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Future nuclear systems: fuel cycle options and guidelines for research

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The French electricity

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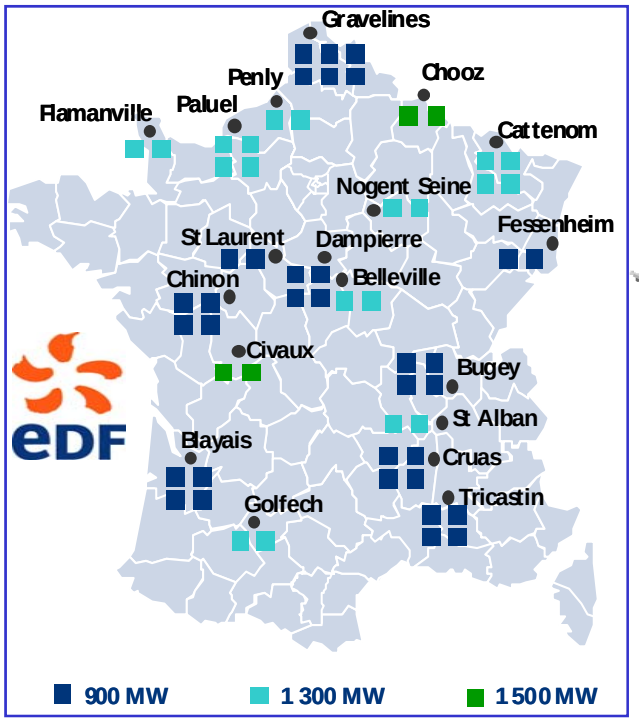
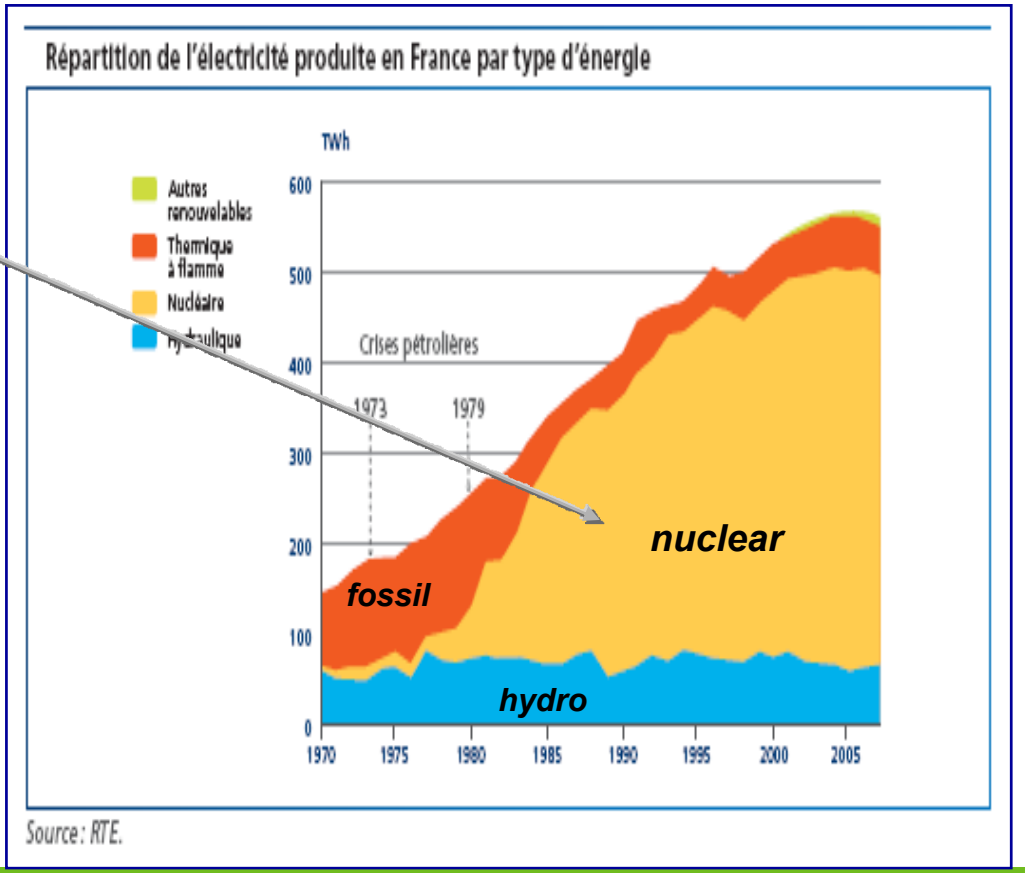
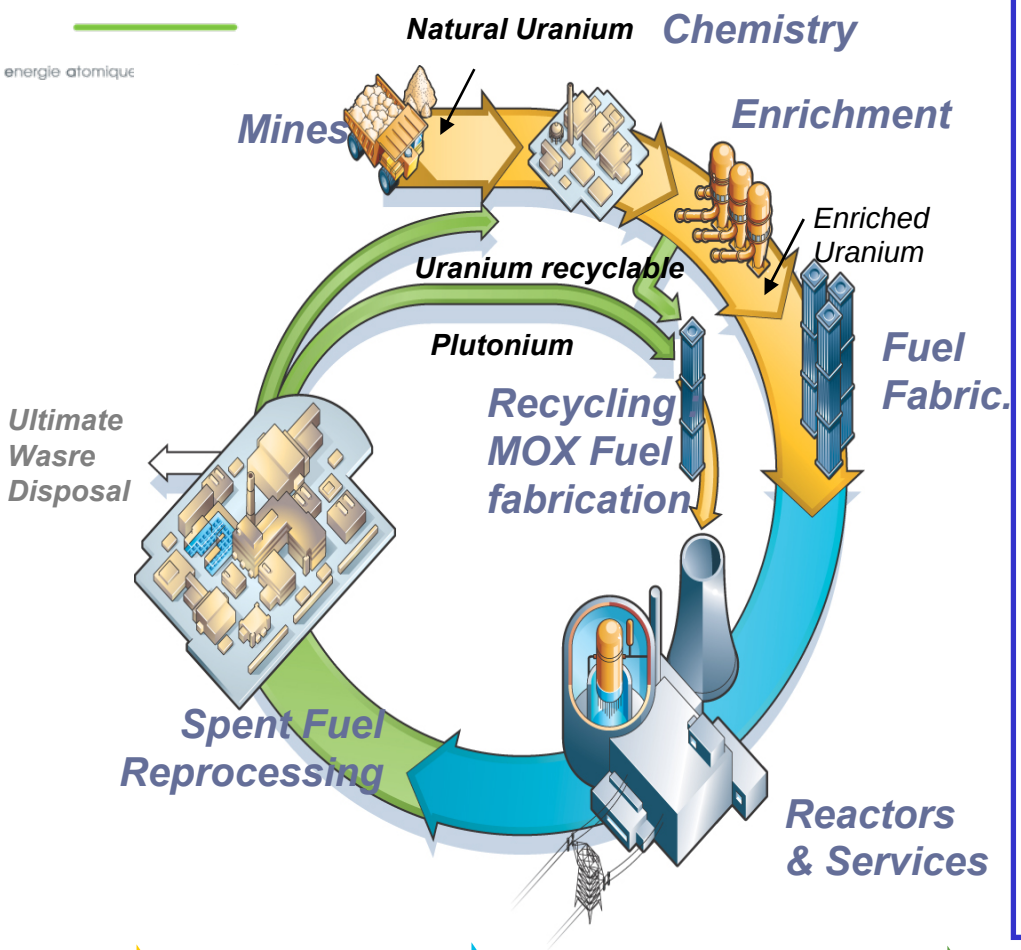
- Nuclear > 75 % of electricity generation
- Low-carbon energy mix : # 4g CO2 per kwh





- 58 PWR
- 63 GWe
- >410 TWh per year

Closing the Fuel cycle with processing … an industrial reality



The example of the French situation :

- **58 PWRs → 410 TWh annually**
- **> 75 % of French electric production**

- **Fuel processing : more than 25 years of experience**

- **1200 t_{HM}/yr of spent fuel discharged from the French PWRs**

- **850 t_{HM} /yr of reprocessed spent fuel domestic + foreign**

- **Until now: ~ 25 000 t_{HM} spent fuel reprocessed**

- **150 t_{HM}/yr MOX fuel produced and used in 22 PWRs**

- **U recycled in 4 PWRs**

Recycling technologies : decades R and D !

