French fuel cycle strategy

and partitioning and transmutation programme

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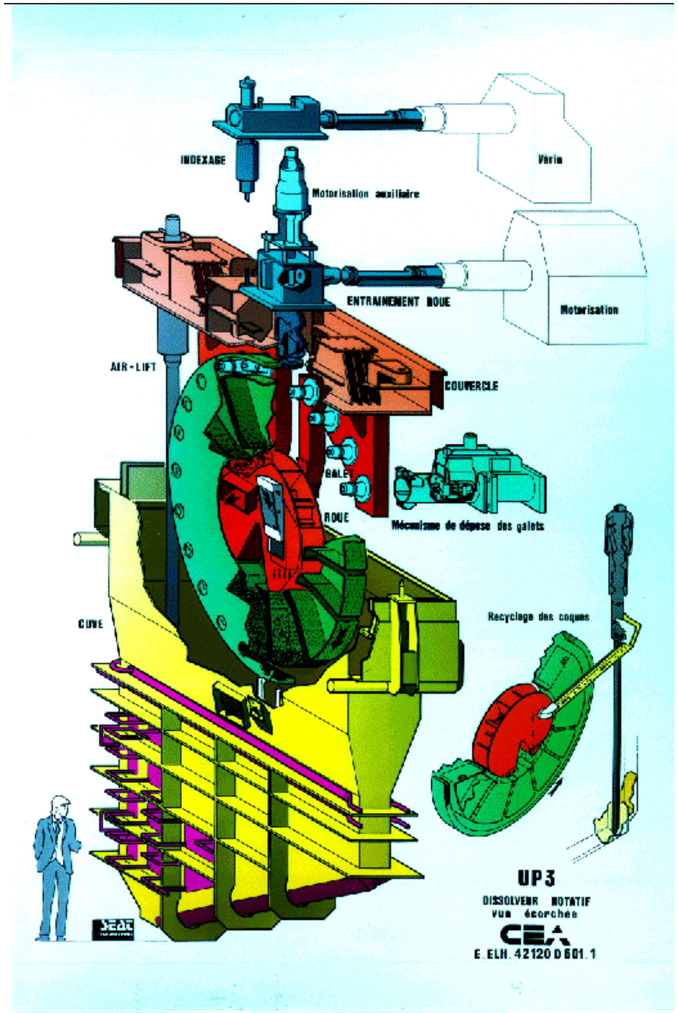
Reprocessing :
The *La Hague* integrated site

UP2-800 :

1994 : Commissioned for PWR fuels
Capacity : **800 t/y**
(Its an upgrade of UP2-400)
Dedicated to French customers (EDF)

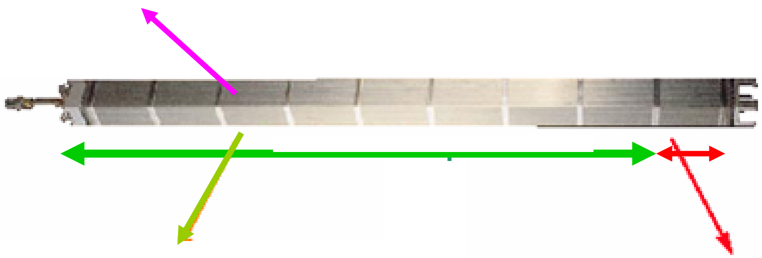
UP3 :

1990 : Commissioned for PWR fuels
Capacity : **800 t/y**
Dedicated to foreign customers



Spent fuel processing

Cladding & structural materials : medium level & long lived waste



Recyclable materials (95 %)

Uranium : 470 kg (94 %)

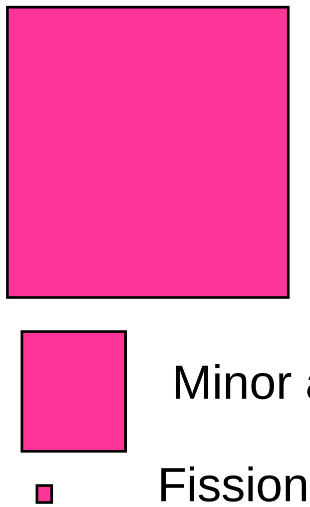
Plutonium : 5 kg (1 %)

Vitrified HL radwaste (5%)

Fission products : 25 kg

Minor actinides : ~ 0,5 kg

Current scheme for the PUREX process



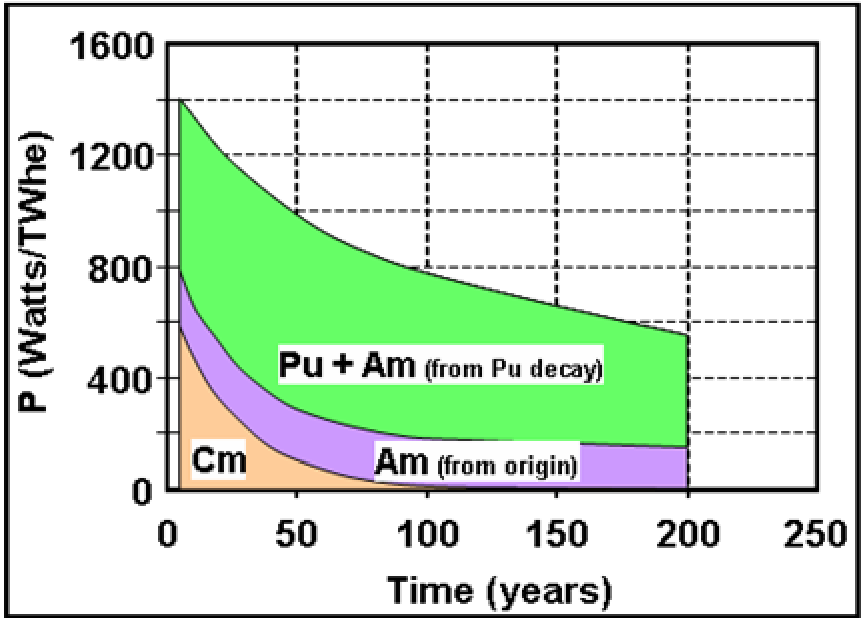
Relative contribution to total radiotoxicity after 1 000 years

