Advanced Aqueous Partitioning :
progress and prospects for recycling processes

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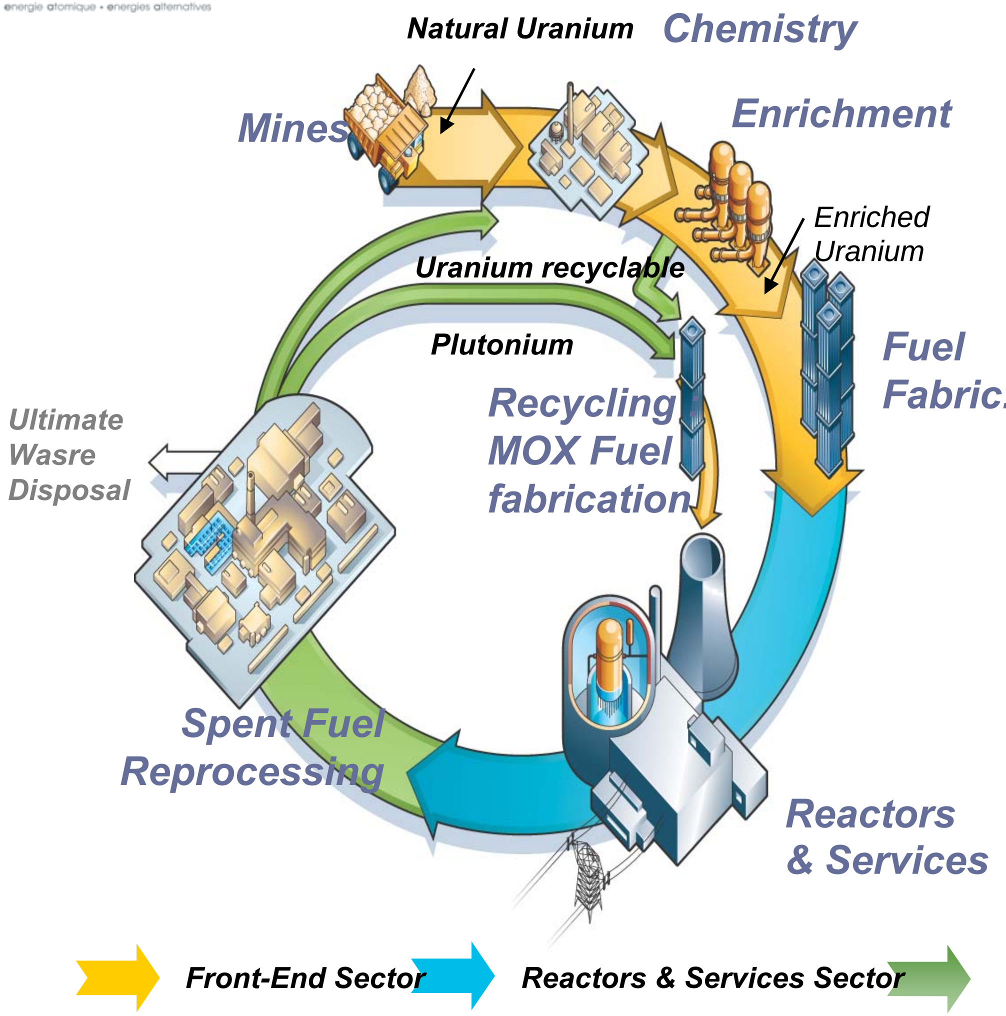
Closing the Fuel cycle (U+Pu)… an industrial reality



The example of the French situation :

- 58 PWRs → 400 TWh annually
- ~ 78 % of French electric production
- Fuel processing : more than 25 years of experience at La Hague
- 1100 t_{HM} /yr of spent fuel discharged from the French PWRs
- 850 t_{HM} /yr of domestic spent fuel reprocessed + foreign fuel
- Until now: ~ 25 000 t_{HM} spent fuel reprocessed and more than 1500 t_{HM} MOX fuel recycled

The 1991 and 2006 French Acts: frame of the Program

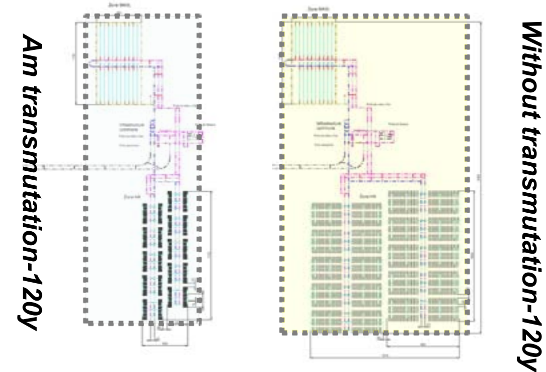
December 30, 1991 and June 28, 2006

- Three Research thematics for nuclear waste management:
  - partitioning and transmutation of LLRNs
  - geological deep repository
  - confinement and interim storage

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

LLRN Recycling strategy

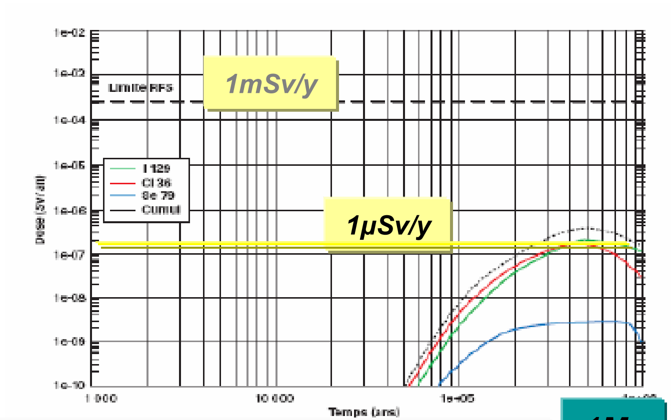
- Aim of recycling : to minimize the **quantity, and residual heat** of long lived nuclear waste
- Potential gain : to decrease the volume and to ease the conditions of a deep geological repository

