FUEL CYCLES OPTIONS FOR SUSTAINABLE SYSTEMS: *THE FRENCH R&D PROGRAM*

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1 – The French nuclear fuel cycle
2 – Recycling , a key-option
3 – Main guidelines for R&D

THE FRENCH NUCLEAR FUEL CYCLE

(UOX)

(MOX)

REACTORS

Spent fuel

Fuel Manufacturing

Reprocessing

Plutonium

WASTE

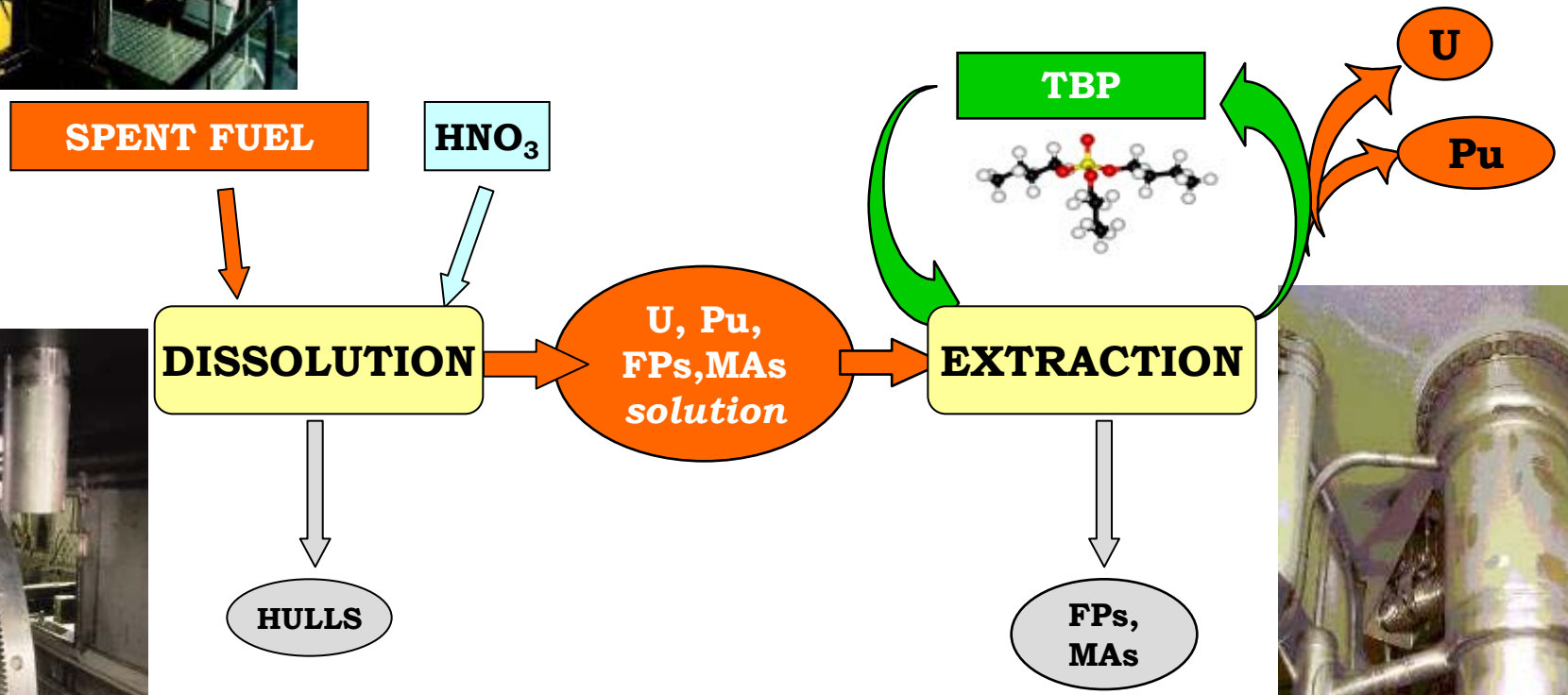
Uranium Enrichment

Uranium

Uranium Mining & Milling

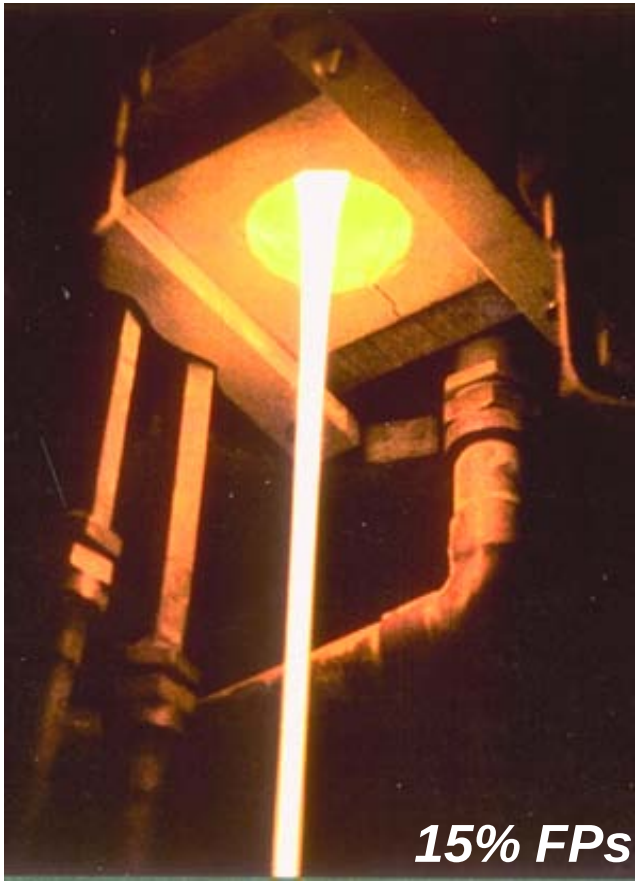
PUREX PROCESS , A HEAVY DEVELOPMENT WORK…

high recovery yields,
high purification yields…



…technological waste
low amounts

FINAL WASTE VITRIFICATION



About 15 canisters /GWe/year

WHY REPROCESSING AND RECYCLING ?

