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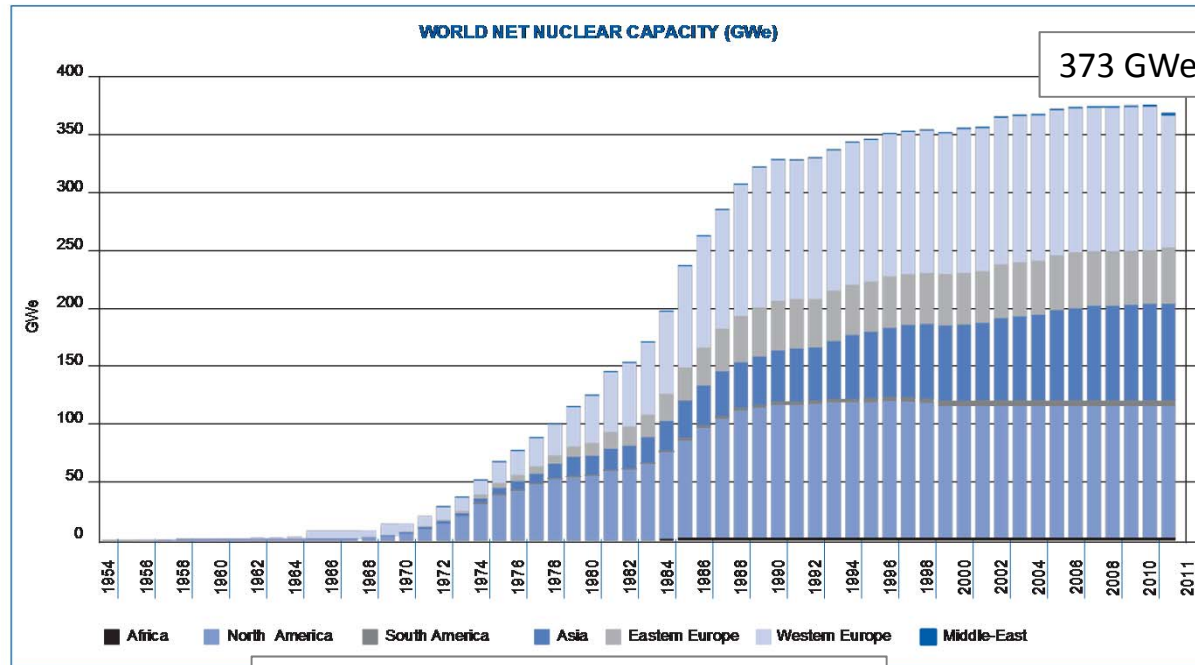
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THE FRENCH PROGRAM FOR A *SUSTAINABLE MANAGEMENT* OF NUCLEAR MATERIALS AND WASTE

Bernard BOULLIS
Fuel Cycle Back-End Programs Director
CEA, Nuclear Energy Division

International Symposium – TOKYO, October 9-10, 2014
Present Status and Future Perspective for Reducing Radioactive Wastes ~ Aiming for Zero-Release~

USED NUCLEAR FUELS FROM THE WORLD NUCLEAR FLEET

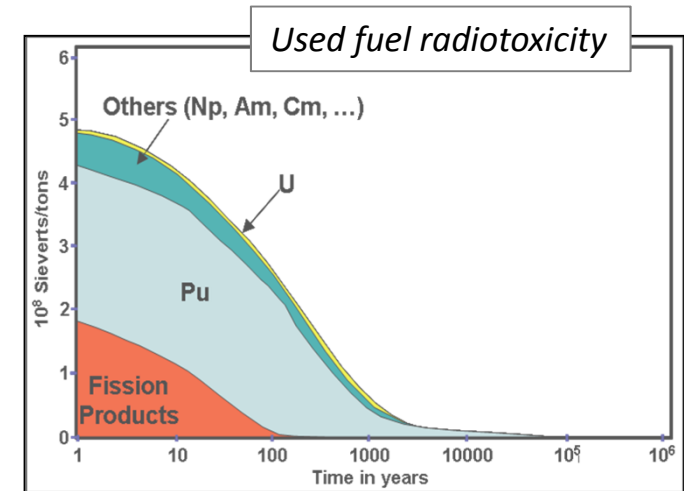


Au 31/

> 66 000 TWh (cumulative)

