# Spent fuel management

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*Future Nuclear Energy Systems*

CEA/Nuclear Energy Division/Division of Nuclear Development and Innovation

# Outline of presentation

1 – Present situation in France

- *1.1 – General context*
- *1.2 –Present situation*

2–Fuel

- *2.1 – MOX in LWR*
- *2.2 –Thorium*
- *2.3 –Gen IV systems*

3– Reprocessing/refabrication

4– Waste

# French Energy Policy

- **Nuclear energy confirmed as an essential part of the French energy Mix and recognition of EPR in the Energy bill**
- **EPR**
  - Decision by TVO to order an EPR in Finland
  - EDF in the process to launch a first EPR unit in Flamanville
- **EDF**
  - Opening of the capital of EDF
  - Progressive opening of the electricity market since 1999: 70 % in 2004 towards 100 % in 2007
- **High Level Long Lived Waste management :** final reports on R&D since 1991 in preparation in 2004 and 2005
- **R&D on 4th generation nuclear systems**

# R&D Strategy of France for Future Nuclear Energy Systems

*Approved by the Ministries of Research and Industry*
*on March 17, 2005*

## 1 – Development of Fast Reactors with a closed fuel cycle along 2 tracks:

- Sodium Fast Reactor (SFR)
- Gas Fast Reactor (GFR)
- New processes for spent fuel treatment and recycling

→ *Decision around 2015/2020 on prototypes*
→ *Industrial deployment around 2040*

## 2 – Nuclear hydrogen production and very high temperature process heat supply to the industry

- Very High Temperature Reactor (VHTR)
- Water splitting processes

## 3 – Innovations for LWRs *(Fuel, Systems…)*

# Law of 1991 : history

- No end point yet available for HL-LL waste
- URL siting studies met with strong public opposition in 1989
- Moratorium on siting studies
- The Parliament office for science and technology investigated the situation and issued a report which led to the adoption of the legislative framework on December 30, 1991 : the 1991 law.

# R&D for long term management of HLLW in France

3 areas of R&D set out by law of December 30,1991 :

- minimization of the quantity and toxicity of waste, by **partitioning and transmutation,**
- feasibility of **deep geological disposal**, whether reversible or irreversible.
- packaging and **conditioning**, for safe long lasting containment, and also studying **long term surface storage,**

15 years of R&D ⇨ 2006 ; evaluation by National Evaluation Commission

CEA : in charge of P&T and conditioning &long term storage

R&D in cooperation between CEA, EDF, AREVA, ANDRA, CNRS, universities, and international cooperations

# French Fleet of Nuclear Power Plants

## *Installed capacity in 2002*

**Nuclear : 63.3 GWe (55%)**

**Thermic : 27.1 GWe (23%)**

**Hydro : 25.4 GWe (22%)**

**Total : 90,4 GWe**

## *Electricity Generation in 2002*

**Production : 533 TWh**

**Exports : 80,6 TWh**

## *Nuclear Electricity Generation*

**58 NPP in operation (EDF)**

**Production : 415 TWh**

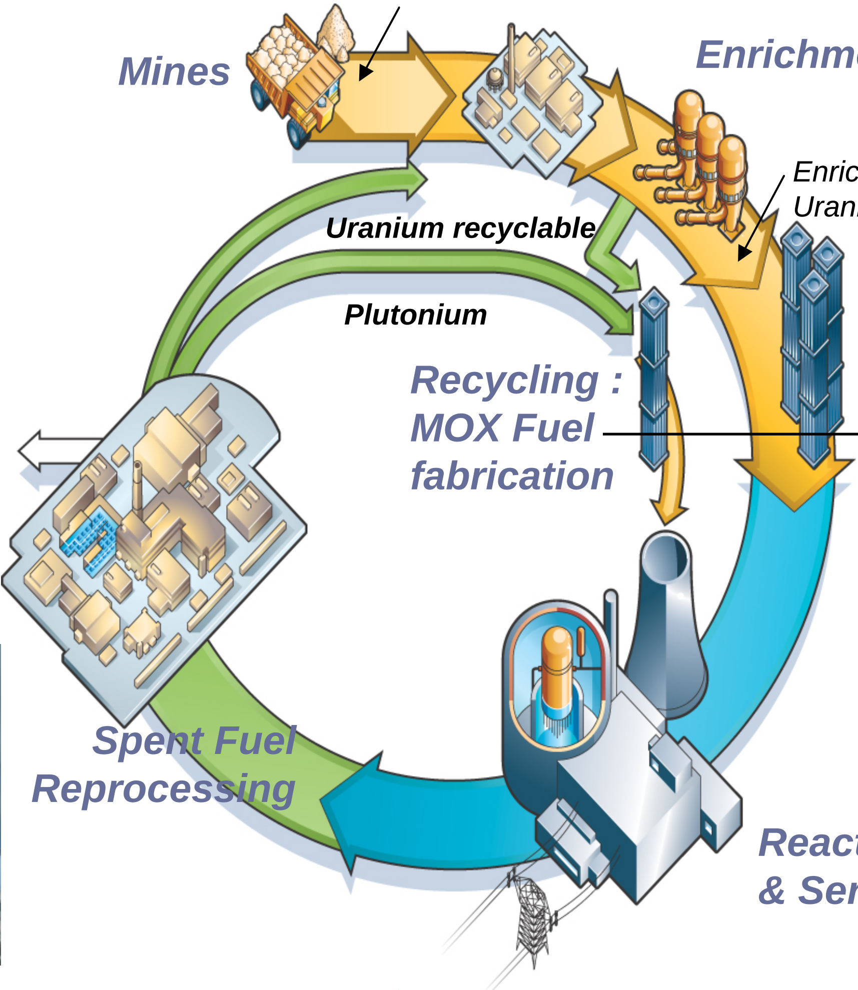
**% electricity : 78 %**

***(source : RTE - 2003)***

# Fuel Management in France

**Vitrified Waste**

Ultimate Wasre Disposal



Natural Uranium

Mines

Chemistry

Enrichment

Enriched Uranium

Fuel fabrication

Uranium recyclable

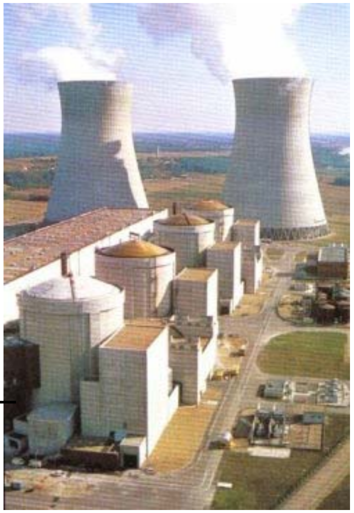
Plutonium

Recycling : MOX Fuel fabrication

Reactors & Services

Spent Fuel Reprocessing

**MELOX Plant**



**Dampierre**

**La Hague Plant**

**Front-End Sector**

**Reactors & Services Sector**

**Back-End Sector**

# Reprocessing & Recycling : Key to Future Energy Resources

Recover all energy available in the fuel

Valuable materials (96%)

Waste (4%)

**Uranium**
**(94 to 96 %)**

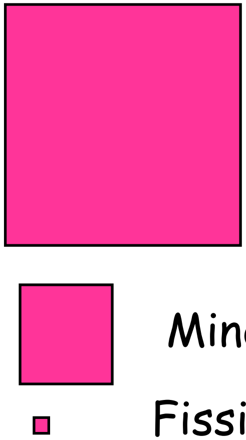
**Plutonium**
**( 1 %)**

**Fission Products**
**(3 to 5 %)**

**Minor Actinides**
**(0,1 %)**

**Reprocessing & Recycling**

Drastically minimise waste radiotoxicity



Plutonium

Minor actinides

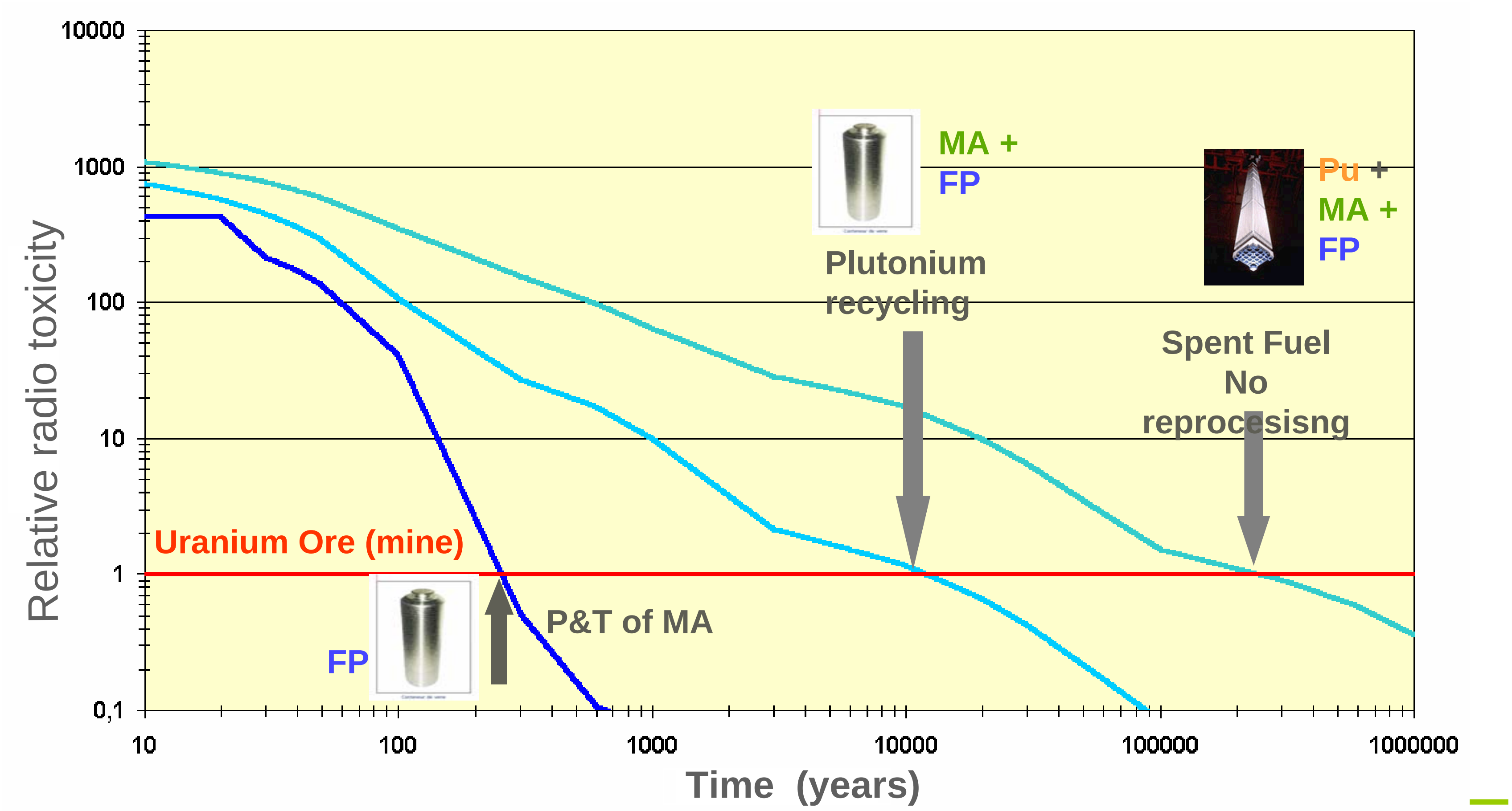
Fission products

*Radiotoxicity after 1 000 years*

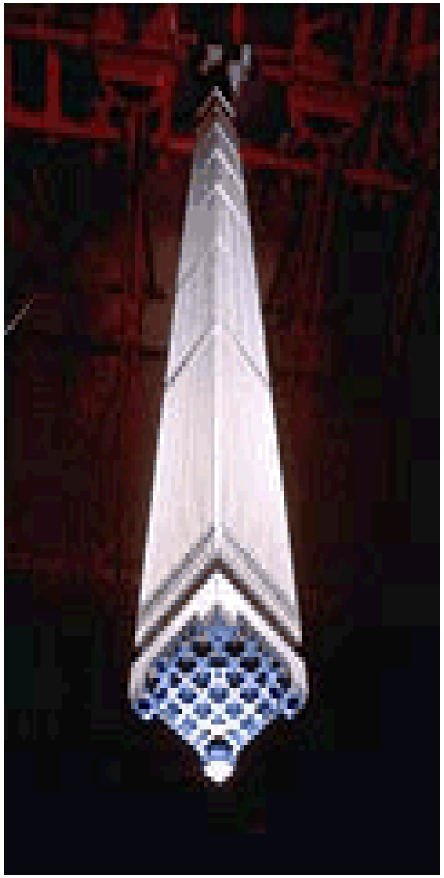
**Pu inventory stabilisation : Pu produced can be used in LWR**

# Nuclear waste management : reduce the long term noxiousness

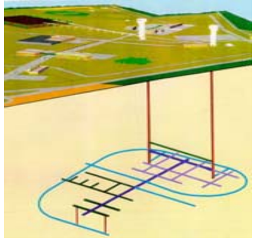
- **Urgent matter for public acceptance of nuclear energy**
- **Minimize the volume and the long term radiotoxicity**
- **1st contributor : Pu ; 2nd contributor : Minor Actinides (MA)**



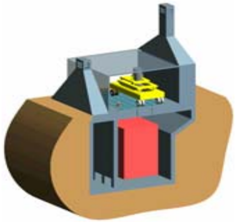
# Waste management strategy



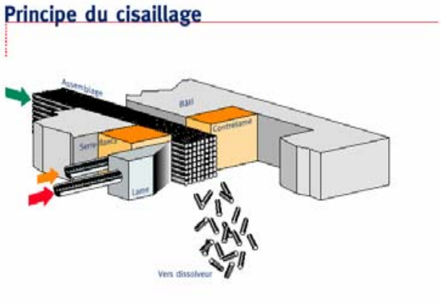
**Ultimate disposal**
**(USA, Suède,…)?**



**Interim storage ?**



**French strategy :**
**Reprocessing in La Hague**
**And then disposal**



# Radwaste types : classification and management paths

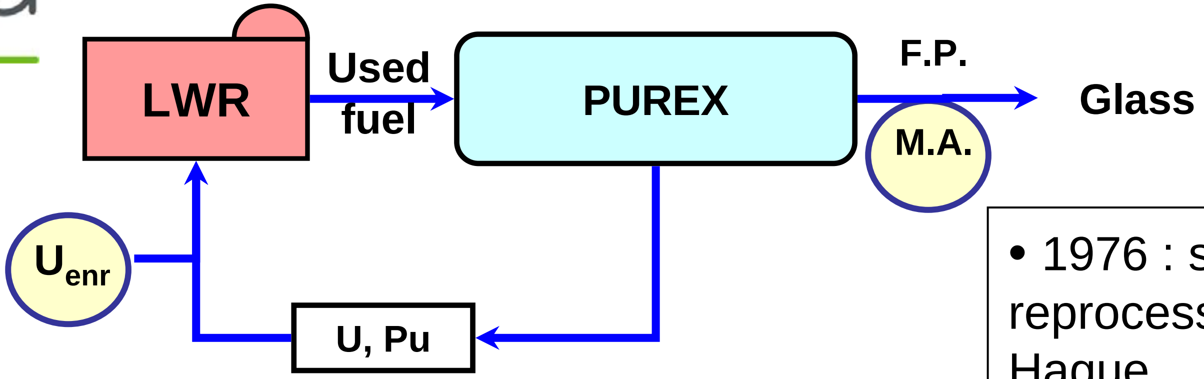
| | Short lived<br>Half-life < 30 years for most key elements | Long lived<br>Half-life > 30 years |
|---|---|---|
| **Very Low Level (VLL)** | Dedicated repository<br>(in operation since 2003)<br>Capacity : 650 000 $m^3$<br>108 219 $m^3$ (as of end of 2002)<br>11,1 % of total volume | |
| **Low Level (LL)** | Final disposal Centre de l'Aube (in operation since 1992)<br>Capacity : 1 M $m^3$<br>778 322 $m^3$ (as of end of 2002)<br>0,07 % radioactivity<br>79,5 % of total volume | Dedicated repository being studied for radium bearing waste (35 717$m^3$) and graphite waste (8 842 $m^3$)<br>0,01 % radioactivity,<br>4,5 % of total volume |
| **Medium Level (ML)** | | 45 359 $m^3$ end of 2002<br>3,87 % radioactivity<br>4,6 % of total volume<br>Under study |
| **High Level (HL)** | December 30, 1991 Law<br>1 639 $m^3$ end of 2002<br>96,05 % radioactivity<br>0,2 % of total volume | |