- **TO *BURN* FISSILE ELEMENTS**

  VALUABLE

  RADIOTOXIC

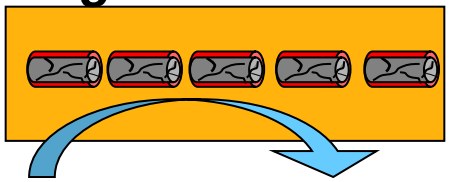
  HEAT-EMITTING

  PROLIFERATION-SENSITIVE

- **TO *STABILIZE* THE ULTIMATE WASTE (LOWERED) FOR DISPOSAL**

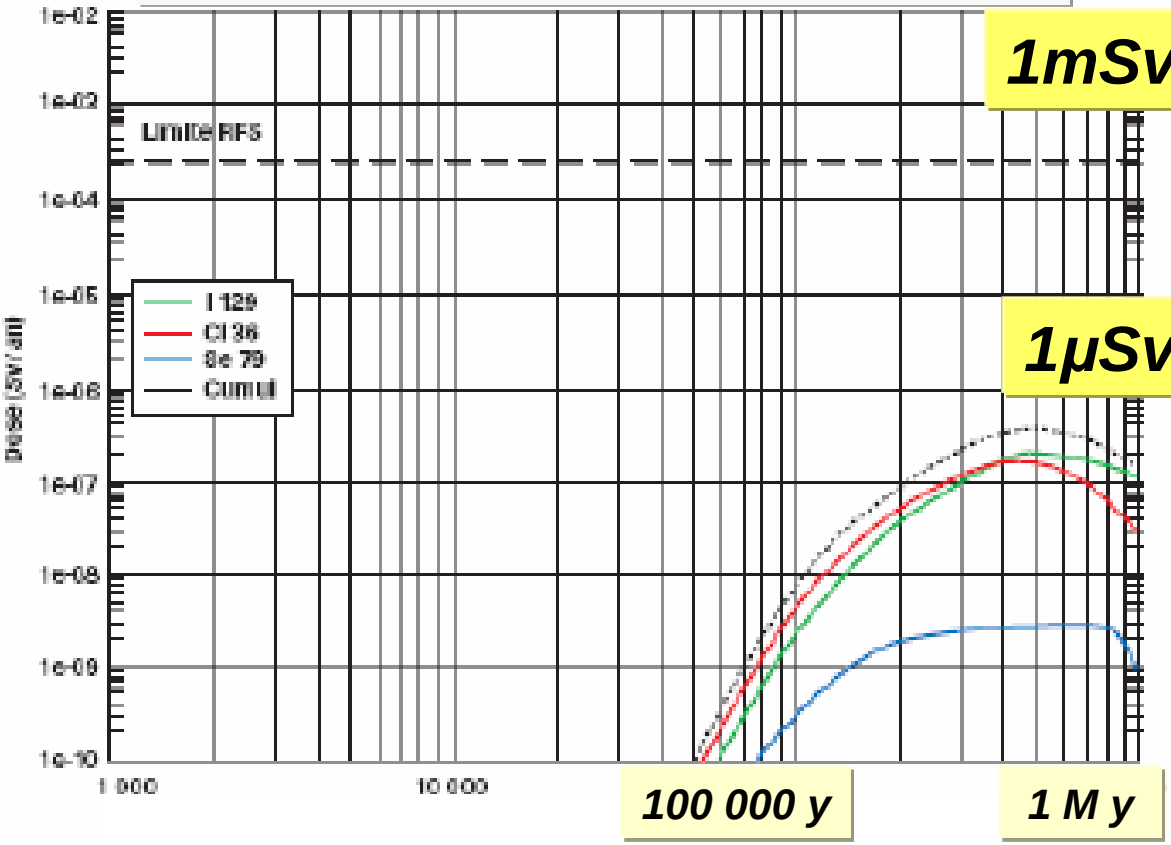
DEEP REPOSITORY

Glass alteration long-term kinetics



#1 µm/1000 years at 25 C

(ANDRA, « CLAY REPORT », 2005)



1mSv/y

1µSv/y

100 000 y

1 M y

Evolution of the dose at the final outlet versus time

THE « NUCLEAR RENAISSANCE » ON THE TRACKS ?

- ***IAEA,2007*: 500-660 GWe by 2030 ?**
- ***Possibly more ?!***

- **This means:**
  - ***hundreds of NPPs to be built***
  - **a large fleet *to be fueled***
  - ***large spent fuel amounts***

HOW TO MANAGE SPENT FUEL?

	2005	2030	2050
Nuclear primary *(GTOE)*	0.7		*2.5 ?*
Nuclear capacity *(GWe)*	360	600?	1400?
Discharged/stored fuel (Mtons)	0.2	0.5?	*1?*
Plutonium inventory *(tons)*	1500	4000?	*8500?*

The back-end of the fuel cycle must be considered soon enough in order to avoid possibly huge stockpiles of spent fuel!