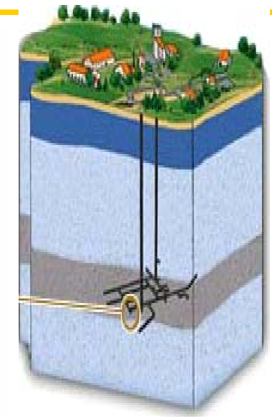


- Fundamental hypothesis : closed cycle, GEN IV fast neutron reactor implemented at mid or long term (whatever the cooling : Na, gaz,…)
- Reference strategy : LLRN (Am, Cm, Np) recovery, and their transmutation in reactors:
  - GEN IV SFR : Pu multi-recycling and MAs recycling, beginning after 2040
  - Homogeneous or heterogeneous recycling
  - Option of the « double strata » LWRs – Accelerator Driven Systems
- The research program for the different options : demonstrations of scientific and technical feasibilities,

  before pre industrial development of recycling expected after 2020

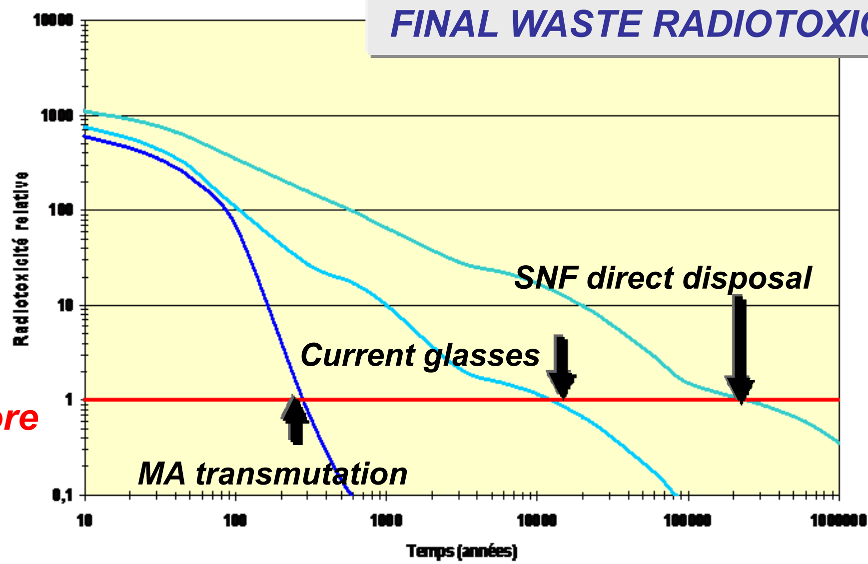
Minor Actinide recycling: the drivers



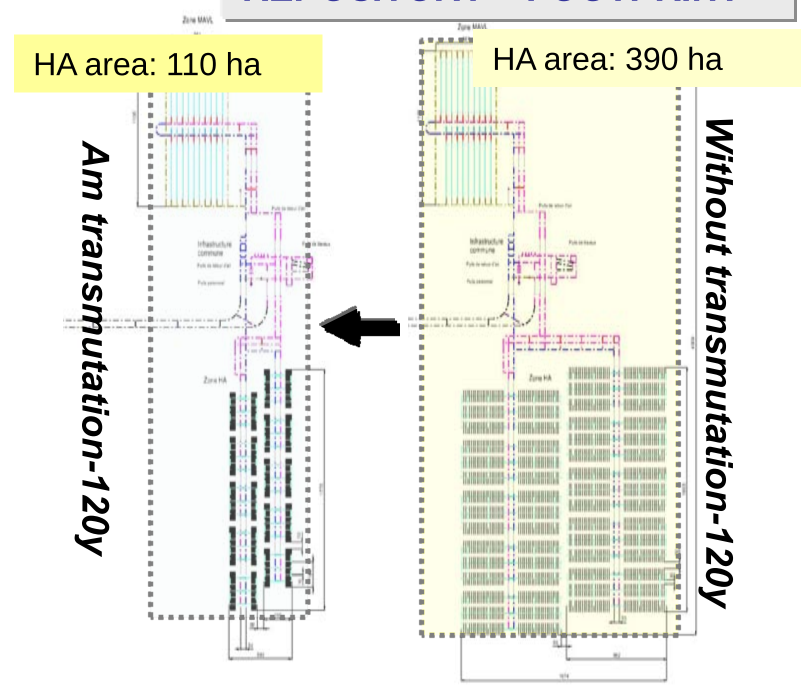


(ANDRA, « CLAY REPORT », 2005)

