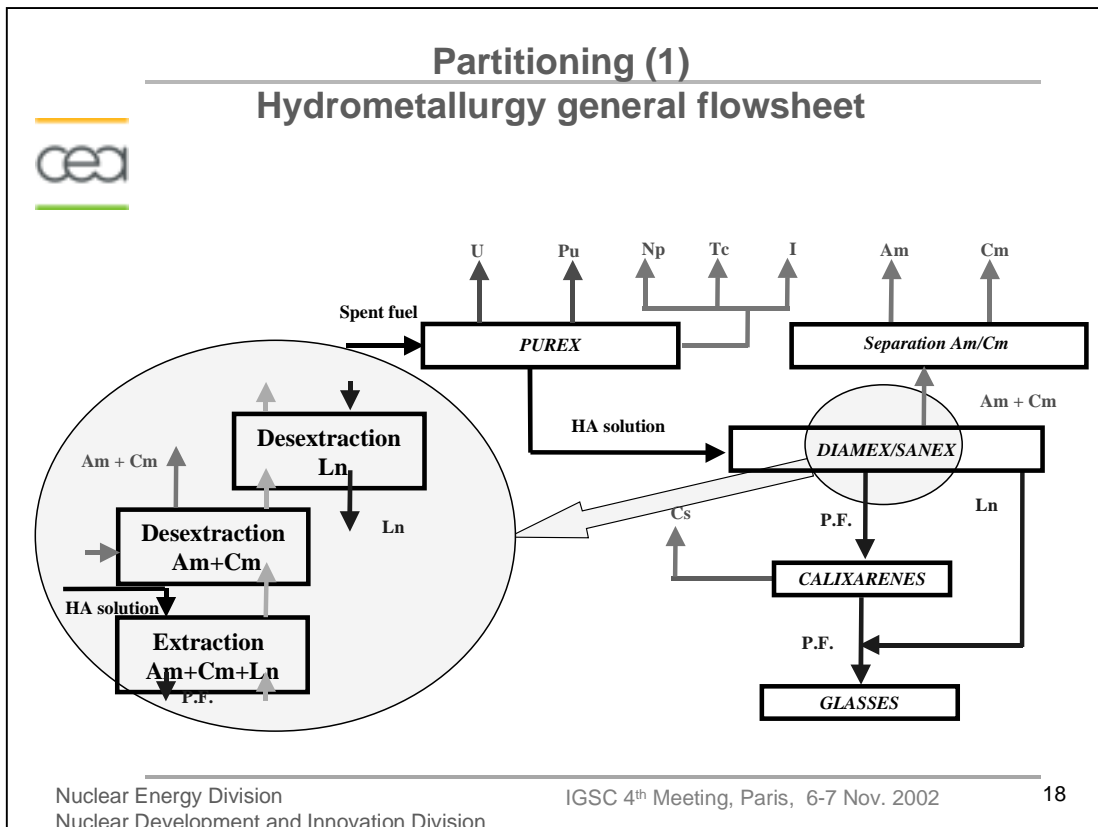
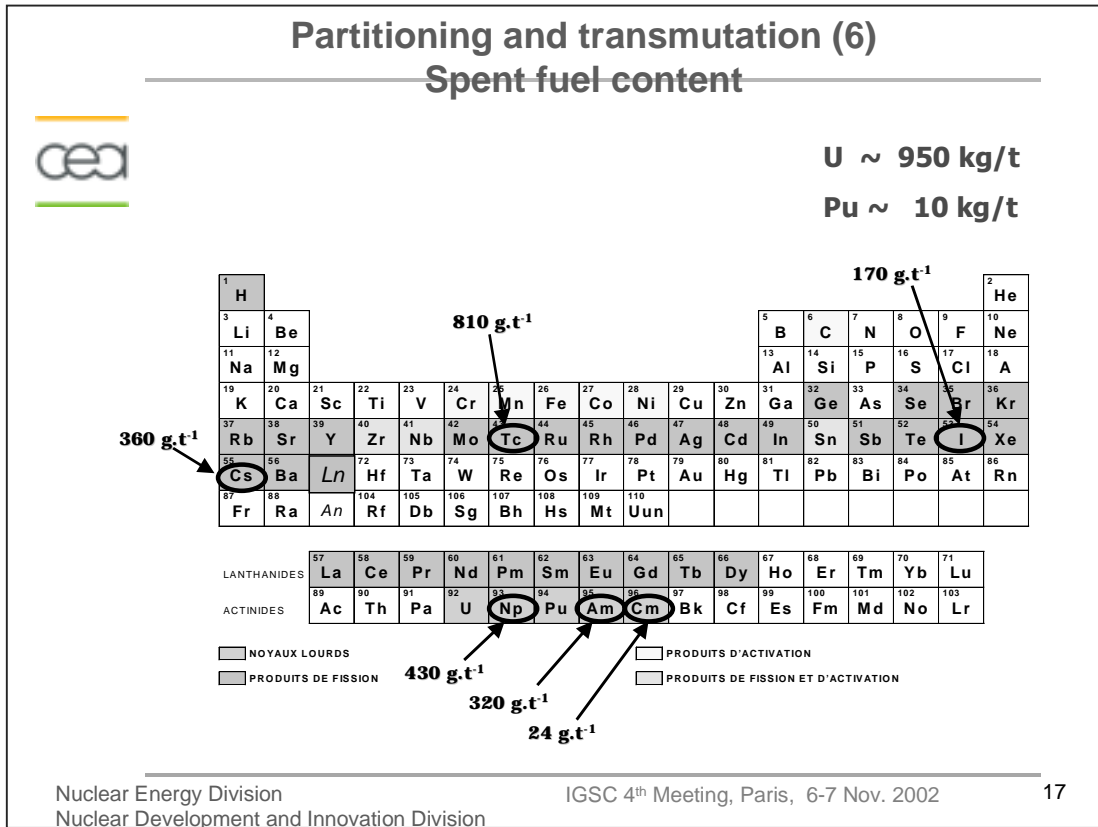
**ATALANTE**