**90% of the overall radwaste volume is currently handled in operating disposal facilities.**

**In green, the two waste categories targeted in the law.**

⇨figures are quoted from the Inventaire national document (October 2004);

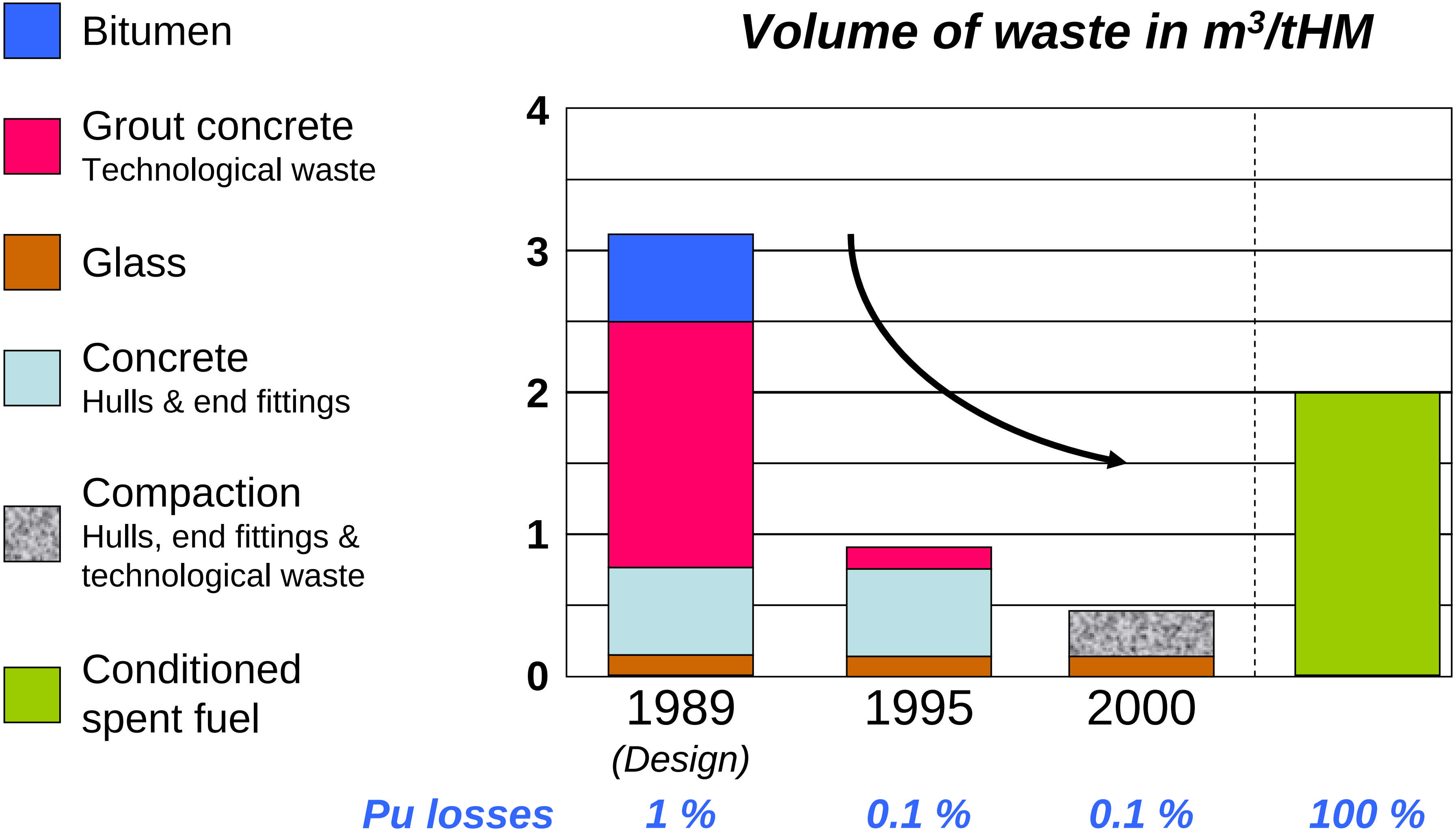
# R&D for waste management



- 1976 : start of SF reprocessing in UP2 at La Hague
- PUREX process
- significant and successful track record : > 19 000 tHM reprocessed as of end of 2003
- 850 tHM reprocessed each year (out of 1150 tHM unloaded from reactor)
- 8 t/a of Pu recycled
- in 20 NPP using MOX fuel
- HL-LL W vitrification

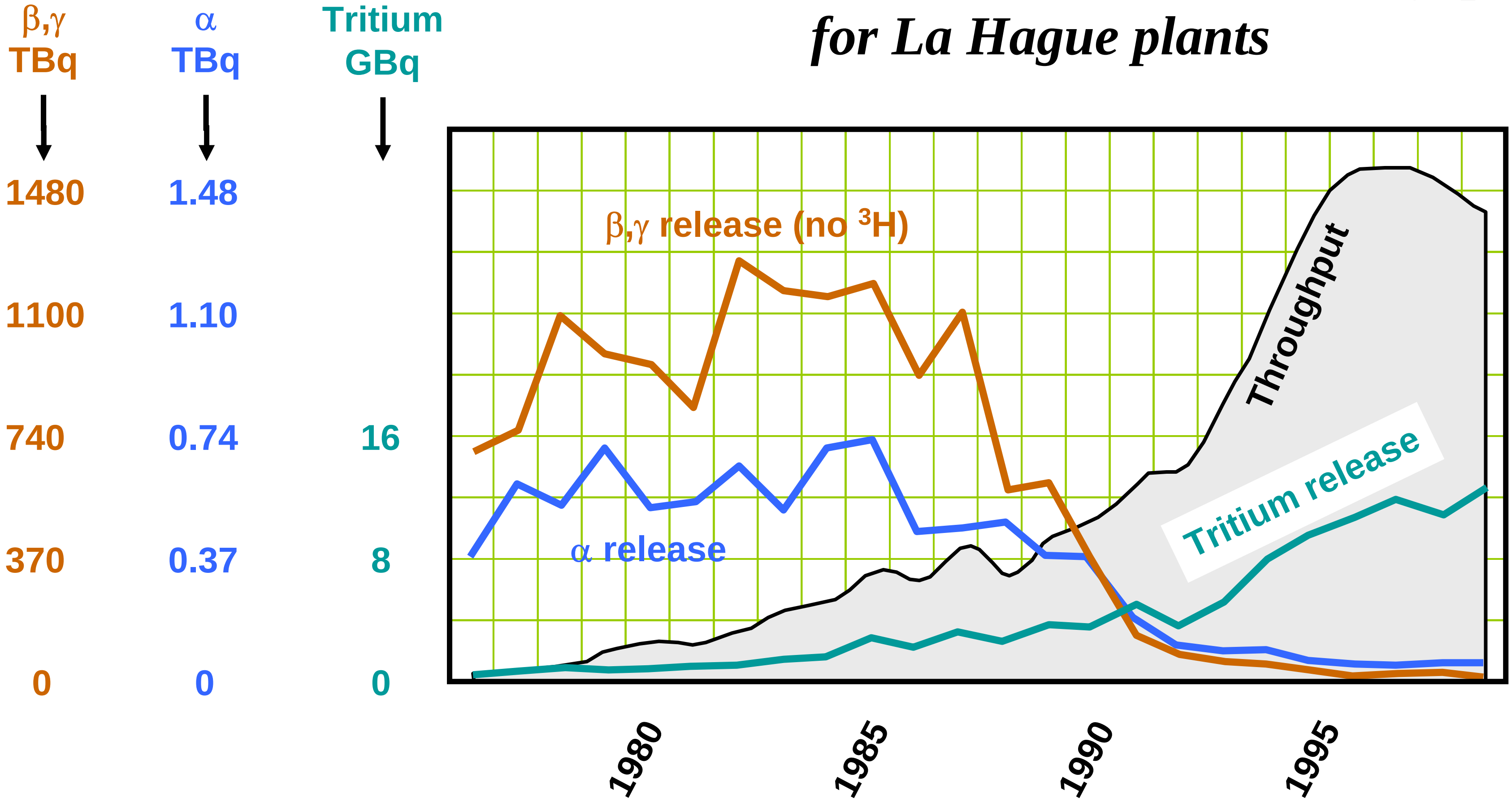
*La Hague SF reprocessing facilities*

# Specific waste volume for the UP3 plant



# Decreasing of the environmental impact

## *Release to the sea relative to the throughput for La Hague plants*



# The reprocessing-recycling option…

- Recovers reusable materials with very high energy potential and even today ensures major savings of natural uranium and oil through the use of MOX fuel:
  - producing more than 10% of the nuclear electricity generated in France.
  - reducing natural uranium consumption by more than 10% in France.
  - avoiding the high cost of enriching natural uranium.
- Reduces the quantities of spent fuel: 7 UOX → 1 MOX
- Diminishes the quantity and toxicity of high-level nuclear waste:
  - waste volume reduction by a factor of about 5.
  - waste radiotoxicity reduction by a factor of 10.
- Contributes to plutonium nonproliferation.
- Contributes to reducing the excess weapons-grade plutonium inventory.

# *Fuel and reactor perspectives*

# *MOX and Thorium fuel*

# *Gen IV Systems*

# The AREVA group industrial facilities

- An industrial complex comprising:
  - 2 plants in France

***MELOX (145 tHM/year)***

***The world leader of the MOX production***

***COGEMA Cadarache (42 tHM/year)***

***End of commercial MOX production on July 31, 2003***

  - 2 plants at Dessel (Belgium), BELGONUCLEAIRE and FBFC-I (assemblies), are part of the COGEMA MOX platform.

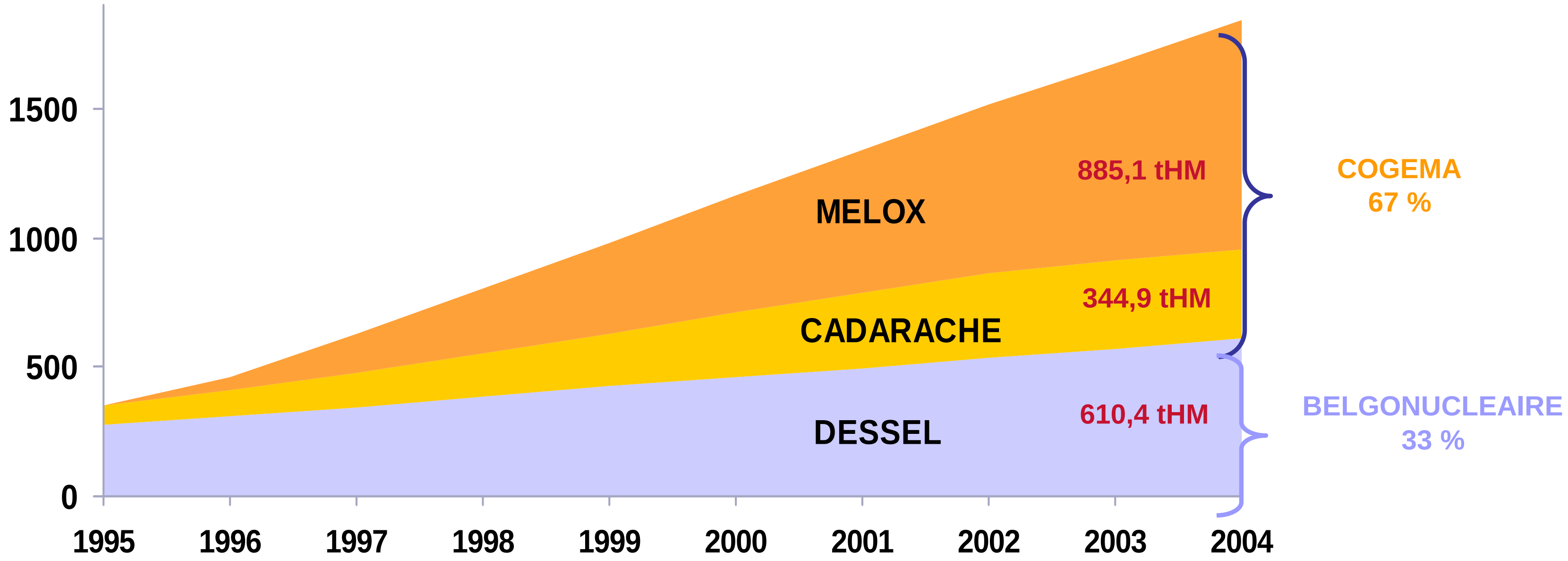
***BELGONUCLEAIRE***

***DESSEL (40 tHM/year)***

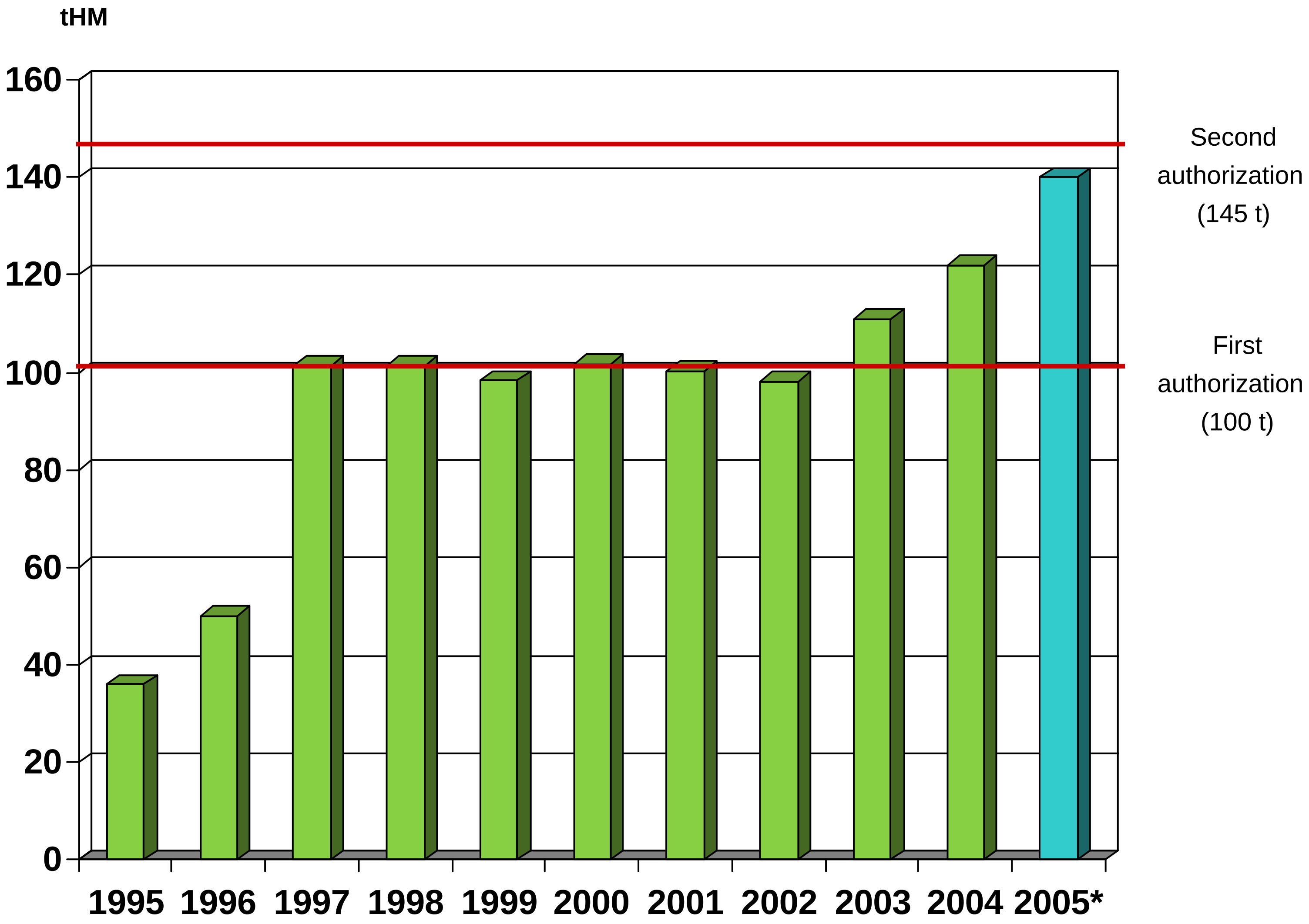
# Mature and competitive industry

- ~ 20 000 t of spent fuel have been treated at La Hague, with continuous optimization of industrial spent fuel treatment
- Significant cumulative production of MOX : 1840 tHM of MOX fuel pellets produced by the end of 2004