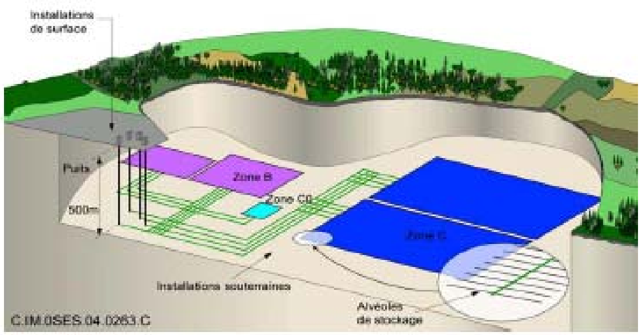
FINAL WASTE RADIOTOXICITY



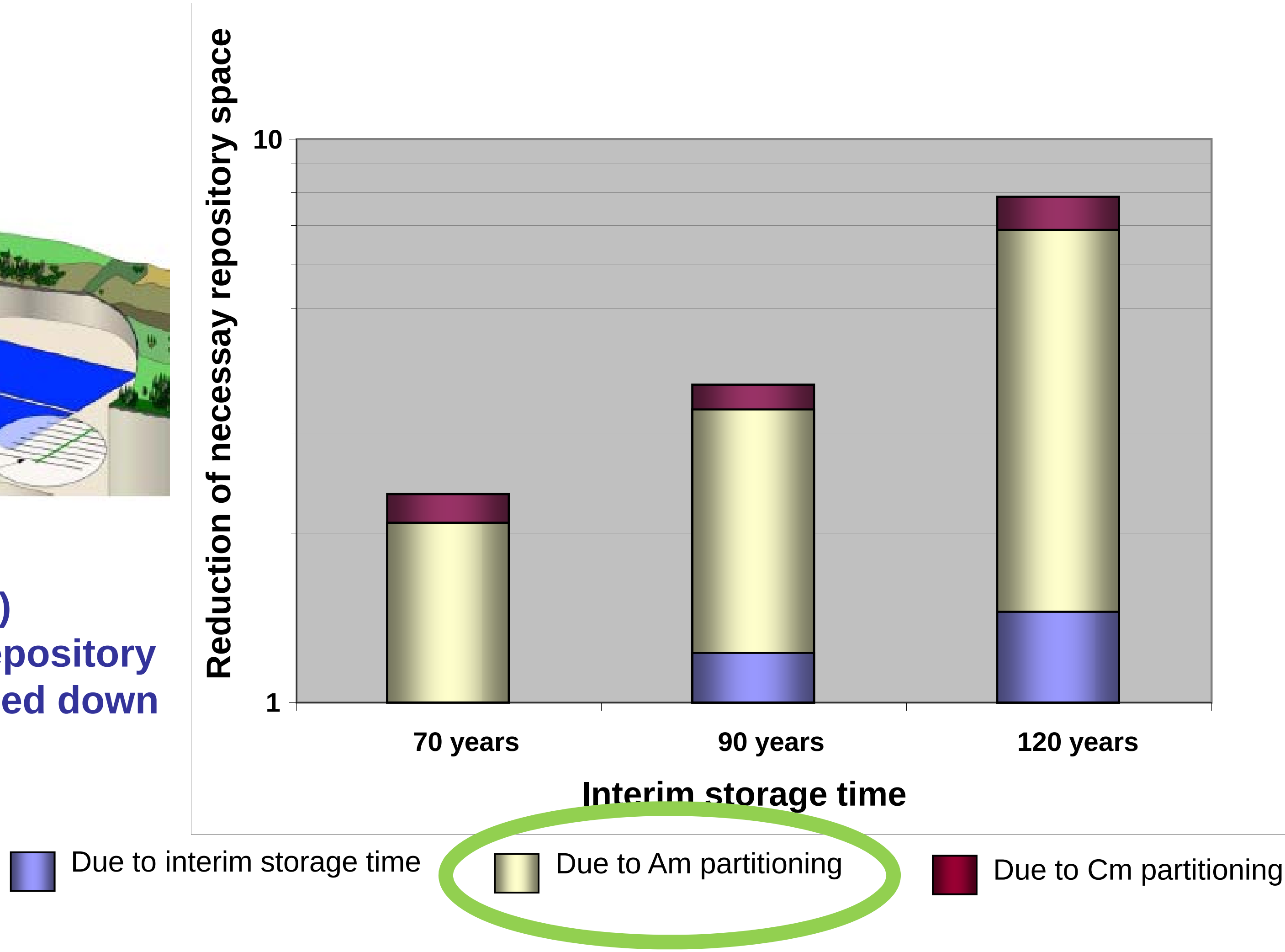
REPOSITORY « FOOTPRINT »



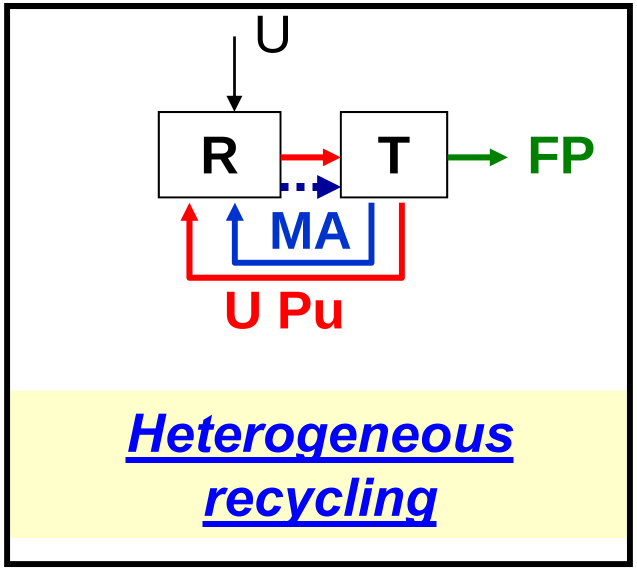
Repository volume reductions, as a function of MA recycling

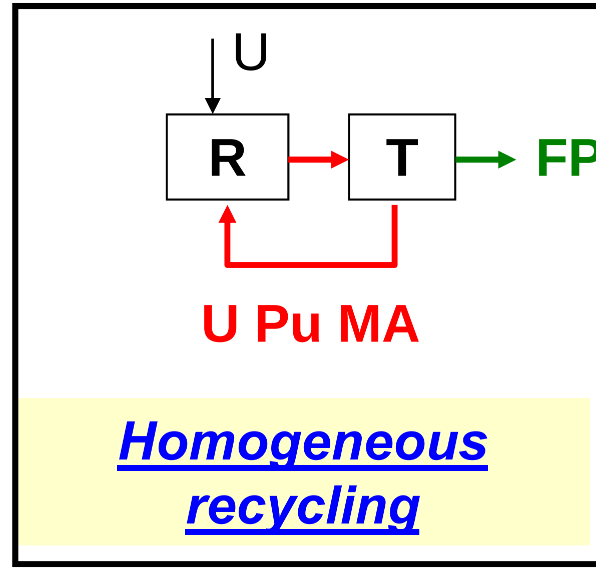


As a function of MA (Am+Cm, or Am only) recycling strategy, repository volume can be reduced down to a factor of 8