FROM « RENAISSANCE » TO *SUSTAINABILITY*

- ***RECYCLING*, THE KEY-POINT !**
  - **RESOURCE SAVINGS**
  - **MINIMIZING WASTE**
  - **BURNING PLUTONIUM**

- **RECYCLING PLUTONIUM IN LWRs, A FIRST STEP ;**

- ***BUT IN A LONG TERM PERSPECTIVE ?***

FROM « RENAISSANCE » TO *SUSTAINABILITY*

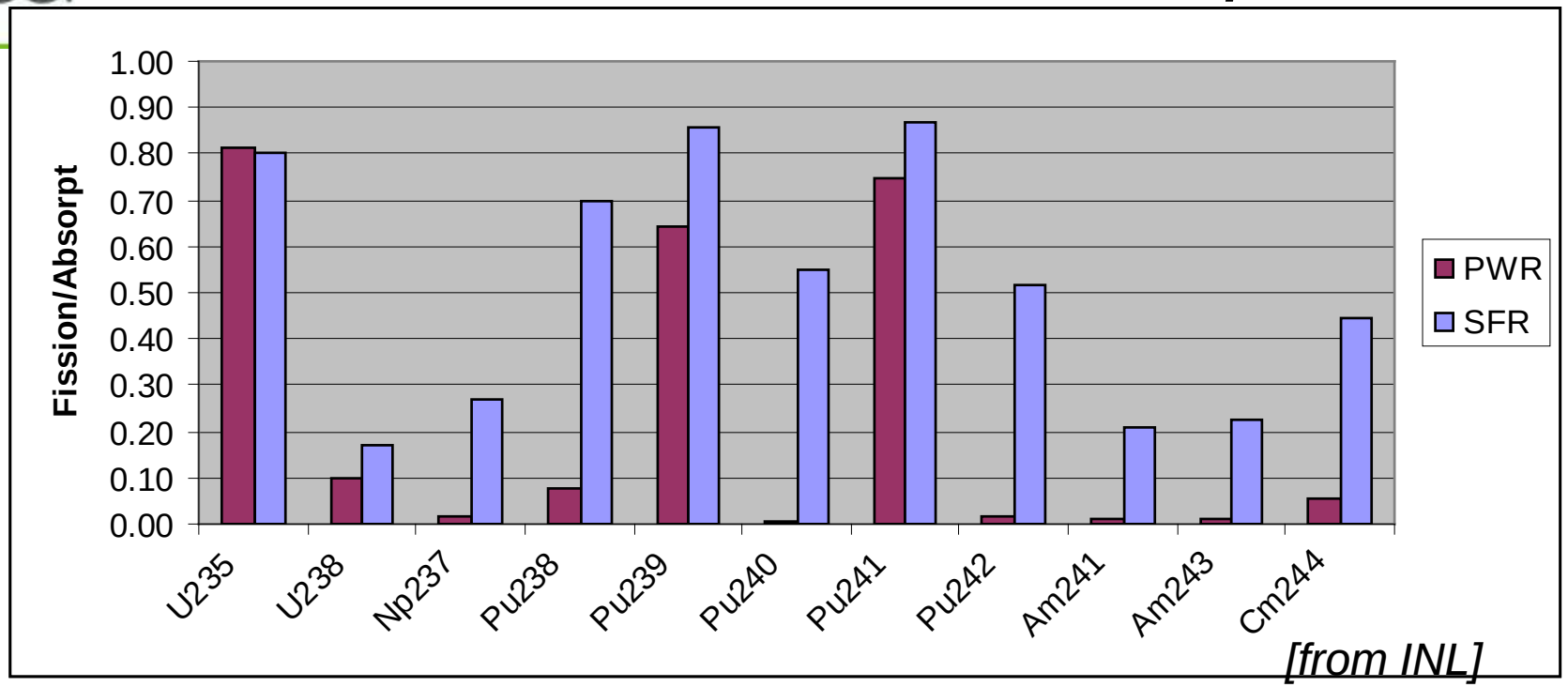
- **LWRs have many advantages, but *can't satisfy alone sustainability goals***

- ***Potentialities of breeding / burning from ^{238}U are largely under-used***

- ***MOX spent fuels multi-recycle in LWRs lead to increased amounts of higher minor actinides;***

SUSTAINABILITY : FAST NEUTRONS SYSTEMS

Fission to Capture ratio

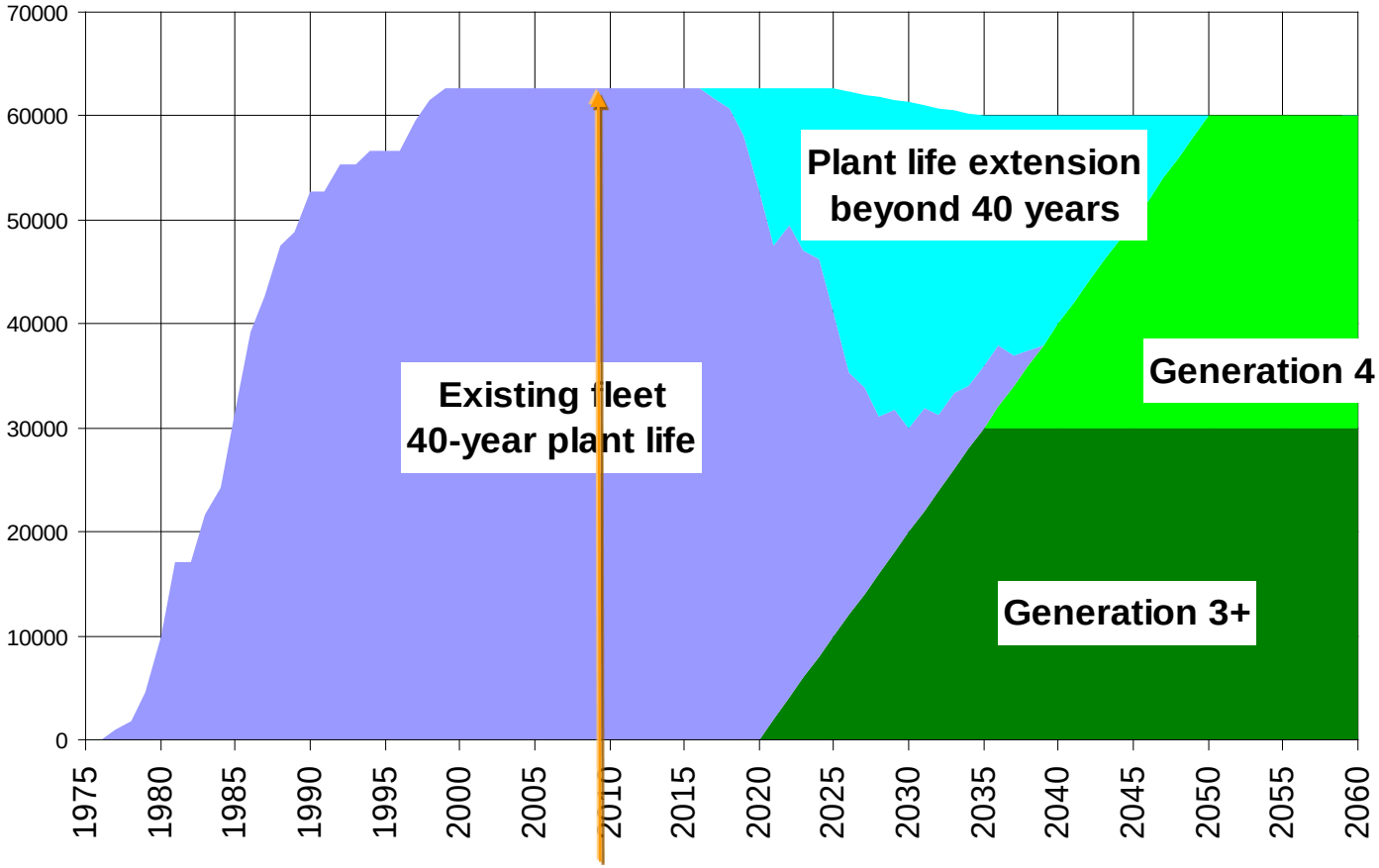


[from INL]