Waste management

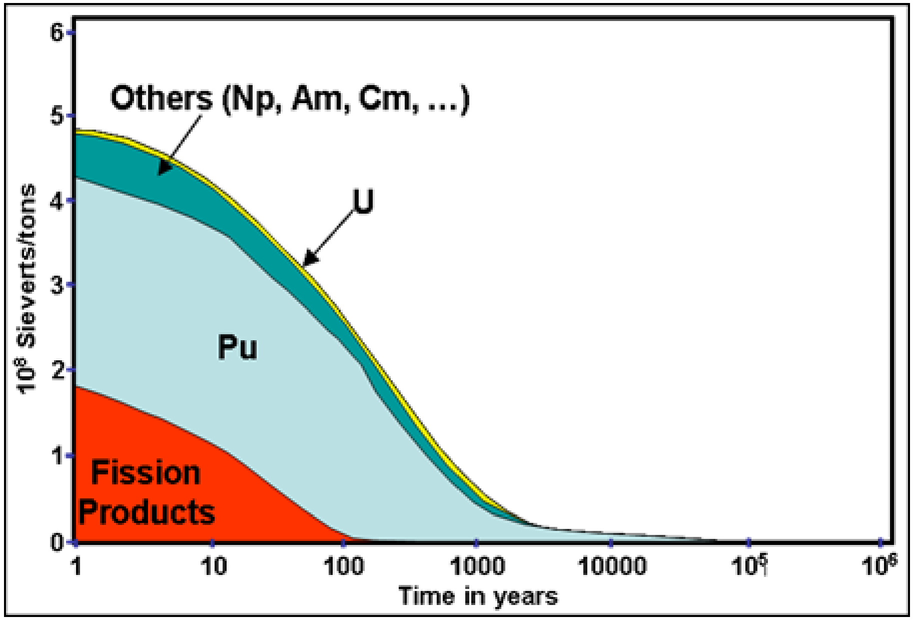
- **Urgent matter for public acceptance of nuclear energy**
- **Recycling minimizes both the repository space and environmental impact**

1st contributor : Pu ; 2nd contributor : Minor Actinides (MA)