The P and T MA recycling options



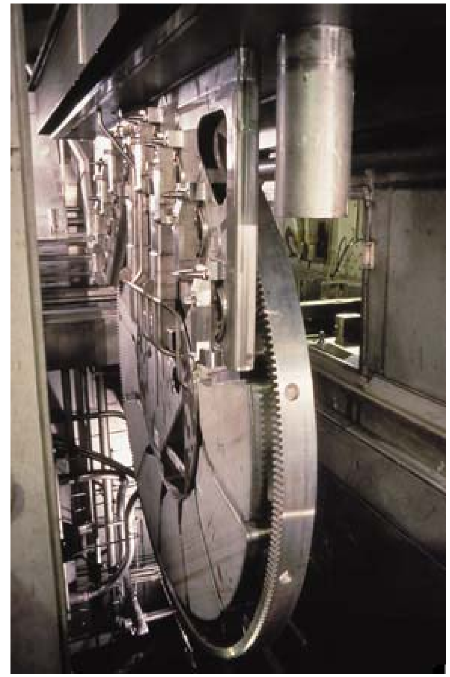


UPu: COEX
MA: SANEX-TODGA
Am: EXAm

PuAmCmNp: GANEX

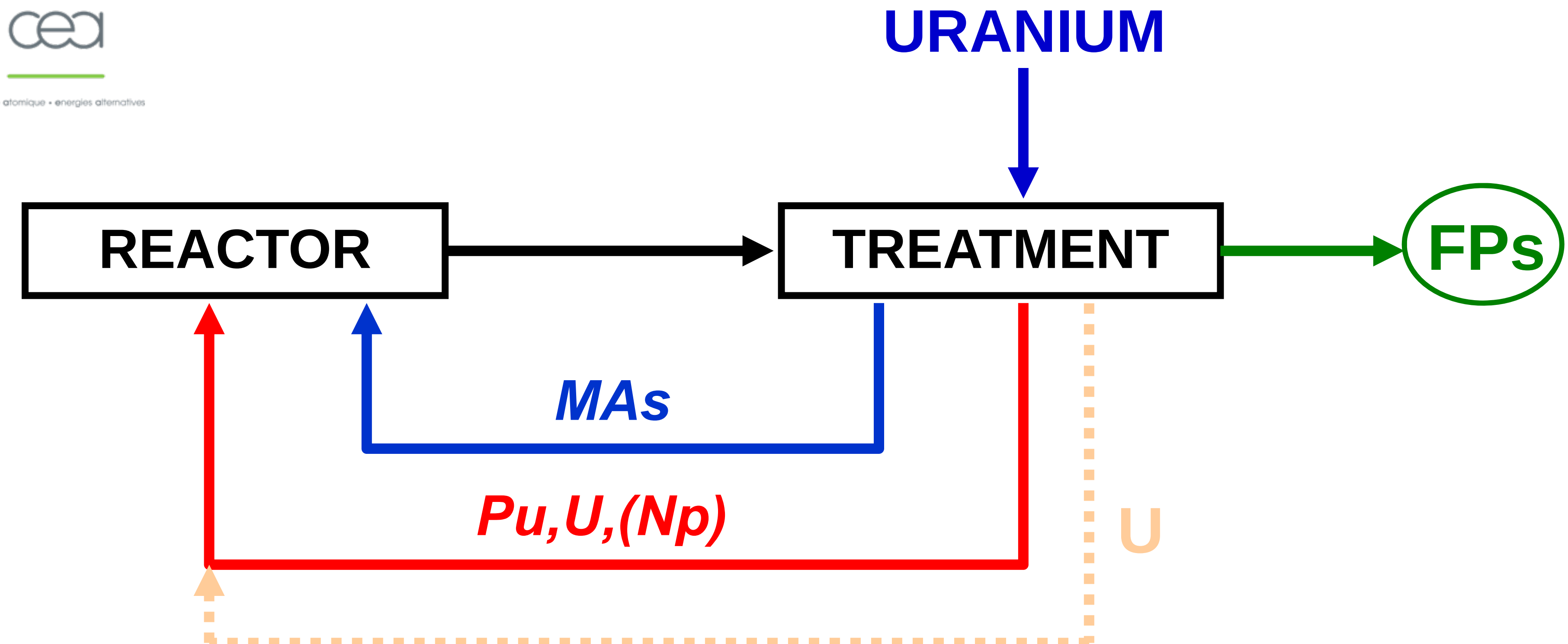
Actinide Partitioning : what processes ?

- **Solvent extraction, first !**
  - Already developed at commercial plant scale (industrial potentiality)
  - high separation yields
  - low amount of secondary waste



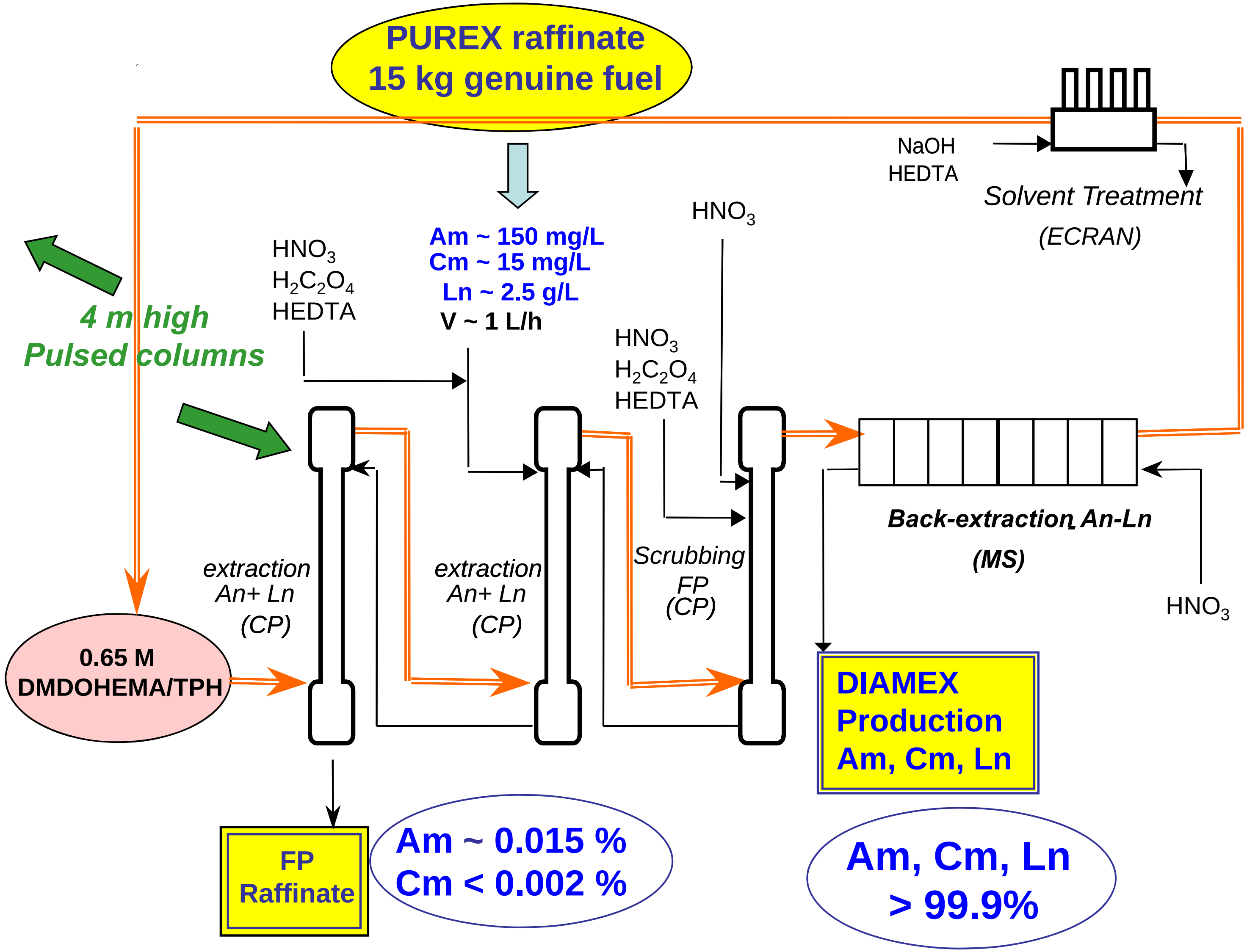
- The main alternative: high temperature pyro_processes