Fission fraction is higher in fast spectrum

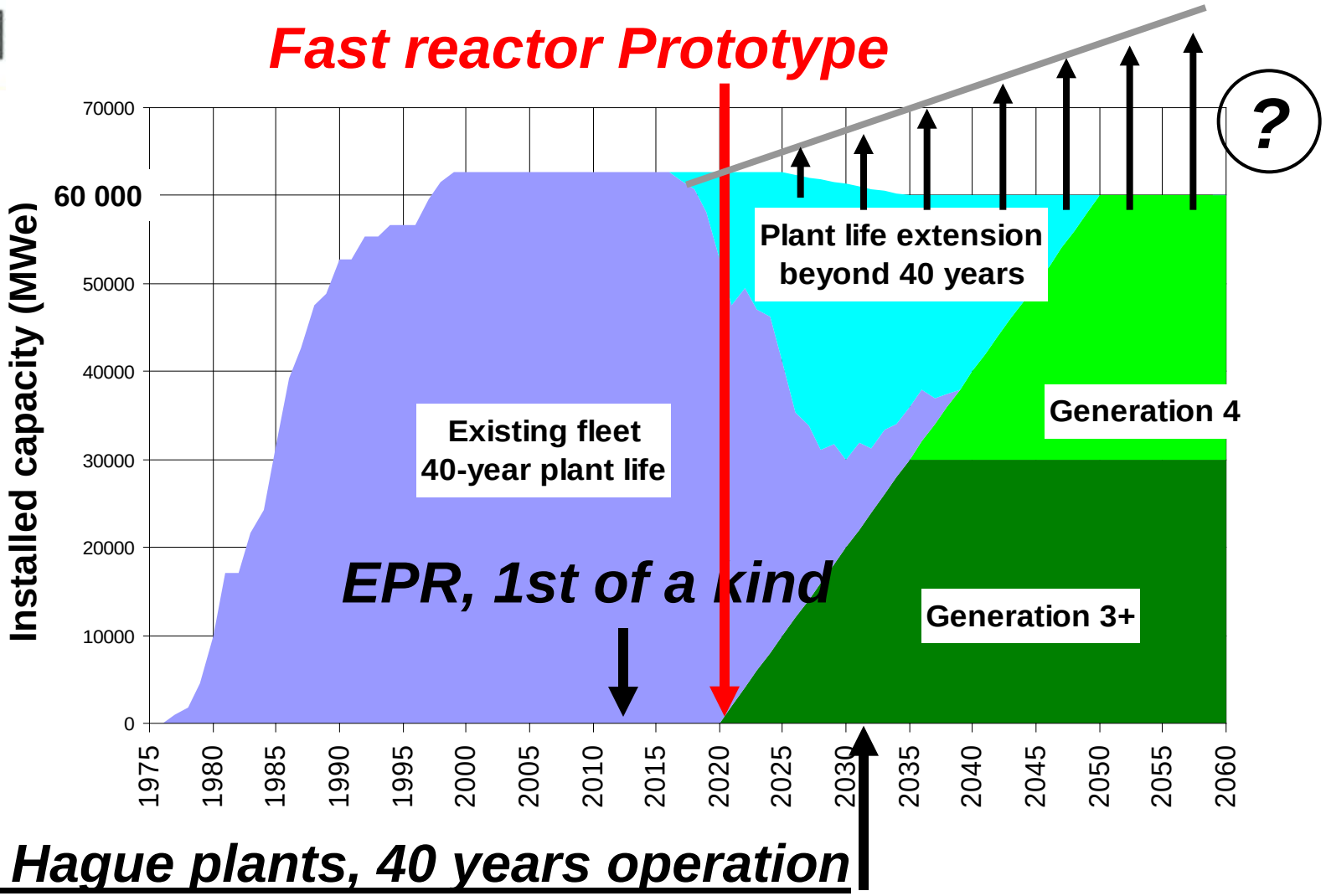
(more excess neutrons, less higher actinide)

A SCENARIO FOR FRENCH NPPs



Source : EDF

A SCENARIO FOR FRENCH NPPs

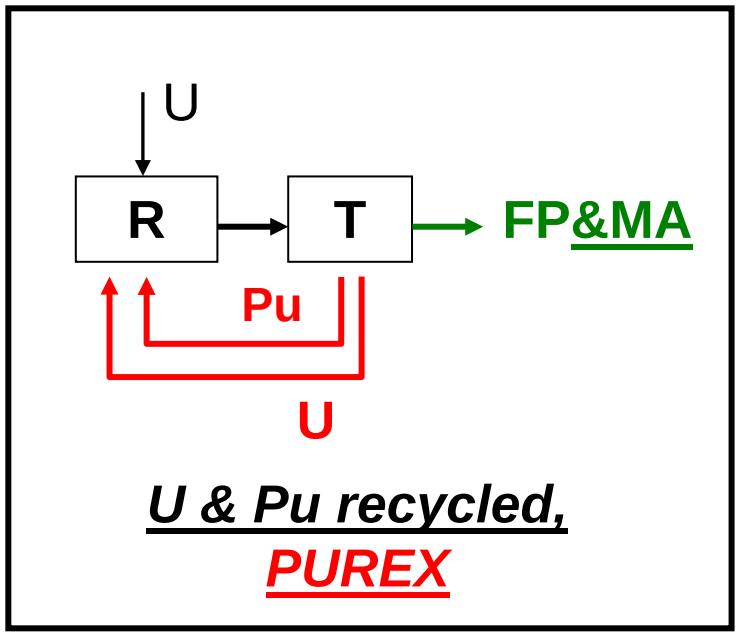


WHICH PROCESS FOR FUTURE FUEL CYCLES ?

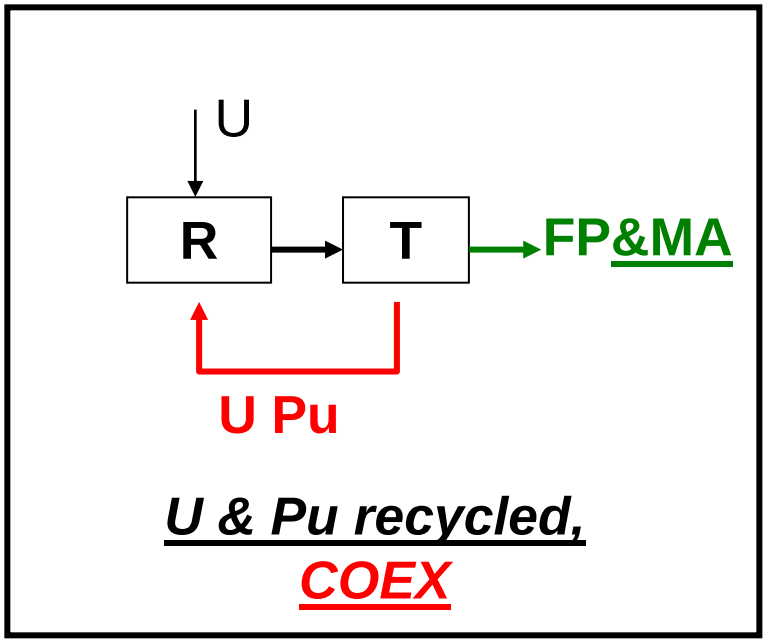
- **A NEED FOR *FLEXIBLE*, *SAFE*, *COST-EFFECTIVE*, *HIGH PERFORMANCE*, *PROLIFERATION RESISTANT*…**