Heat load of the TRU

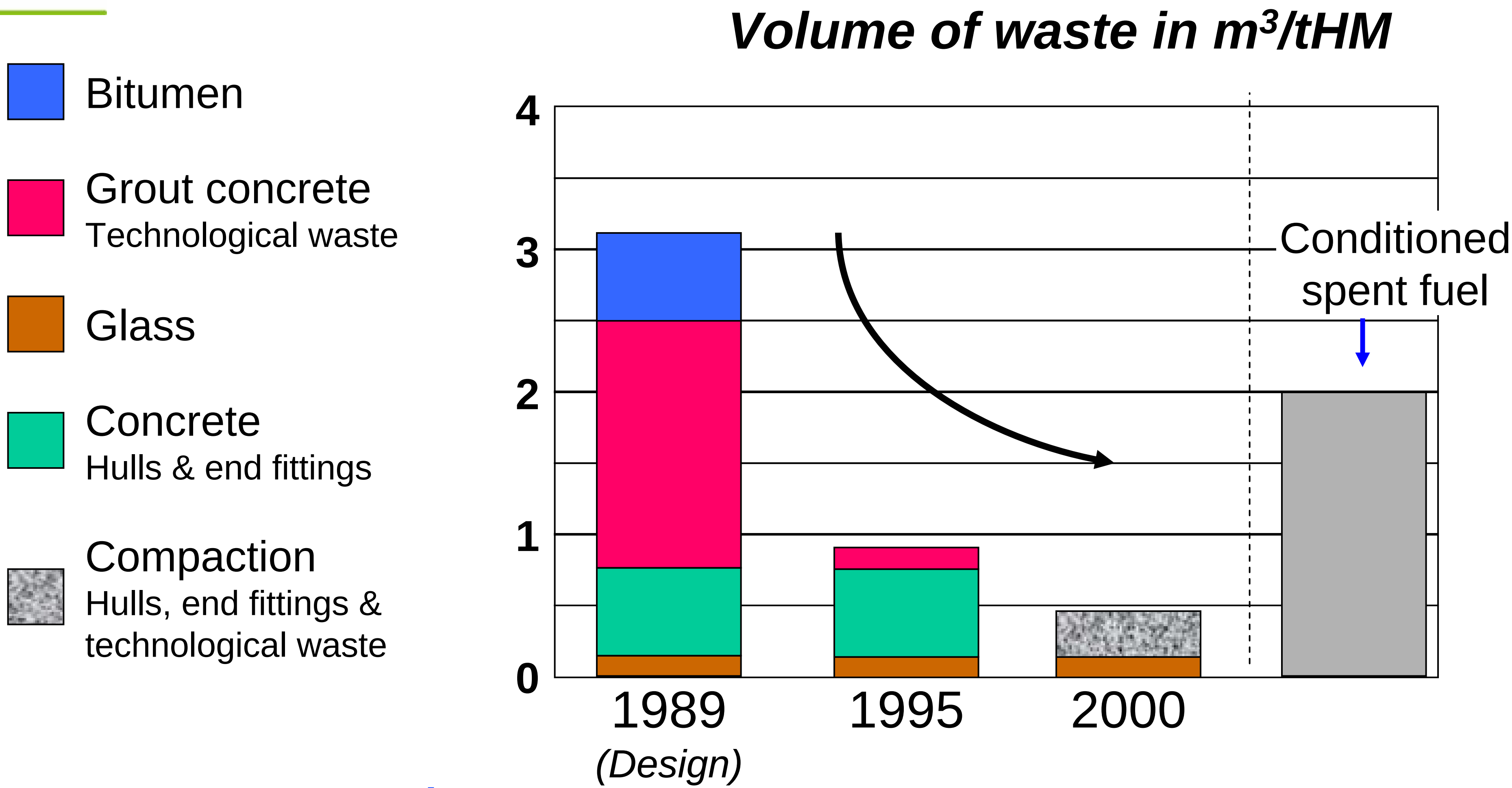


Potential radiotoxicity



(^{241}Pu ---> ^{241}Am ---> ^{237}Np)

Fuel treatment optimization : Specific waste volume for the UP3 plant



Pu losses ***1 %*** ***0.1 %*** ***0.1 %*** ***100 %***

Which goals?

Goal 1 research : solutions that would allow partitioning and transmutation of long lived radionuclides present in HL LL waste and reduce the overall radwaste quantity and toxicity.

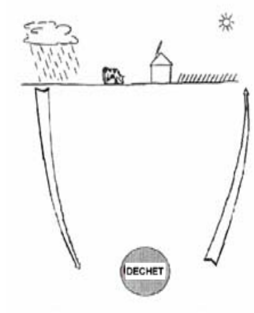
Goal 2 research : feasibility of reversible or irreversible repository in deep geological formations.

Goal 3 research : conditioning processes and feasibility of long term storage, above-grade or below-grade.

⇨Deadline set in law : 2006

Partitioning : key nuclides

⇨ minor actinides : Am - Cm - Np
major contributors to long term radiotoxic inventory;



⇨ fission products : I - Cs - Tc
- long lived isotopes significantly present in spent fuel,
- with a potential for mobility within rock formations;

⇨ processes : hydro-metallurgy (consistent with PUREX) and pyro-chemistry (more innovative);

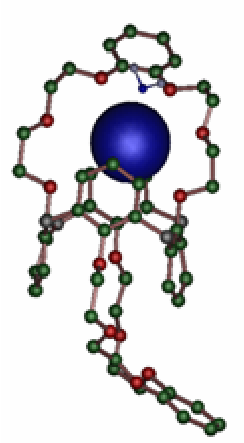
⇨ partitioning of nuclides present in the already vitrified HL waste would be rather difficult.

Research steps

⇨ **Fundamental research : a wide co-operative framework**

- **exploration : new extracting systems ;**
- **fundamentals : in-depth study of mechanisms at work ;**

A few hundreds of new molecules



⇨ **Applied research :**

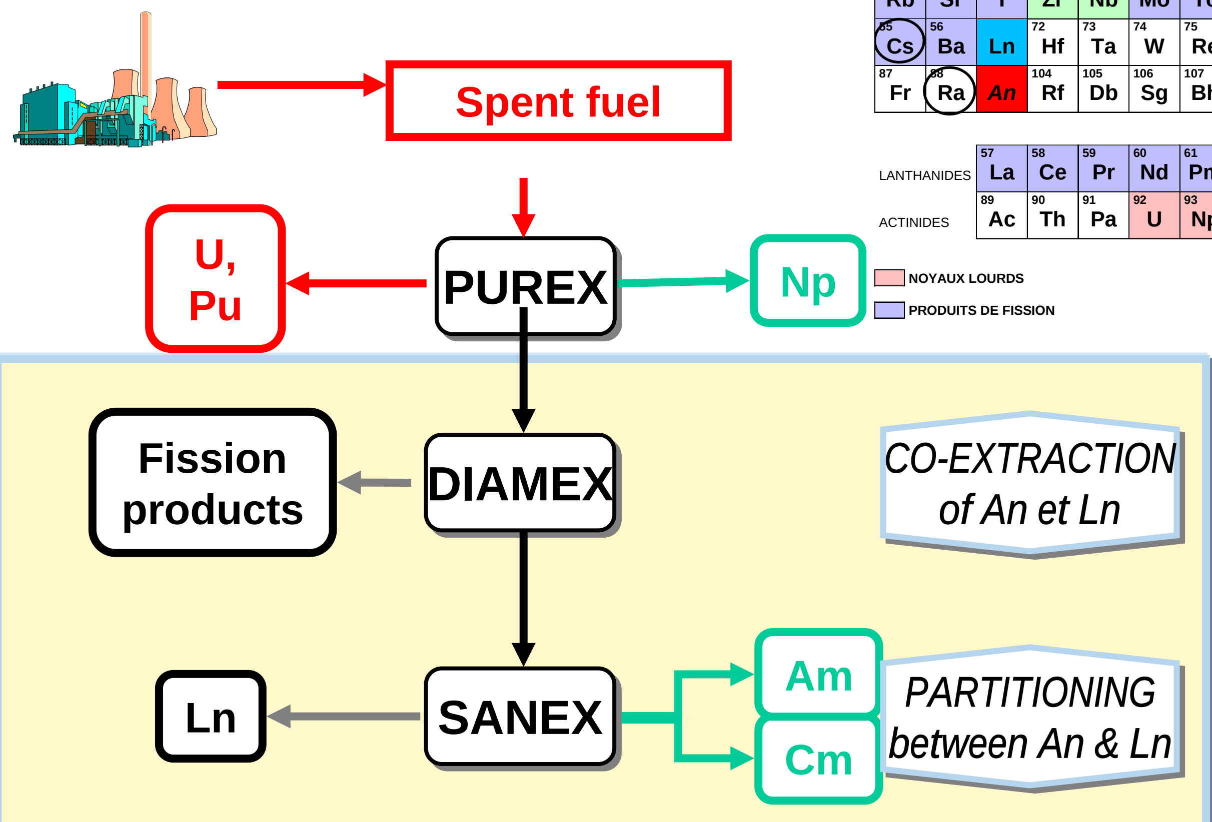
- **process design ;**
- **lab experiments on actual spent fuel material ;**
- **« demonstration » experiments : integration, representativeness, long-lasting performance ;**