> 250 000 tons used fuels

*Pu content > 2000 tons
(currently increasing > 70 tons/y)*



USED FUEL STOCKPILES:

- **a concern:**
 - fissile elements
 - radiotoxic
 - heat emitter
- **an asset**
(1g Pu# 1toe)

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THE FRENCH PROGRAM FOR A *SUSTAINABLE MANAGEMENT* OF NUCLEAR MATERIALS AND WASTE

- 1 - The current French nuclear fuel cycle*
- 2 - Trends and options for the future*
- 3 - Advanced Recycling Technologies :
the French R&D program*

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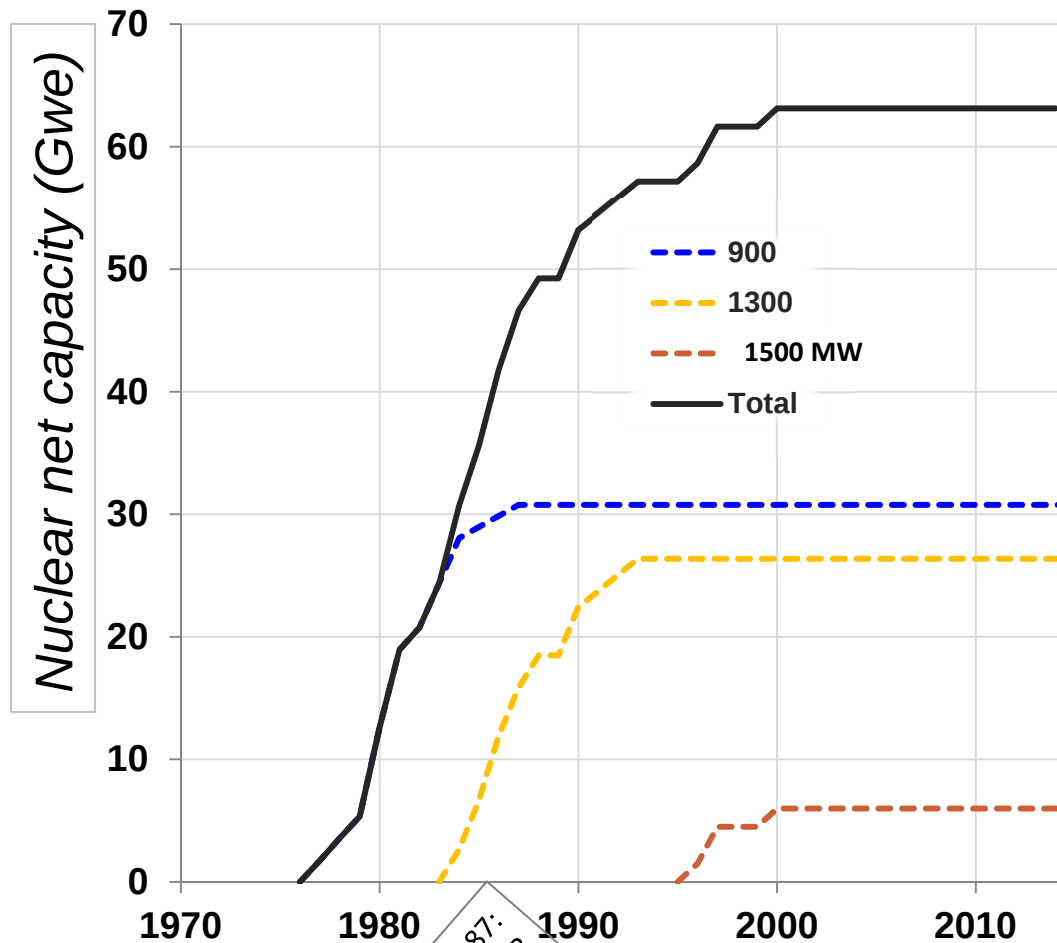