Cumulative production of MOX fuel pellets (tHM)

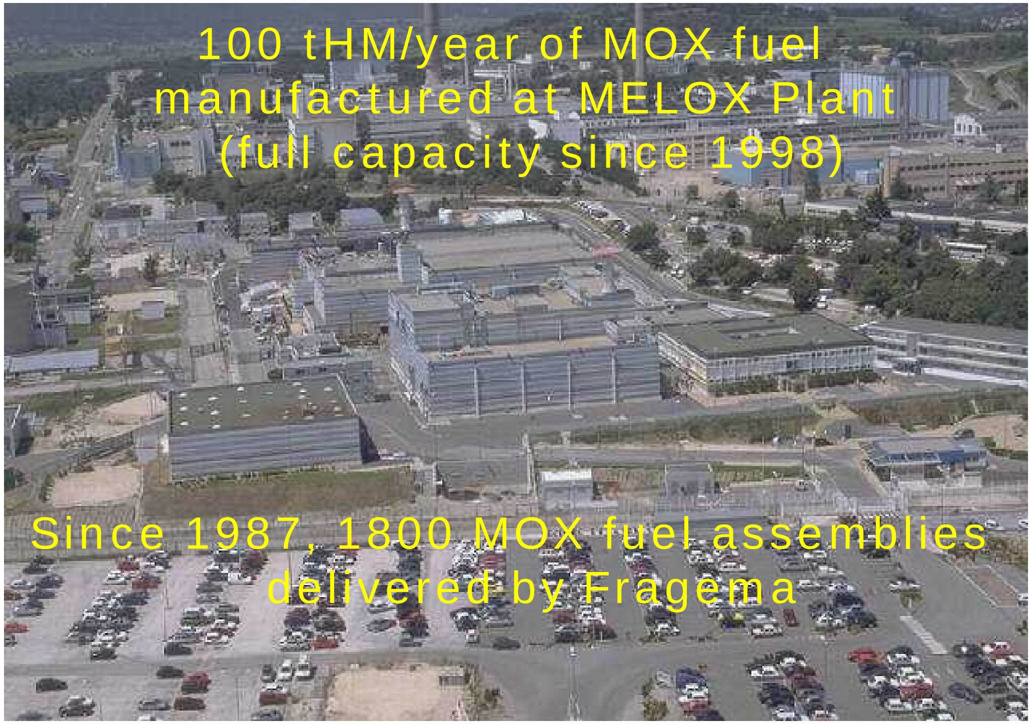


# MOX annual production in MELOX



* 2005 target (140 t)

# MOX fuels in French PWRs

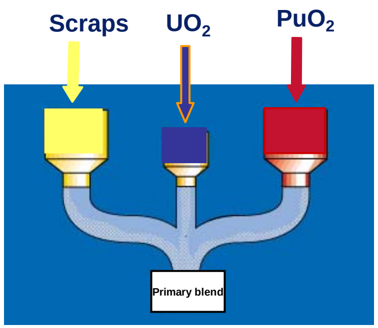


100 tHM/year of MOX fuel manufactured at MELOX Plant (full capacity since 1998)

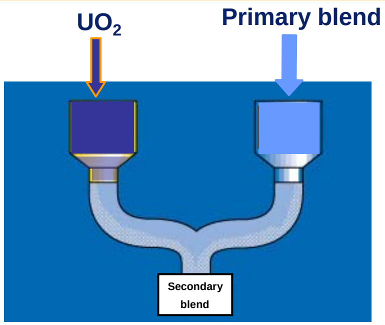
Since 1987, 1800 MOX fuel assemblies delivered by Fragema

- 20 French, 2 belgian, 3 german reactors loaded with MOX
- 2 Reactors (Cruas 3 & 4) loaded with reprocessed uranium

# Key advantages of MIMAS process



1 *Preparation of primary blend*



2 *Preparation of secondary blend*

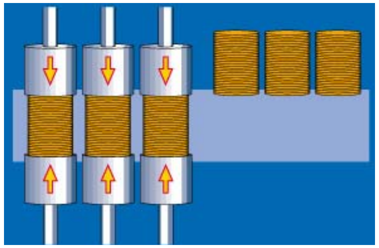
- Powder mixing is the key point of MIMAS process.
- MIMAS process allows an on-line recycling of almost all the scraps.
- MIMAS process performances and reliability are world-wide recognized.
- More than 30 years operational experience in reactors (PWR & BWR) have demonstrated the high quality of MOX fuel fabricated by the COGEMA group.
- MOX fuel behavior in reactor is similar to $UO_2$ fuel, in normal and incidental conditions.

# The fuel fabrication process

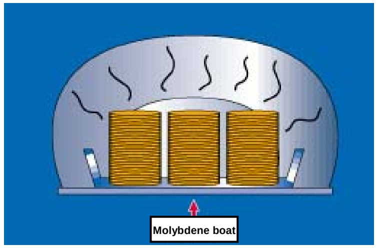
**MIMAS**

**PROCESS**

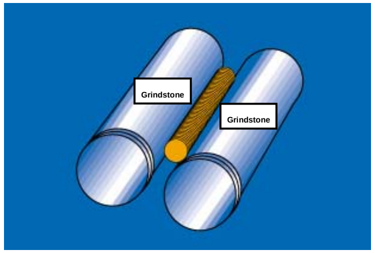
**1** ***Powder blend***



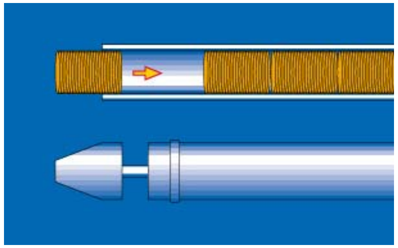
**2** ***Pressing or pelletizing***



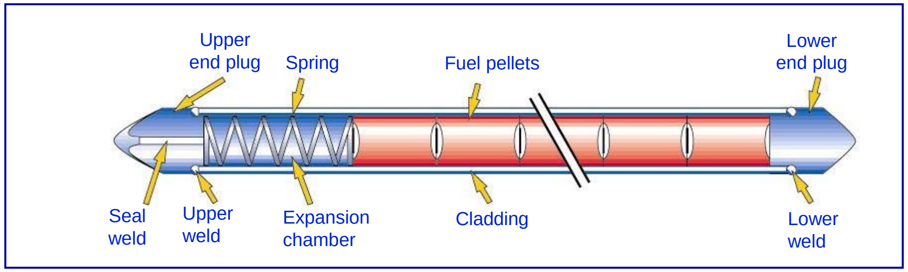
**3** ***Sintering***



**4** ***Grinding***



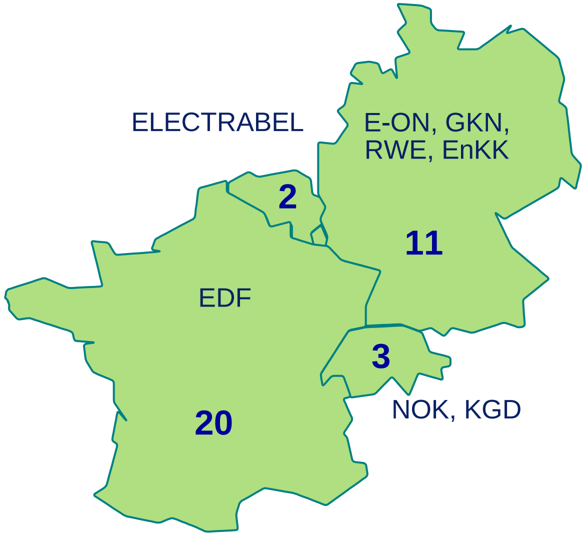
**5** ***Rod cladding***



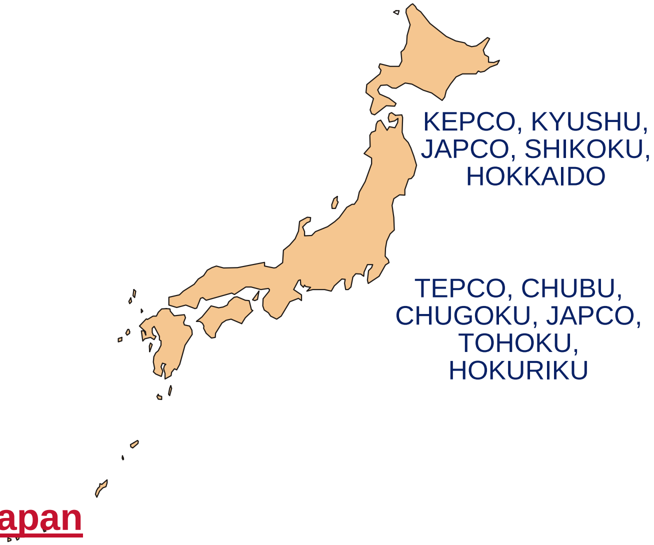
*Light water type fuel rod*

**6** ***Assemblies fabrication***

# 37 commercial LWR loaded with MOX significant cumulative production of MOX



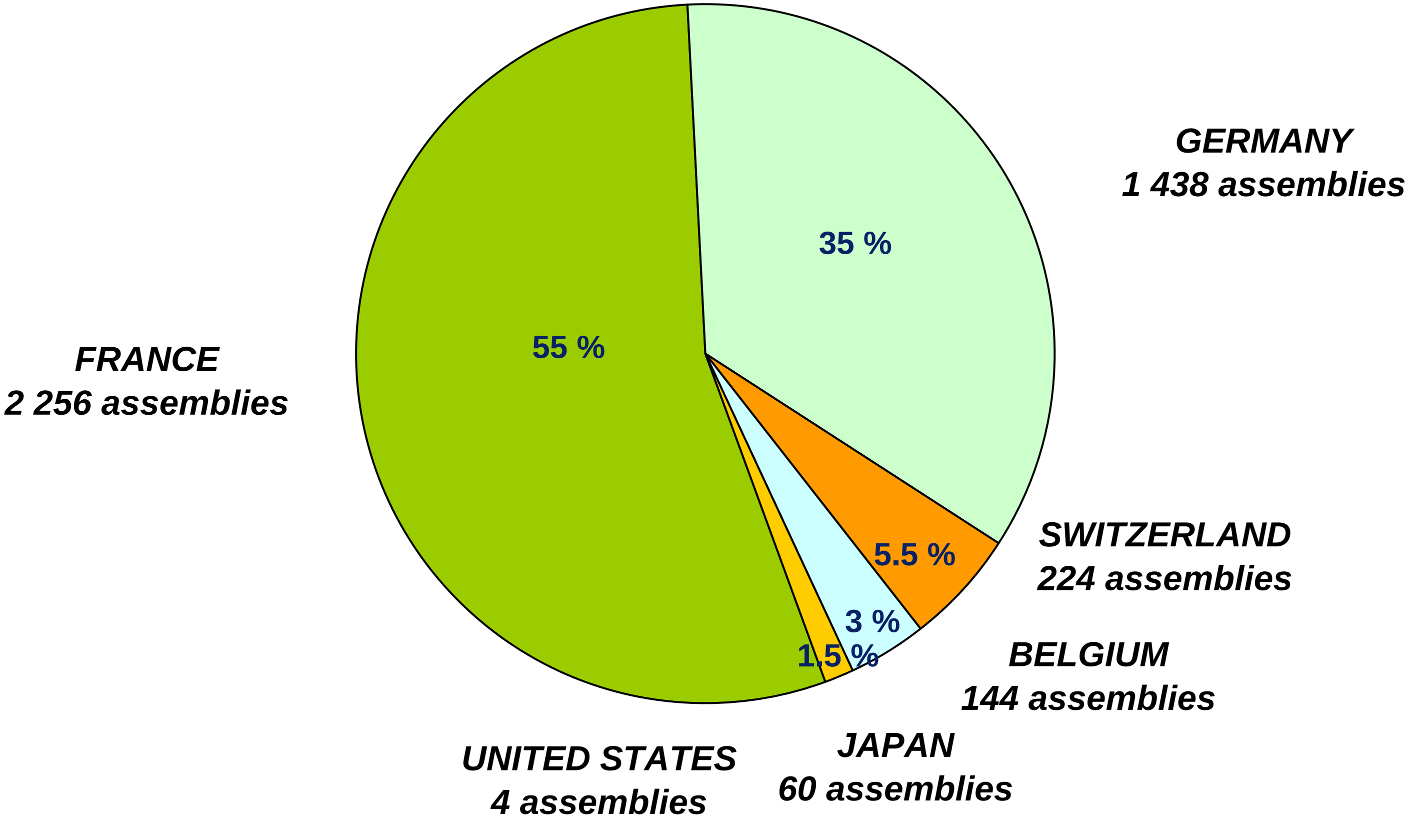
**En Europe**
**36 «moxified» reactors**



**In Japan**

- **Delivery of 60 MOX fuel assemblies to TEPCO in 1999 and 2001**
- **10 utilities committed to load MOX**