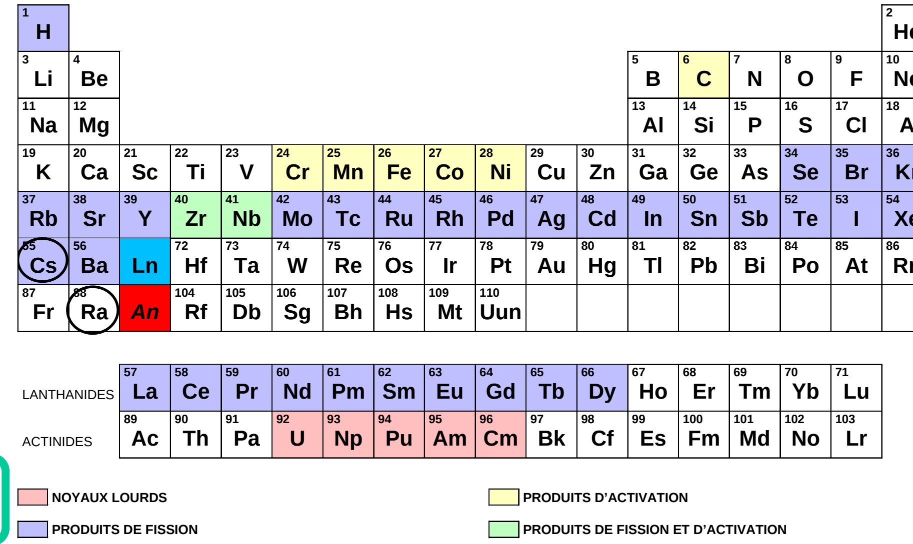
Scale : 1/10000

Scale : 1/100 à 1/1000

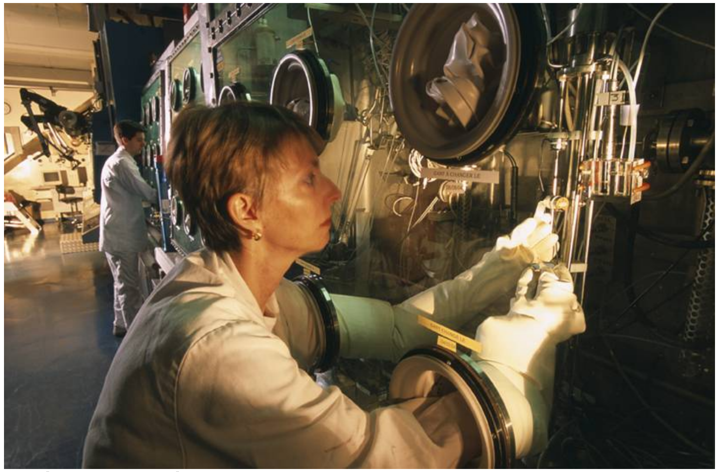
⇨ **A true challenge : a sophisticated partitioning chemistry under highly radioactive conditions.**

Actinides partitioning : research path used



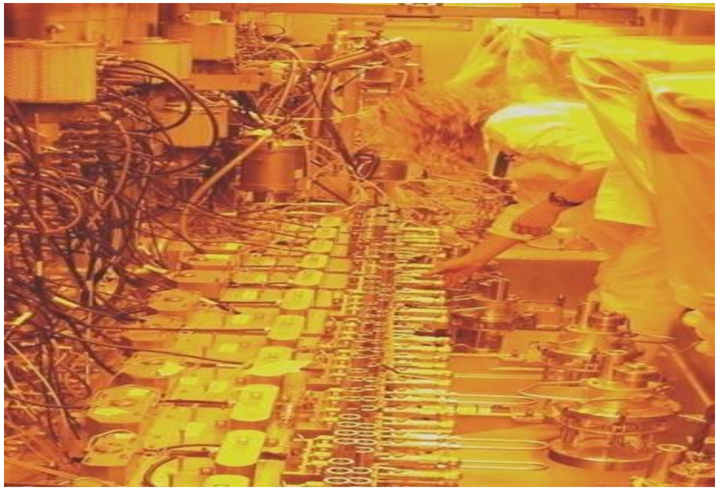


The ATALANTE facility…



From basic studies to demonstrative experiments …

… up to kgs of spent fuel

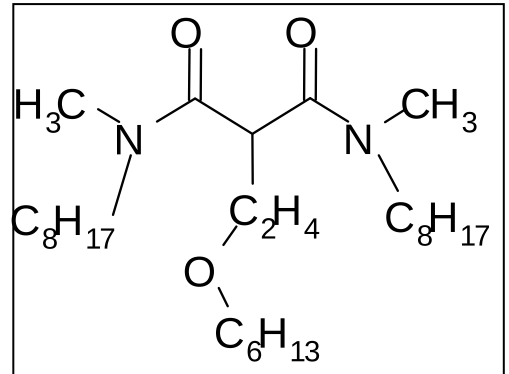


Am, Cm, Np, Tc, I et Cs partitioning : lab scale results

Americium & curium : recovery ratio up to 99,9% for Am & 99,9% for Cm ;