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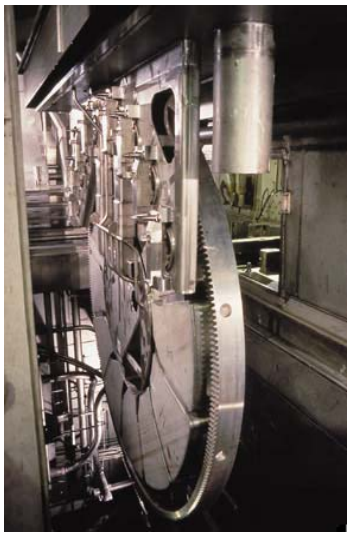
high yields…



SPENT FUEL

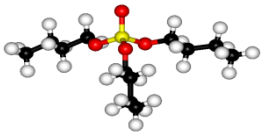
HNO_3

DISSOLUTION

HULLS

U, Pu, FPs,MAs *solution*

TBP



EXTRACTION

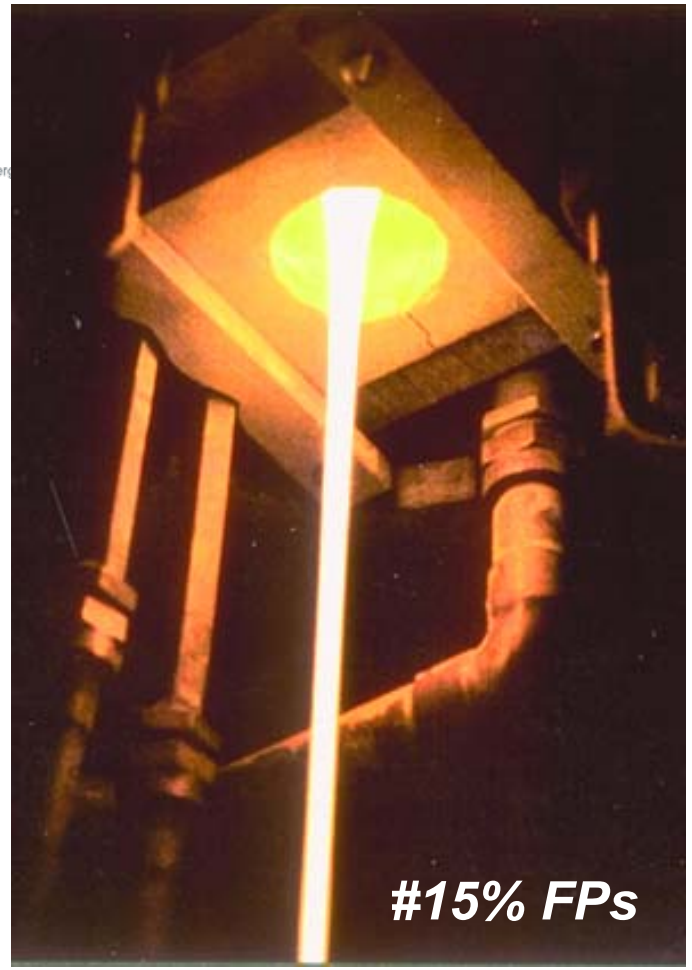
U

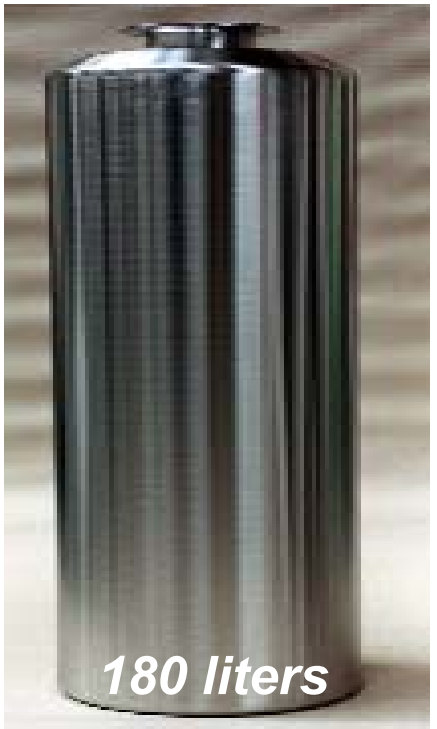
Pu

FPs, MAs

…technological waste low amounts

Final waste vitrification





 # 10 glass canisters /reactor 1GWe /year --- # 600 canisters /year

Glass canisters disposal in the deep geological repository

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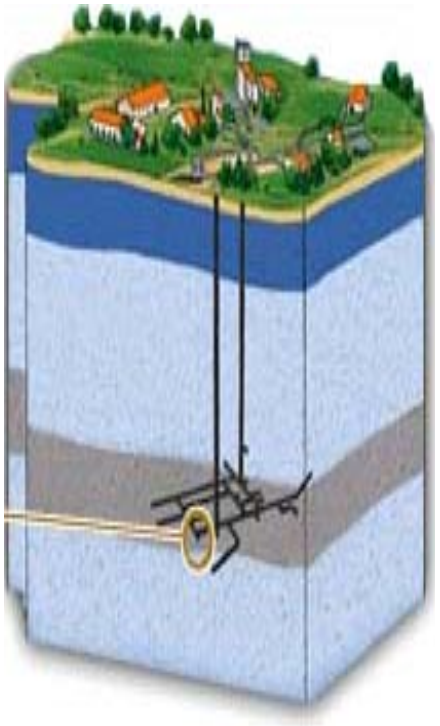
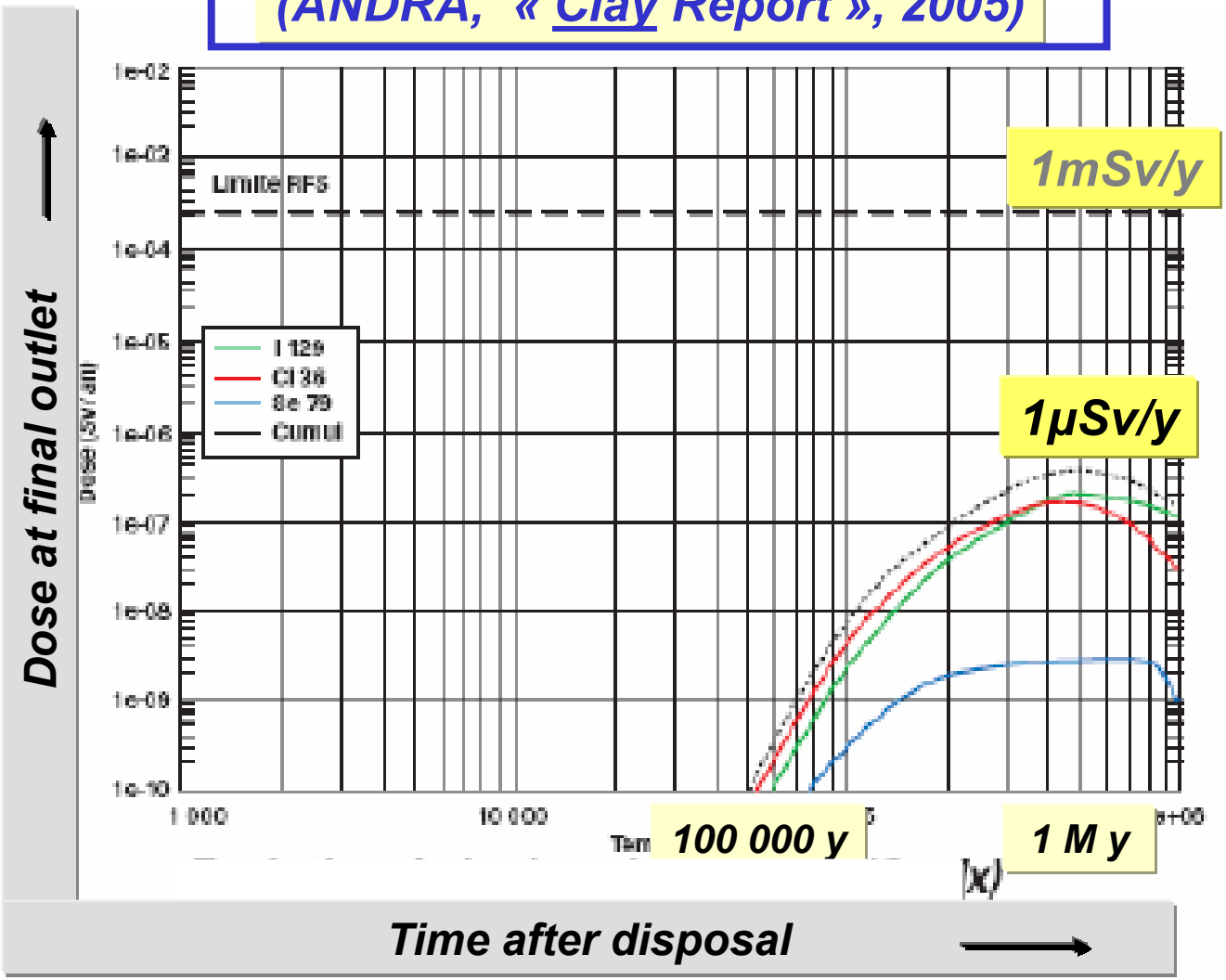