# MOX fuel assemblies delivered by country



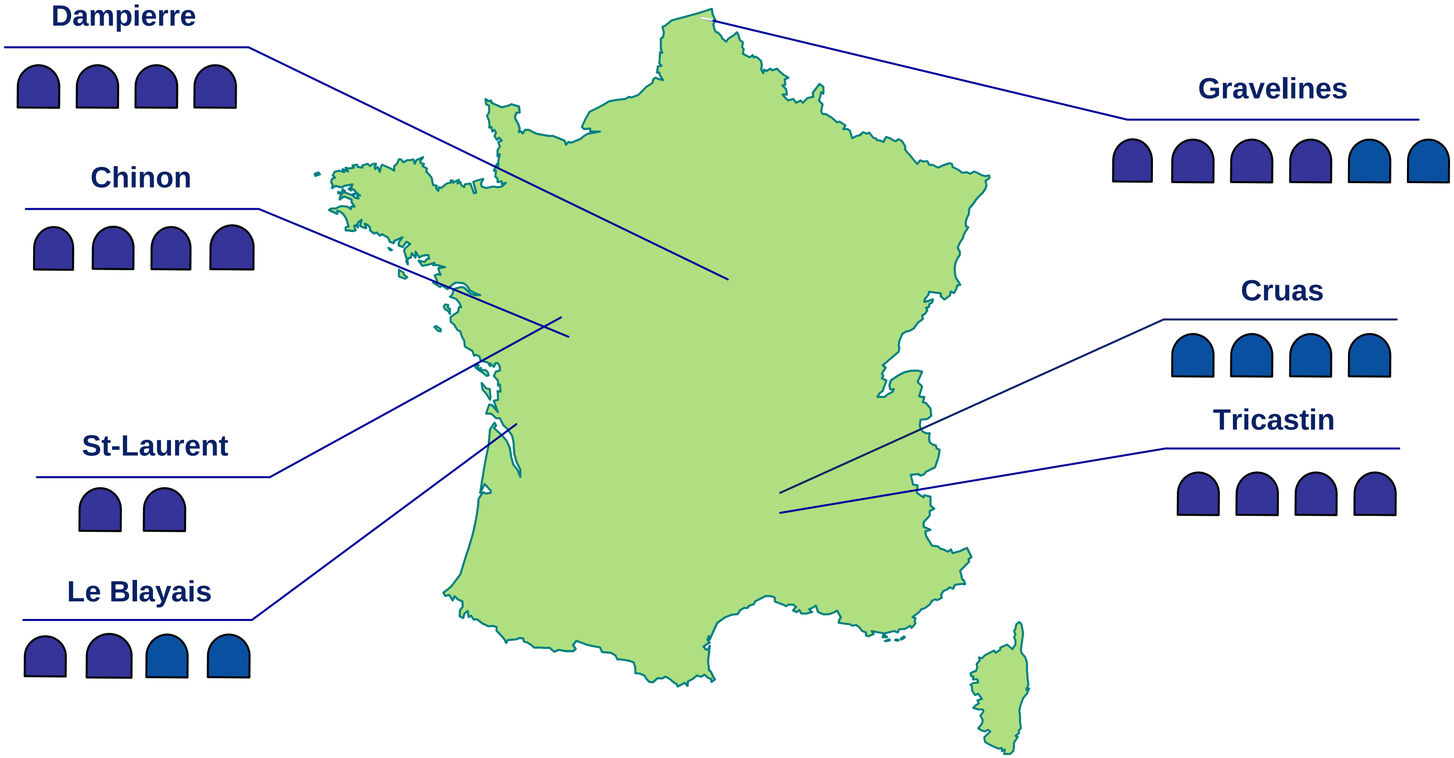
- 4 122 MOX fuel assemblies delivered to customers by end of 2004.
  - 83% of whom for PWR
  - 17% of whom for BWR

# MOX review in Europe

| | Reactors in operation | MOX authorized reactors | " Moxified " reactors | First MOX loading date |
|---|---|---|---|---|
| • **Germany** | 21 | 11 | 11 | 1972 |
| • **Switzerland** | 5 | 4 | 3 | 1984 |
| • **France** | 58 | 20 | 20 | 1987 |
| • **Belgium** | 7 | 2 | 2 | 1995 |

**MOX, a recycling solution used for more than 30 years**

# 900 Mwe EDF PWR loaded with MOX fuel



- In France: 58 reactors in operation, 20 "moxified" reactors with 1/3 MOX in the core*

**MOX loaded reactors**

St-Laurent : B1 (1987), B2 (1988)
Dampierre : 1 (1990), 2 (1993), 3 et 4 (1998)
Le Blayais : 2 (1994), 1 (1997)
Tricastin : 2 et 3 (1996), 1 et 4 (1997)
Gravelines : B3 et B4 (1989), B1 (1997), B2 (1998)
Chinon : B4 (1998), B3 et B2 (1999), B1 (2000)

**Technically capable reactors**

Gravelines C5 et C6
Blayais 3 et 4
Cruas 1 à 4

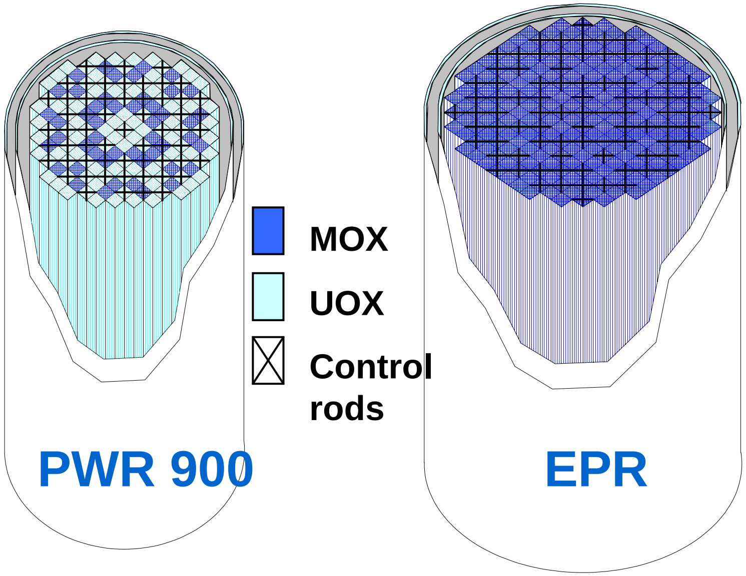
* EPR: 100% moxification possible

# Generation III

$3^d$ generation : improving the backend of the fuel cycle :
Higher flexibility for MOX

Increased capacity forconsuming Plutonium

Possibility of cores with 100% MOX



**Net balance of Plutonium in Kg Pu/year**

- **PWR 900 $UO_2$ :**
  **+ 200**
- **PWR 900 MOX :**
  **0**
- **EPR 100% MOX :**
  **- 670**

# Thorium

The studies about the Thorium cycle have stopped in 1970/1980 but some new interest arises in 90’ :

- Possibility of a higher Pu consumption with Th matrix
- Minimizing the wastes radiotoxicity and the MA production

with today questions about natural ressources and the capability for Thorium to replace Uranium.

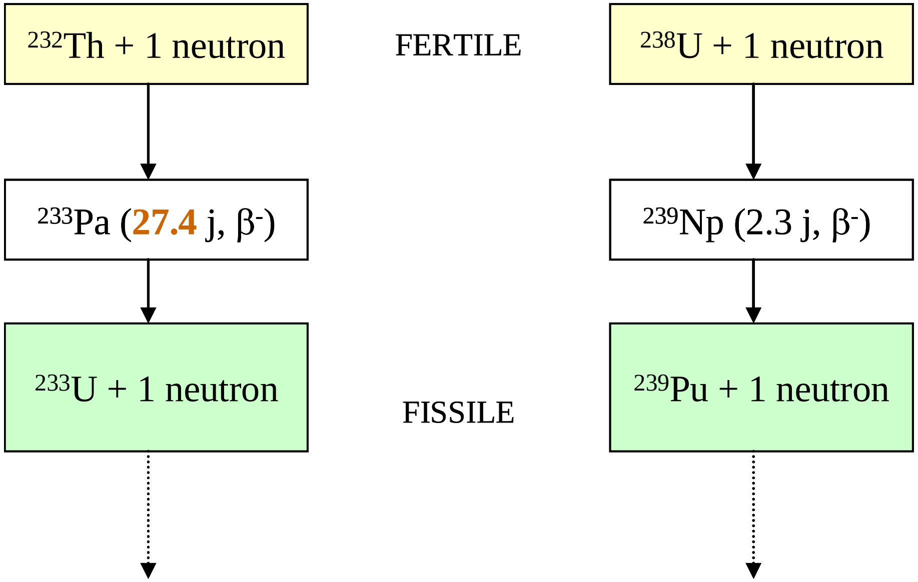
# Thorium : natural ressources

| | Réserves (Mt) | Ressources (Mt) | Average natural abundance |
|---|---|---|---|
| Uranium | 4 | 12 (conventionnal)<br>20 (unconventionnal, sea water excepted) | 2 à 4 ppm (earth's crust)<br>3.3 ppb (sea water) |
| Thorium | 1.5 | 4.1 (conventionnal) | 5 à 10 ppm (earth's crust)<br>0.5 ppb (sea water) |

- **Estimation : two times more Thorium than Uranium**
  - Radioactive period is three times larger
  - But the accessibility is lower
- **Thorium is localized mainly in Asia (India) and South America (Brasil)**

# Thorium : main isotopes

| Thorium | Uranium | |
|---|---|---|
| $^{232}$Th | $^{235}$U | $^{238}$U |
| 100 % | 0.70 % | 99.30 % |
| fertile | fissile | fertile |



$^{232}$Th + 1 neutron

FERTILE

$^{238}$U + 1 neutron

$^{233}$Pa (**27.4** j, $\beta^-$)

$^{239}$Np (2.3 j, $\beta^-$)

$^{233}$U + 1 neutron

FISSILE

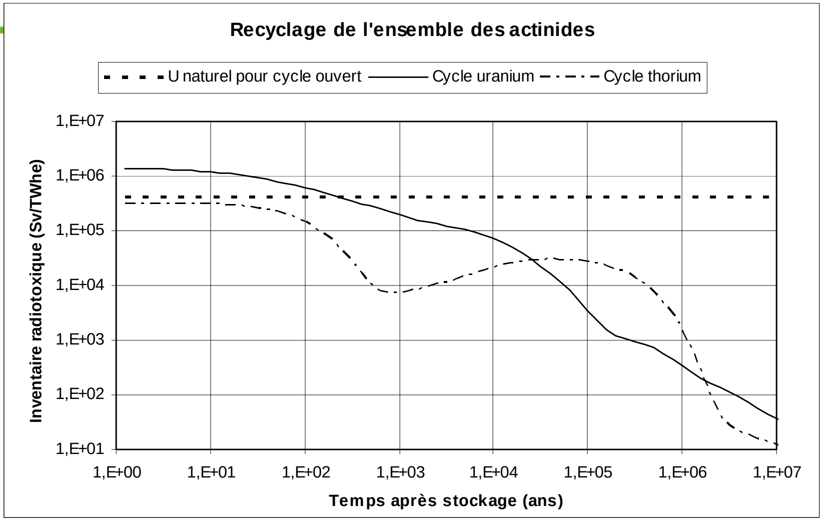
$^{239}$Pu + 1 neutron

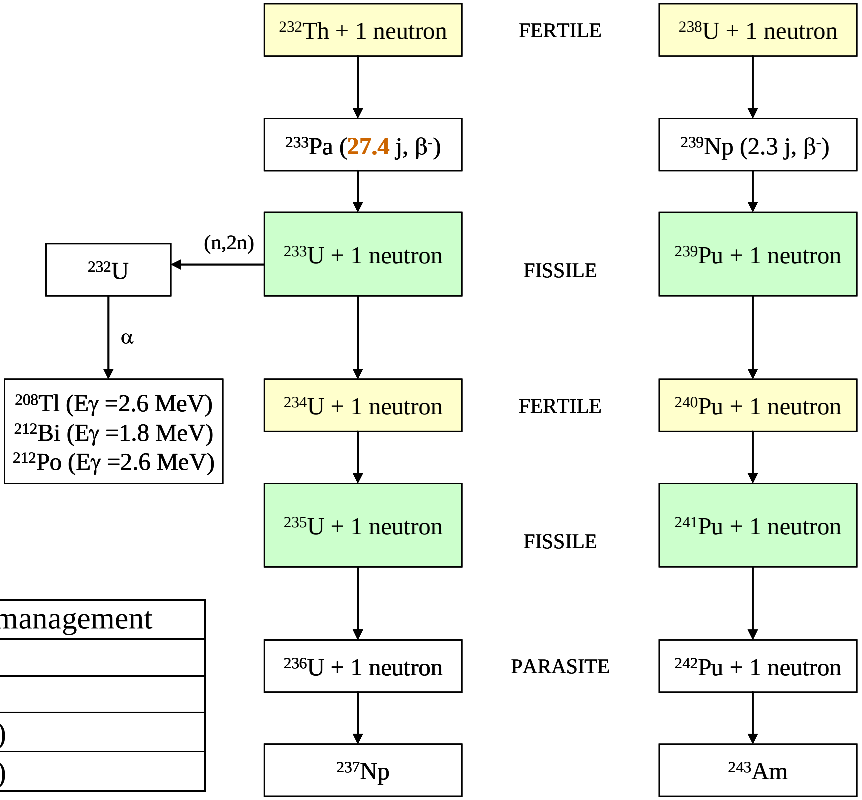
# Thorium : neutronical properties

| Fissile Isotopes | $^{235}$U | | $^{239}$Pu | | $^{233}$U | |
|---|---|---|---|---|---|---|
| | Thermal | Fast | Thermal | Fast | Thermal | Fast |
| $\sigma_f$ (barn) | 582 | 1,81 | 743 | 1,76 | 531 | 2,79 |
| $\sigma_c$ (barn) | 101 | 0.52 | 270 | 0.46 | 46 | 0.33 |
| $\alpha = \sigma_c/\sigma_f$ | 0,17 | 0,29 | 0,36 | 0,26 | 0,09 | 0,12 |
| $\nu$ | 2,42 | 2,43 | 2,87 | **2,94** | 2,49 | 2,53 |
| $\eta$-1 | 1,07 | 0,88 | 1,11 | **1,33** | **1,29** | 1,27 |
| $\beta_{eff}$ | 650 pcm | | 210 pcm | | 276 pcm | |

| Isotopes fertiles | $^{238}$U | | $^{232}$Th | |
|---|---|---|---|---|
| | Thermal | Fast | Thermal | Fast |
| $\sigma_c$ (barn) | 2,73 | 0,32 | **7,40** | 0,33 |
| $\beta_{eff}$ | 1480 | | 2030 | |

➔ *Thorium cycle ($^{232}$Th, $^{233}$U) will perform the best in thermal or epithermal spectra*





$^{232}$Th + 1 neutron

FERTILE

$^{238}$U + 1 neutron

$^{233}$Pa (27.4 j, $\beta^-$)

$^{239}$Np (2.3 j, $\beta^-$)

$^{232}$U

(n,2n)

$^{233}$U + 1 neutron

FISSILE

$^{239}$Pu + 1 neutron

α

$^{208}$Tl (Eγ =2.6 MeV)
$^{212}$Bi (Eγ =1.8 MeV)
$^{212}$Po (Eγ =2.6 MeV)