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## Partitioning (2)


### Diamex extracting molecule



CCCCNC(=O)C(C)C(=O)NCCCC

**DiMéthyl DiButyl Tétradécyl MALonamide**

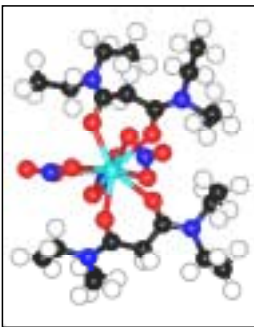
DMDBTDM A



CCCCCNC(=O)C(C)C(=O)NCCCC

**DiMéthyl DiOctyl Hexyl Ethoxy MALonamide**

DMDOHEMA



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## 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

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## Partitioning (4)

### Criteria and main milestones from now



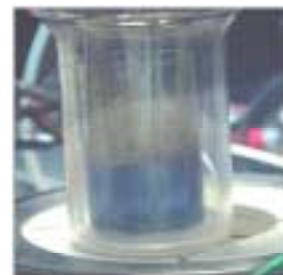
- **Criteria :**
  - selective recovery efficiency
  - stability (medium effects)
  - industrialisation, secondary waste minimisation
- **Milestones from now by 2004 :**
  - processes and technologies optimisation
  - “representative” hot runs (a few kg of spent fuel)
  - global evaluation processes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

