energie atomique • energies alternatives

FUTURE NUCLEAR FUEL CYCLES:
TOWARD SUSTAINABILITY, A FRENCH VISION…

Bernard BOULLIS,

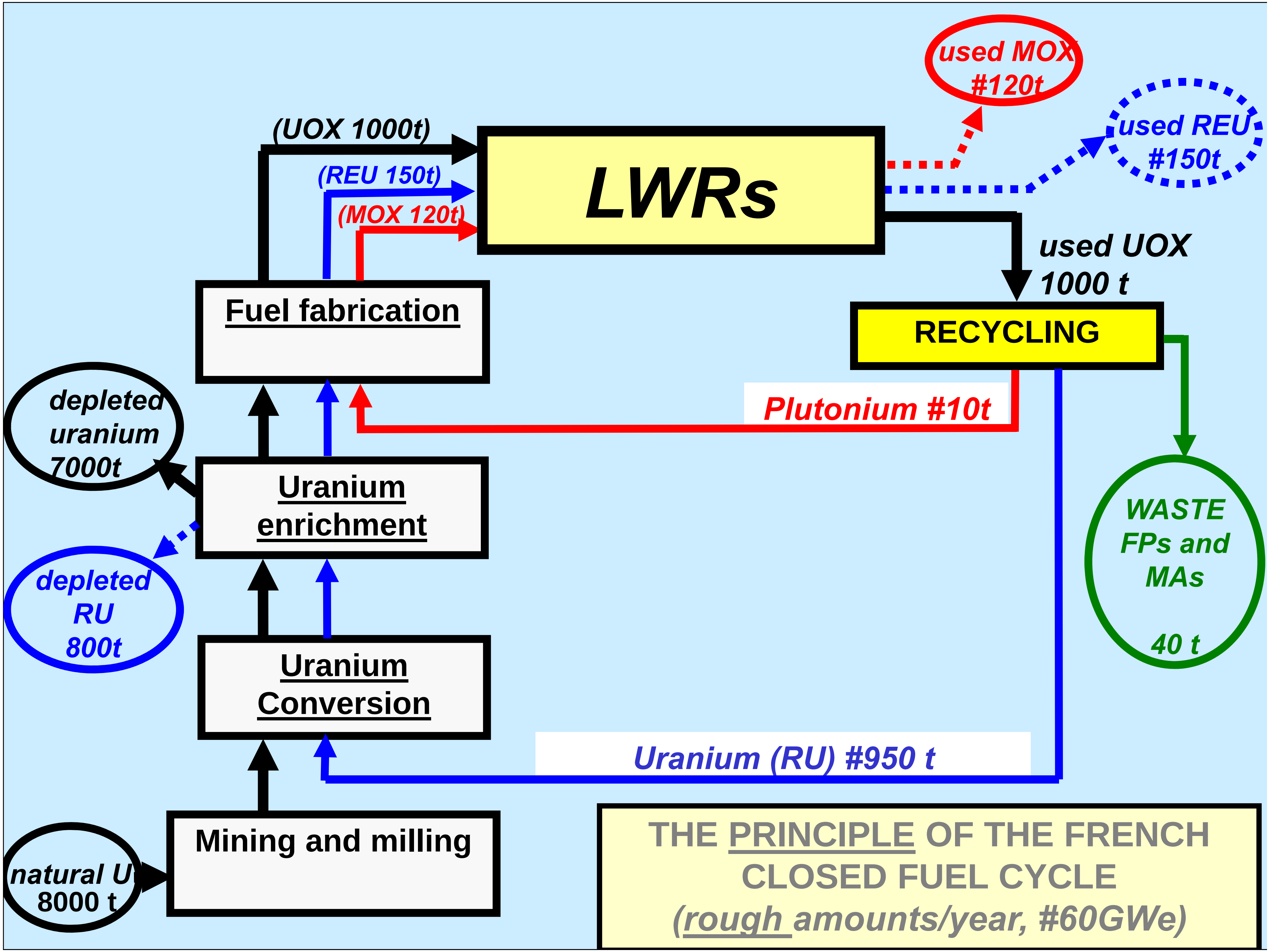
CEA, Nuclear Energy Division

Program Director, Nuclear Fuel Cycle Back-end

energie atomique • energies alternatives

FUTURE NUCLEAR FUEL CYCLES:
TOWARD SUSTAINABILITY, A FRENCH VISION…

- ***THE CURRENT FRENCH NUCLEAR FUEL CYCLE***
- ***TOWARD SUSTAINABILITY: SOME GUIDELINES***
- ***TOWARD SUSTAINABILITY : TRANSITION SCENARIOS***


(UOX 1000t)
(REU 150t)
(MOX 120t)
LWRs
used MOX
#120t
used REU
#150t
used UOX
1000 t
Fuel fabrication
RECYCLING
Plutonium #10t
depleted
uranium
7000t
Uranium
enrichment
depleted
RU
800t
WASTE
FPs and
MAs
40 t
Uranium
Conversion
Uranium (RU) #950 t
Mining and milling
natural U
8000 t
THE PRINCIPLE OF THE FRENCH
CLOSED FUEL CYCLE
(rough amounts/year, #60GWe)

RECYCLING TECHNOLOGIES : DECADES R&D!

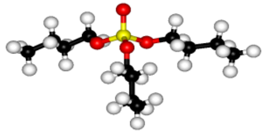
reliable...

high yields...

SPENT FUEL

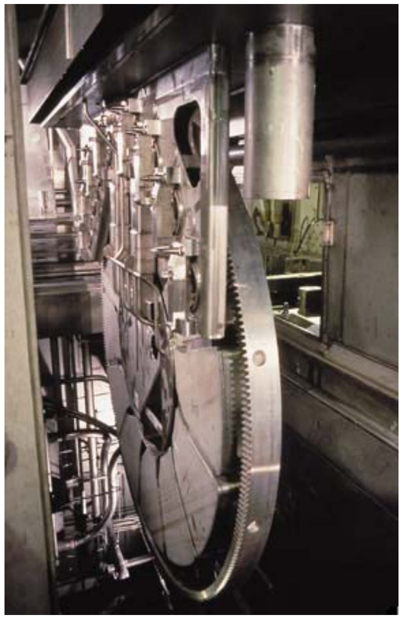
HNO_3

TBP



U

Pu



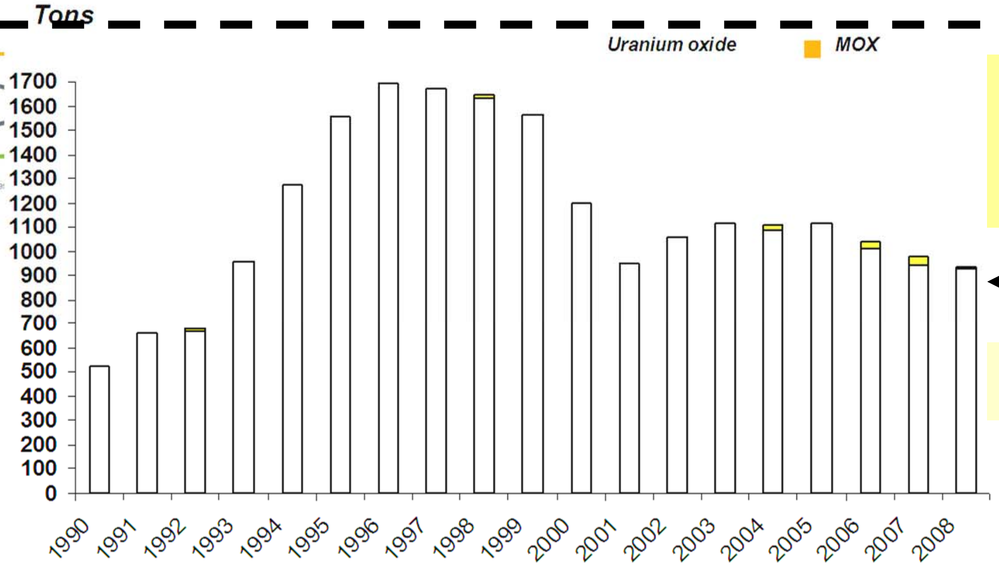
DISSOLUTION → U, Pu, FPs,MAs *solution* → EXTRACTION