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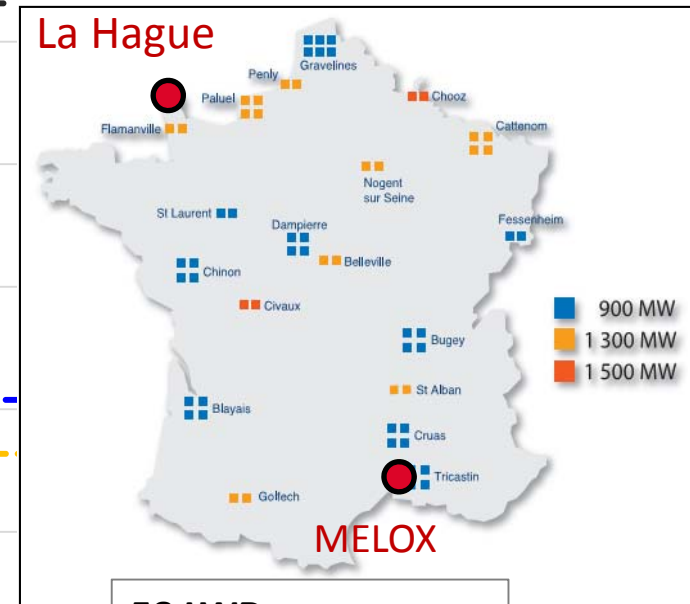
1 - THE CURRENT FRENCH NUCLEAR FUEL CYCLE