Fuel cycle, the MA heterogeneous recycling option

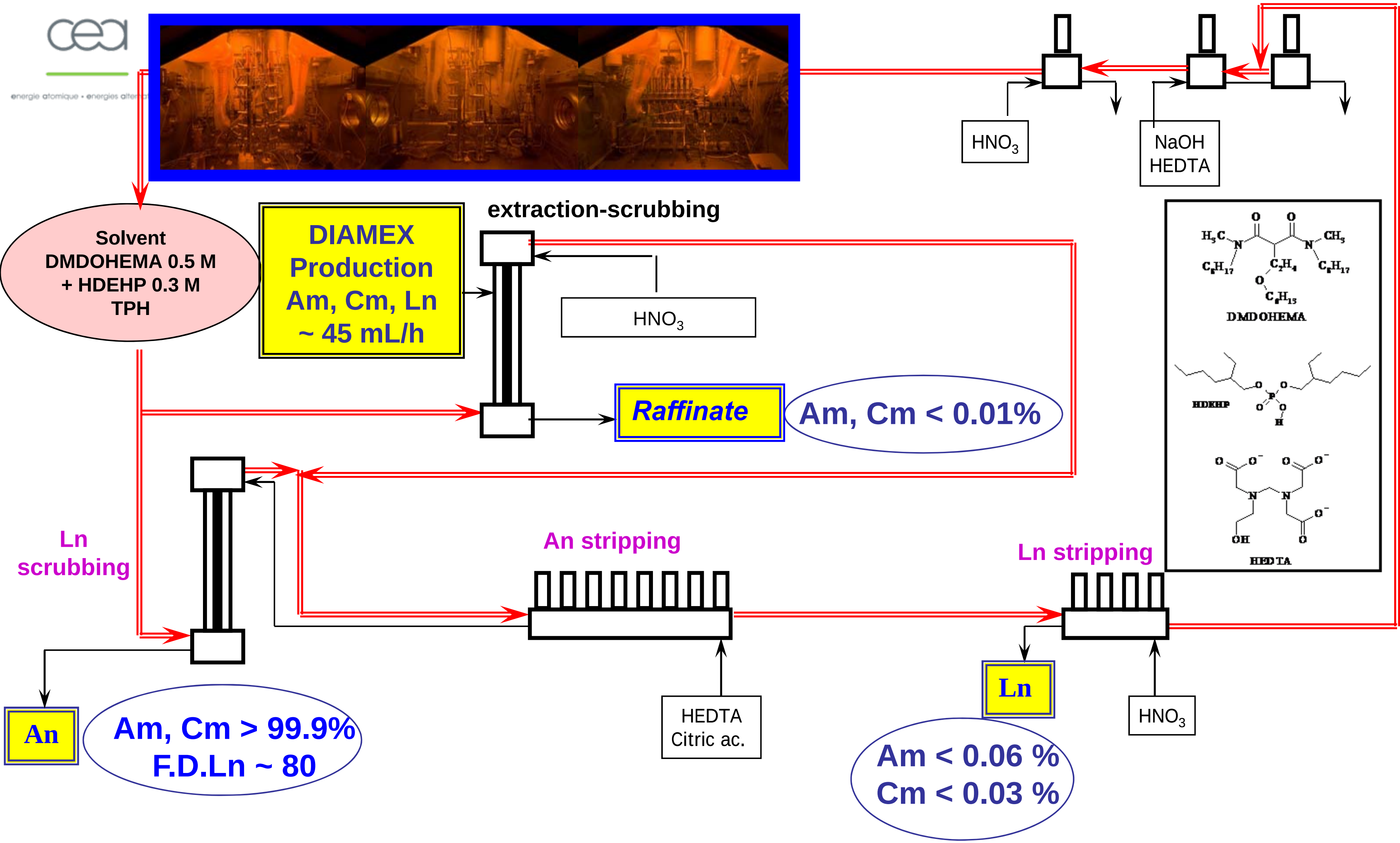


- U, Pu, Np by COEX™ without anywhere, anytime « pure » plutonium
- Am (and Cm) separation : DIAMEX, SANEX-TODGA, EXAm…
- Am (and Cm) recycled on dedicated « targets-blankets »

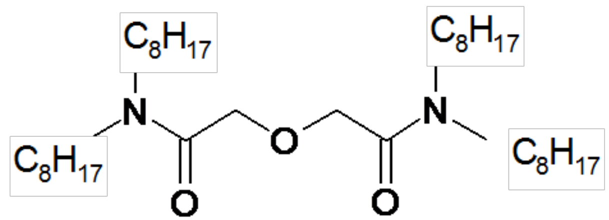
DIAMEX demonstrative hot run, November 2005