HULLS

FPs, MAs

...technological waste
low amounts

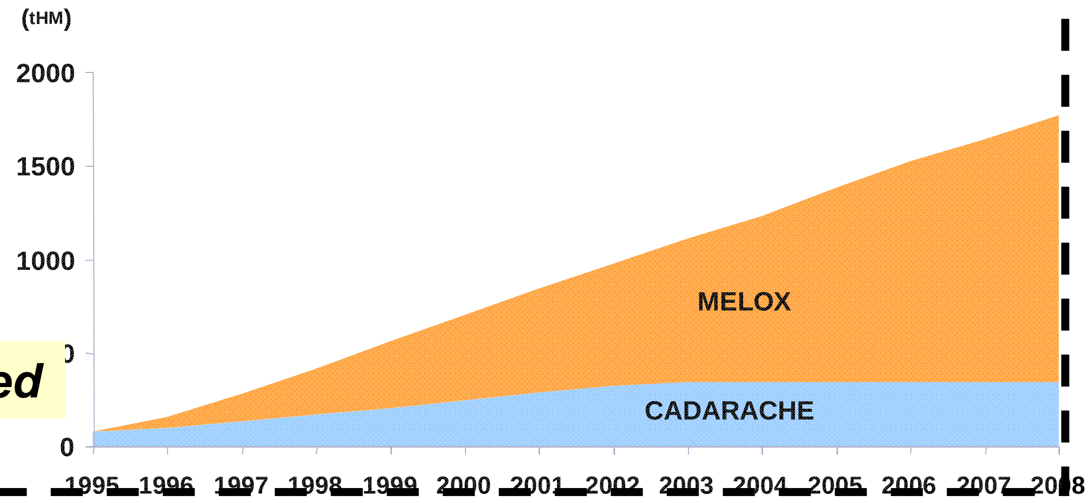
SPENT FUEL RECYCLING IN FRANCE



La Hague plant (tons/year)

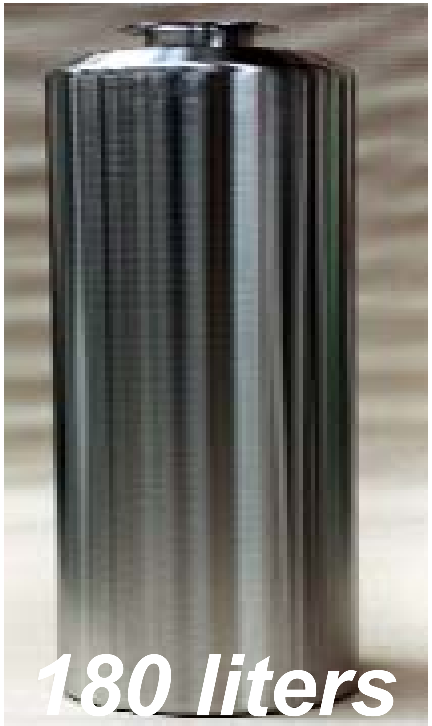
> <u>27 000 tons</u> SNF processed

MOX fuel fabrication (cumulative tons)



 # <u>1800 tons</u> MOX fuel manufactured

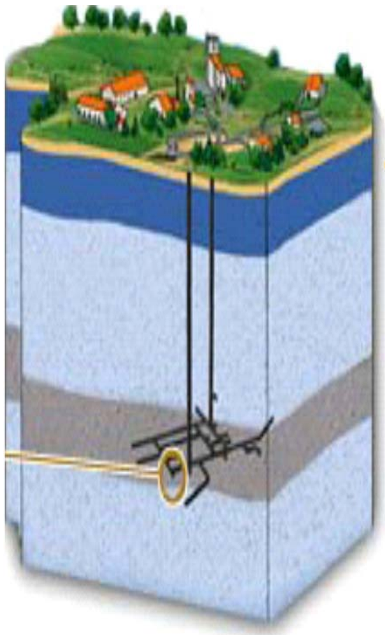
FINAL WASTE VITRIFICATION

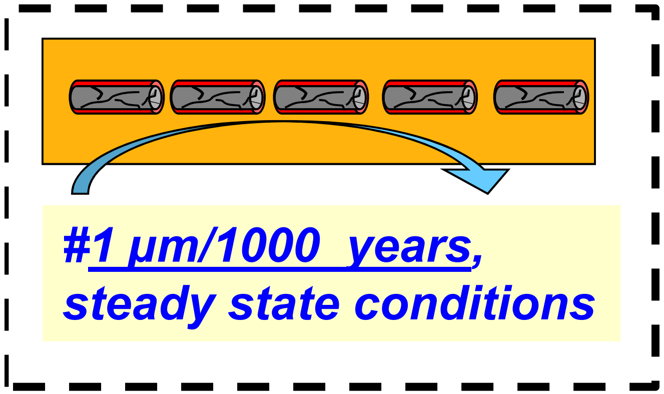


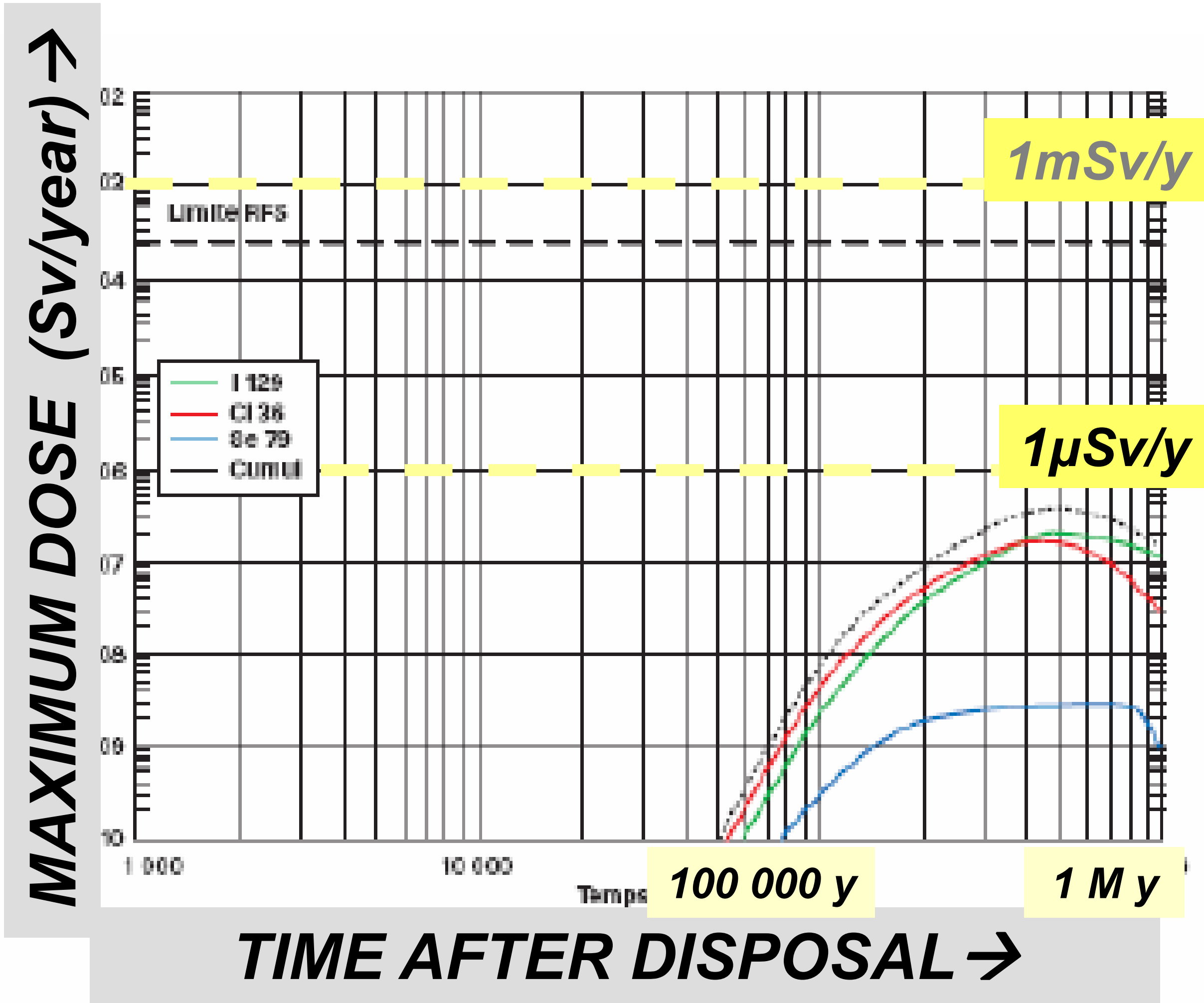
 # 17 000 canisters produced

 # 10-15 glass canisters /reactor /per year

GLASS CANISTERS DISPOSAL







(ANDRA, « CLAY REPORT », 2005)