(ANDRA, « Clay Report », 2005)



Current recycling strategy : the rationale

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- saving uranium resources, still at low scale
  (#10% of French nuclear electricity from MOX fuels)

- mastering the growth of plutonium inventory
  (Pu flux adequacy : Pu from processing= Pu refueled)

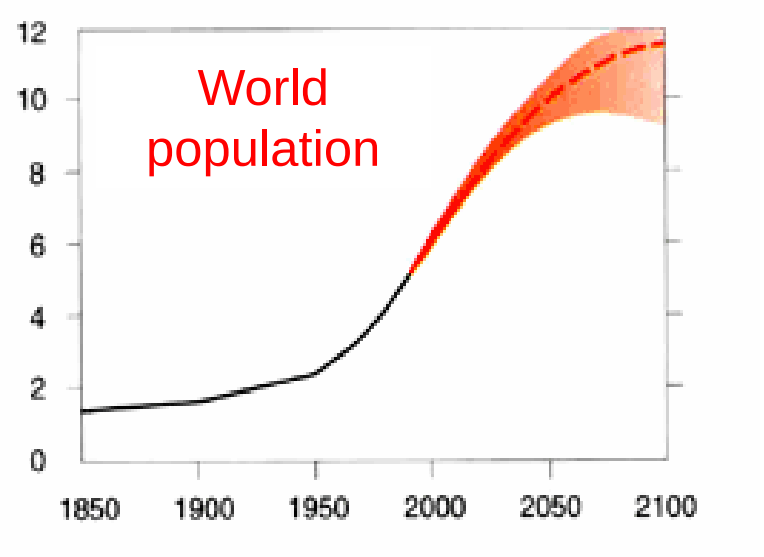
- safe and secure ultimate glass waste, without plutonium

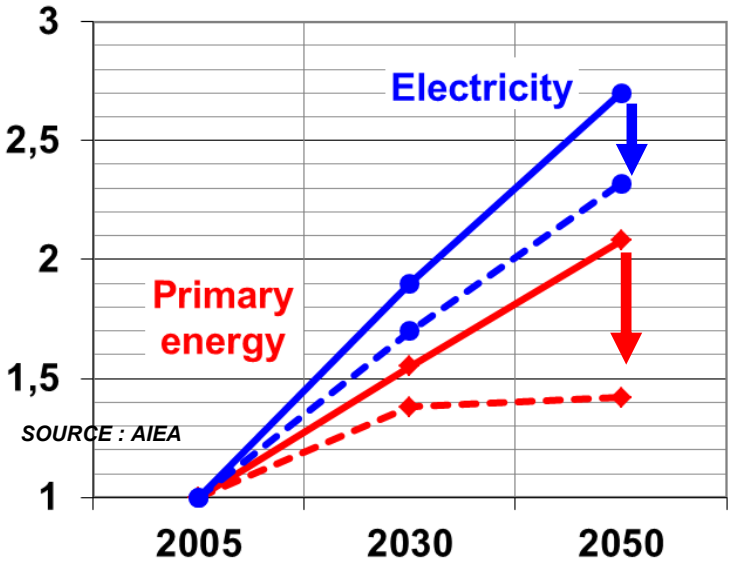
- the plutonium available for future use is safely concentrated in MOX spent fuels (7 UOX -> 1 MOX)

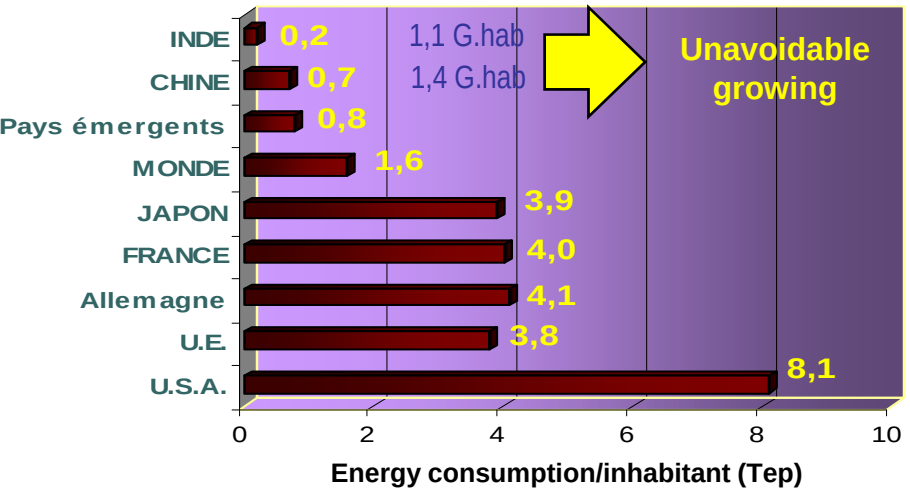
- an already large industrial experience, operated under international safeguards
  (#25 000 tons SNF reprocessed, # 2000 tons MOX produced)

to be pursued with Generation III reactors

World context : a very significant energy need in the near-future







- **Significant increase of the energy need, even when promoting "*green economy*"**
  - **likely increase of world population: up to ~11.10^9 by 2100**
  - **economic growing of Asian countries, especially India and China**
- **The increase of electricity is still much higher, due to energy transfer from fossil energies**

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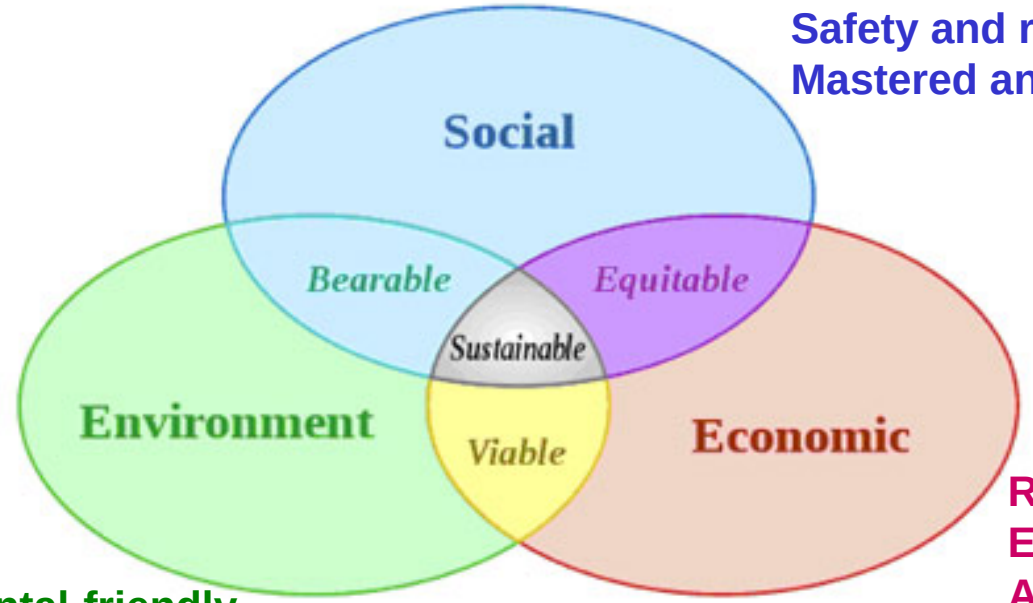
« A development which meets the needs of the present, without compromising the ability of future generations to meet their own needs »