…RECYCLING PROCESSES

THE COEX CONCEPT

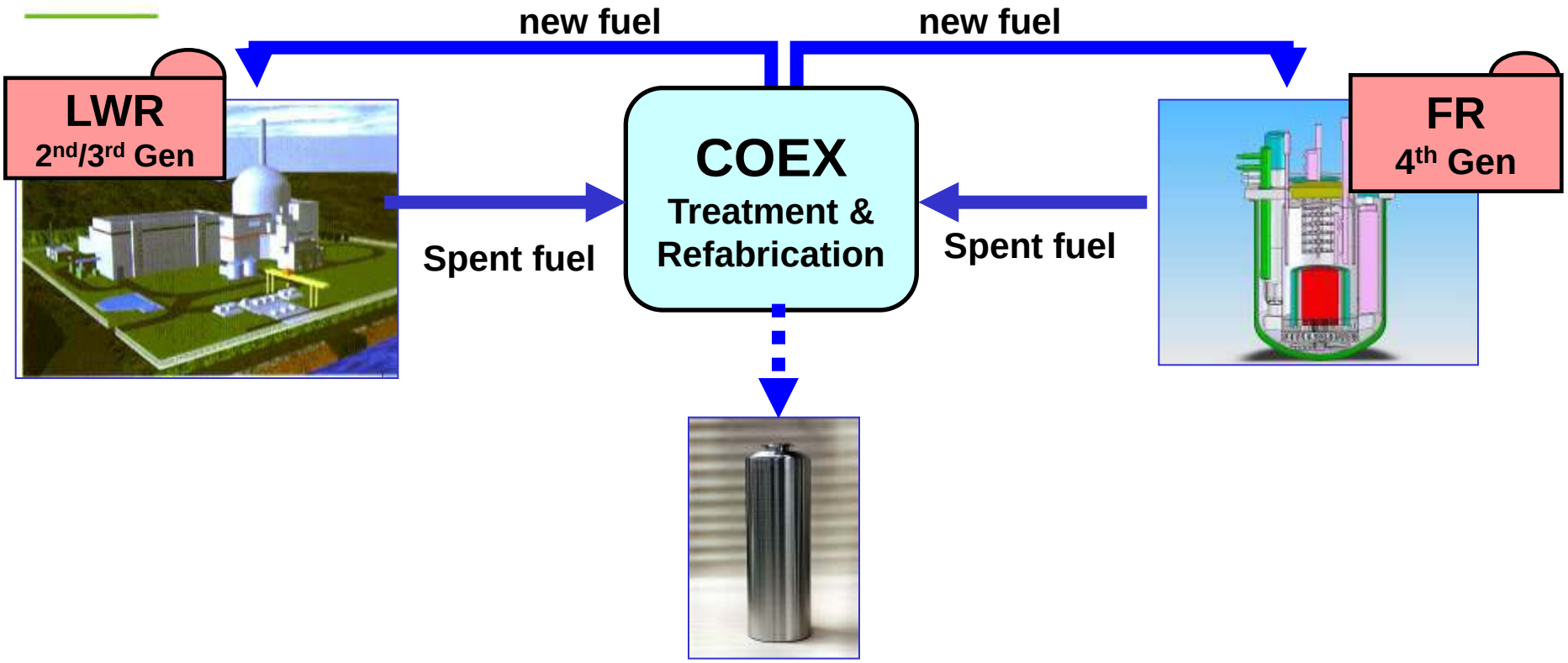


Today…



Future plants?…

THE COEX PLANT



could be afterwards improved, adapted to new fuels…

AND FINAL WASTE DISPOSAL ?

Low Level W

Very LLW

ANDRA FACILITIES

High LW

THE FRENCH 2006 ACT (RW management)

➧ **PRINCIPLES** :

- ***RECYCLE (reprocess)***
  to decrease waste amount & toxicity
- ***RETRIEVABLE GEOLOGICAL REPOSITORY,***
  for ultimate waste

➧ **A « ROADMAP » :**

- ***2012 : assess the industrial potentialities of diverse P&T options (prototype by 2020)***
- ***2015 : repository defined (operation by 2025)***

MINOR ACTINIDE RECYCLE, IN ADDITION ?