## Partitioning (5)

### Alternative process by pyrochemistry




- One step process
- Can be integrated on reactor sites



### Transmutation (1)

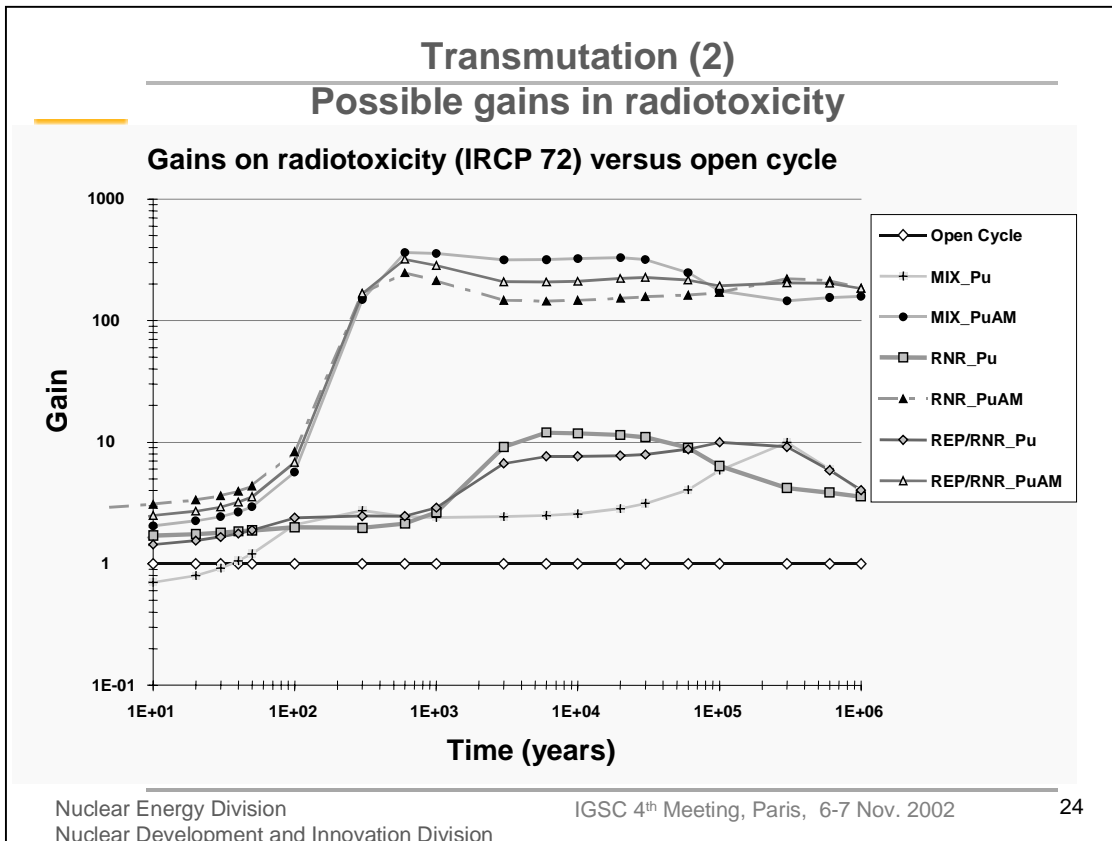
~~Scenarios based on reactor core physics~~



- 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

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### Transmutation (3)