Safety and reliability
Mastered and limited risks

Reasonable economic costs
Energetic independence
Available resources

Environmental-friendly
Low-GHG emission
Resources preservation

Sustainability is a must

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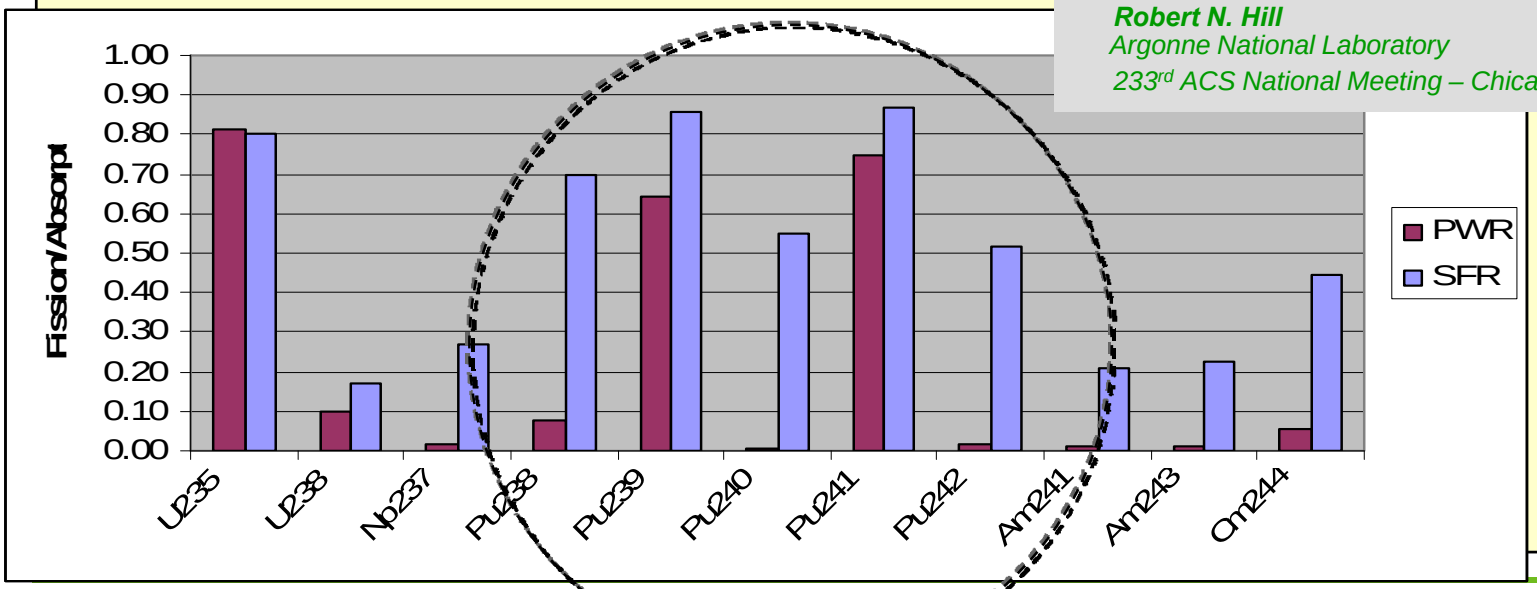
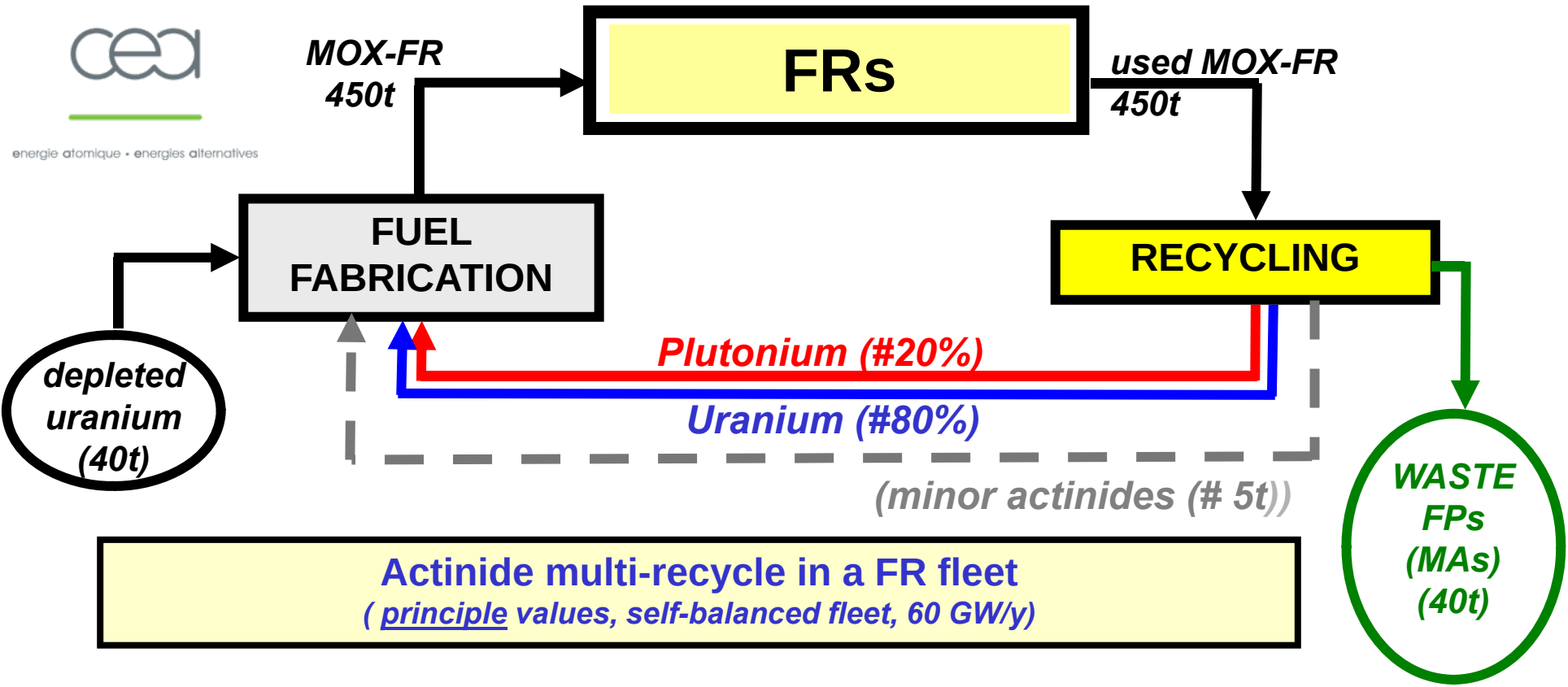
Fast Reactors, the best answer…

- efficient burning of plutonium
- full use of uranium
- no enrichment needs
- potentialities at a later step for improving waste management by minor actinide recycling



Robert N. Hill
Argonne National Laboratory
233rd ACS National Meeting – Chicago,, 2007

Long term sustainable nuclear systems



A progressive deployment ?

- initially fueled with plutonium, coming from spent MOX
- breeding gain could be adjusted in the future
  (**according to energy needs**)

From PWRs to FRs…a French schematic pathway

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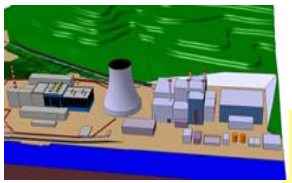

ASTRID
Fast reactor Prototype

?

60 000

Installed capacity (MWe)

70000
60000
50000
40000
30000
20000
10000
0

1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060

Plant life extension beyond 40 years

Existing fleet 40-year plant life

?

Generation 4

Generation 3+

Average plant life : 48 years

The 1991 and 2006 French Acts: frame of the Program

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December 30, 1991 and June 28, 2006

- **Three Research thematics for nuclear waste management:**
  - **recycle by P and T to decrease waste amount and toxicity**
  - **geological deep repository, retrievable**
  - **confinement and interim storage**

- **A "roadmap"**
  - **2012 : industrial potentialities of the diverse recycling options, and decision to build a prototype for transmutation tests by 2020**
  - **2015 : repository defined, and operation by 2025**

Fuel cycle technologies : guidelines for R and D…

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1- Adaptation
(specific or innovative fuels)

Fuel cycle technologies : guidelines for R and D…

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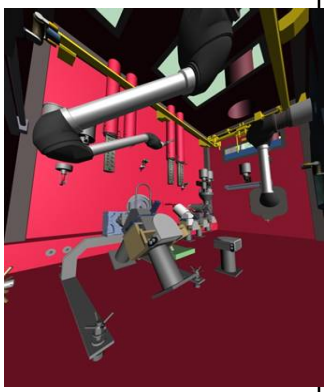
2- Improvements
(a « sustainable goal »…)