PLUTONIUM FUTURES 2014 – LAS VEGAS, 7-13 SEPTEMBER 2014

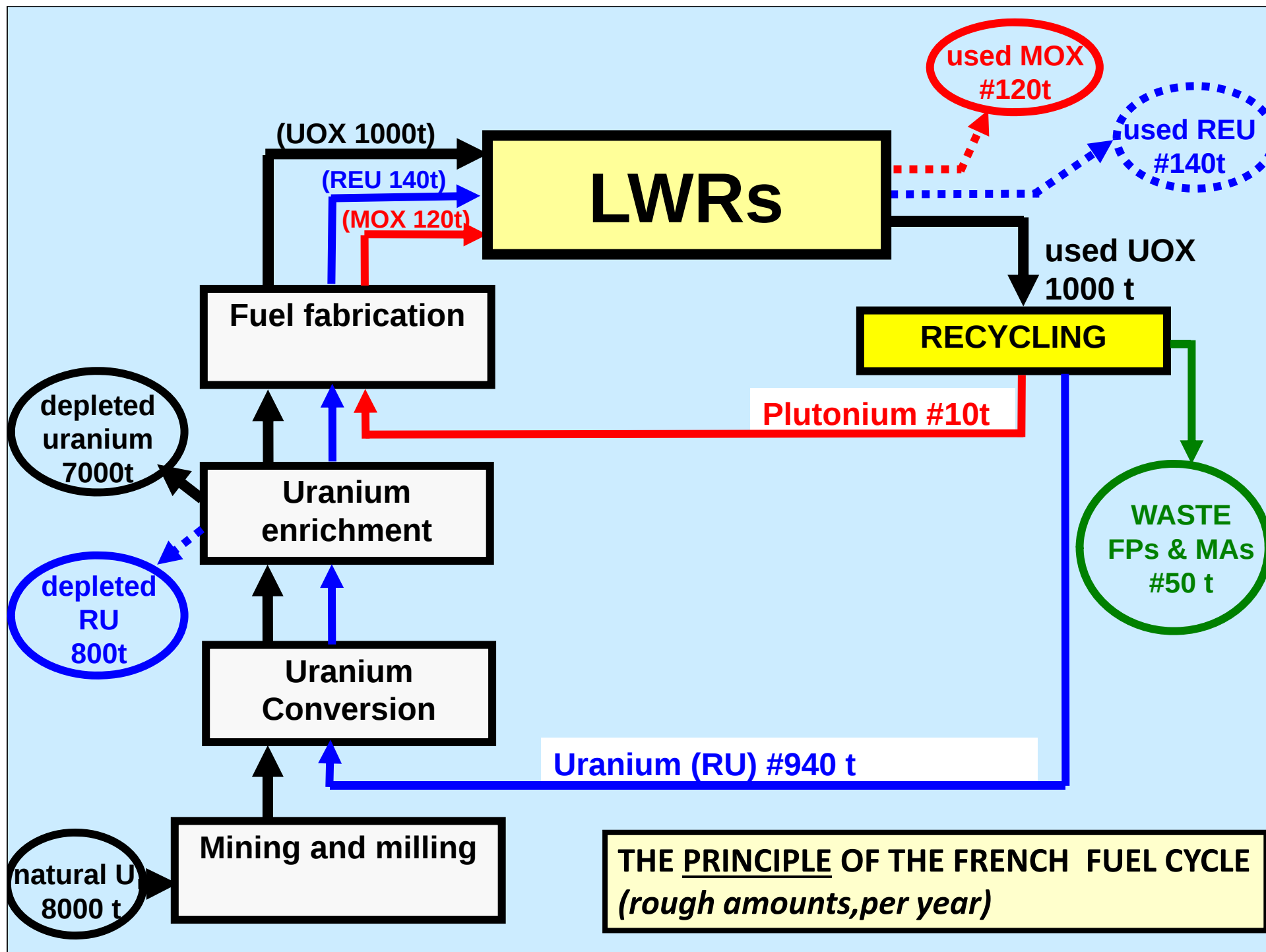
THE FRENCH NUCLEAR FLEET



1987:
1st MOX fuel in LWR



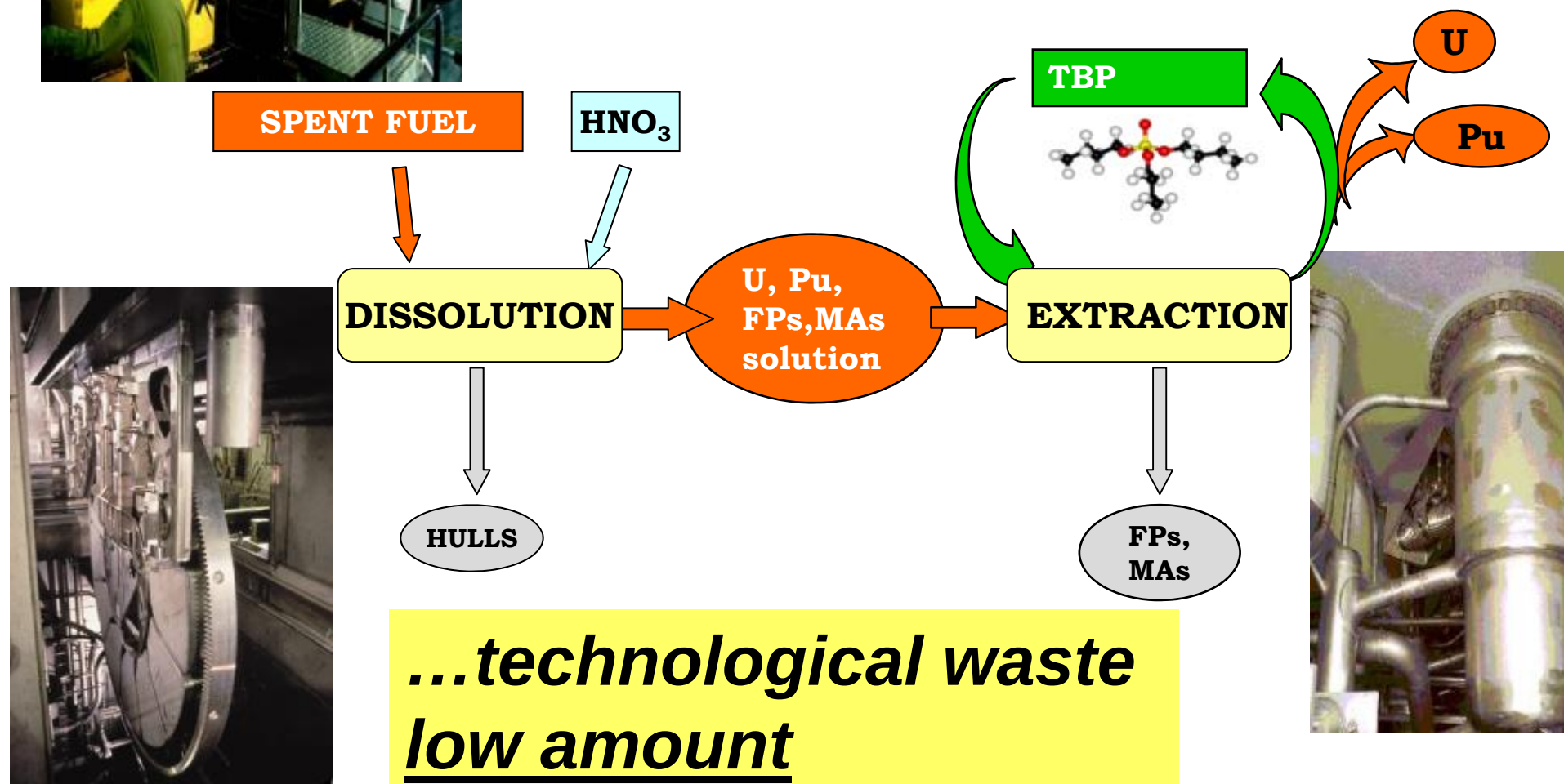
58 LWR
24 licenced for MOX
4 licenced for REU