⇨ long-lasting performance tested (« accelerated » simulation within an irradiation loop) ;

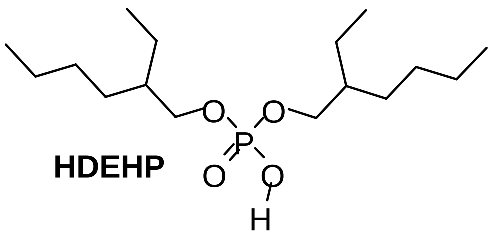
⇨ confirmation test with the use of « industrial » technology have been successful in 2005 ;



DMDOHEMA

Neptunium : recovery ratio up to 99% ;

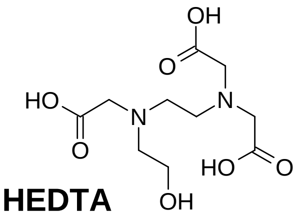
Technetium : recovery ratio from 45 à 90%;



HDEHP

Iodine :

- recovery ratio > 97% with PUREX;
- additional recovery up to ~ 99% possible ;



HEDTA

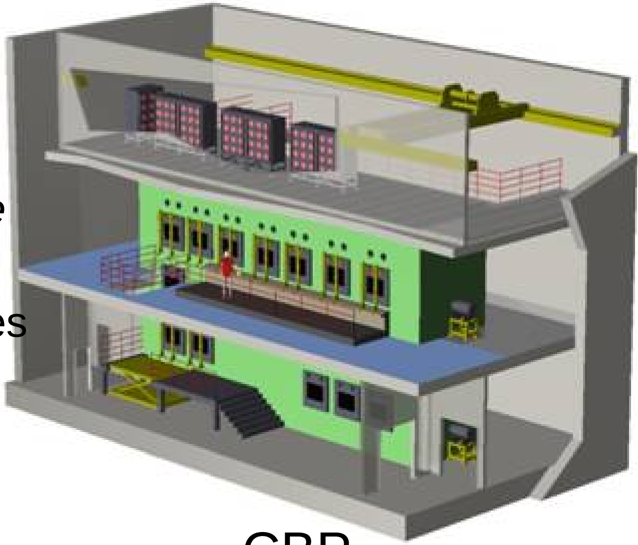
Caesium : recovery ratio > 99,8%, with the use of the calixarene extractant.

Conclusion …. for partitioning R&D

⇨ A large scope for research :
from fundamentals to applications;

- the actinides: the key target;
- partitioning of nuclides present in the already vitrified HL waste is no more considered.
- a scope wide open : *(numerous options explored and co-operations);*
- feasibility of pyro-chemical processes not yet demonstrated;
- molecules and partitioning processes successfully tested at the lab scale;
- and successfully tested in 2005 within the Atalante hot cells *(to replicate an industrial-like set-up);*
- a research booster for partitioning and actinides chemistry;
- further steps will be required prior to any industrial implementation.