Current improvement: increasing proliferation-resistance of Pu-recycling

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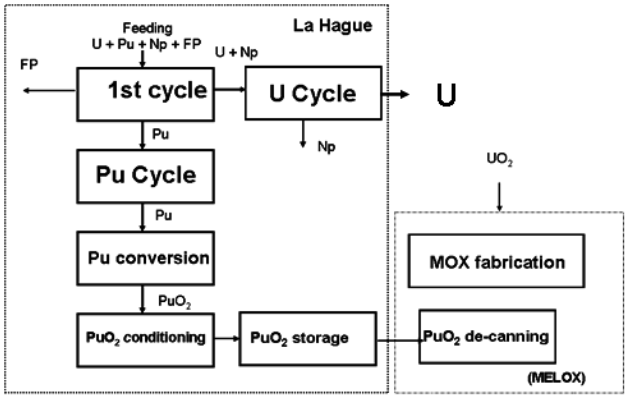
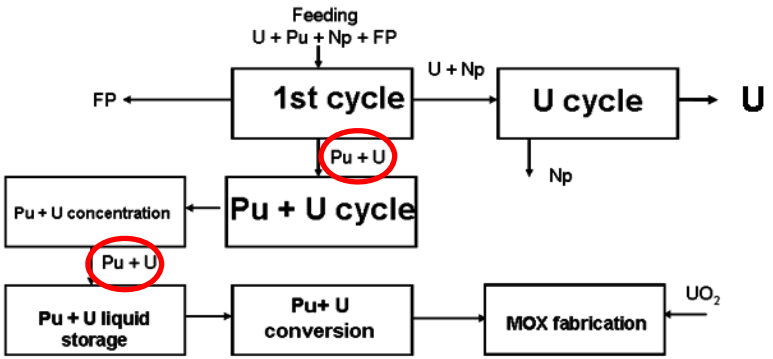
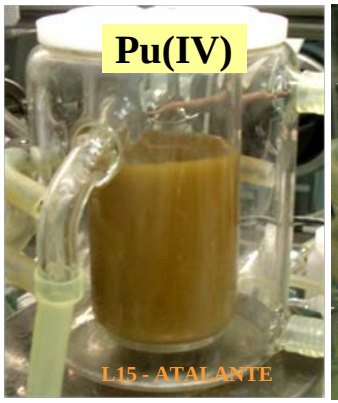
PUREX
MELOX



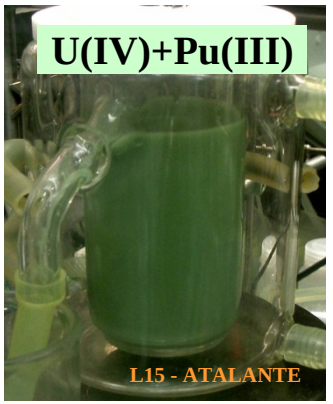


COEX™

- **In order to avoid production of pure Pu in the recycling process, implementation of the COEX™ process**
  - **Co-extraction of U and Pu**
  - **Oxalic coconversion of U and Pu: precipitation of oxalic solution, then calcination to UPu oxide solid solution**



$Pu^{IV}(C_2O_4)_2 .6\ H_2O$



$(N_2H_5^+,H^+)_{2,9}U^{IV}_{1,1}Pu^{III}_{0,9}(C_2O_4)_5 .nH_2O$

Current improvement for vitrification : the cold crucible technology

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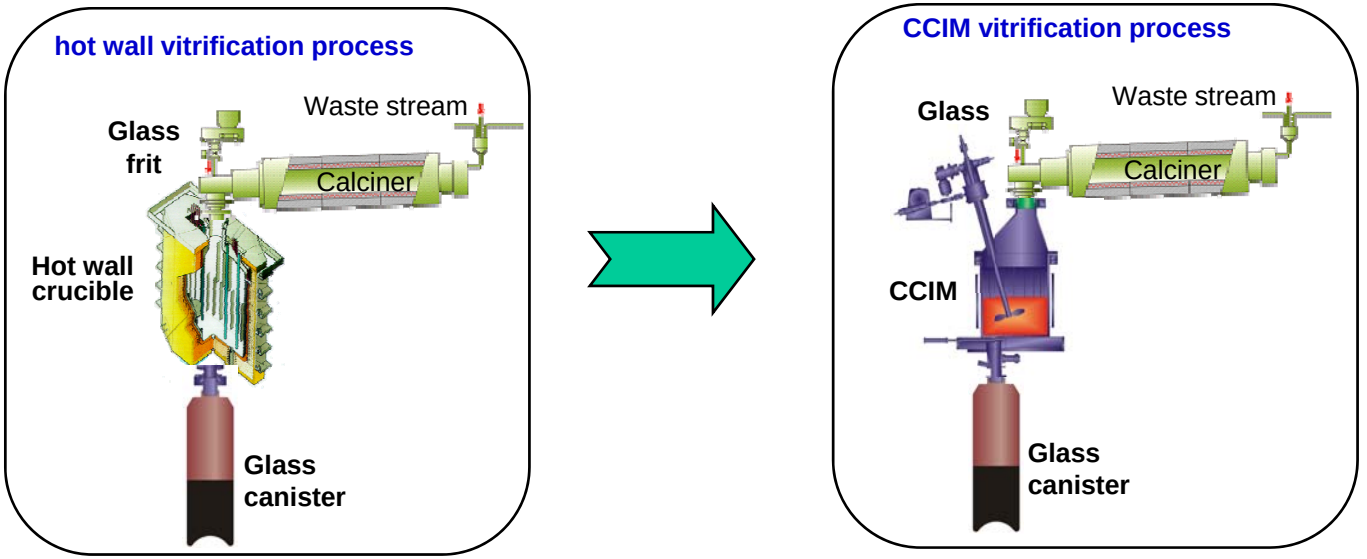

- **Cooled wall, direct induction heating**
- **Corrosion issues drastically decreased**
- **Higher temperature, higher reactivity, FPs higher concentration glass**

in operation at La Hague , 2010

Fuel cycle technologies : guidelines for R and D…

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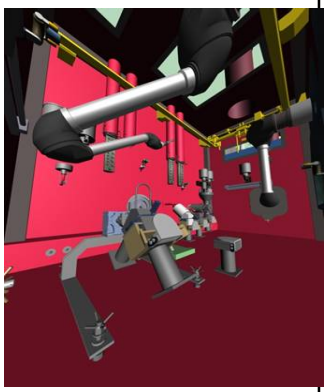
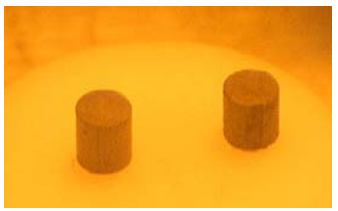
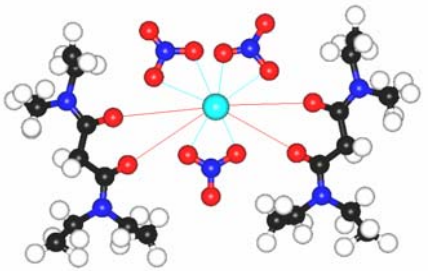
1- Adaptation
(specific or innovative fuels)

2- Improvements
(a « sustainable goal »…)



3- Exploration
P and T, minor actinide recycling





Minor actinide recycling: drivers

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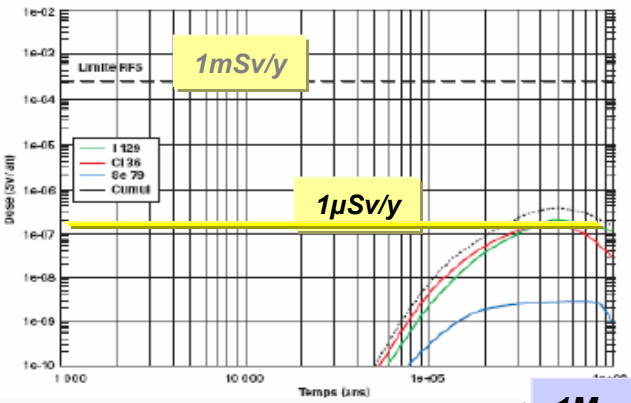
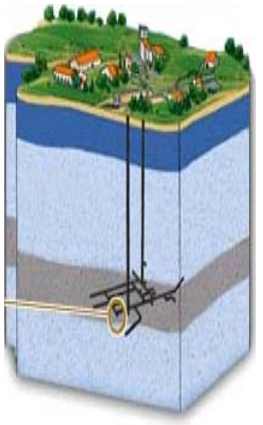
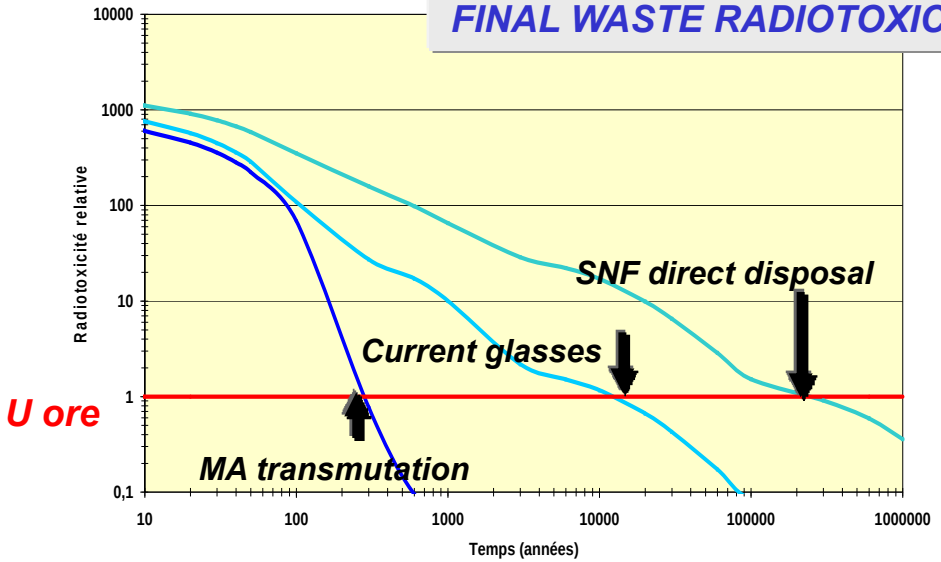