$^{234}$U + 1 neutron

FERTILE

$^{240}$Pu + 1 neutron

$^{235}$U + 1 neutron

FISSILE

$^{241}$Pu + 1 neutron

$^{236}$U + 1 neutron

PARASITE

$^{242}$Pu + 1 neutron

$^{237}$Np

$^{243}$Am

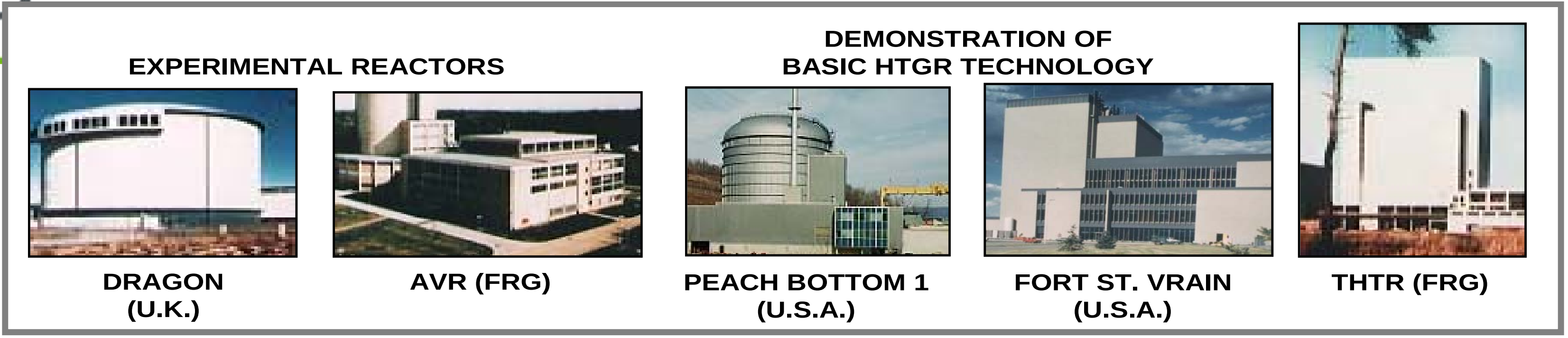
| Dose (n+γ) | Fuel Fabrication | Spent fuel management |
|---|---|---|
| MOX | 1 | 1 |
| Th/Pu | 2 | 5 |
| U / Th / Pu | 2 | 30400 (γ >> n) |
| Th/U | 1 | 13100 (γ >> n) |

- *hot cells, and automatic remote-controlled facility, are needed for Thorium cycle*
- *No clear advantage for radiotoxicity*

# Thorium cycle : Historics

| | | | |
|---|---|---|---|
| Indian Point | PWR 162 MWe | 62-80 | Th + U 93% |
| Elk River | BWR 22 MWe | 63-68 | Th + U 93% |
| Shippingport | REP 60 MWe | 77-82 | Th + U233<br>FIR 1,01 |
| Peach Bottom | HTR 40 MWe | | |
| Dragon | HTR | | |
| AVR | HTR | | |
| MSRE | MSR 7,5 MWth | 65-69 | |

# Le Retour d'Expérience des HTR. Des prototypes de réacteurs HTR ont été réalisés dans les années 60 à 90



| | Dragon | Peach Bottom | AVR | Fort Saint Vrain | THTR300 | HTTR | HTR10 |
|---|---|---|---|---|---|---|---|
| Lieu | Winfrith (GB) | Pennsylvanie (EU) | Jûlich (Allemagne) | Colorado (EU) | Schmehausen (Allemagne) | Oarai (Japon) | (Chine) |
| Divergence | 1964 | 1966 | 1966 | 1974 | 1983 | 1998 | 2001 |
| Arrêt | 1975 | 1974 | 1988 | 1989 | 1989 | - | - |
| MWth | 20 | 115.5 | 46 | 842 | 750 | 30 | 10 |
| MWe | | 40 | 15 | 330 | 300 | | |
| Pression He (bar) | 20 | 24,6 | 10 | 48 | 40 | 40 | 30 |
| T entrée | 335 | 343 | 175 | 406 | 262 | 395 | 250-300 |
| T sortie | 835 | 715 | 850 | 785 | 750 | 850-950 | 700-900 |
| Puissance volumique (MW/m3) | 14 | 8.3 | 2.3 | 6.3 | 6 | 2.5 | 2 |
| Eléments combustible | primes | prismes | boulets | prismes | boulets | prismes | boulets |
| Cycle | varié | U/Th | U5/Th | U5/th | U5/Th | U enrichi | U enrichi |

# Thorium : Summary

- Natural ressource larger than uranium
- Physical properties favourable in thermal and epithermal spectra
- Past experience in PWR, HTR and MSR
- Small advantage for waste radiotoxicity before 10 000 years

**but**

- U5 or Pu needed for starting
- Fuel cycle closing has not be demonstrated
- Penalties compared to Uranium in fuel cycle facilities and necessity to create specific facilities

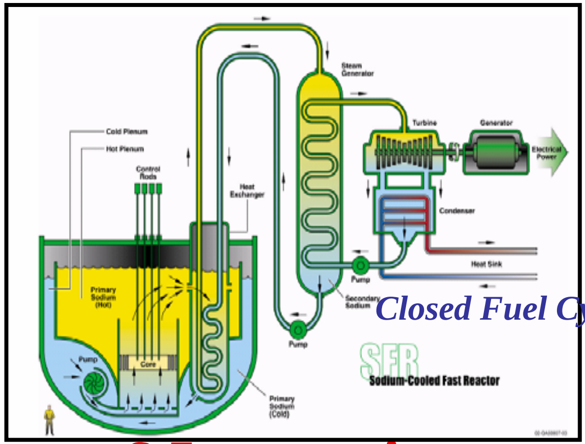
# Development of future nuclear energy systems

- **Technical maturity by 2030**
- **With significant advances in :**
  - Sustainability
  - Safety and reliability
  - Proliferation and physical protection
  - Economics
- **Competitive in various markets**
- **Designed for different applications**
  - Electricity, Hydrogen Desalinated water, Heat

*GIF Chartered July 2001*

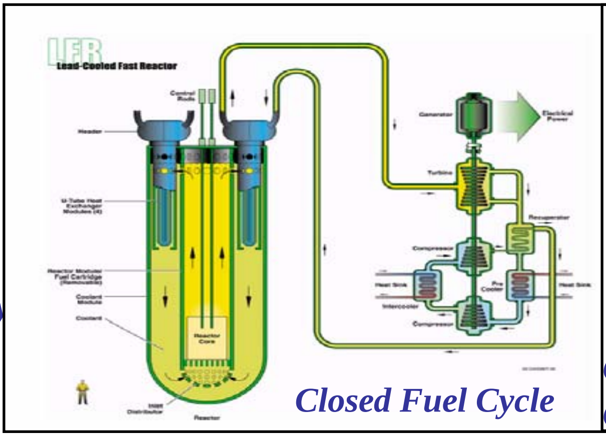
# Generation IV : systems selected

*Sodium Fast Reactor*



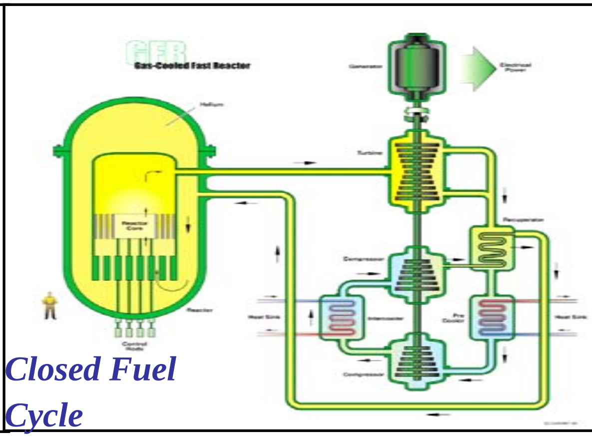
*Closed Fuel Cy*

*Lead Fast Reactor*



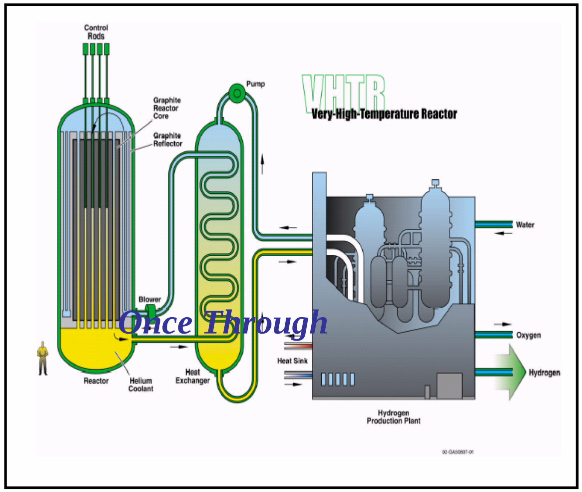
*Closed Fuel Cycle*

*Gas Fast Reactor*

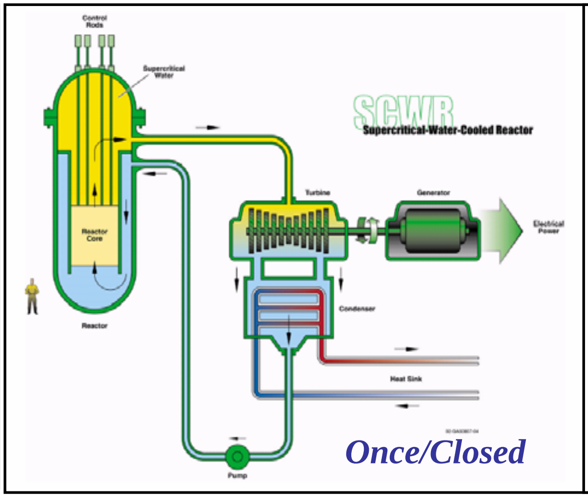


*Closed Fuel Cycle*

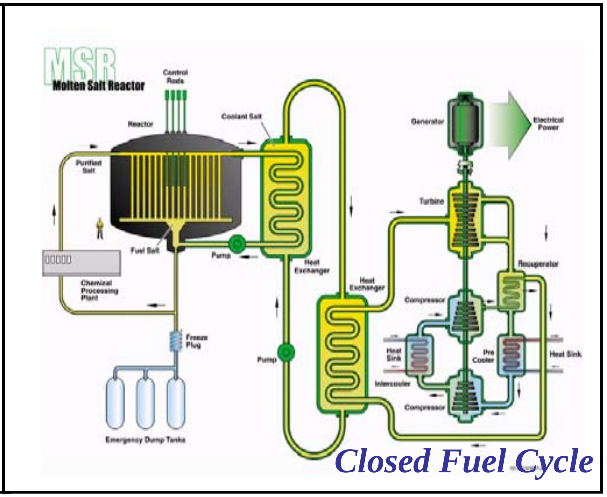
**6 Innovative concepts with technological breakthroughs**



*Once Through*



*Once/Closed*

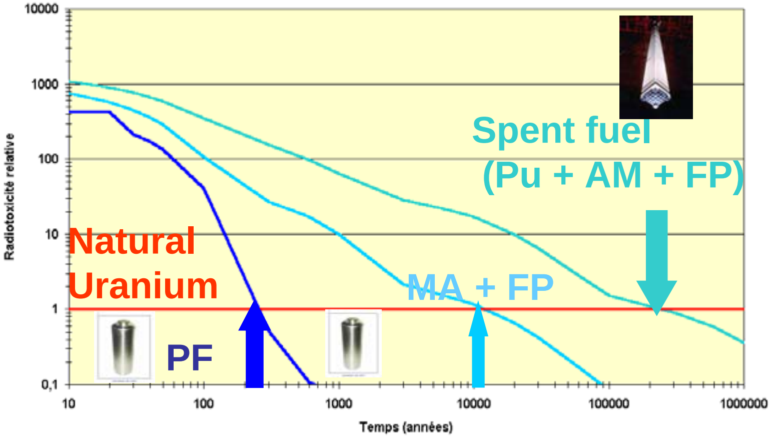


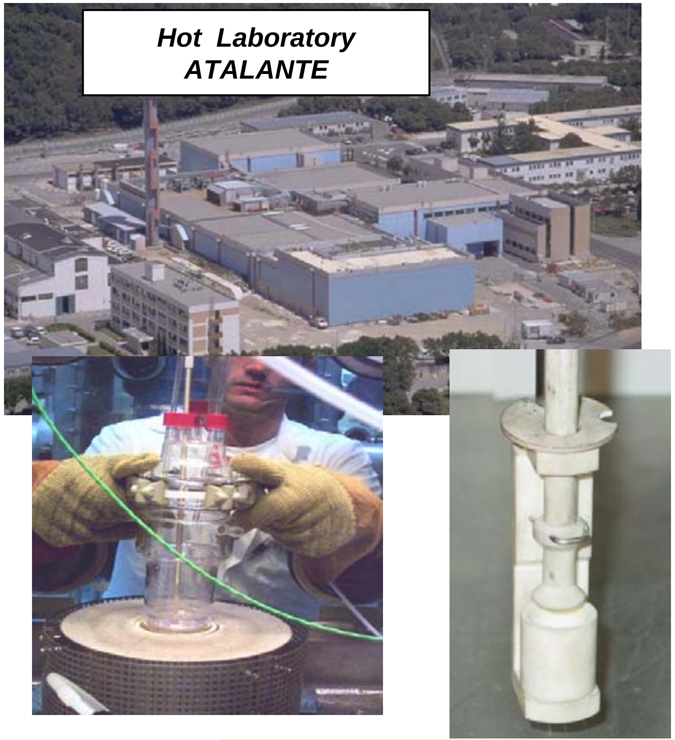
*Closed Fuel Cycle*

*Very High Temperature Reactor* *Supercritical Water Reactor* *Molten Salt Reactor*

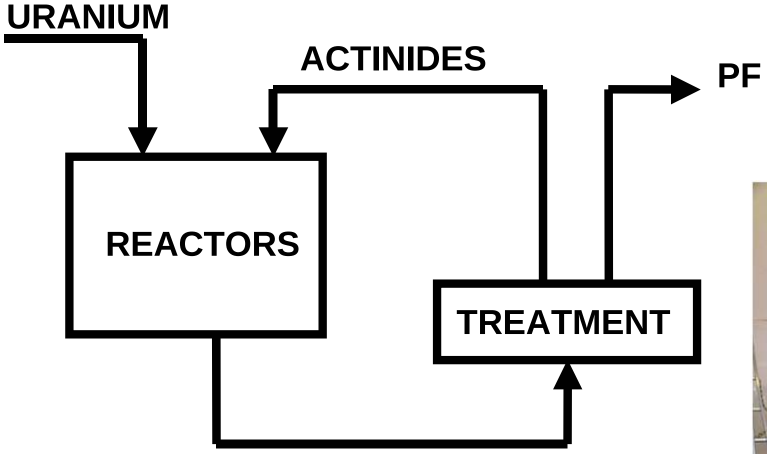
# Generation IV fuel cycle options

- Recycling of all Actinides
- Group separation of all Actinides
- Integration of treatment and re-fabrication processes and technologies
- Minimizing waste





*Hot Laboratory ATALANTE*



URANIUM

ACTINIDES

PF

REACTORS

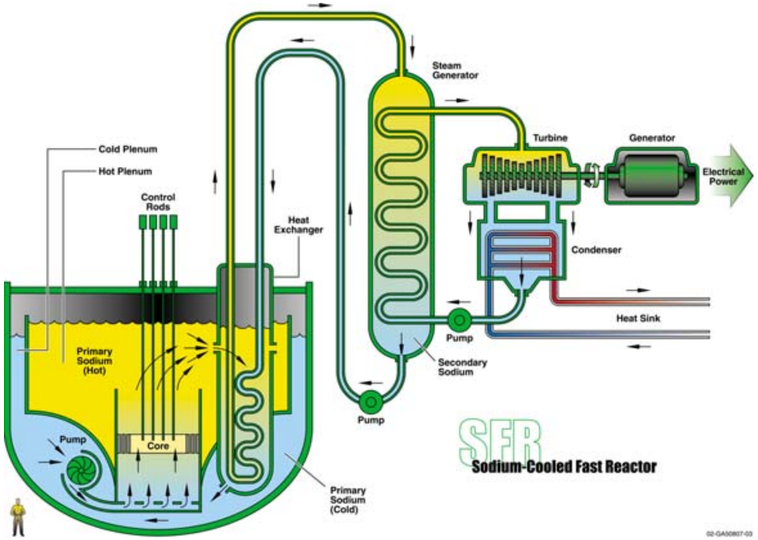
TREATMENT

*Drastic reduction of ultimate waste long-term radio-toxicity*

*Process of “external gelation”*

# Sodium Fast Reactor **SFR**

- A new generation of sodium cooled Fast Reactors
- Reduced investment cost
  Simplified design, system innovations
  *(Pool/Loop design, ISIR – SC $CO_2$ PCS)*
- Towards a passive safety approach
- Integral recycling of actinides
  Remote fabrication of TRU fuel