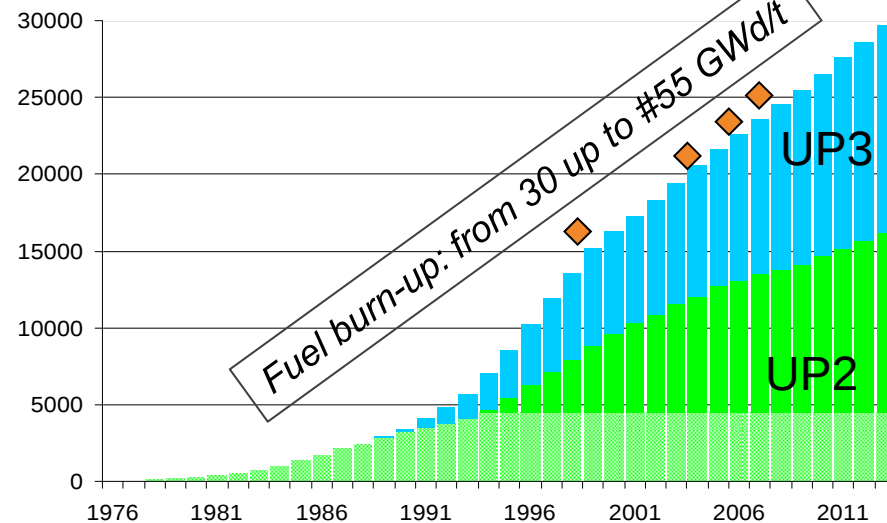
RECYCLING TECHNOLOGIES : DECADES R&D !



high yields...



USED FUEL RECYCLING IN FRANCE



La Hague plant
(UNF tons)

> 30 000 tons
processed

♦ Used MOX fuel
(#70 tons processed)