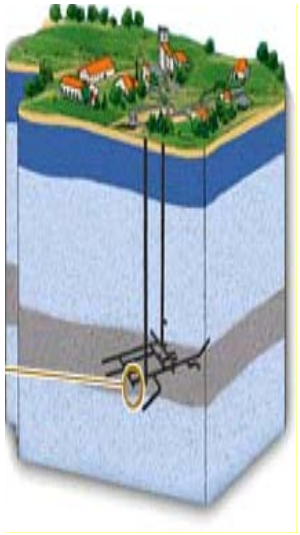
AMOUNTS IN LWR SPENT FUEL

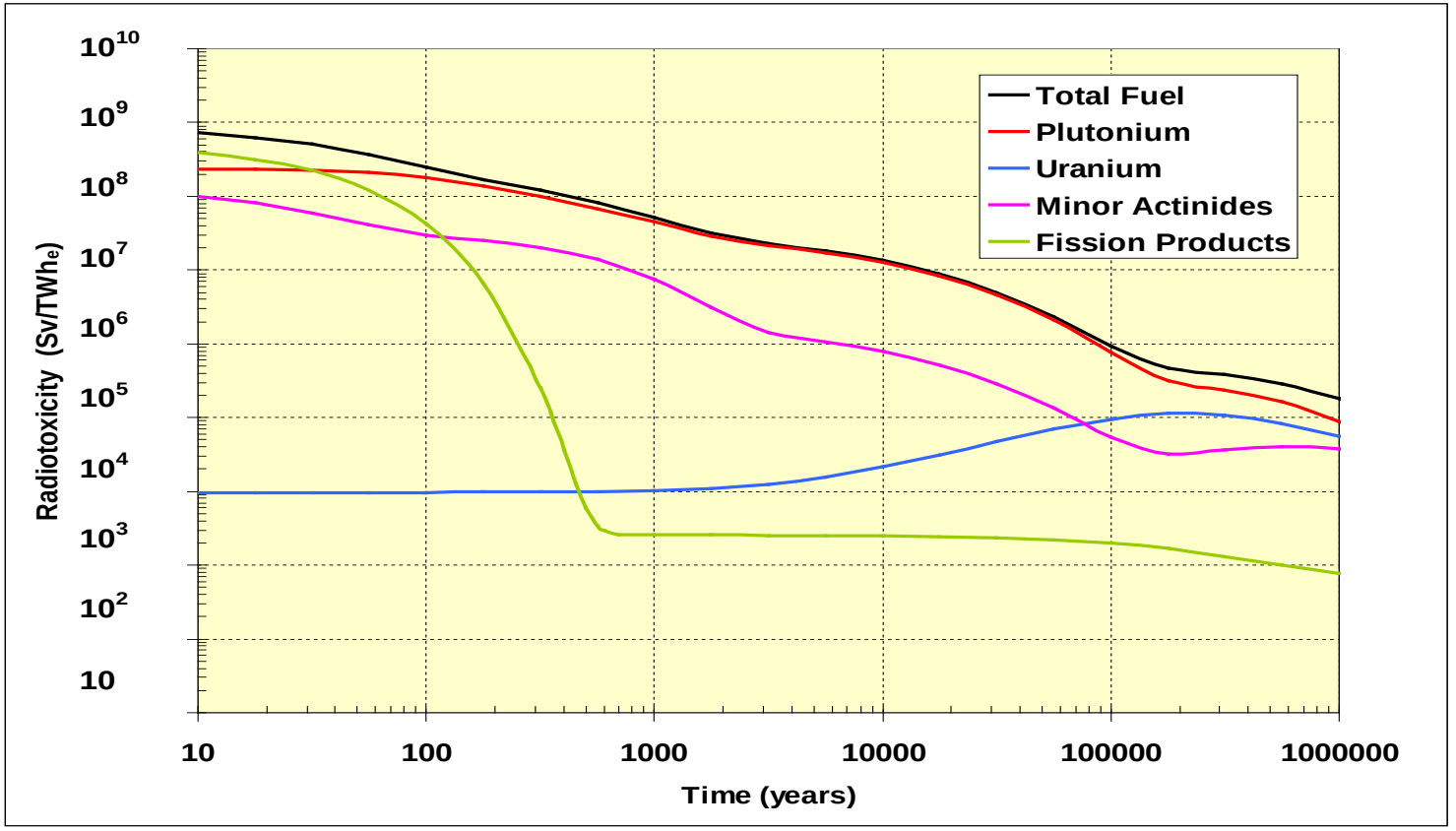
- **TOTAL MAs : *about 0.1%***

- **Np: 400 g/t (^{237}Np)**
- **Am: 400 g/t (^{241}Am, ^{243}Am)**
- **Cm: 40 g/t (^{244} Cm, ^{245}Cm)**

[UOX, 45 GWd/t]

LONG TERM RADIOTOXICITY OF SPENT FUEL

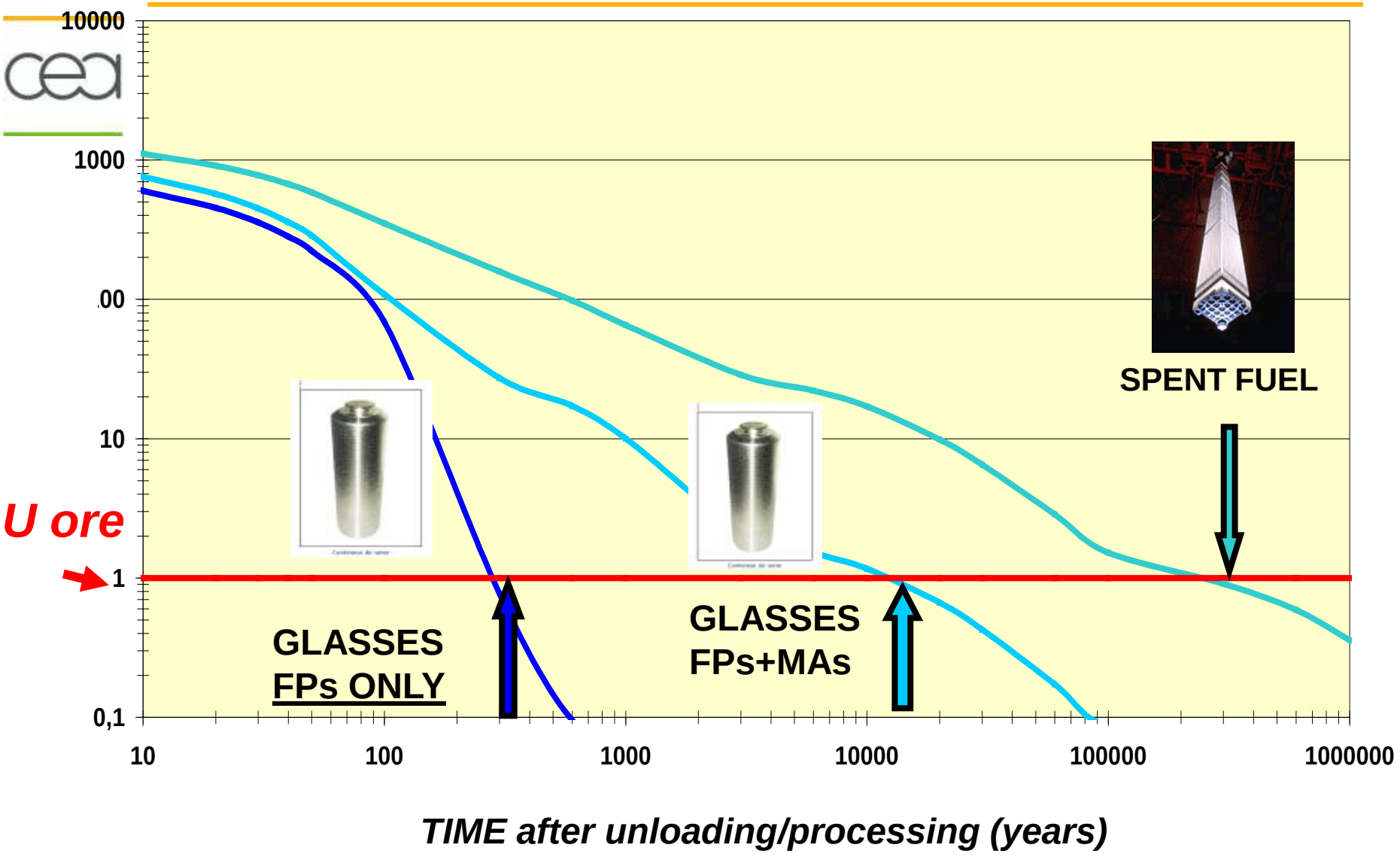




(Ingestion Doses Coefficients from ICRP72)