Atalante in Marcoule



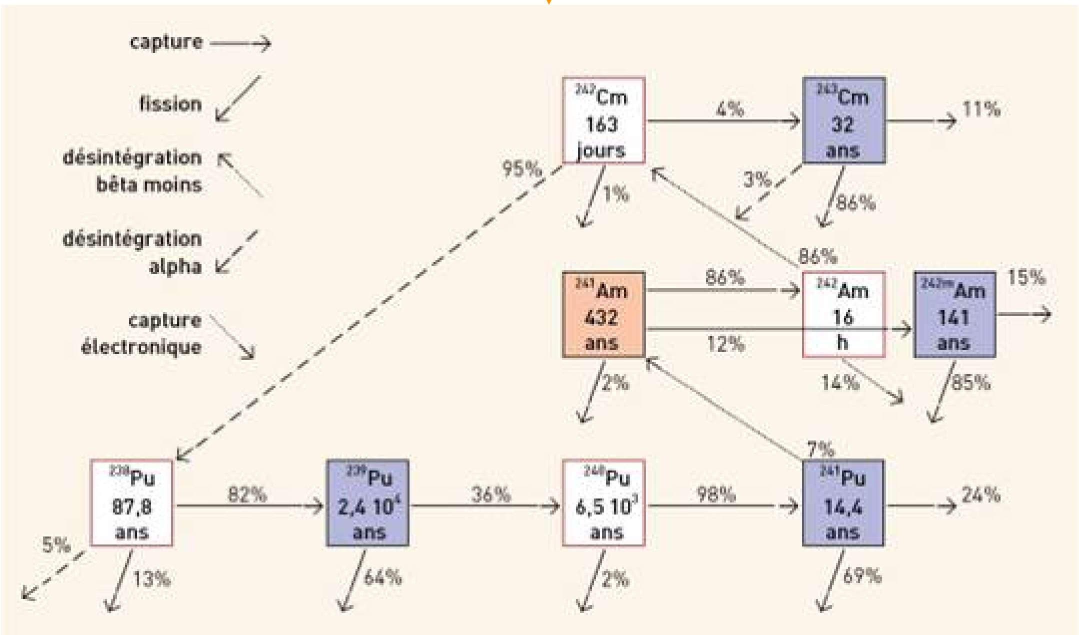
CBP

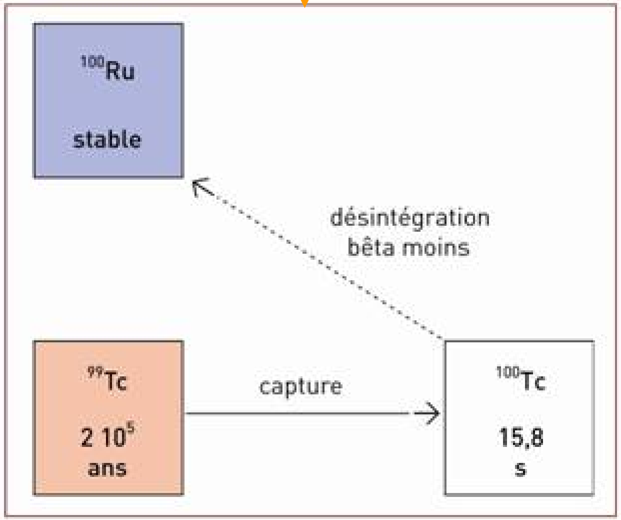
Transmutation : capture & fission

⇨ Making use of neutron flux (within a reactor) to turn LL radionuclides into stable or shorter-lived isotopes through neutron capture or fission reactions.

For actinides, fission reaction, not neutron capture, must be considered.

For fission products, neutron capture reactions are observed resulting in stable or short-lived nuclides.





Transmutation output according to neutron spectrums used

R&D on basic nuclear data :

⇨**Nuclear data obtained on actinides cross-sections is used to rank the transmutation potential of various systems.**

- **Two recycling modes have been considered : homogeneous mix within the nuclear fuel or heterogeneous in targets at higher concentrations;**

- **There is obviously a net advantage in using a fast neutron flux to get higher fission rate, however increasing the fission rate requires multiple recycling ;**

⇨**Fast neutron flux and spectrum are more efficient to transmute actinides through fission reaction.**

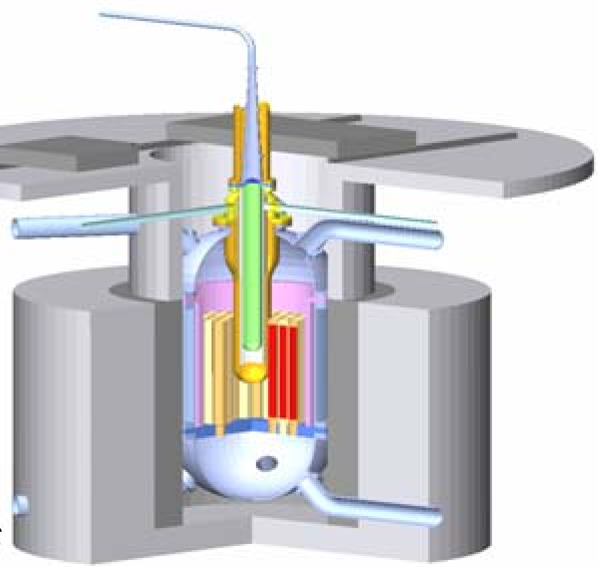
Transmutation tools : existing reactors?(1/2)

• PWR : the scientific feasibility to transmute americium is established; however more enriched uranium is needed in the fuel and more curium is produced as a result, which is not recyclable in PWR;

• FNR : minor actinides transmutation is established with no detriment on the normal operating conditions of the reactor.

⇨FNR should be able to help eliminate minor actinides produced in the existing PWR fleet of reactors and to manage those produced within FNR.

Transmutation tools : future reactors ? (2/2)


ADS

- FNR-gas (GEN IV) :
  - up to 5 % of minor actinides concentration in fuel could be acceptable (only limited by the fuel behaviour under irradiation);

- Hybrid systems (ADS) : 5th et 6th European FP, CEA/CNRS collaboration :
  - significant R&D work is on-going,
  - ADS concept is highly complex, however there appears to be so far no show-stoppers towards demonstrating the feasibility of an experimental facility,
  - nevertheless, stumbling stones have been highlighted.

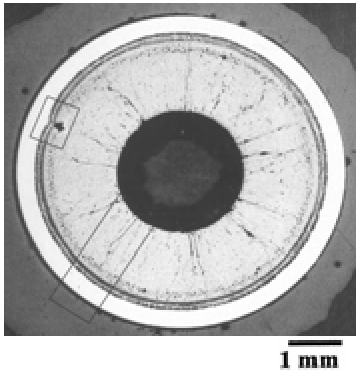
Nuclear fuel for transmutation : current R&D programmes

⇨ Reactors in use or considered :

- irradiation reactors : HFR,SILOE;
- fast neutron research reactors :
  - PHENIX,
  - JOYO, MONJU (Japan),
  - BOR 60 (Russia).

⇨ Design and fabrication of experimental fuel, and associated safety case ;

- irradiation (minimum 5 years),
- non destructive and destructive examinations,
- 35 irradiation experiments have been conducted or are on-going.