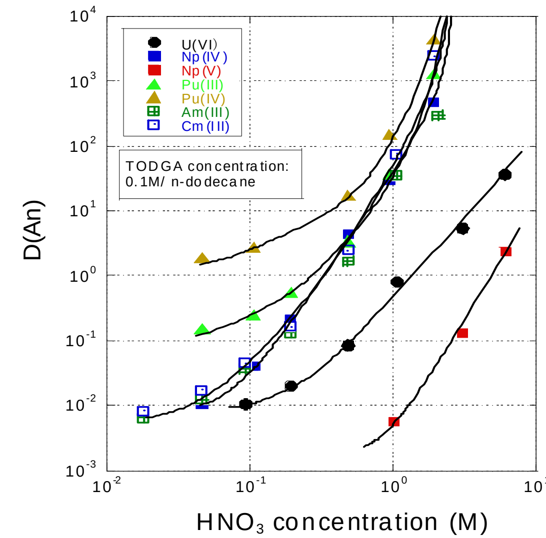


SANEX demonstrative hot run, December 2005

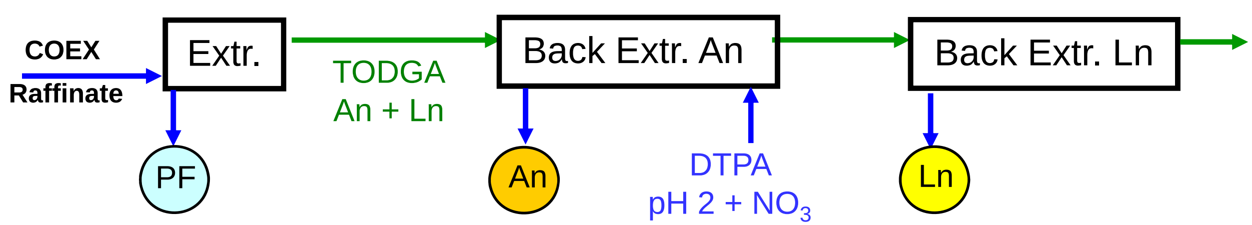


- **Co-extraction An (III) and Ln (III) with TODGA, using HNO_3 4N**





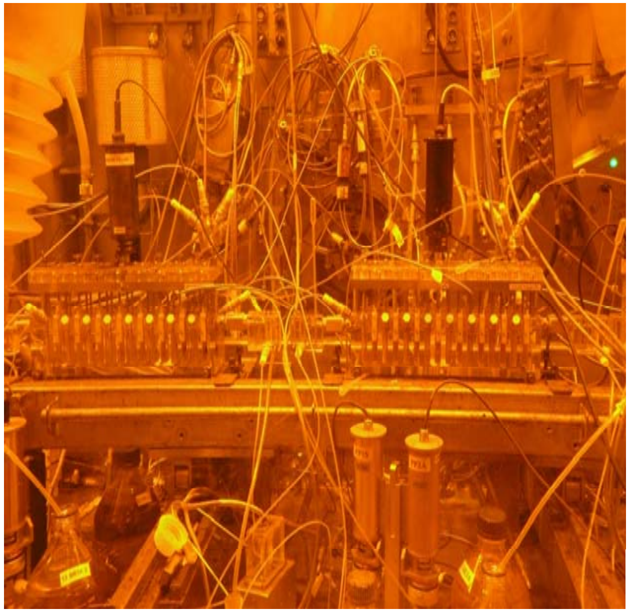
- **Selective back-extraction of An (III)**
  - **With polyamino-carboxylic hydrophile complexing agent**



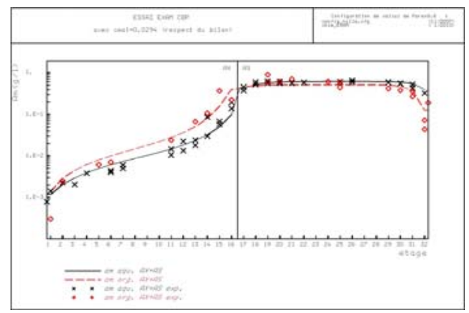
- **<u>Advantages</u> : simple scheme, TODGA synthesis low cost**
- **<u>Drawbacks</u> : high sensitivity of the Am-Cm back extraction step to pH and temperature**

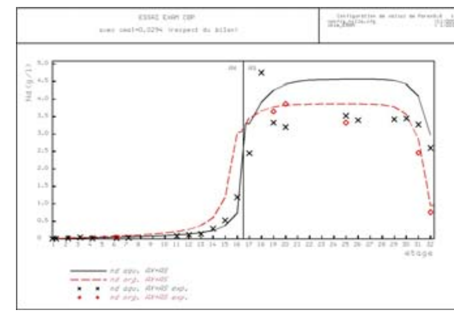
EXAm demonstrative hot run, April 2010 in CBP-Atalante

energie atomique • energies alternatives



- ~**1 kg SNF** dissolved
- **~ 60 h test**, with genuine solution
- spectrophotometer for **on line Nd and Am measurements** during the test ⇨ essential tool to follow the test operation
- ~ several hundreds sampling analytical determinations **for concentration profiles** (to be compared to model)





EXAm performances :

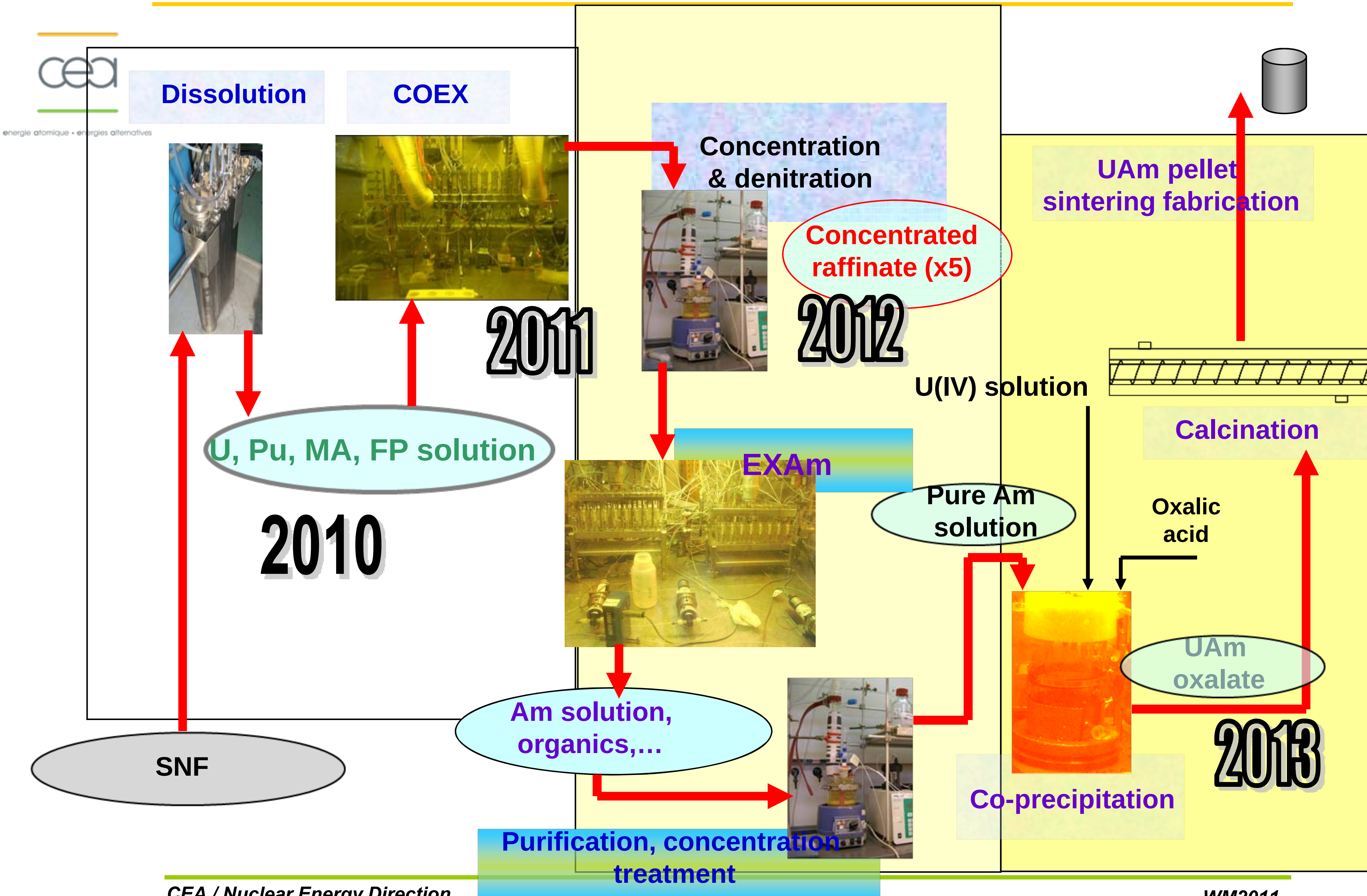
- **Decontamination Factor F_D (Cm/Am)** = $\dfrac{\left(Cm/Am\right)_{\text{Exam raffinate}}}{\left(Cm/Am\right)_{\text{Am Charge}}}$ = **1/500**