1My

(ANDRA, « CLAY REPORT », 2005)

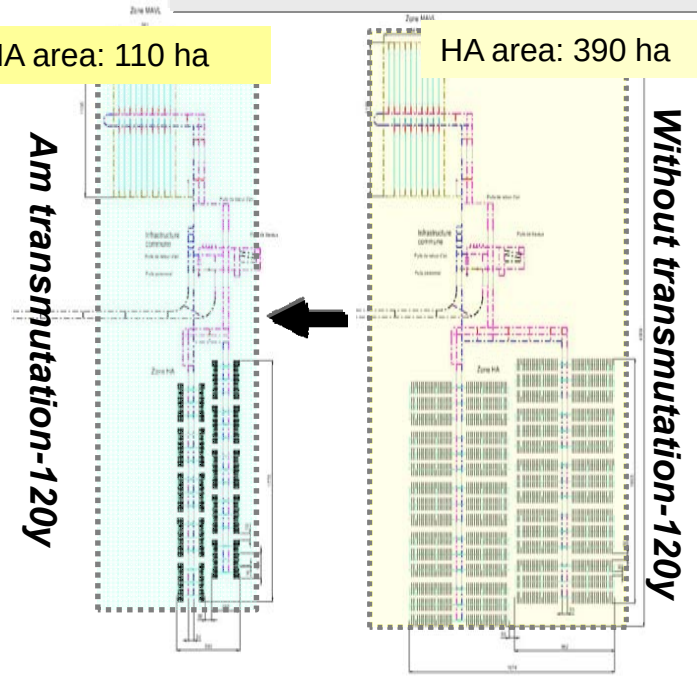
FINAL WASTE RADIOTOXICITY



REPOSITORY « FOOTPRINT »

HA area: 110 ha

HA area: 390 ha



MA Partitioning and Transmutation: the 2012 milestone

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- **Design** Separation processes
  Transmutation devices
  Transmutation fuels
  for industrial implementation
- Assess benefits / costs of MA P and T strategies
- Explore transition scenarios
- MA = Am, Cm, Np
  Interest of a specific approach vs. grouped approach

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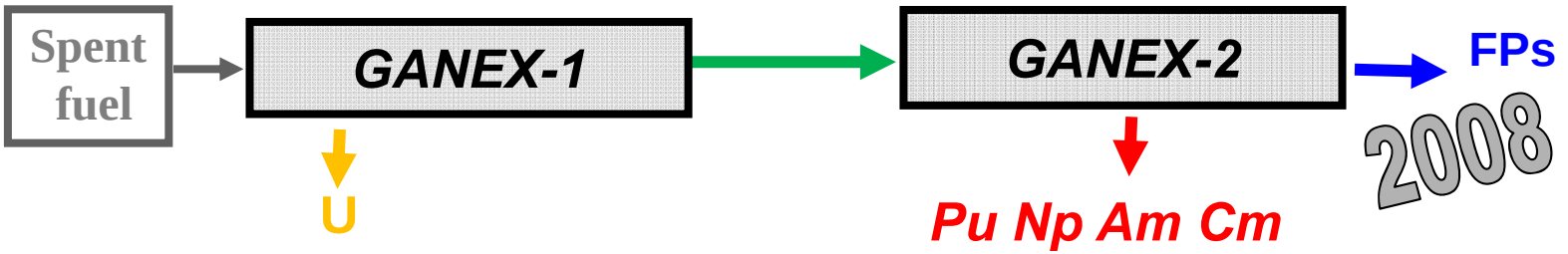
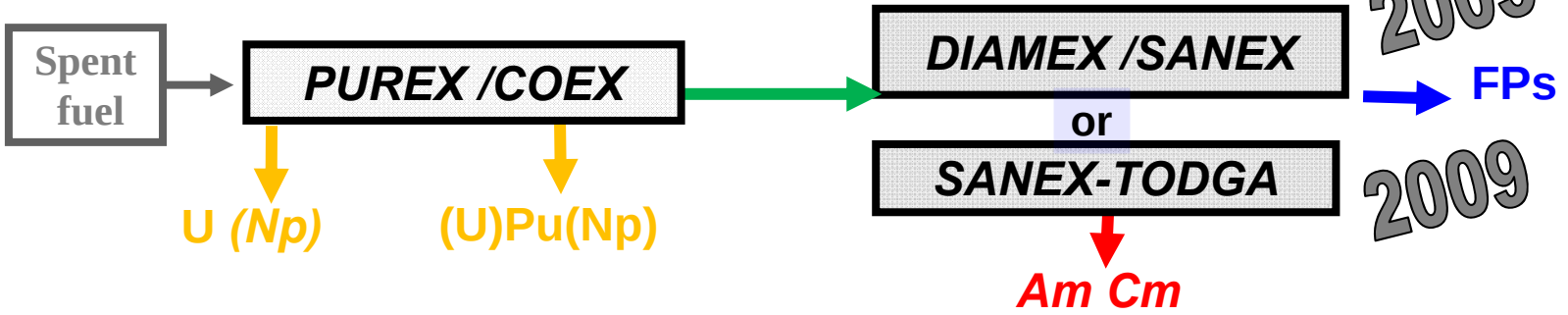
Grouped separation:

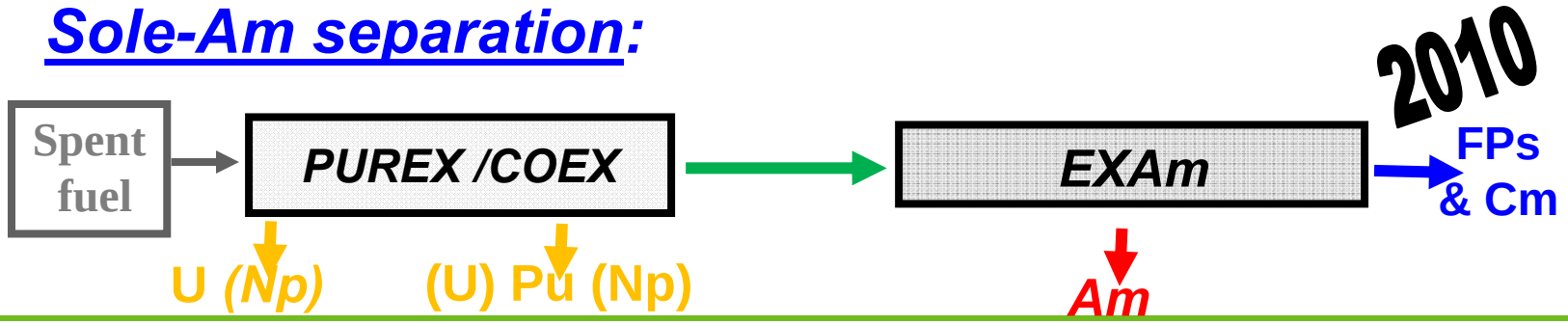
Date of HA test



Enhanced separation:



Sole-Am separation:



MA Recycling options…

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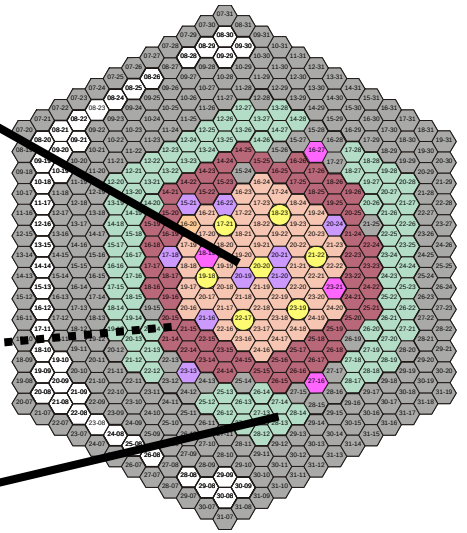
HOMOGENEOUS (#1% MA, diluted in the fuel)