CURRENT RECYCLING STRATEGY :
THE RATIONALE

cea
energie atomique

- **saving uranium resources**
  (#10% of French nuclear electricity from MOX fuels);
- **mastering the growth of plutonium inventory**
  (Pu flux adequacy : Pu from processing= Pu refueled)
- **safe & secure *ultimate waste without plutonium*;**
- **the plutonium available for future use is concentrated in MOX spent fuels *(7 UOX -> 1 MOX)***

- **an already *large industrial experience* , operated under international safeguards**
  (#27 000 tons reprocessed, # 1800 tons MOX)
- **suitable option for Generation III reactors**

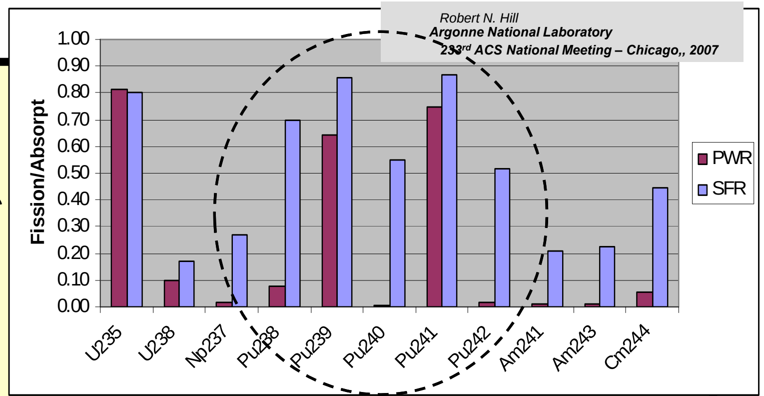
GENERATION 4 NUCLEAR SYSTEMS *(GIF, 2000)*

main criteria for design:

(1) safety, (2) sustainability , (3) cost

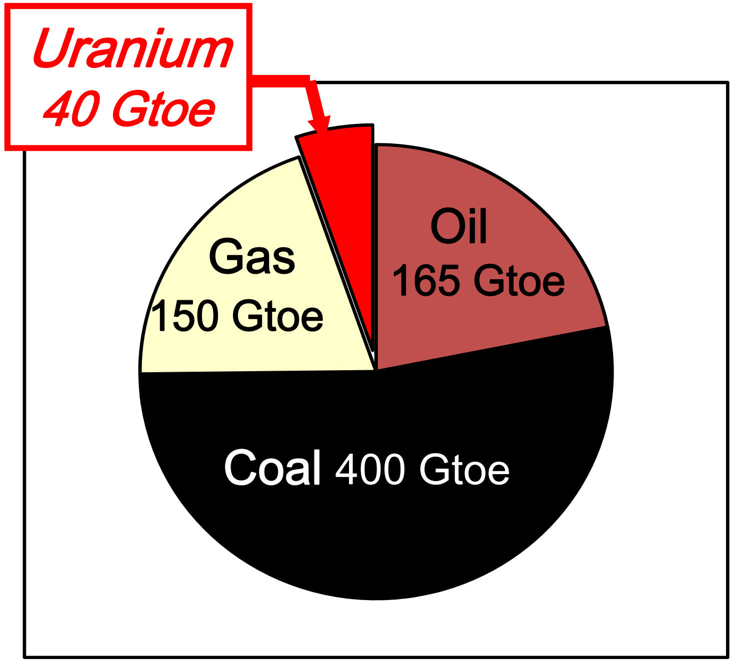
(i) SYSTEMATIC RECYCLE, (ii) FAST NEUTRON REACTORS

- ***manage/take advantage of Pu amounts in spent fuels***



- ***drastic extension of natural uranium resource (up to > 100)***
- ***possible drastic decrease of long-lived elements content in final waste (MA transmutation)***

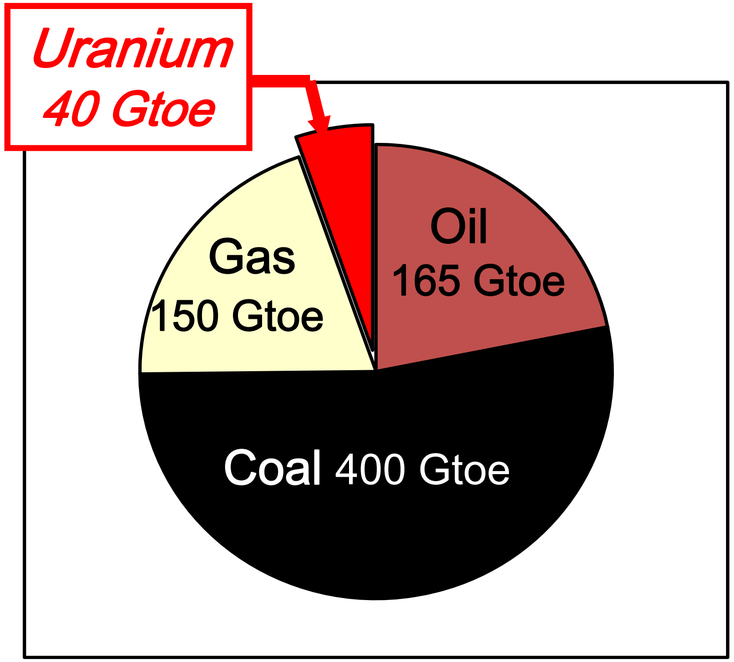
FOSSILE FUELS POTENTIAL RESERVES



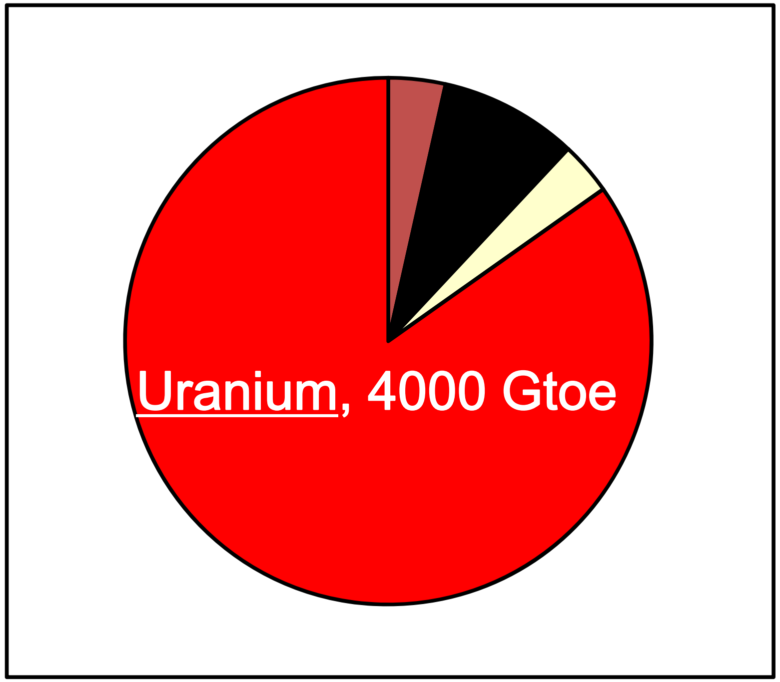
Uranium use
in thermal neutrons reactors

Identified conventionnal resources, Gtoe
(WEC, 2010)
(Oil 165 Gt, coal 826Gt, gas 180 Tm^3,uranium 3,3Mt)