- **Am recovery ratio** = $\dfrac{(Am)_{\text{Charge}} - Amloss}{(Am)_{\text{Charge}}}$ = **98.5 %**

Process validated

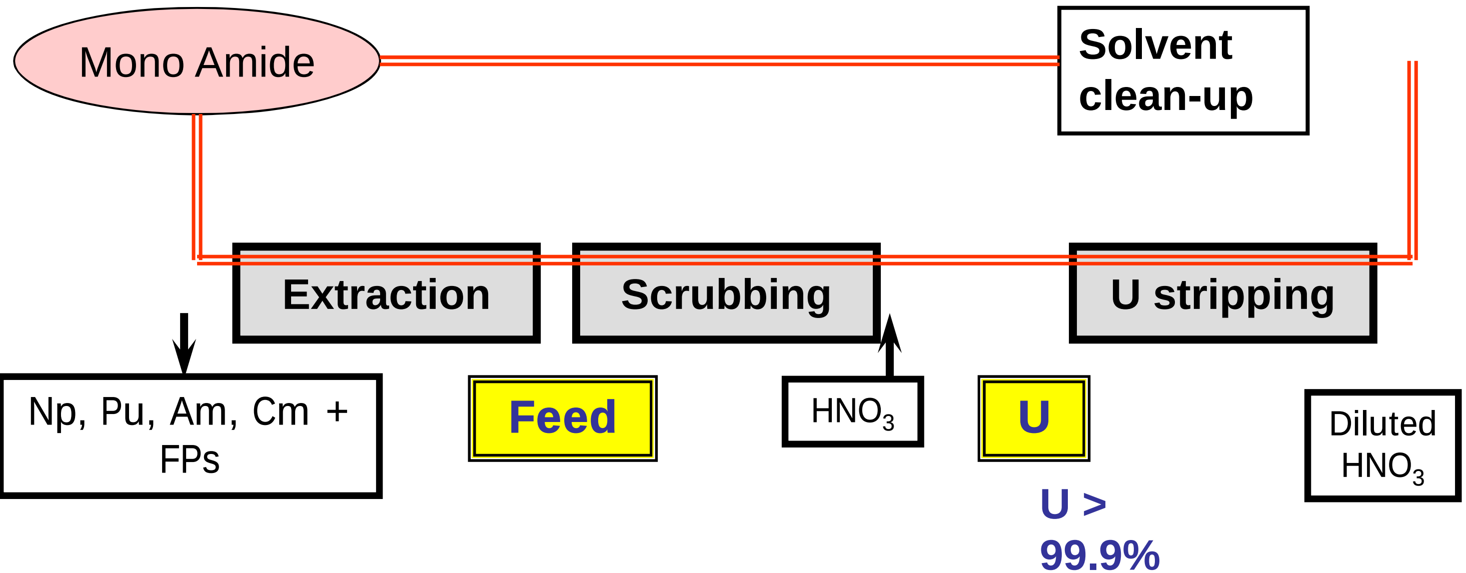
- **Key steps : Am stripping ; Mo stripping to be improved**

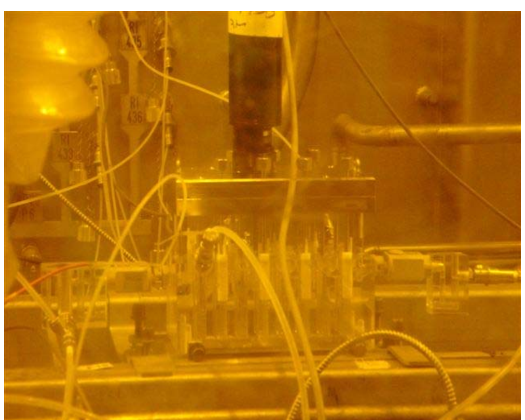
Integral test of Am recycling: from SNF solution to UAm pellet



1st step : *U selective extraction*

(performed successfully in June 2008)