Results validation :

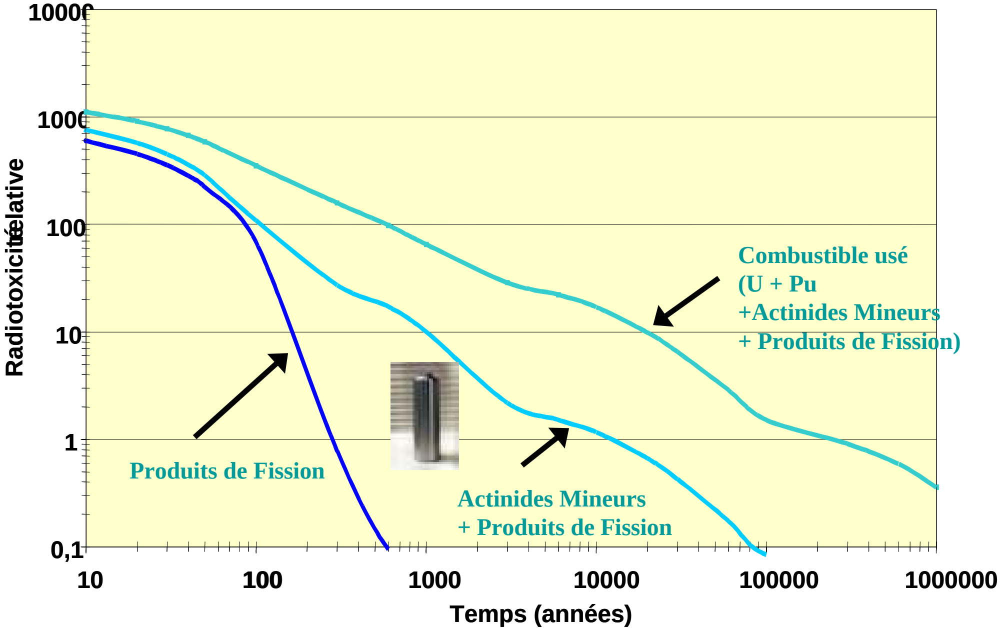
- **actinides concentration and burn-ups;**
- **fission rate for one cycle :**
  i.e. 70% of the americium contained in one target has undergone fission.

Conclusion … for transmutation

⇨ the feasibility of transmuting actinides such as Am and Np is recognised in fast neutron reactors according to experiments run in SFR;

⇨ ADS systems are quite complex, and their technical and economical viability for actinides transmutation is yet to be proven;

⇨ transmutation of technetium 99 is feasible, but not efficient;
transmutation of caesium 135 is no longer pursued;
transmutation of iodine 129 is not currently feasible.



⇨ Reducing the ultimate waste radiotoxic inventory is possible with implementing a continuous improvement step-wise process;

⇨ Goal 1 cannot apply to current ultimate waste (vitrified).

⇨ An international expert peer-review report is available

Future nuclear systems for a nuclear renaissance

- **It clearly means fast reactors for sustainability,**
- **Sodium fast reactor is more mature**
- **Gas fast reactor is an alternate track**
- **Minor Actinides recycling may be a progressive approach**

President Chirac statement (Jan 06) :

« A number of countries are working on future generation reactors, to become operational in 2030-2040, which will produce less waste and will make a better use of fissile materials.
I have decided to launch, starting today, the design work by CEA of a prototype of the 4th generation reactor, which will be commissioned in 2020.
We will naturally welcome industrial or international partners who would like to get involved. »

The Radwaste Management Act (June 06) :

"Transmutation : studies to be carried out within the R&D framework of future nuclear energy and ADS systems - aiming at 2012 for the technical feasibility evaluation (industrial level), and 2020 for the commissioning of a prototype".

Nuclear Fuel Cycle Goals

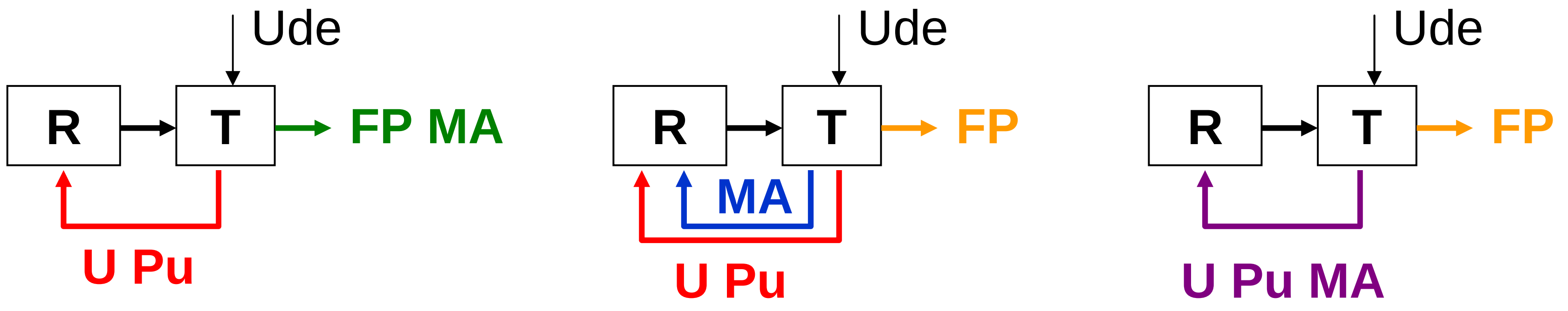
→ **Natural resources conservation**

→ **Waste minimisation**

→ **Proliferation resistance**

50 more electricity produced with the same quantity of natural uranium

All paths should be kept available, **they could be used in a sequence.**



U & Pu recycling | **Heterogeneous recycling** | **Homogeneous recycling (GenIV)**