FOSSILE FUELS POTENTIAL RESERVES



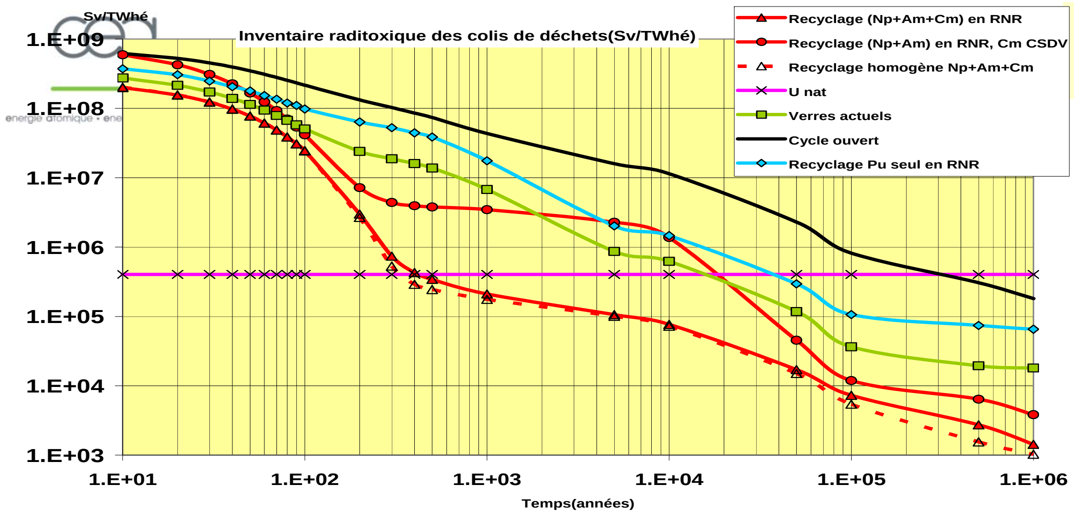
Uranium use
in thermal neutrons reactors



Uranium use
in fast neutrons reactors

Identified conventionnal resources, Gtoe
(WEC, 2010)
(Oil 165 Gt, coal 826Gt, gas 180 Tm³,uranium 3,3Mt)

WHY TRANSMUTATION ?



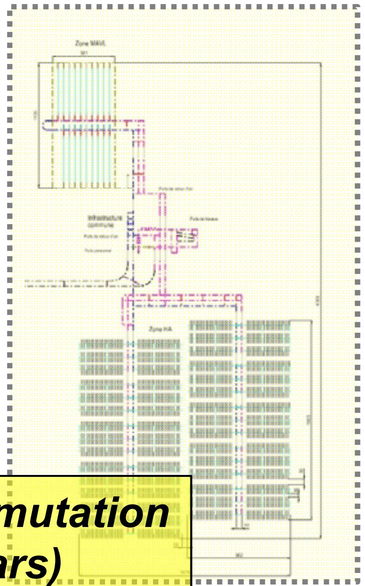
decrease LT waste toxicity

#100, all MA recycled:

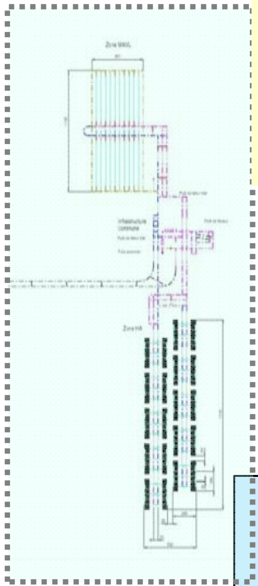
Decrease repository footprint

HA galeries : 12 times
HA storage zone: 5 times
Total footprint : > 2times

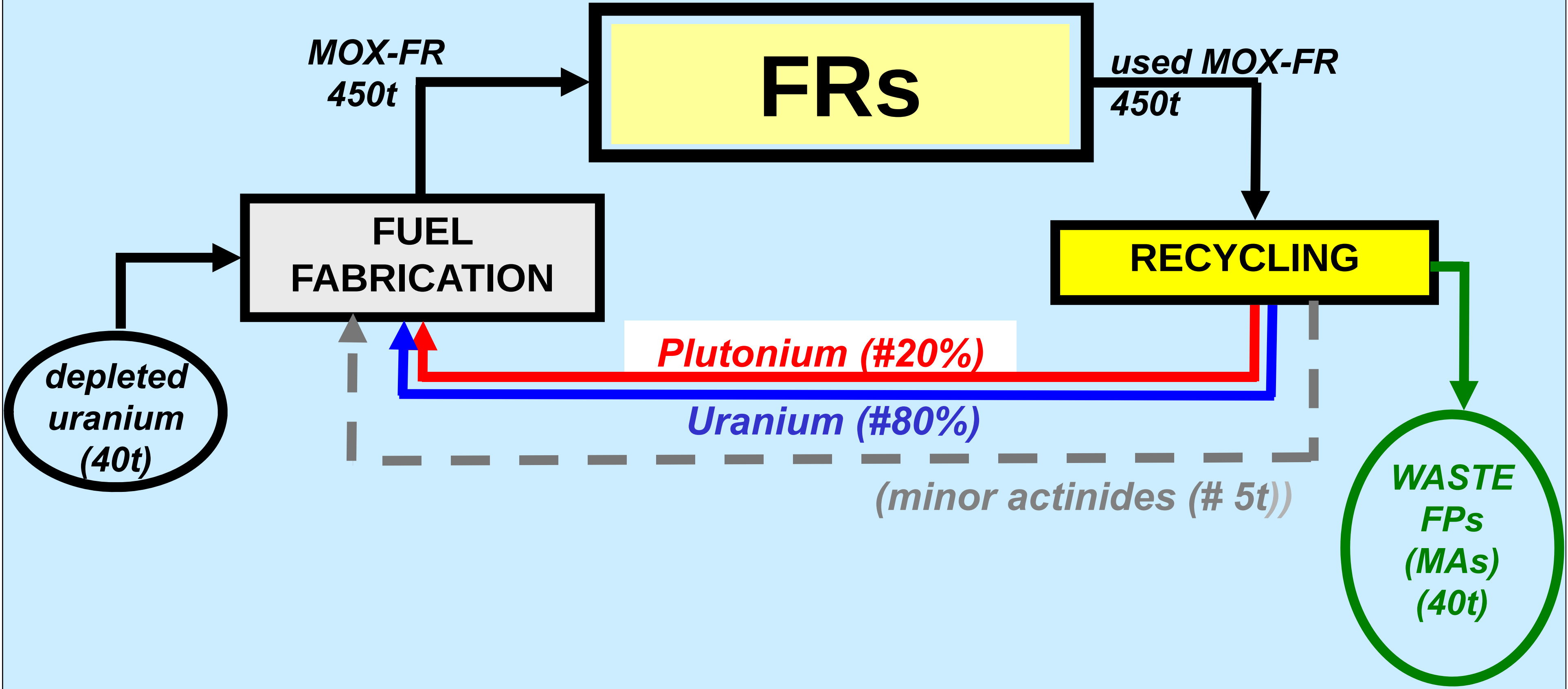
ANDRA-CEA, 2010 (clay repository)



without transmutation (120 years)



Transmutation MA (120 years)



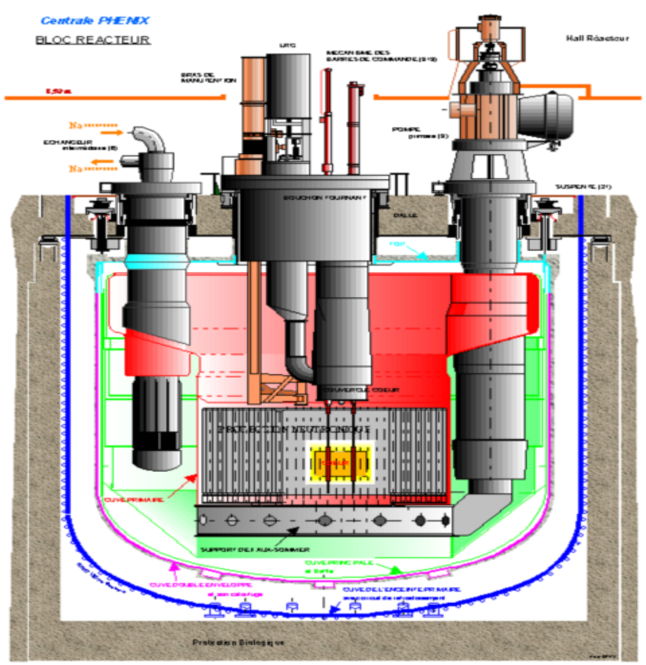
ACTINIDE MULTI-RECYCLE IN A *FR* FLEET

(principle values, self-balanced fleet, 400 TWh/y)

THE ASTRID PROTOTYPE

Basic options:

- *600 Mwe*
- *« pool » type*
- *Na-Na-H_2O*
- *oxyde fuel*
- *self –sustainable core*
- *core catcher*
- *transmutation capabilities*