Main contributors **[1000 – 10.000 years] : Pu >> MAs >> FPs**

FINAL WASTE RADIOTOXICITY



FUTURE FUEL CYCLES

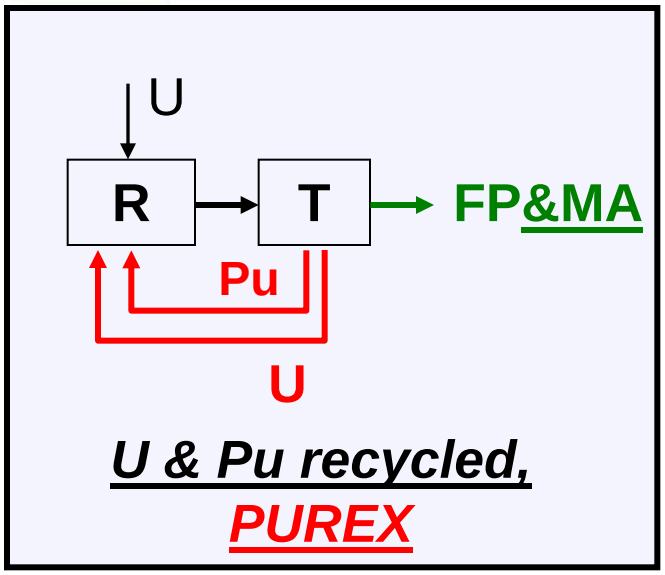
SEVERAL OPTIONS,

WHICH COULD BE

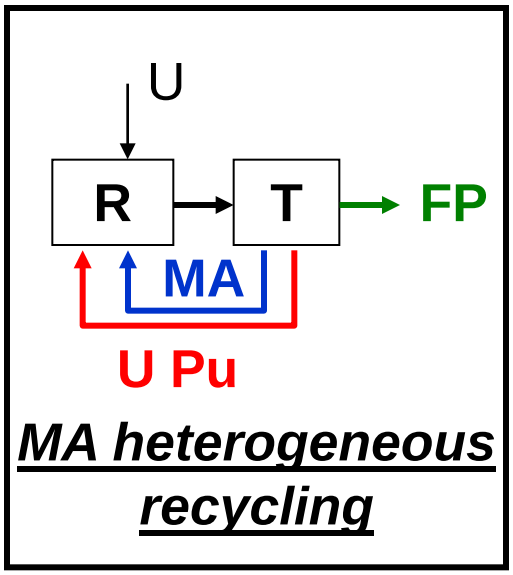
SUCCESSIVELY DEPLOYED

- ***HETEROGENEOUS, HOMOGENEOUS***
- ***AMERICIUM ONLY, ALL-ACTINIDES…?***

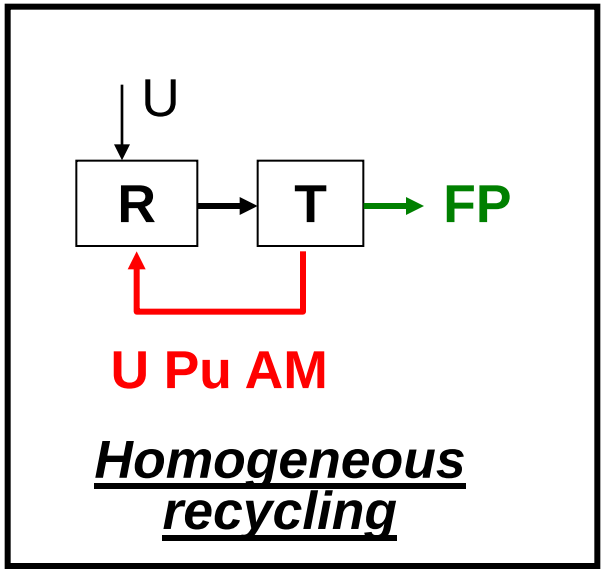
WHICH OPTION FOR THE FUTURE ?



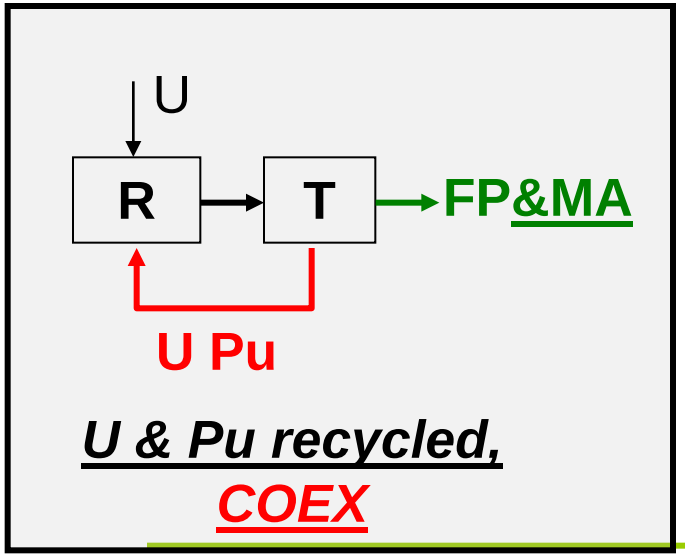
U & Pu recycled, PUREX



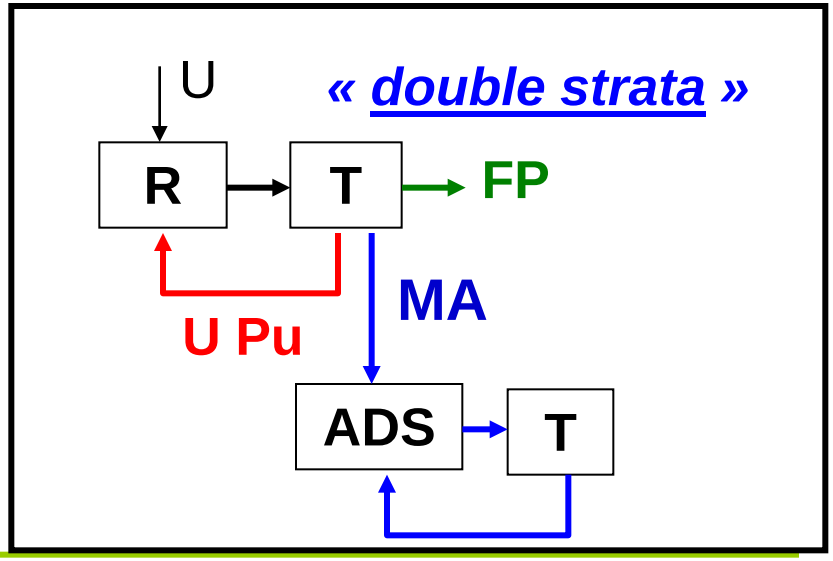
MA heterogeneous recycling



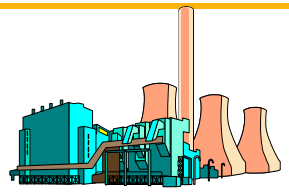
Homogeneous recycling



U & Pu recycled, COEX



ATALANTE 2005 HOT RUNS



(15 kg UOX spent fuel)