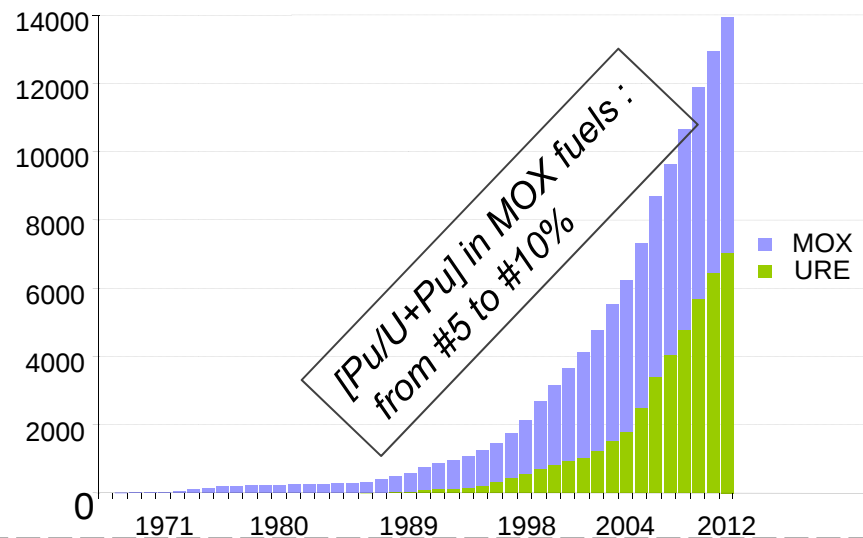
MELOX plant



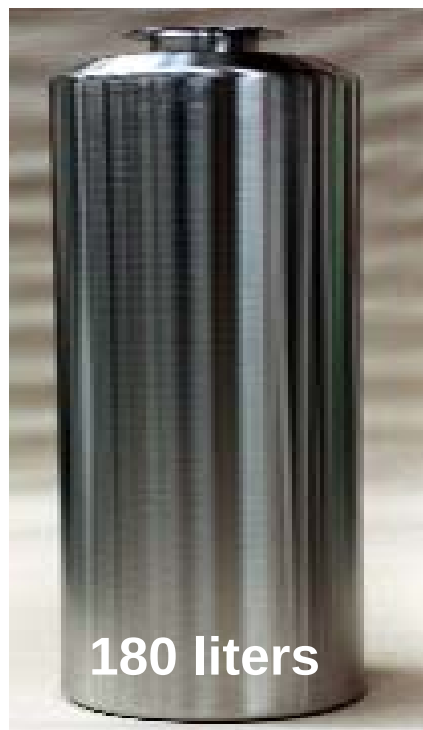
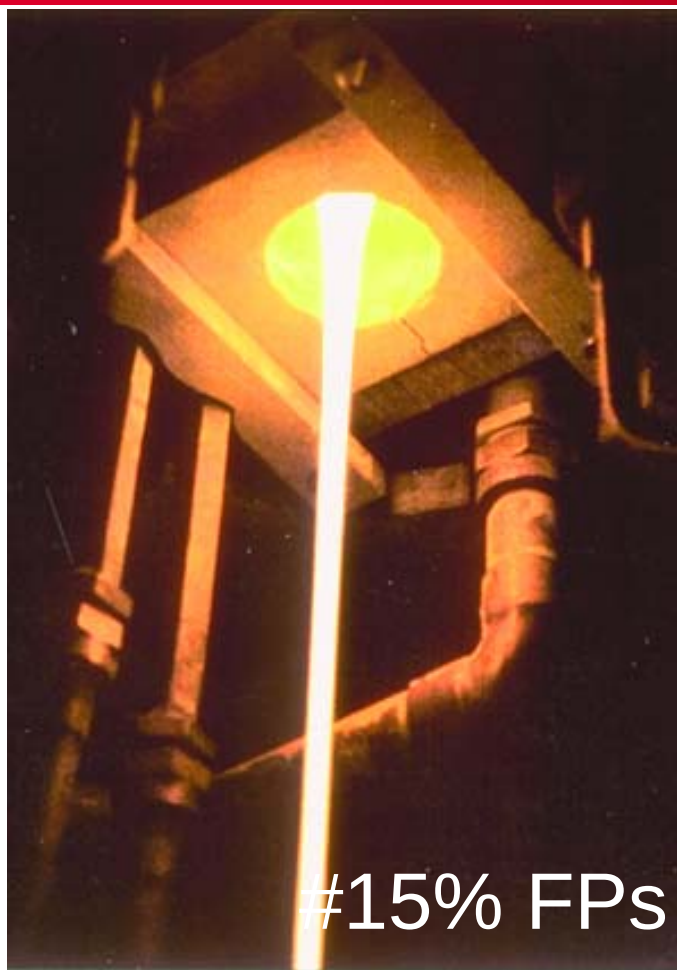
MOX & REU Fuels
(sub-assemblies)