Preliminary selection options (2010) — *decision* (2012) — *Decision to build* (2017) — *Fuel loading*

2009 2010 2011 2012 2013 2014 2015 2016 2017

Conceptual design -1 → *Conceptual design -2* → *Basic design* → *Detailed design & Construction*

ASTRID

GENERATION 4 SYSTEMS : WHEN COMMERCIAL DEPLOYMENT ?

energie atomique • energies alternatives

1 - ACCURACY OF THE NEEDS

2 - FRs INDUSTRIAL MATURITY

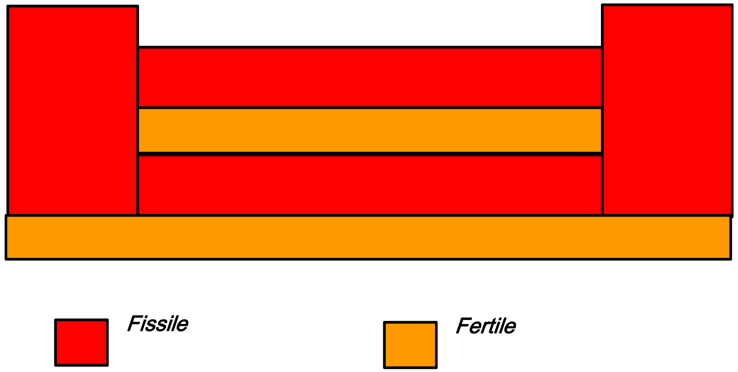
- ***safety improvements***
  (core optimization, residual heat removal, instrumentation, corium management, …)
- ***operability***
  (fuel handling, ISIR,…)
- ***cost-effectiveness***
  (simplified conception, availability, life-time…)

3 – FUEL CYCLE MATURITY

SODIUM FAST REACTORS NEEDS

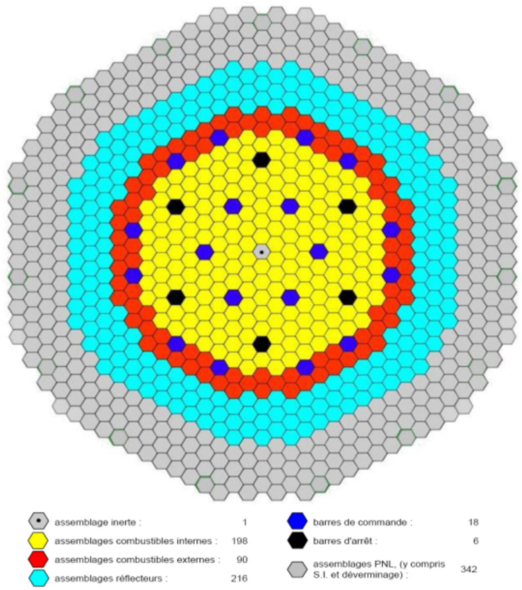
ASTRID (UNDER DESIGN) SFR CORE

(self-sustainable, improved safety)



 # 10 tons Pu / Gwe

Figure 1 : Configuration du cœur CFV-1500-AIM1



***spent MOX fuels*: 1000 tons (2007), # 4000 tons (2040)**

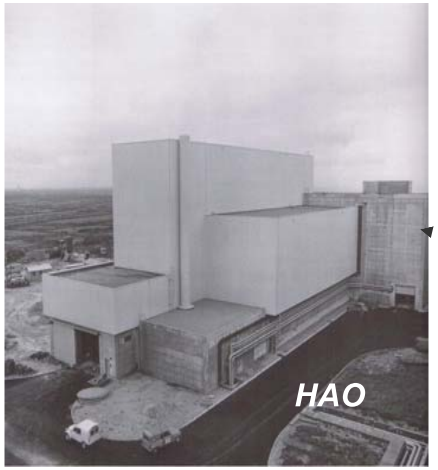
***depleted uranium*: 250000 tons (2007), # 450 ktons (2040)**

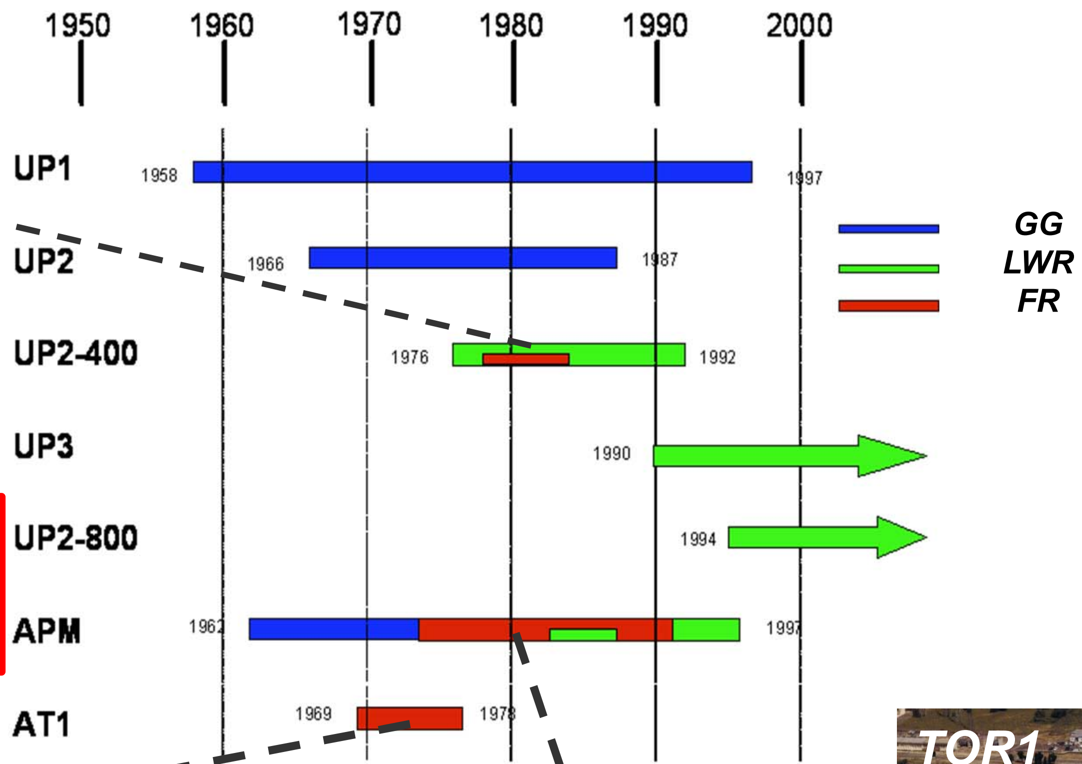
FAST REACTORS OXIDE FUELS FABRICATION

OXYDE SFR FUELS FABRICATION1963 - 1999

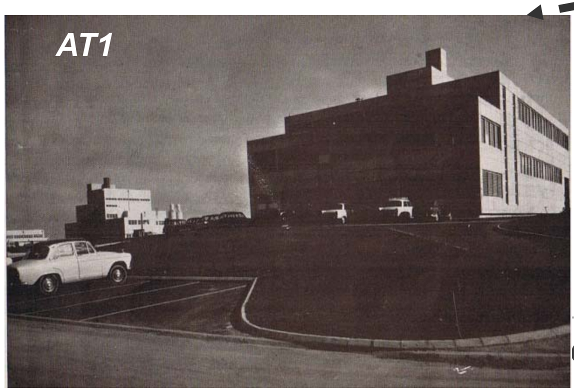
Réacteurs	Nb. d'aiguilles	Nb. de pastilles (millions)	Pastilles (t_{ML})	Masse Pu (t)
Rapsodie	28 536	1	1,2	0,35
Phénix	180 941	12,6	32,4	8,2
Super-Phénix	208 396	16,9	71,2	12,7
PFR (GB)	9 555	0,7	1,6	0,54
Total	427 428	31,2	106,4	21,8