**→ 2009 : Feasibility – 2015 : Performance → 2020+ : SFR Demo**

*Japan*

*France*

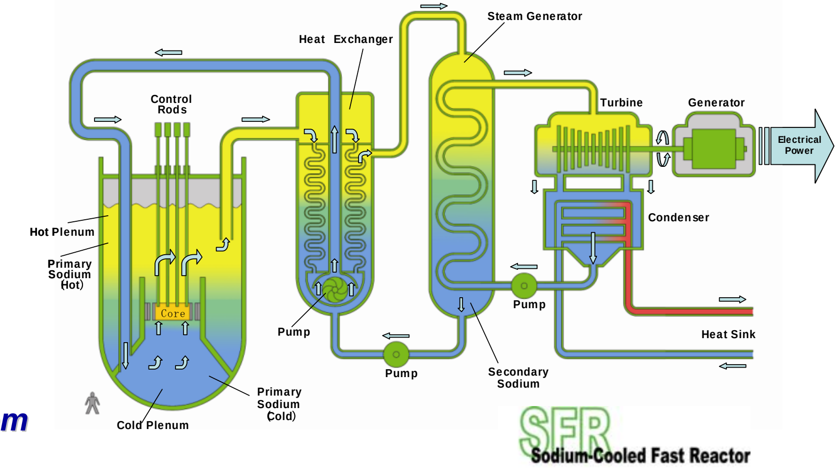
SFR Steering Committee

*U.S.A.*

*Euratom countries*

*South Korea*

*United Kingdom*



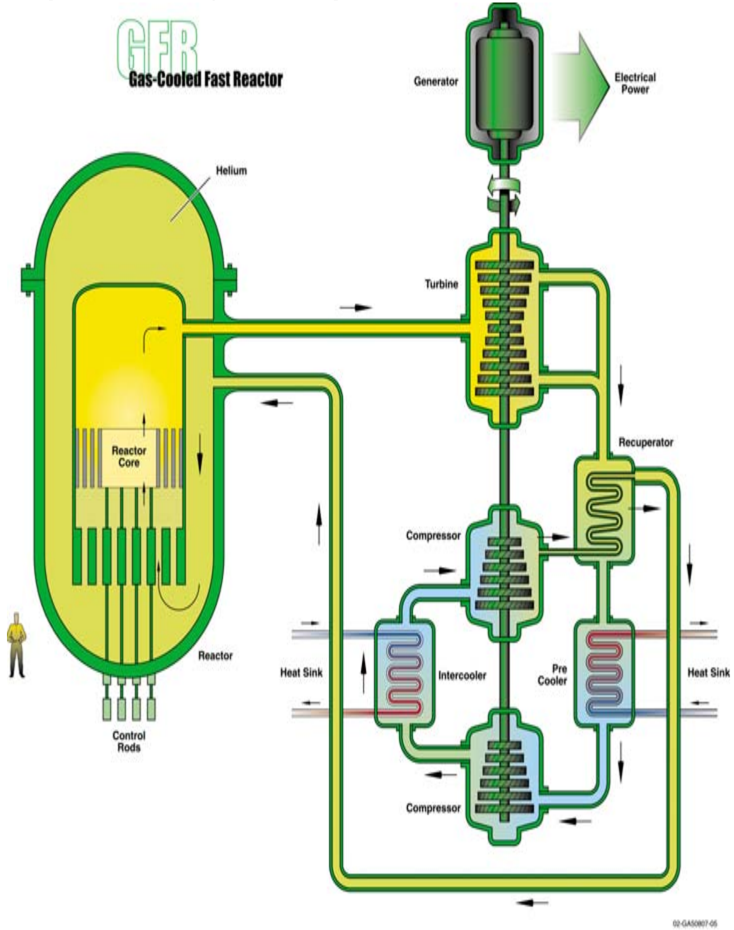
# CEA contribution for Advanced fuels SFR

- Advanced Fuel Fabrication
  - SUPERFACT Irradiation (Synthesis documents are available at JNC)
  - FUTURIX fuel fabrication
  - METAPHIX (Joint study with EU under collaboration of CEA)
  - Technological developments for Remote Fabrication: innovative equipments; simulation
  - Remote fabrication (FR) e.g. at MELOX (MOX) and ATALANTE (for experimental fuels)
  - Current PHENIX irradiations including SOL GEL fuels
- Irradiation behaviour of advanced fuels
  - CAPRIX high Pu content fuels in Phenix
  - SUPERFACT MA bearing oxide fuel in Phenix
  - FUTURIX irradiation
  - PIE of experiments on nitride fuel from Phenix [FUTURIX irradiation] and current irradiation in BOR-60: BORA BORA
  - CONFIRM irradiation in R2 of Studsvik
  - NIMPHE 1 & 2
  - METAPHIX (Joint study with EU under collaboration of CEA)
- Advanced core material
  - 12YWT material irradiation in OSIRIS
  - Current PHENIX irradiations including advanced austenitic materials
- Tools for core design
  - Set of available CEA computer codes

# Gas Fast Reactor **GFR**

- A new concept of Gas cooled Fast Reactor
  → Natural uranium resource saving, minimum production of waste
- **Robust fuel** *(ceramics)*
- 1200 MWe – **t He ~ 850 °C –** Co-generation *(electricity + H2)*
- **Active + passive safety approach**
- **Integral recycling of actinides**
  **Remote fabrication of TRU fuel**