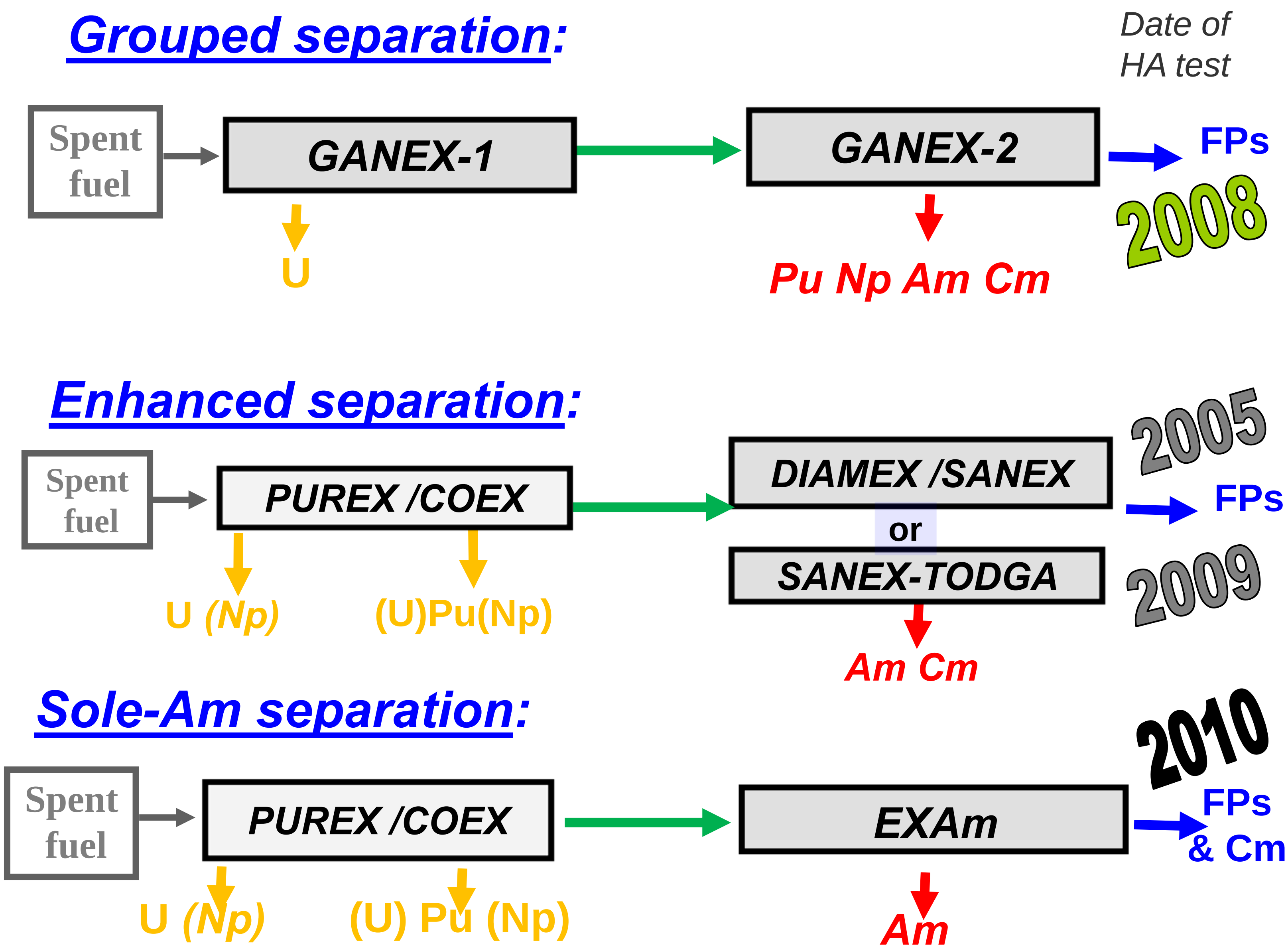


2nd step :

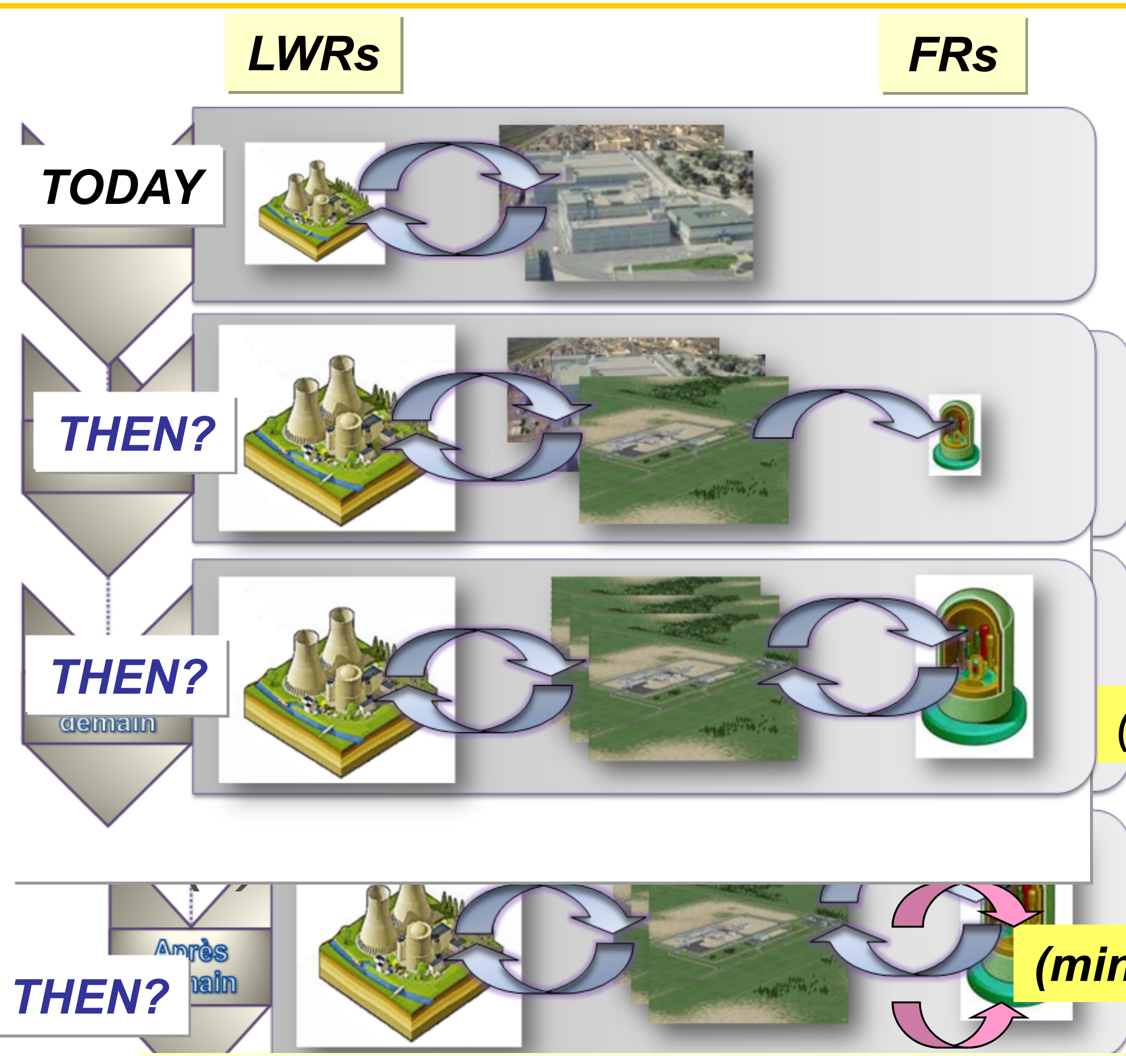
Pu-Np-Am-Cm co-recovery *(diamide-based process)*

(performed in November 2008)

MA partitioning options



Fleet and Fuels will evolve…



(HBU, MOX)

(feeding FRs)

(multi-recycle FRs)

(minor actinide recycle?)

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

En résumé… towards sustainable nuclear energy, the 2012 milestone

- 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

- 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, Korea,…)

  - 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)