Spent Fuel

99.9 %

U, Pu, *Np*

PUREX

Two step strategy

Fission Products

DIAMEX

CO-EXTRACTION of MAs and Ln

<0.01 %

Ln

SANEX

99.9 %

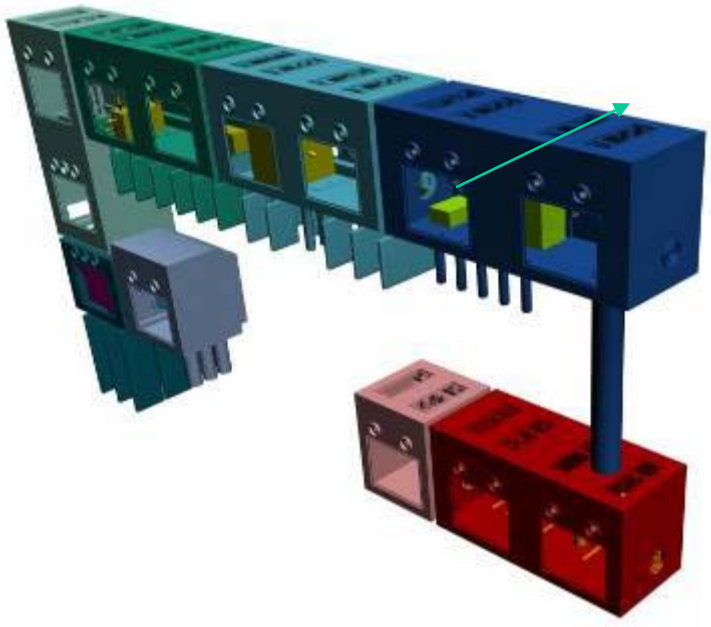
Am, Cm

SEPARATION of MAs from Ln

ADVANCED OPTIONS: THE 2012 MILESTONE

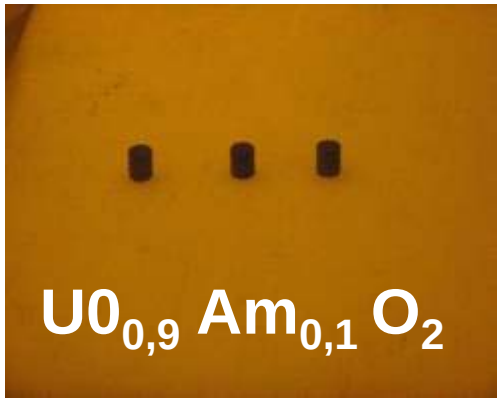
- **Assess *benefits /costs ratio* for diverse recycling (P&T) options considering diverse criteria**
- ***Design* / Optimize *separation processes*, *fuels*, *fabrication processes***
- **and gather technical elements for *industrial operation evaluation***

CEA, The ATALANTE FACILITY



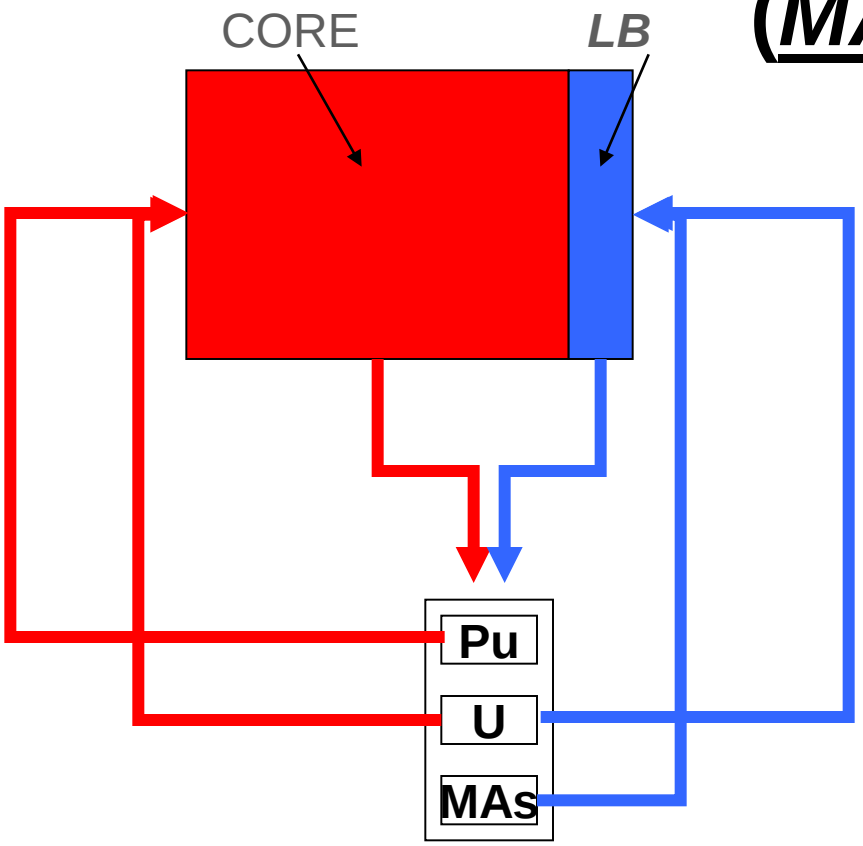
Homogeneous

Heterogeneous



HETEROGENEOUS MULTI-RECYCLE

- **Core : $UPuO_2$**
- **MA "loaded blankets" : $U,\underline{MA},O_2$ ($\underline{MA}$ =Np/Am/Cm)**



FUEL FABRICATION NEW FACILITIES

SFR / MOX FUEL FABRICATION

(the core of the prototype, tons)

MINOR ACTINIDES PILOT

(experimental pins, kgs)

As a summary…

- **FUEL CYCLE OPTIONS:**
  from RENAISSANCE TO SUSTAINABILITY

- ***RECYCLING*, *A KEY-POINT!***
- ***MATURE TECHNOLOGIES* AVAILABLE TODAY**

- ***FUTURE OPTIONS*:**
  - **OPEN *OPTIONS***
    (what to recycle, and how)
  - **A *PROGRESSIVE* APPROACH,**
    (from today's technologies)
  - **A NEED FOR *FLEXIBLE* PROCESSES**
    (different reactors, with diverse needs)