- **→ 2012: Feasibility - 2017: ETDR**
  **2020: Performance → 2025+: GFR Demo**



**France**

**U.S.A.**

**Japan**

GFR Steering Committee

**Euratom countries**

**Switzerland**

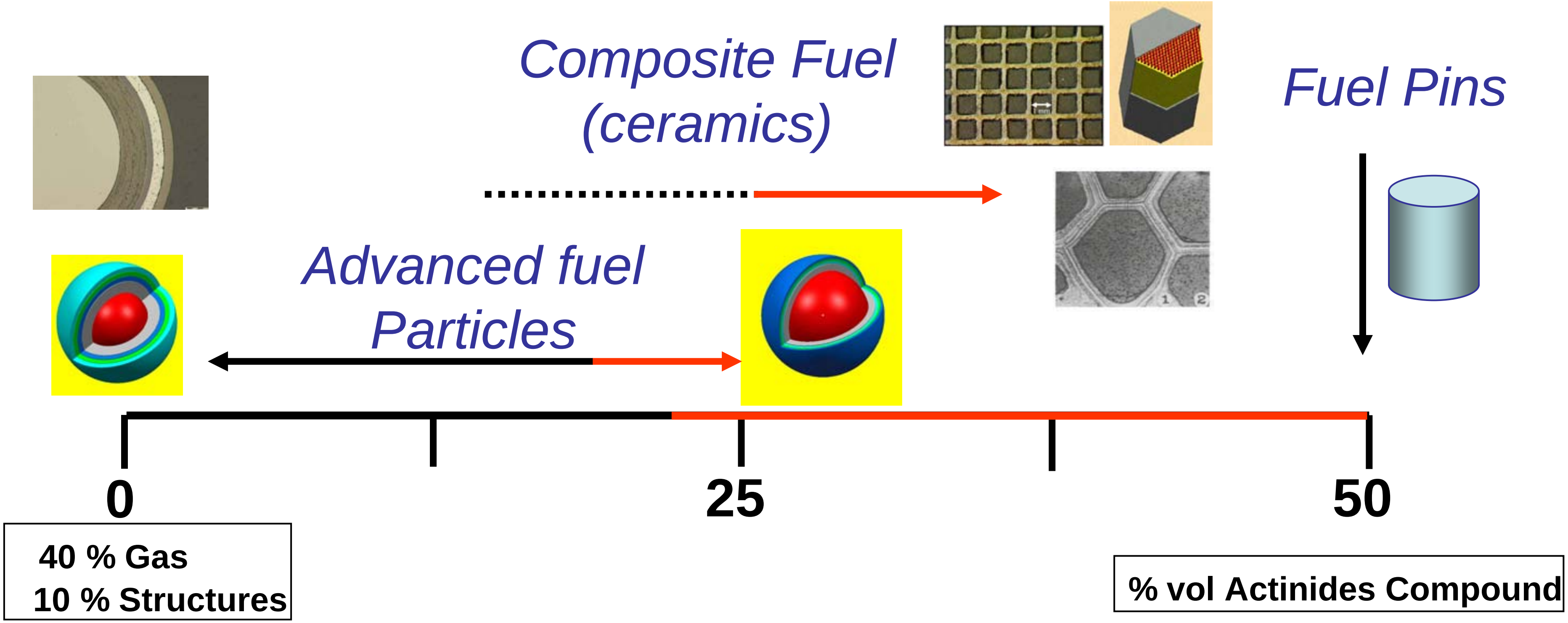
**South Africa**

**South Korea**

**United Kingdom**

# GFR Candidate Fuel Concepts

- I-NERI on-going with the US



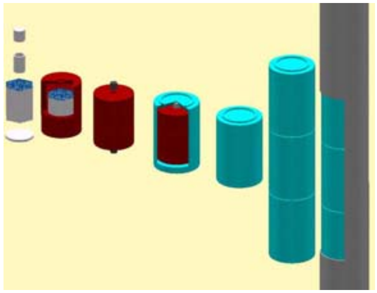
*Composite Fuel (ceramics)*

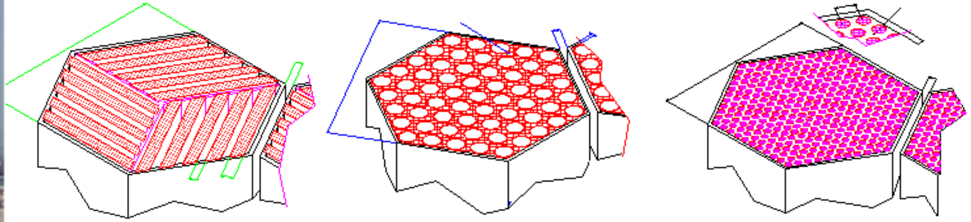
*Fuel Pins*

*Advanced fuel Particles*

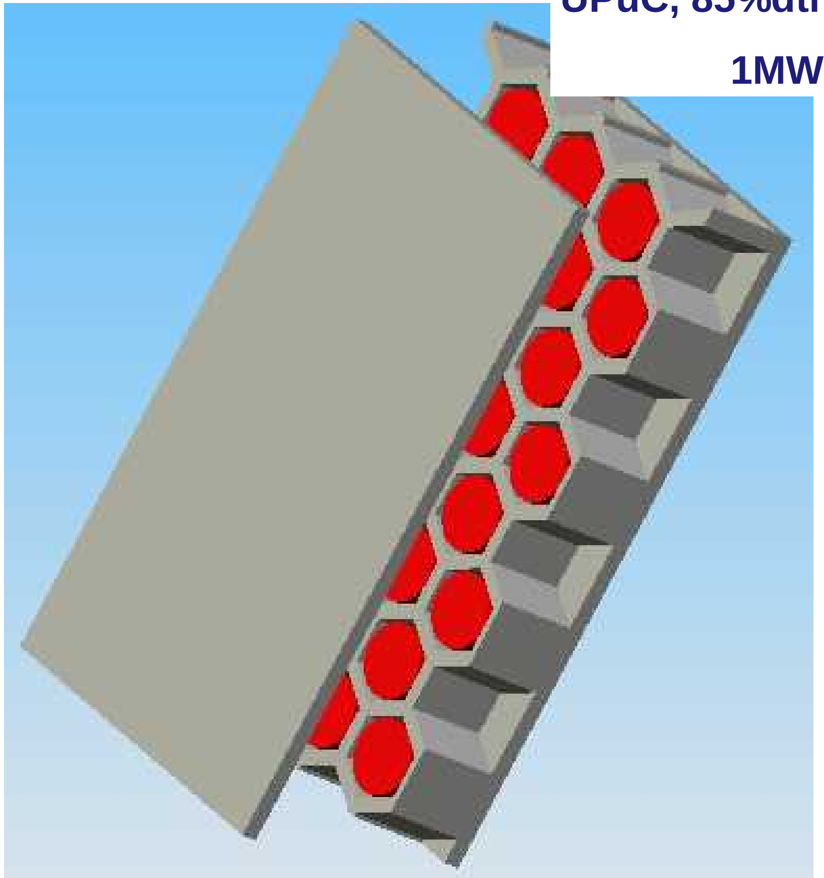
**40 % Gas**
**10 % Structures**

**% vol Actinides Compound**



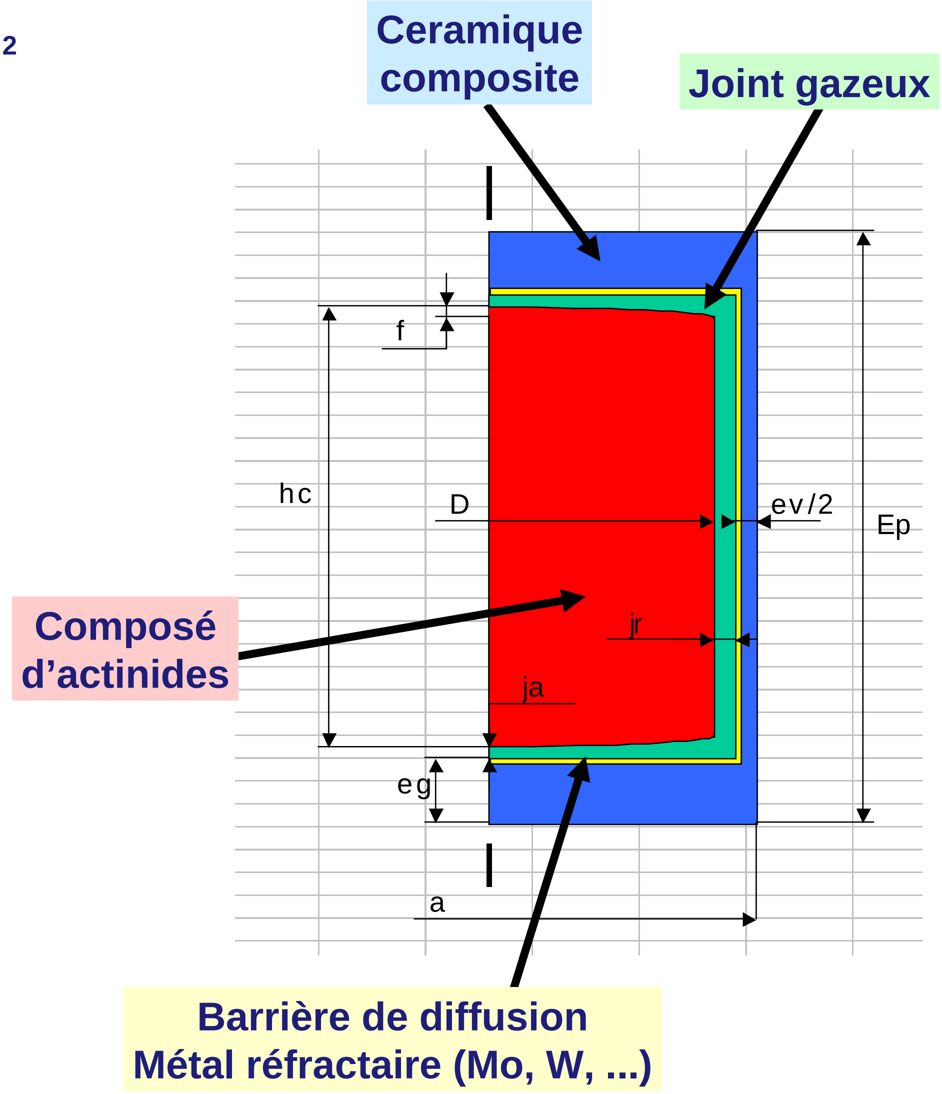


# Concept plaque à pastilles (ex-dispersé)



**UPuC, 85%dth, 100MW/m$^3$**

**1MW/m$^2$**



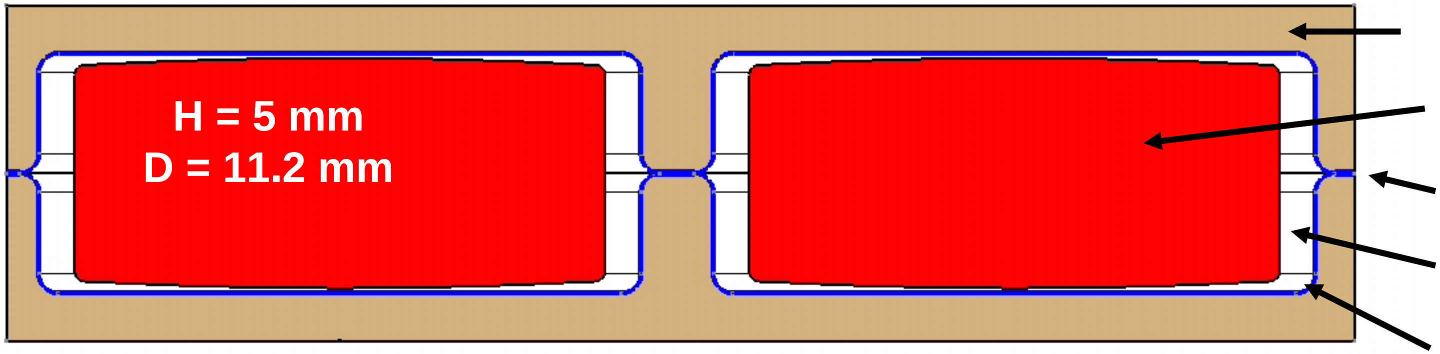
**Ceramique composite**

**Joint gazeux**

**Composé d'actinides**

**Barrière de diffusion**
**Métal réfractaire (Mo, W, ...)**

# Plaque à pastilles : schéma conceptuel actuel



**Céramique « avancée »**

**Composé d'actinides**

**Plan de fermeture**

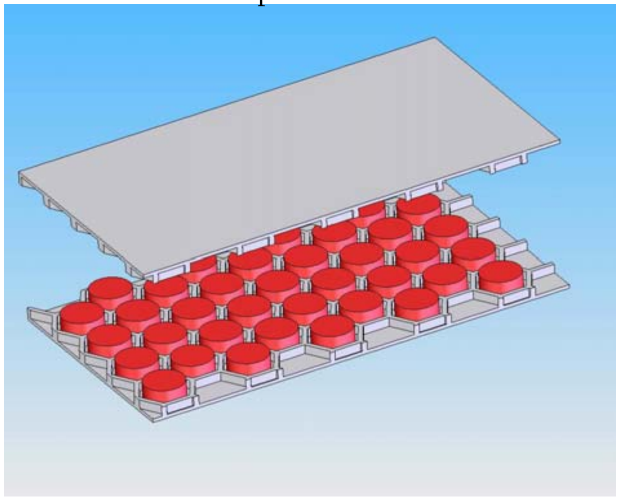
**Espace gaz**

**Liner (métal, x…)**

Pas hexagonal: 14mm
Epaisseur des plaques d'échange~1mm
Epaisseur des voiles hexagonaux~1mm
Epaisseur de liner: 50 –100µm
320W max par pastille

~1 MW/m$^{é}$ max de surface d'échange
Dimensions plaque:12x25 cm
Nombre de pastilles par plaques: 168
Nombre de plaques dans un cœur de 2400 MW: ~63000
Compatible avec une densité de puissance de 100MW/m$^{3}$

**Céramiques avancées:**
**Composite SiC-SiCf, f= Hi NICALON Stoechiométrique**
**Interfaces et interphases à définir (SiC, $^{11}$BN, PyC?…)**
**Travail sur fibres nanostructurées, évaluation du ZrC, du $Ti_3SiC_2$**
**Densification par imprégnation, ...**
**Matériau d'étanchéité:**
**W-Re, Mo, Mo-Re, Ti, Nb, V, Cr**
**Traitements de surface éventuels à définir**



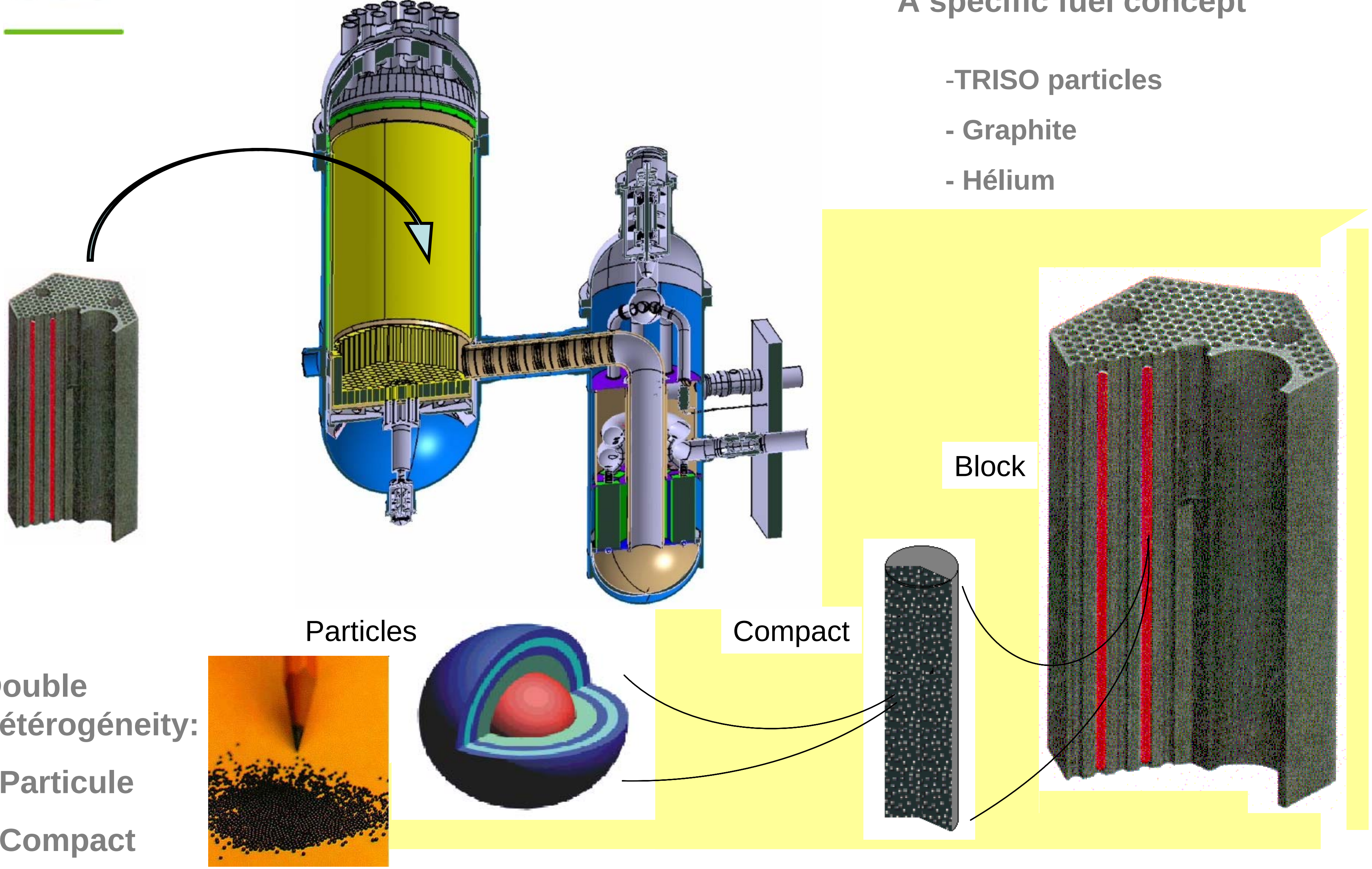
# ANTARES Design

## A specific fuel concept

-TRISO particles

- Graphite

- Hélium



**Double hétérogéneity:**

- Particule

- Compact

# Molten Salt Reactor MSR

## Objectives for the MSR

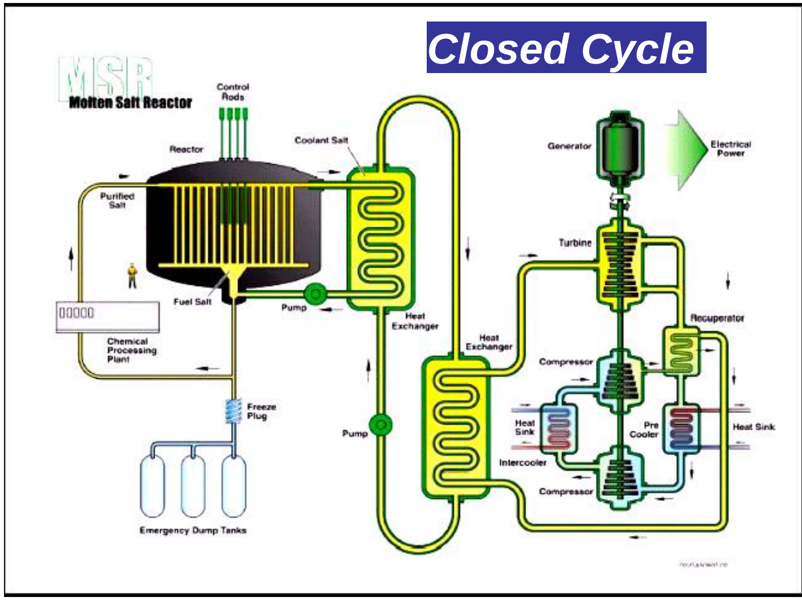
- Regeneration with U-Th cycle
- Epithermal neutrons
- 1700 MWth - 800 °C
- Coupling to process heat applications
- Effective capacity of regeneration ?
- Corrosion of structural materials
- Treatment of used salt
- Deployable around 2035

*Main CEA activity on safety issues & pyrochemistry*

***France***

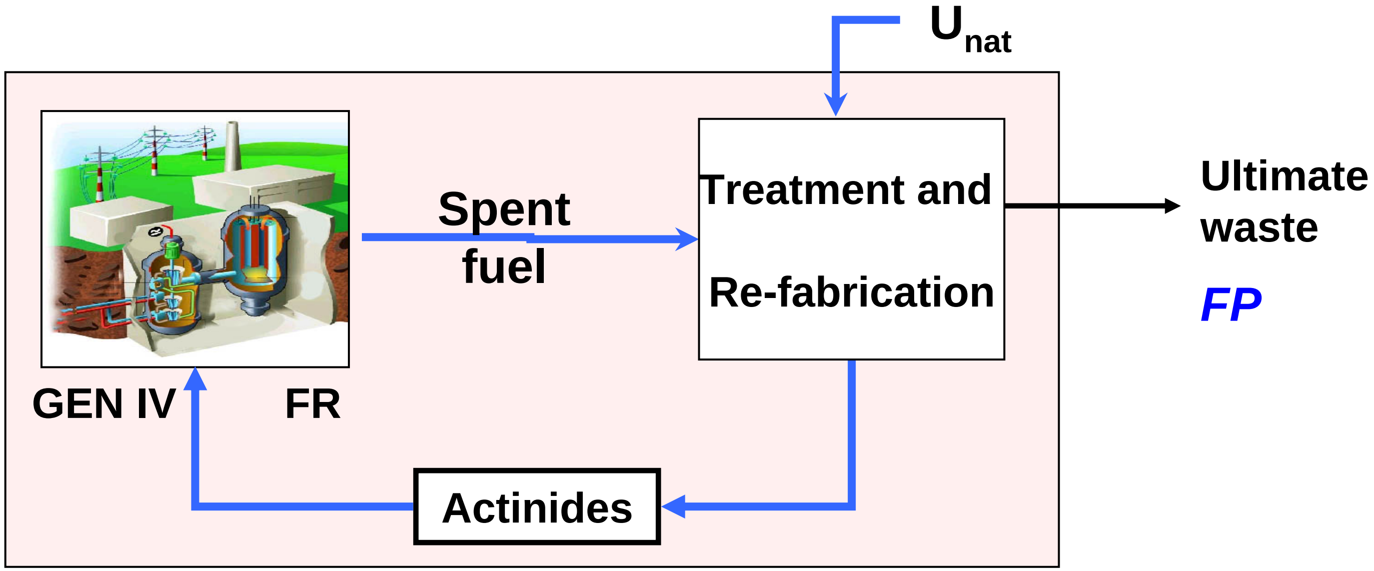
***Euratom countries***

MSR Steering Committee



# *Perspective for reprocessing*

# Gen IV Systems: an integrated cycle with full actinide recycling



$U_{nat}$

Spent fuel

Treatment and

Re-fabrication

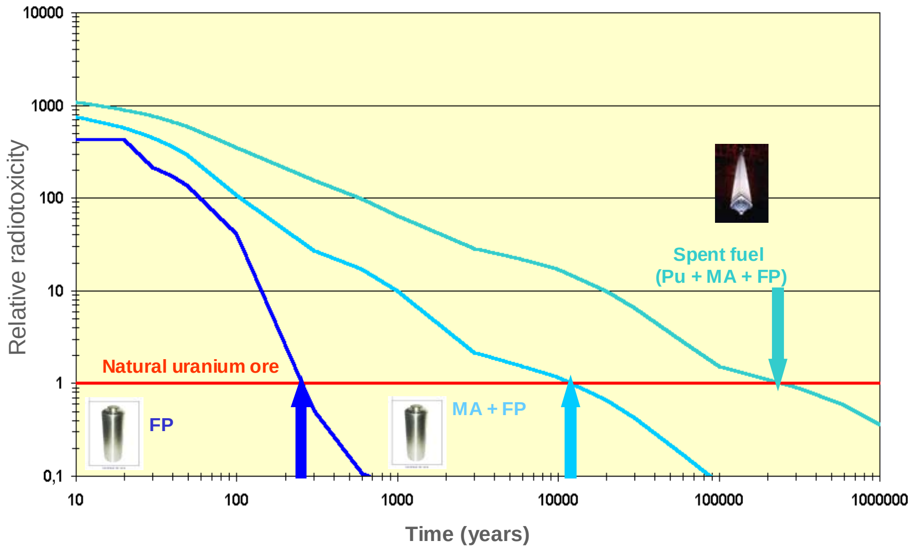
Ultimate waste

***FP***

GEN IV FR

Actinides

- **A drastic minimization of ultimate waste :**
  - **- Very small volumes,**
  - **- Decrease the heat loading**
  - **- hundreds of years versus hundreds of thousands**