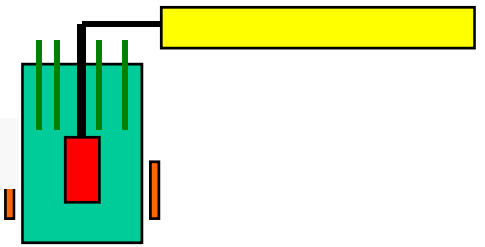


HETEROGENEOUS:

Once-through targets *(inert matrix)*

Multi-recycled MA-bearing blankets
(# 10-20% MA on UO2)

« **DEDICATED STRATA** » (ADS)



Heterogeneous recycling: an option for MA transmutation

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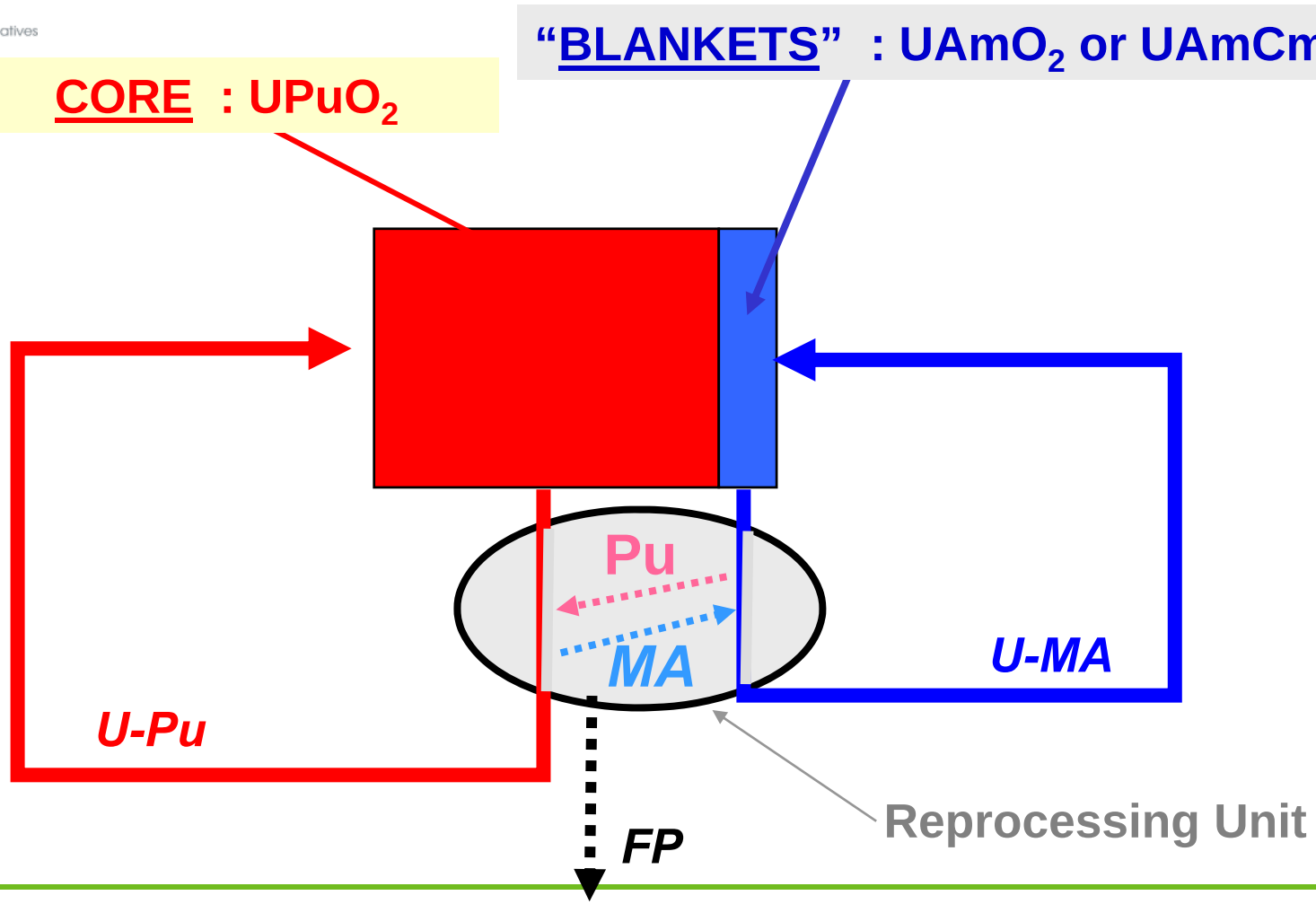

Am Transmutation

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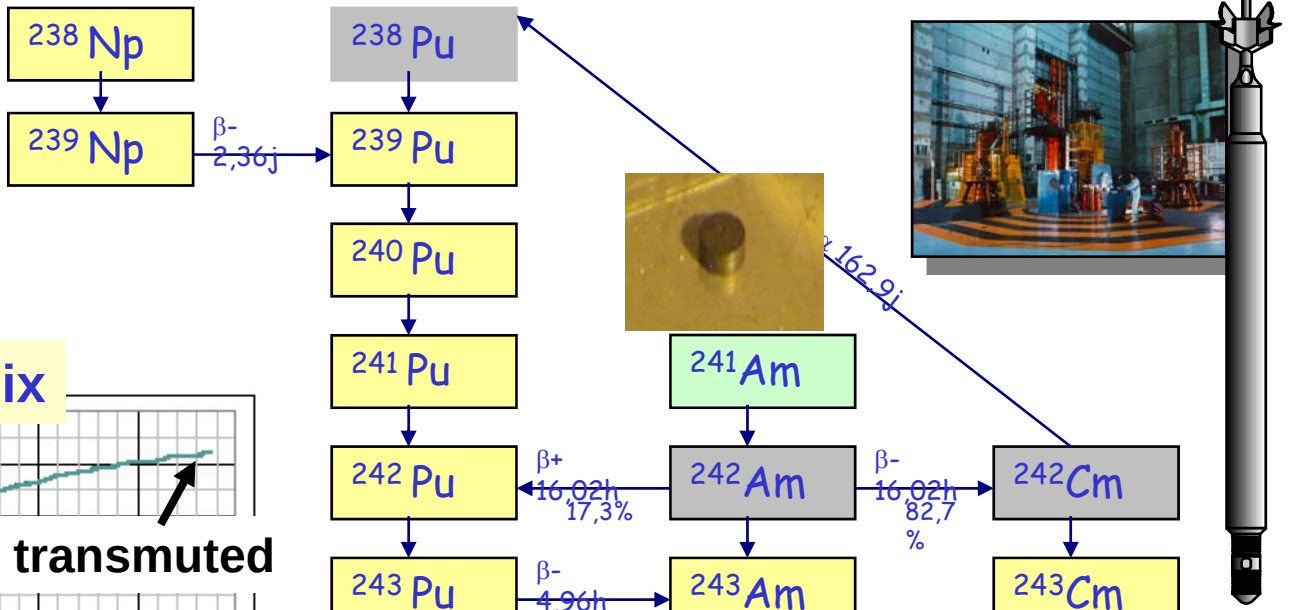
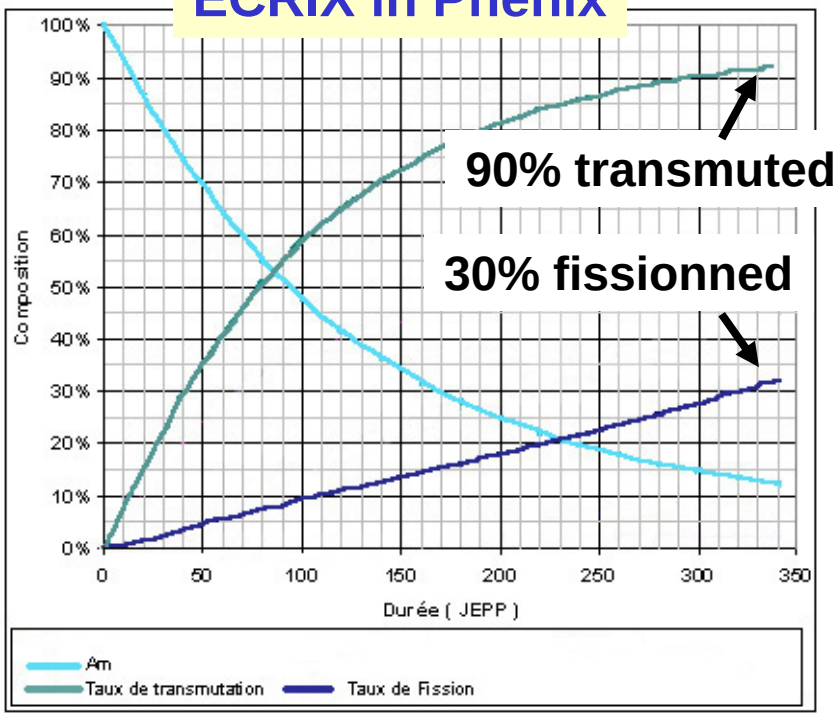
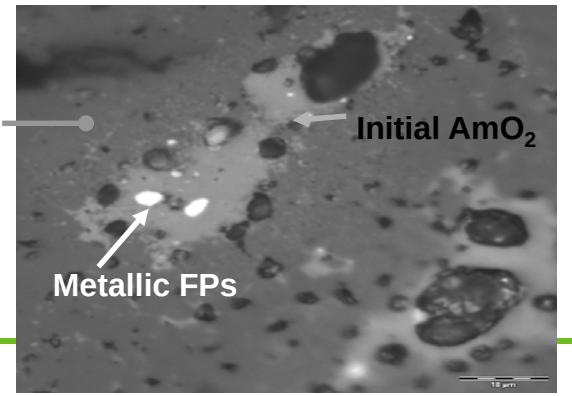