The next generations of reprocessing facilities

Gen II

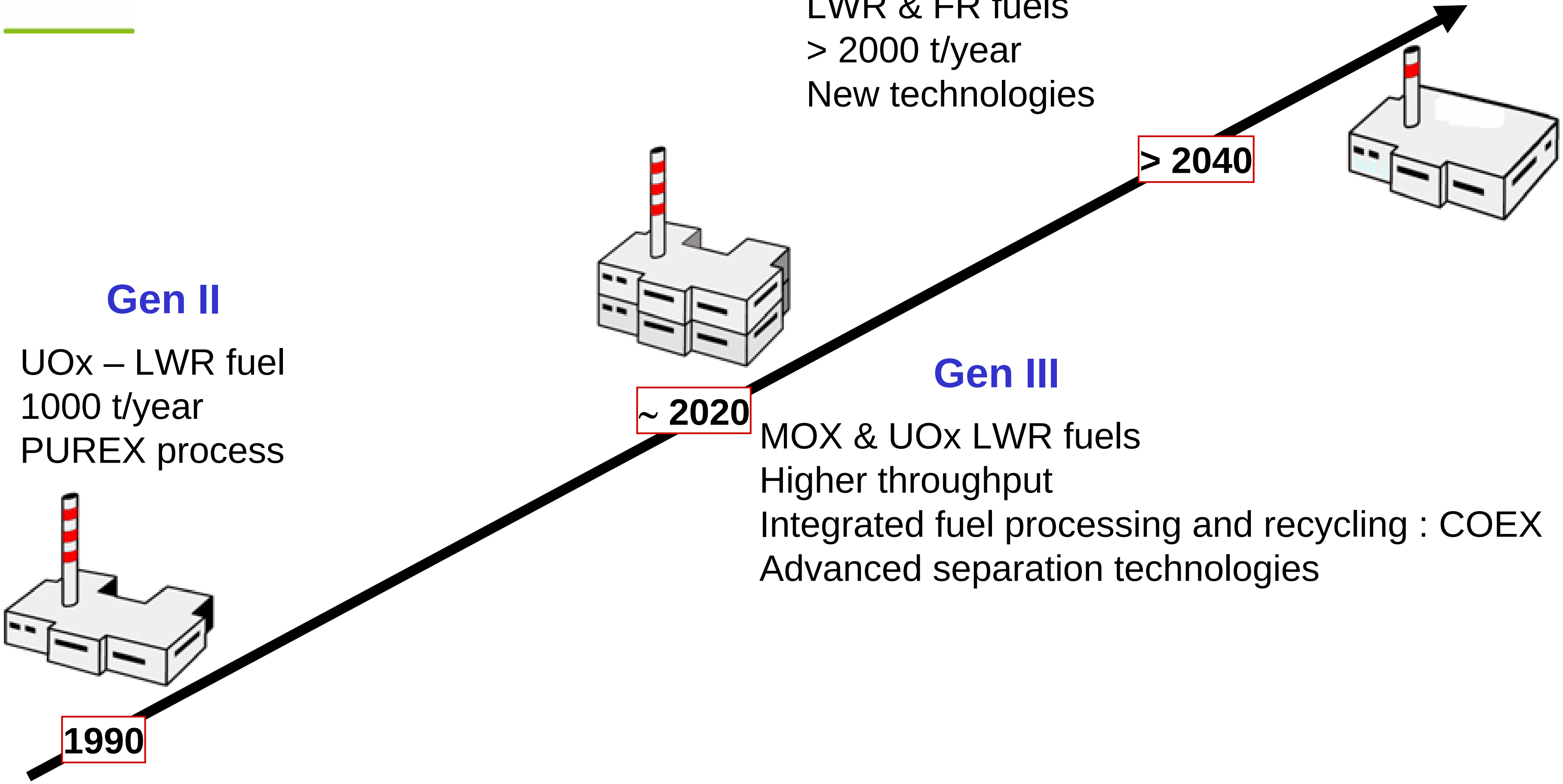
UOx – LWR fuel
1000 t/year
PUREX process

Gen III

MOX & UOx LWR fuels
Higher throughput
Integrated fuel processing and recycling : COEX
Advanced separation technologies

Gen IV

LWR & FR fuels
> 2000 t/year
New technologies



Looking for a long term management strategy?

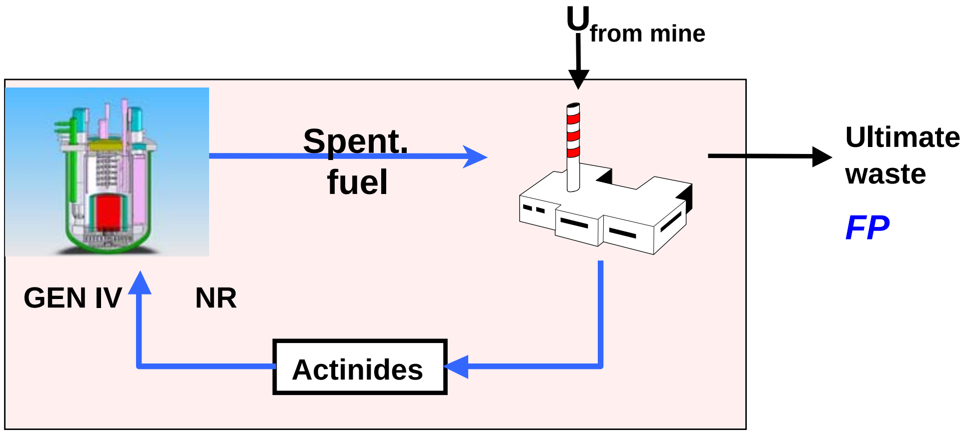
⇨ **Results already in use :**

- improved industrial facilities and processes;
- since 1991, significant waste volume reduction (by a factor of 6);
- feasibility of disposal

⇨ **A continuous improvement process to be continued:**

- for opening the scope of possible solutions;
- and defining future electricity generating systems.

⇨ **A new bill.**



- **Minimising ultimate waste**
- **Optimal use of energy-bearing natural resources**
- **Proliferation resistance**