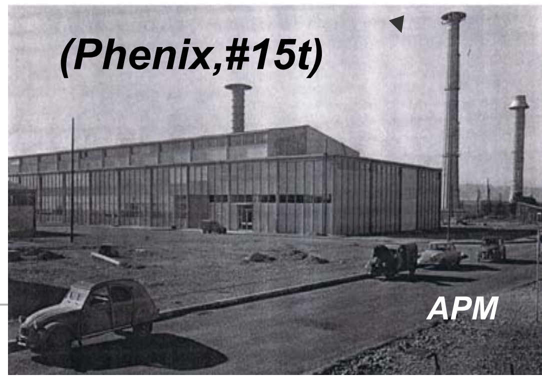
FR FUEL REPROCESSING IN FRANCE

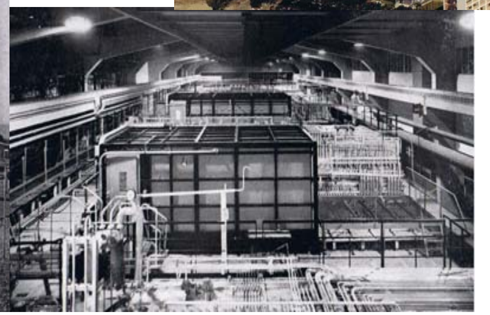




 # 25 tons
FR fuel reprocessed





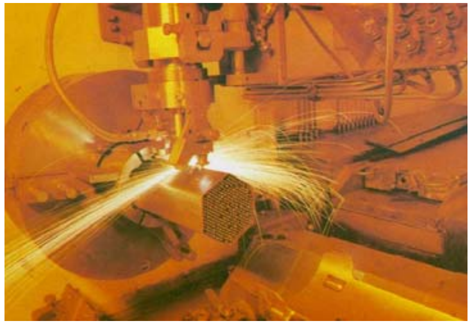


REPROCESSING FR FUELS

SFR fuels : ***specific <u>sub-assemblies</u>,***
increased <u>Pu content</u>,
increased <u>radioactive content</u>

<u>PROCESS ADAPTATION NEEDED</u>:

- ***<u>Structure elements management</u>***
- ***<u>Fuel dissolution</u>*** ***(dismantling, dissolving)***
- ***FPs <u>vitrification</u>*** ***(platinoids)***
- ***<u>Criticality risk management</u>*** ***(specific design)***



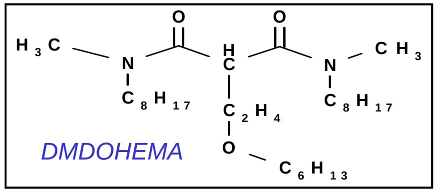
MA RECOVERY FOR RECYCLE

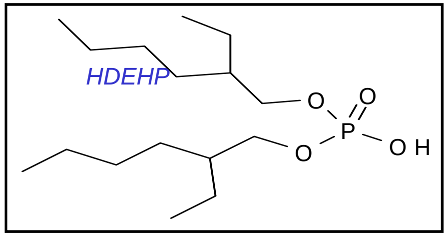
SNF → ***PUREX /COEX*** → ***DIAMEX /SANEX*** → **FPs.**

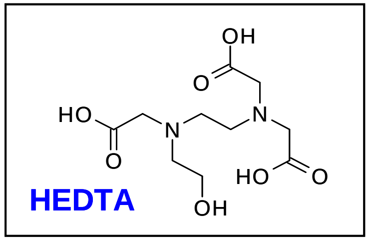
PUREX /COEX → **U**, **UPu**

DIAMEX /SANEX → ***Am (and Cm)***

innovative partitioning processes developped by CEA based on the design of new extractants







MA recovery processes have been successfully experimented, (kgs -sale , genuine spent fuel)

THE 2006 FRENCH ACT
(RW & nuclear materials management)

➡ **PRINCIPLES** :

– ***RECYCLE*** ***(reprocess)***
to decrease waste amount & toxicity

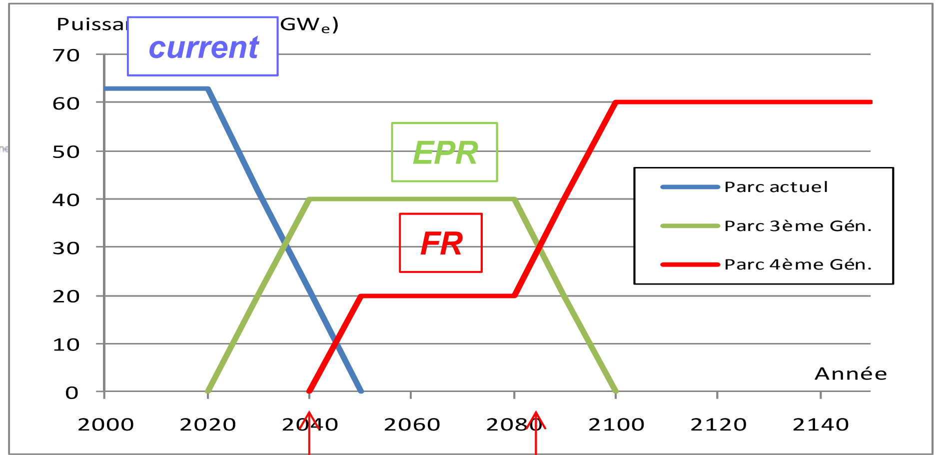
– ***RETRIEVABLE GEOLOGICAL REPOSITORY,***
for ultimate waste

➡ **A « ROADMAP » :**

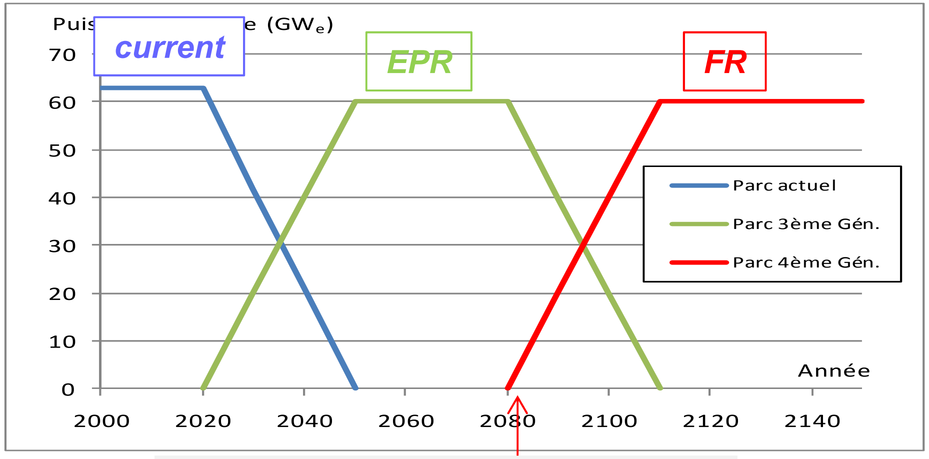
–***2012*** ***: assess the industrial prospects***
for advanced recycling options
(prototype 2020)

–***2015*** ***: repository defined***
(operation by 2025)

SCENARIOS FOR FR DEPLOYMENT

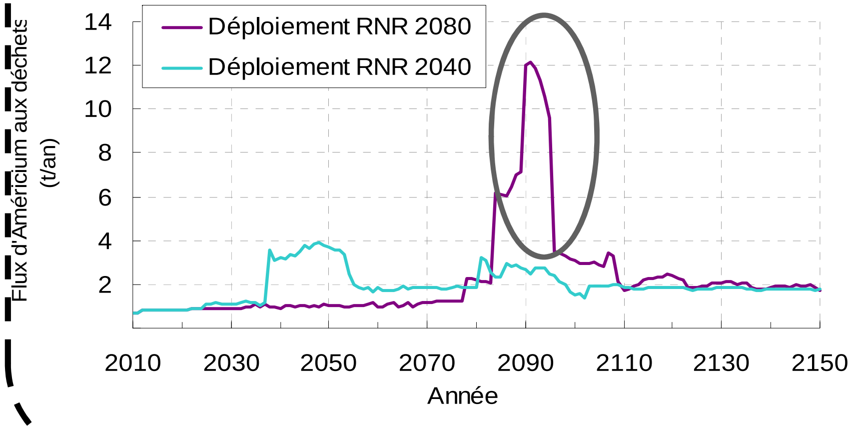


« 2 steps » FR deployment

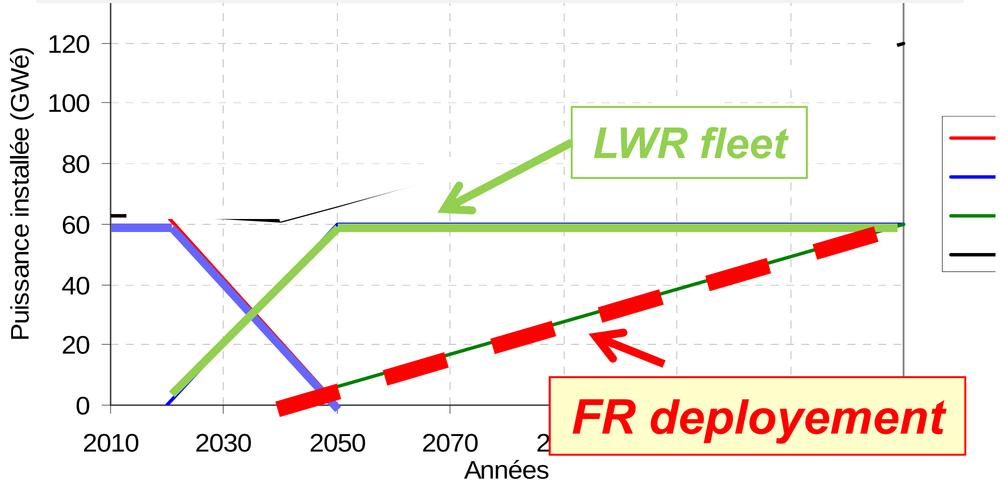


delayed FR deployment

Americium to waste



Progressive / flexible FR deployment



MA TRANSMUTATION :