ECRIX in Phénix





Fuel cycle technologies : guidelines for R and D…

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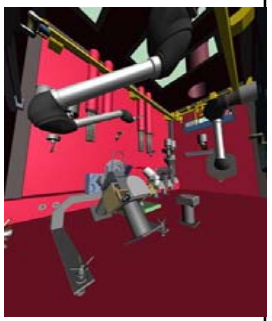
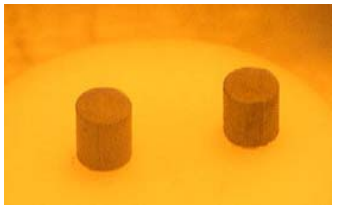
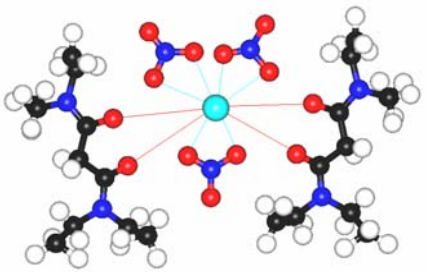


1- Adaptation
(specific or innovative fuels)

2- Improvements
(a « sustainable goal »…)

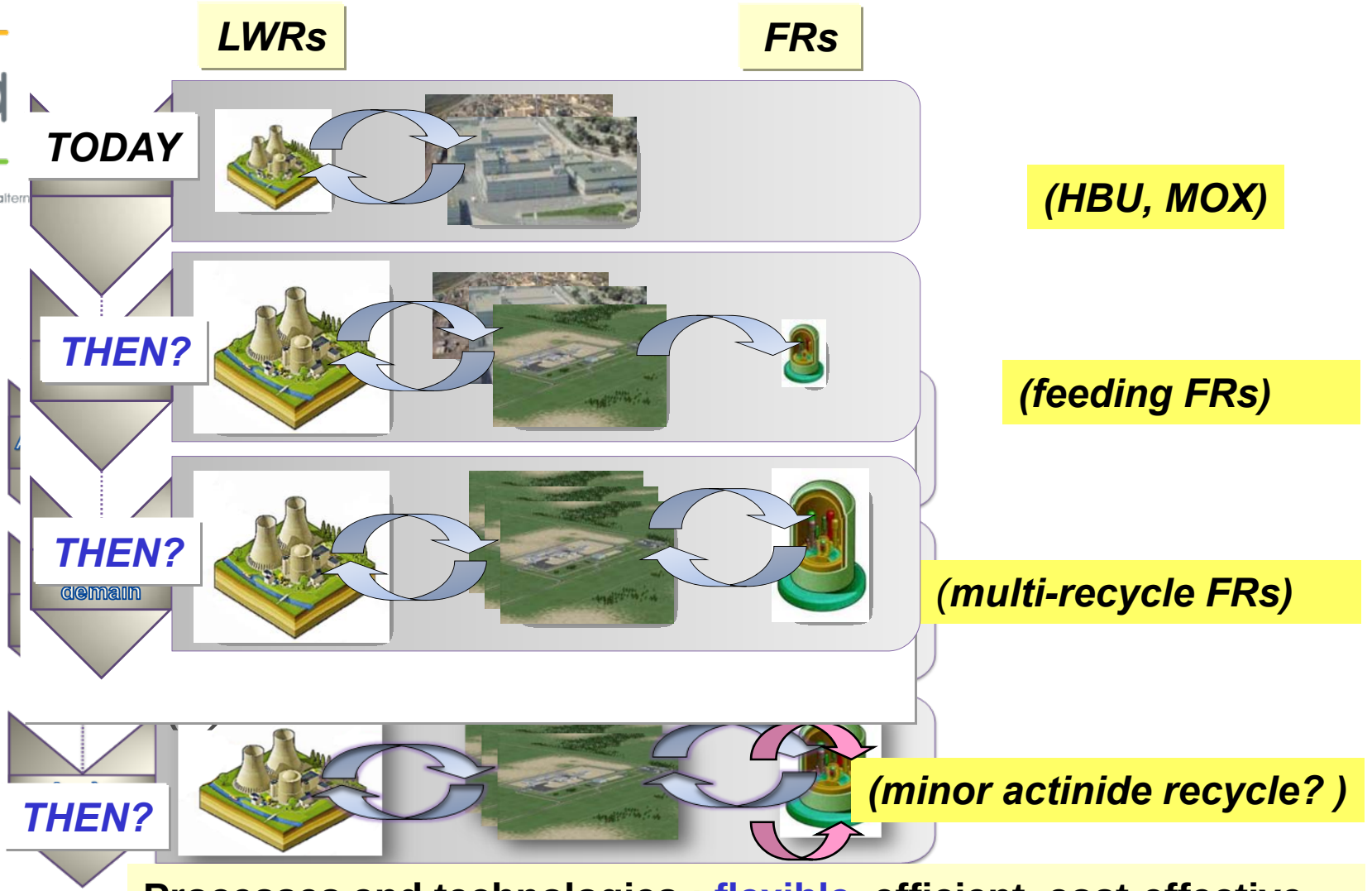
3- Exploration
P and T, minor actinide recycling





4- Alternative process
« Dry processes… »

Fleet and Fuels will evolve…



Processes and technologies : flexible, efficient, cost-effective, clean, proliferation-resistant…

En résumé… towards sustainable nuclear energy, the 2012 milestone

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- Nuclear energy, as a GHG-free energy, is anticipated to develop in the next century to answer the increase of energy needs and has to be sustainable

- Current Pu mono-recycling with MOX in PWR already contributes in France to decrease waste volume and toxicity, while saving U resources
  ➔ first step to sustainability

- Increasing sustainability for nuclear energy requires improved actinide recycling, and shifting stepwise towards fast reactor systems in order to:
  - 1st step : multi-recycle Pu and U for saving resources
  - 2nd step : recycle minor actinides for stabilizing their inventories, reducing the waste toxicity, reducing the repository volumes and costs

  … ➔ strong implications for public acceptance

- In the framework of the 2006 waste management Act, France developed and has now a portfolio of several MA partitioning processes that basically demonstrate the feasibility of their recycling, in homogeneous or heterogeneous mode

En résumé… towards sustainable nuclear energy, the 2012 milestone

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- For 2012, relative benefits of these different options have to be assessed in terms of economy, "densification" of the final storage, industrial feasibility, flexibility, safety, proliferation resistance,…
- Industrial feasibility : design / optimize separation processes, transmutation fuels and their fabrication processes, and gather technical elements for industrial operation evaluation
- Both science-based and process-oriented actinide separation and transmutation research is continuing at CEA, within French and international collaborations (EU ACSEPT project, ACTINET-I3 network, USA, Japan, Russia,…)
- An integrated test is planned : closing the Am cycle by preparing Am-bearing fuels using Am recovered from spent fuel by the EXAm process: fuel to be tested at pellet scale under fast flux, then after 2020 at pin scale using the ALFA (Atalante Laboratory For Actinides bearing fuel manufacturing) and ASTRID (Advanced Sodium Technological Reactor for Industrial Demonstration)