#### Transmutation with present technology



Fast  
neutrons  
reactors



Light  
water  
reactors

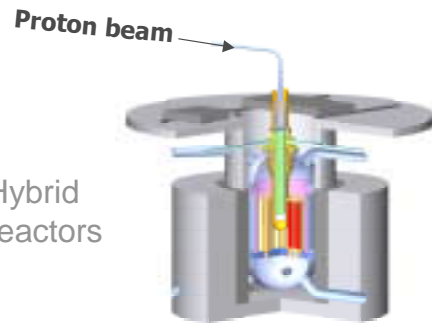


#### New perspectives.....

Advanced  
gas cooled  
reactors



Hybrid  
reactors

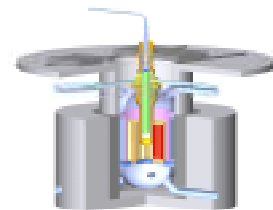


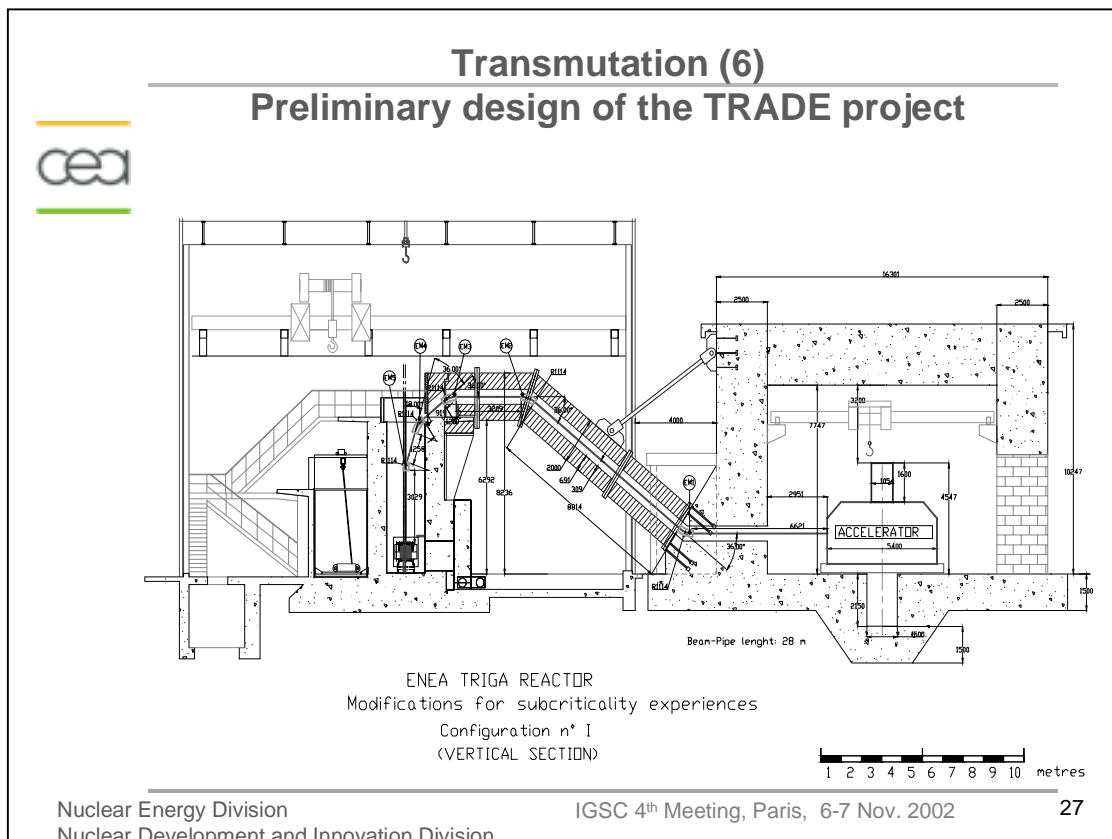
### Transmutation (4)

#### 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 (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 ( $\text{MAO}_x$ ,  $\text{MAZrYO}_x$ , ...)
  - Matrices ( $\text{Al}_2\text{O}_3$ ,  $\text{MgAl}_2\text{O}_4$ ,  $\text{MgO}$ , ...)
  - Composites

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### Transmutation (8)

#### First results on targets and fuels for Transmutation

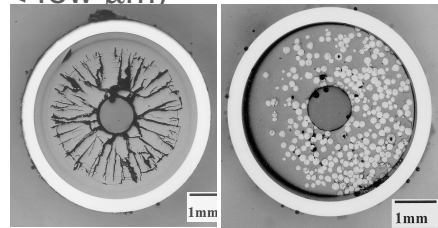
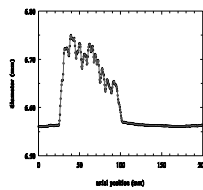


• **Matrices :**

- $Al_2O_3$  : 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  $\mu m$ )
- Macromasses (> 100  $\mu m$ )



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 HLLW 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 HLLW 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 LLRN
- 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 HLLW waste management (3)

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- 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 !!*