DECREASE MA AMOUNT FIRST!

PU RECYCLE *IN FRS*:

#up to 5 times less MA produced / Pu transmuted

(vs.recycle in LWRs)

SHORT DECAY TIME *(BEFORE REPROCESSING)*

Am in MOX 47GWj/t, at discharge : *#8 kg/TWh*

after 6 months : *8.5*

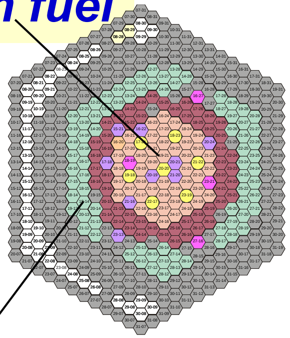
5 years : *14*

20 years : *25*

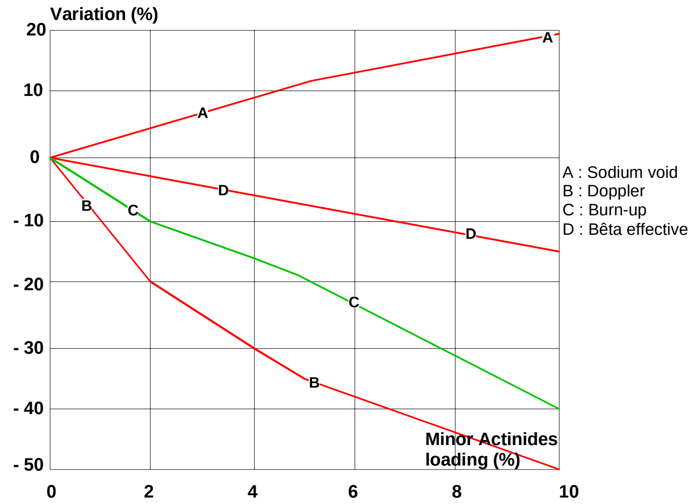
50 years : *32*

TRANSMUTATION, *HOW ?*

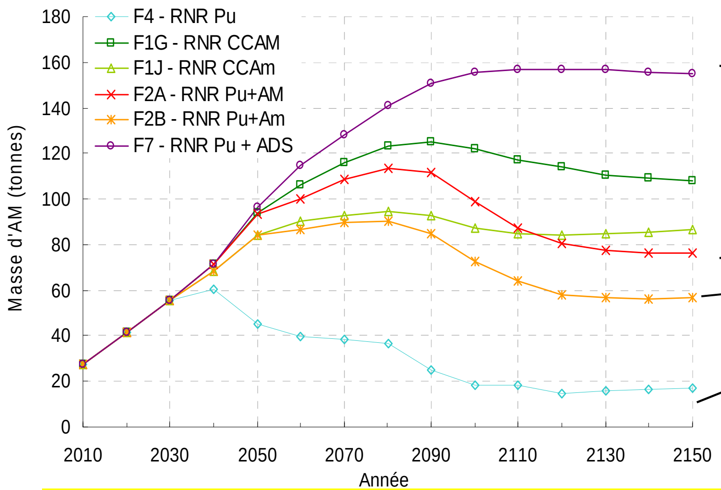
HOMOGENEOUS
(#1% MA) in fuel



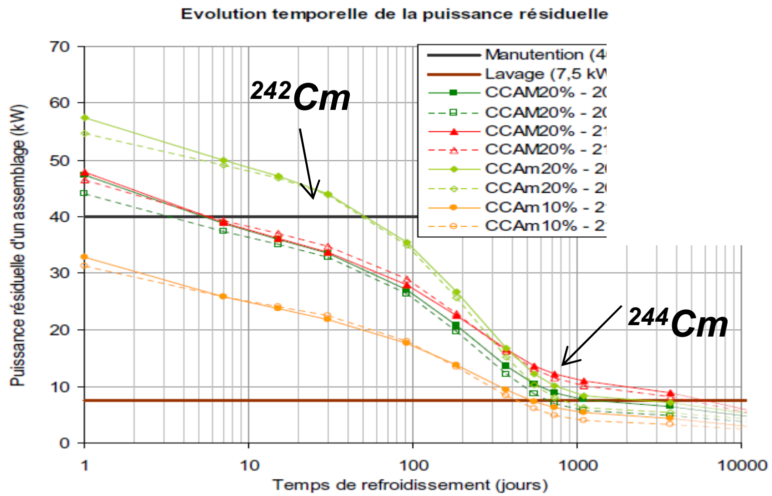
Multirecycled MA-bearing blankets
(# 1 row 10%)