- **An optimal use of energetic materials**

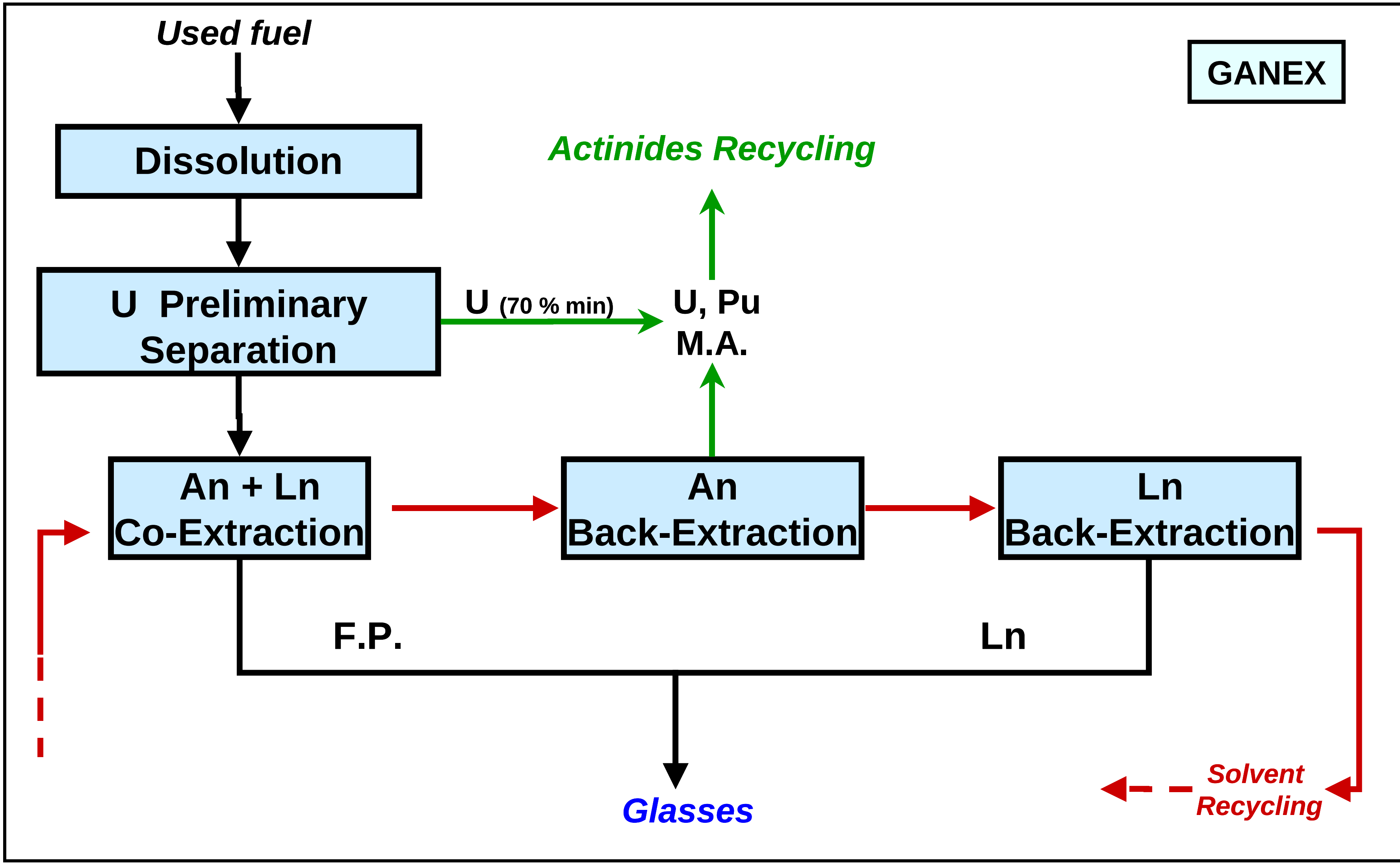
# Requirements

- ☐ High actinide recycling is of most importance (close or even better than 99 %) as it impacts directly the potential of radioactivity of the final waste
- ☐ Actinide grouped separation : managing the actinides alltogether is good for simplifying the cycle (number of fluxes) and enhancing the resistance to proliferation risk
- ☐ If possible, It is better to avoid blankets for proliferation risk, but also because it increases the amount of fuel to be reprocessed.

# « Unit operations » in the fuel cycle

| | | |
|---|---|---|
| Head end processes | Dismantling | Reactor dependent |
| | Dissolution | Cross-cutting |
| | Separation | Cross-cutting |
| Back end processes | Conversion | Cross-cutting |
| | Refabrication | Reactor dependent |
| Ancillary operations | FP Confinement | Cross-cutting |
| | Waste management | Cross-cutting |

# Grouped Actinides Extraction : the GANEX Process



**GANEX**

*Used fuel*

**Dissolution**

**U Preliminary Separation**

**U (70 % min)**

**U, Pu M.A.**

*Actinides Recycling*

**An + Ln Co-Extraction**

**An Back-Extraction**

**Ln Back-Extraction**

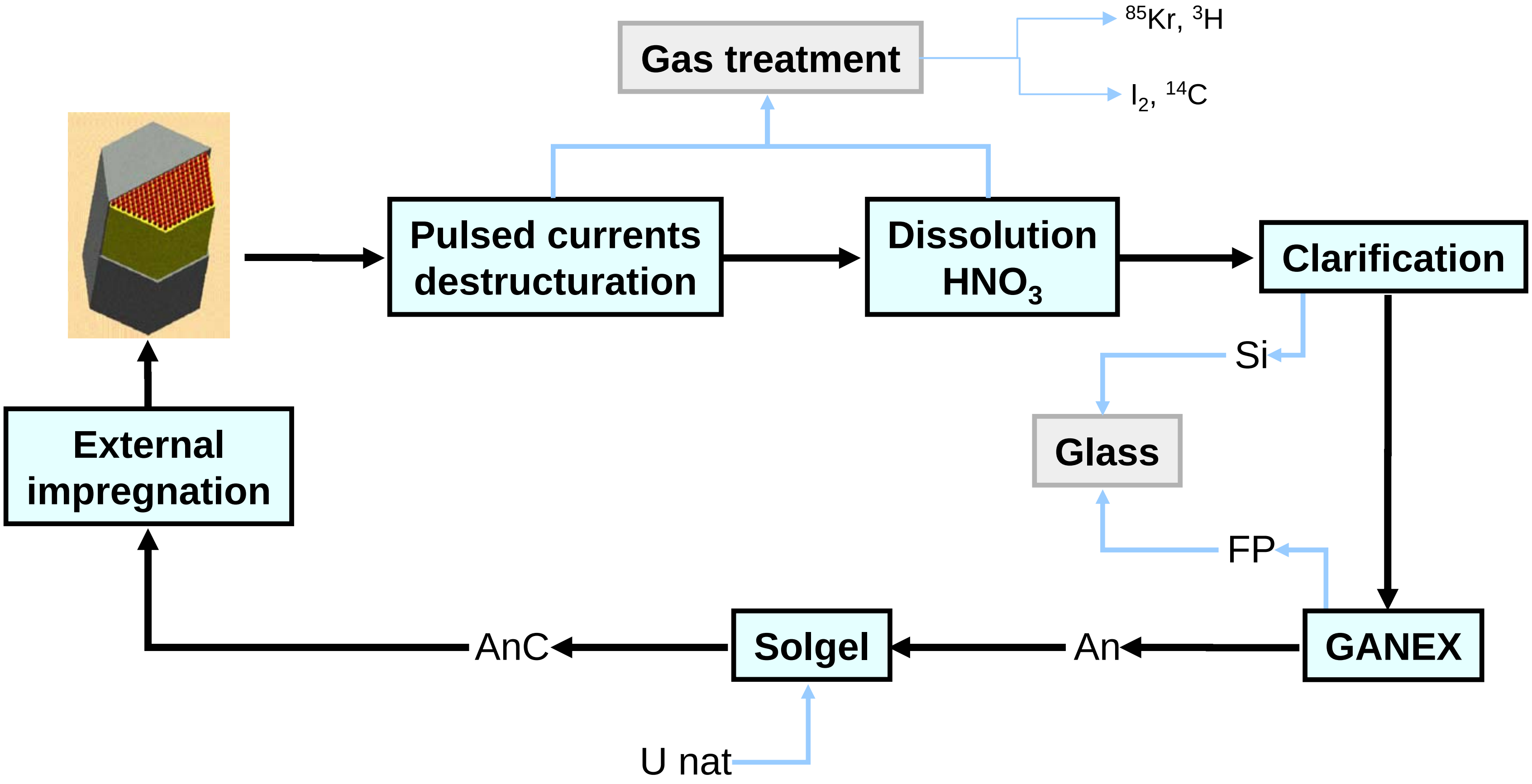
**F.P.**

**Ln**

*Glasses*

*Solvent Recycling*

# Example of technological blocks implementation



**Gas treatment**

$^{85}Kr$, $^{3}H$

$I_2$, $^{14}C$

**Pulsed currents destructuration**

**Dissolution $HNO_3$**

**Clarification**

Si

**Glass**

FP

**GANEX**

An

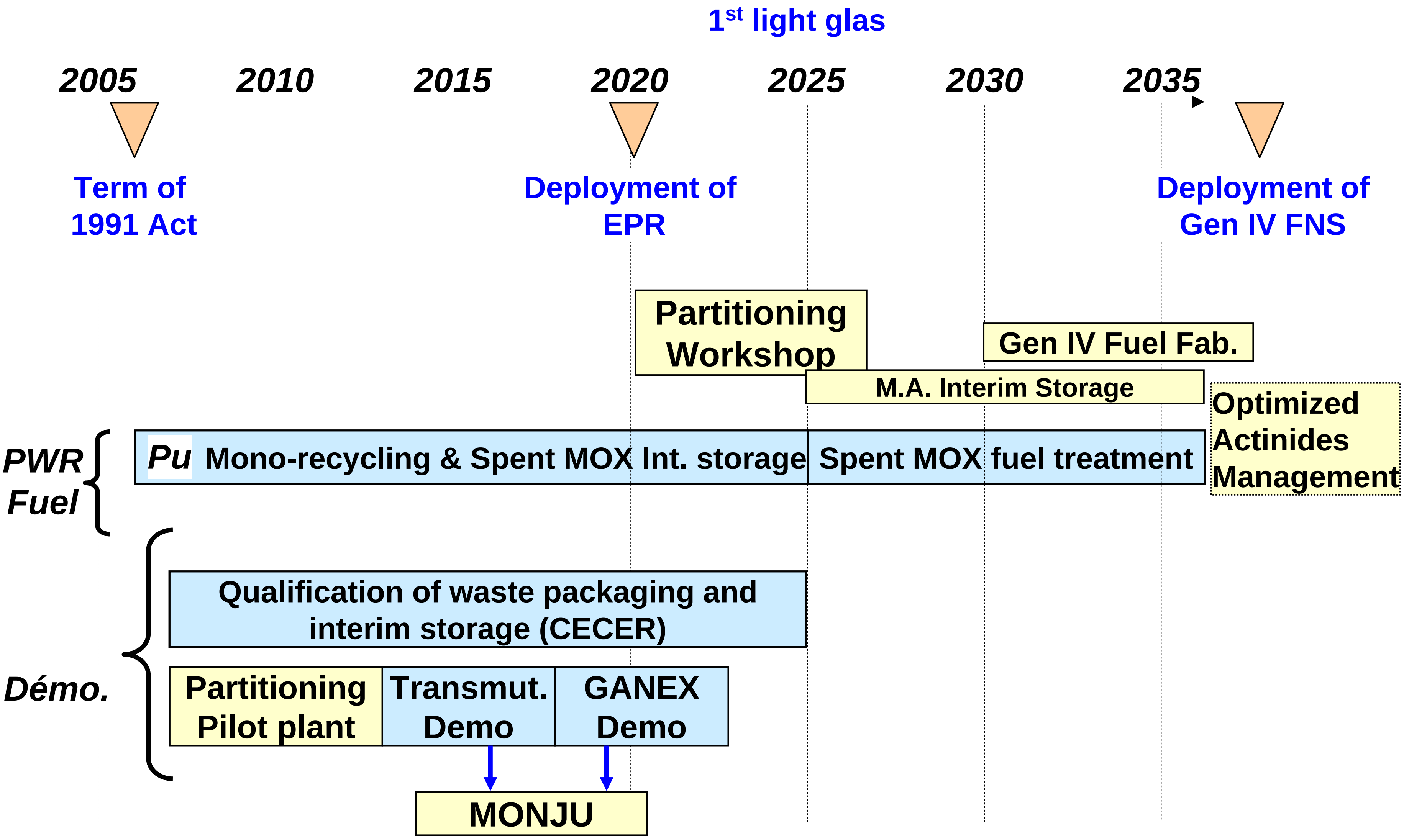
**Solgel**

U nat

AnC

**External impregnation**

# Global Actinide management: technology demonstrations



**1st light glas**

**2005 2010 2015 2020 2025 2030 2035**

**Term of 1991 Act**

**Deployment of EPR**

**Deployment of Gen IV FNS**

**Partitioning Workshop**

**Gen IV Fuel Fab.**

**M.A. Interim Storage**

**Optimized Actinides Management**

***PWR Fuel***

***Pu*** **Mono-recycling & Spent MOX Int. storage**

**Spent MOX fuel treatment**

***Démo.***

**Qualification of waste packaging and interim storage (CECER)**

**Partitioning Pilot plant**

**Transmut. Demo**

**GANEX Demo**

**MONJU**

# SFR R&D : Fuel Cycle

- The GEN IV goal is to develop an integrated approach based on recycling of all the actinides in such a way that the actual waste to be definitely disposed will only be the fission products.

This matter is a cross-cutting project with other GEN IV systems.

- Aqueous processes :
  - specifically suited for the treatment of ceramics fuels (oxydes, nitrides, carbides), the objective is to benefit from the very large industrial experience gained with current PWR and BWR fuels reprocessing while coping with the new SFR criteria.
- Pyroprocessing :
  - It is the natural choice for the treatment of metallic fuels which are still considered for the SFR. The program, run in collaboration with the EC (6th Framework Program), Japan and the US, focuses on the actinides separation feasibility (this has never been fully demonstrated yet).

# R&D Axes (1) : dismantling

Strong incentive to improve dismantling (including fuel chopping and crushing technologies, sodium distillation and reduction technologies) for :

- Minimizing the volume of ultimate high activity waste
- Optimizing the interface with the dissolution step and the ancillary activities (gas trapping, waste production and management)
- Increasing the dissolution rate
- Reducing the inclusion of cladding/spurious materials inside the fuel solution

# R&D Axes (2)

- Dissolution :

  R&D to focus on the assessment of the dissolution procedures for pyrometallurgy (with oxide or metal). No need for hydometallurgy in the viability phase.

- Separation

  Complementary R&D program for hydrometallurgy in order to validate the concepts and select one or two concepts for process development.
  For pyrometalurgy fundamental research is needed on process chemistry and engineering. Chloride or fluoride media, separation performance of molten salt, electrodeposition or precipitation have to be examined.

- FP confinement

  In hydrometallurgy glass and vitrification to optimize. For pyrometallurgy nothing is proved to-day and the containment material has to be defined.

# R&D Axes (3) : waste management

- ☐ Hydrometallurgy :
  - ✓ Treatment of organic solvent
  - ✓ Management of specific chemicals used for oxydation and reduction reactions procedures for pyrometallurgy (with oxide or metal). No need for hydometallurgy in the viability phase.
- ☐ Pyrometallurgy :
  - ✓ To estimate the waste composition
  - ✓ To find the suitable treatment
  - ✓ To find stable condition process