CORE SAFETY

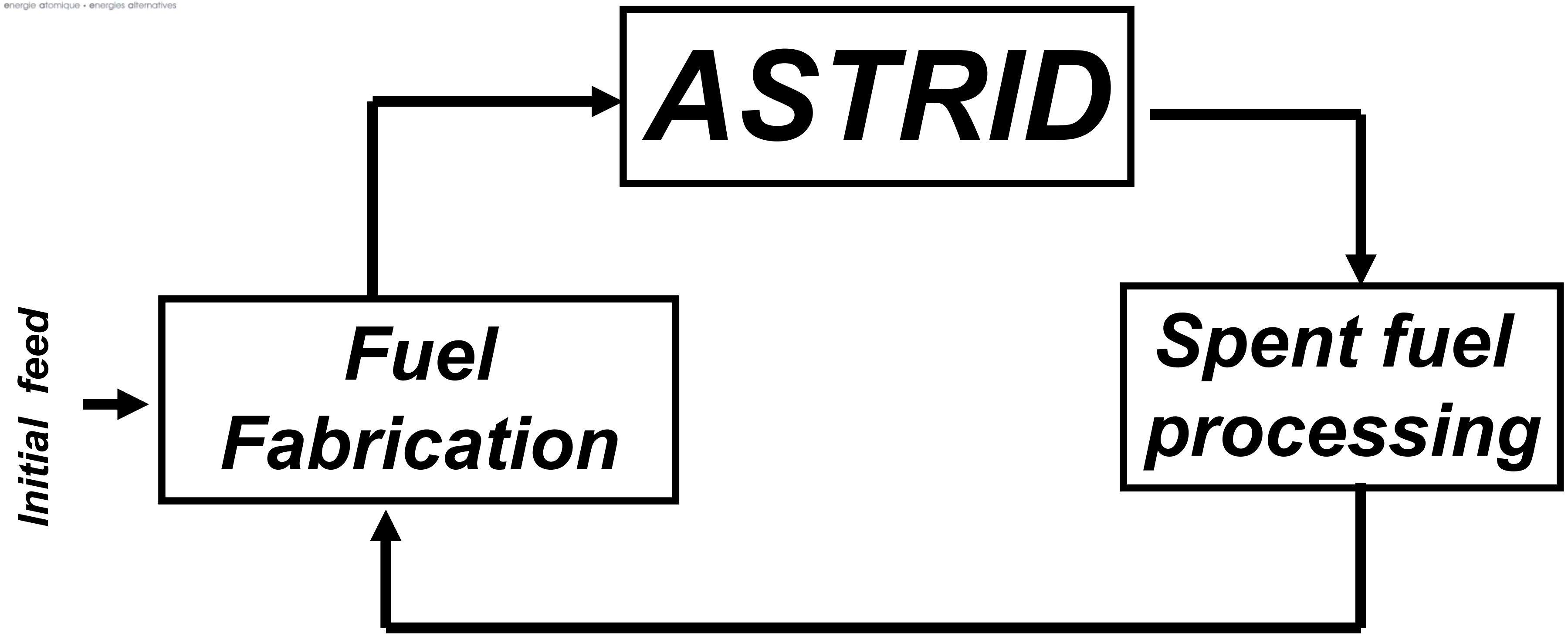


MA in cycle inventory



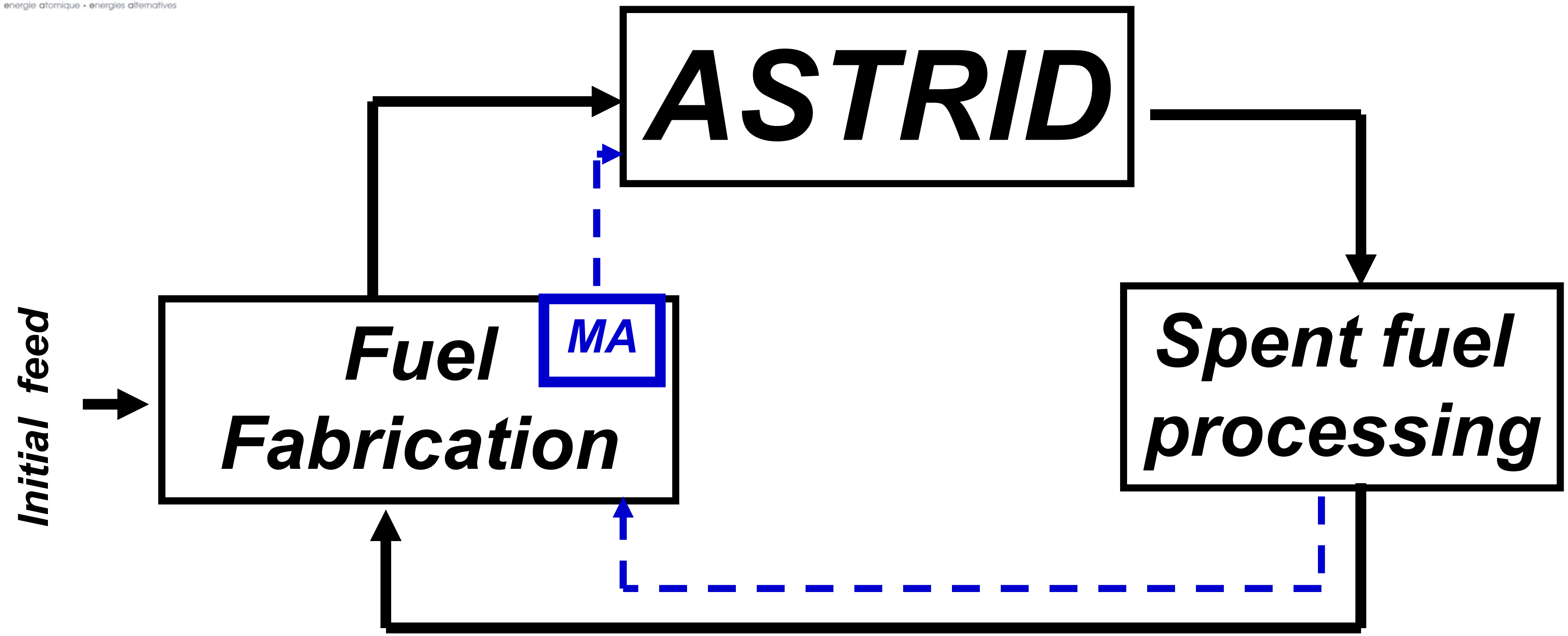
FUEL HANDLING

ASTRID FUEL CYCLE



1st goal : Feeding ASTRID (Pu & U multirecycle

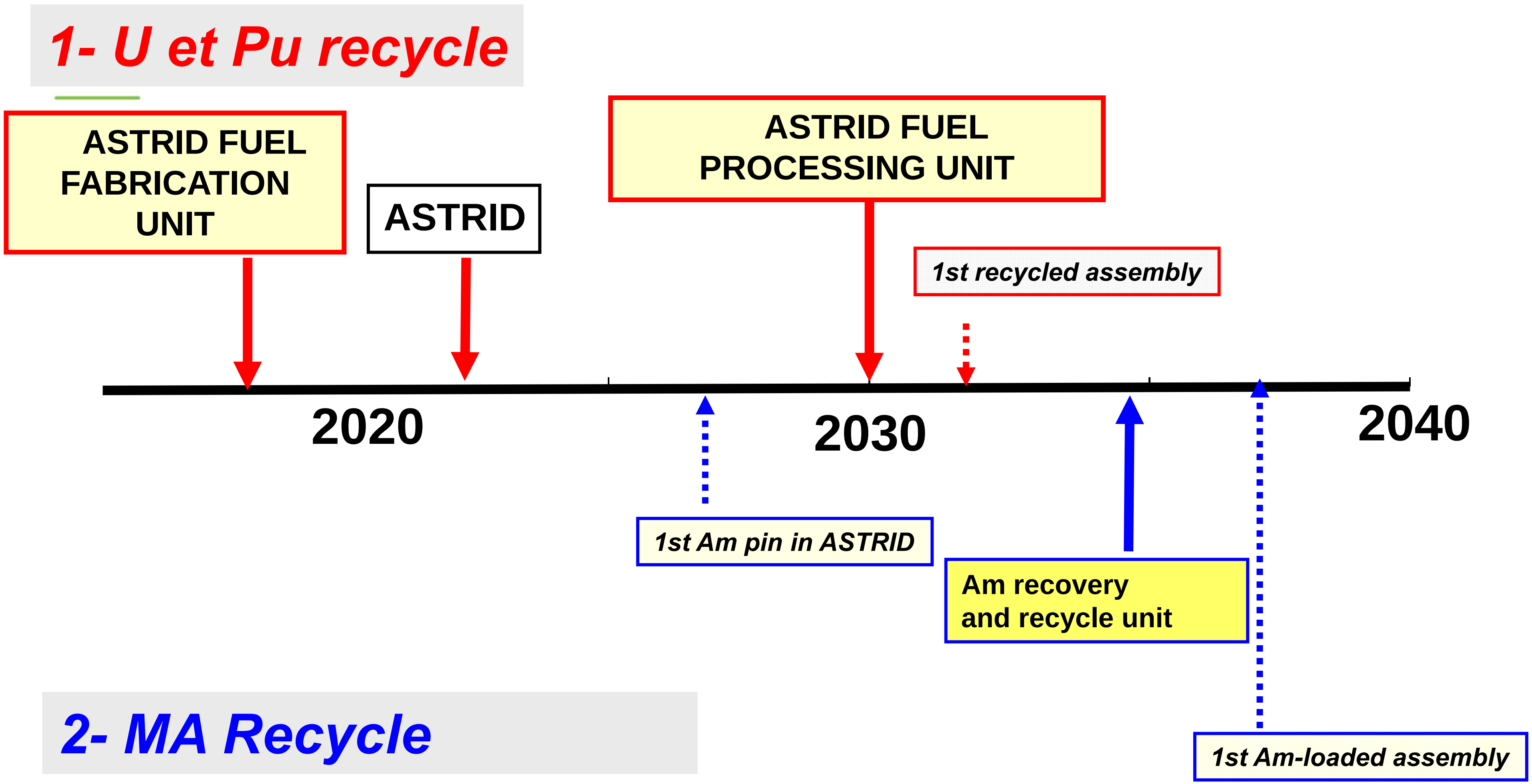
ASTRID FUEL CYCLE



1st goal : Feeding ASTRID (Pu & U multirecycle)

2nd : Minor Actinide (Am ?) recycle ?

ASTRID FUEL CYCLE



en résumé…

- ***U-Pu multirecycle in fast reactors for sustainable nuclear systems;***
- ***The french route : ASTRID prototype (from 2020), and the appropriate fuel cycle***
- ***commercial deployment : from around 2040, diverse possible options***
- ***possible decoupling of 4th generation goals, could be reached independantly /progressively**: (Pu utilization, U resource drastic extension, MA transmutation…)… <u>think flexible</u>!*