1800 tons MOX fuel manufactured

Assemblies



FINAL WASTE VITRIFICATION



17 000 glass canisters produced

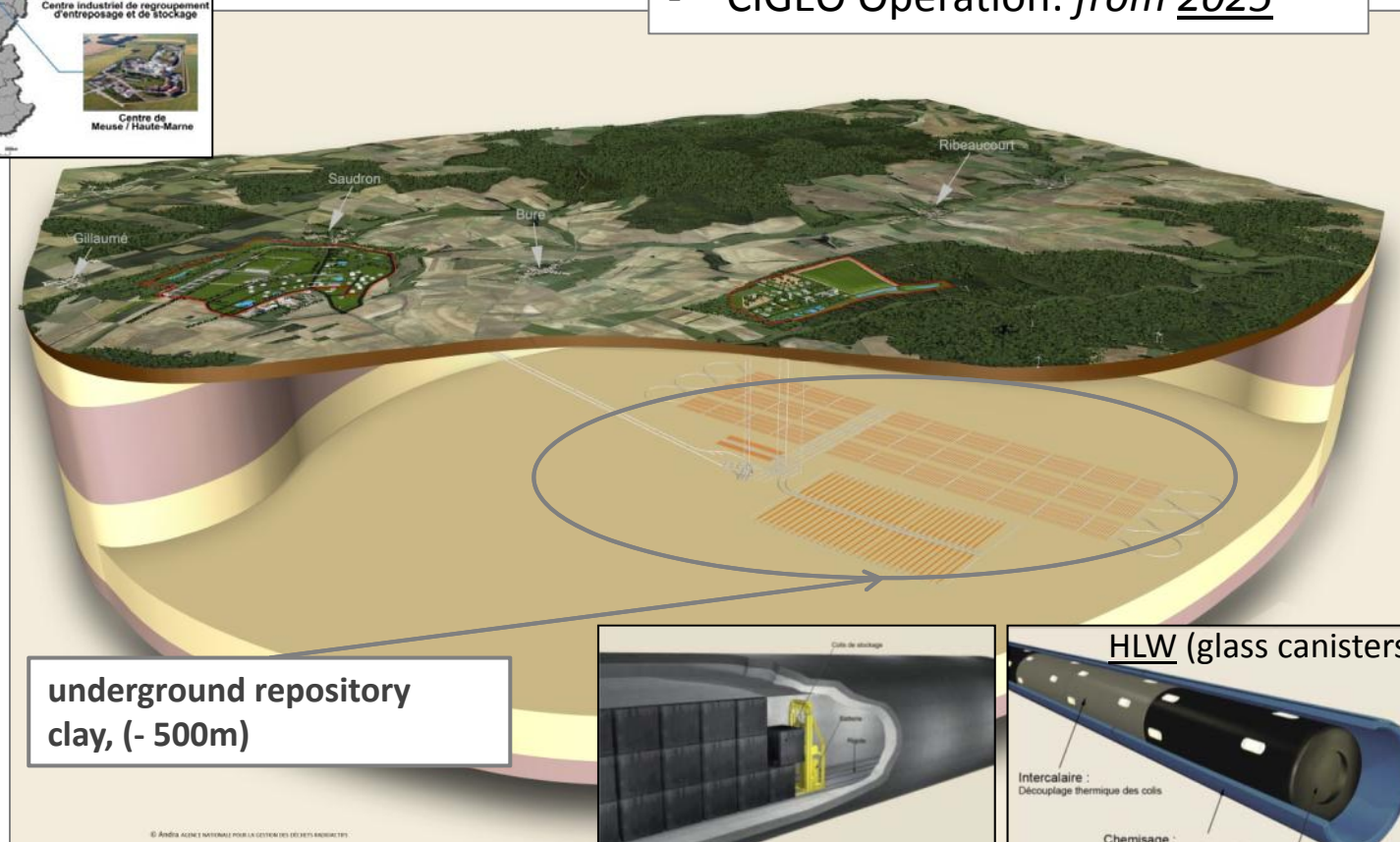
10-15 glass canisters /reactor /per year

LONG-LIVED WASTE FINAL DISPOSAL: *THE CIGEO PROJECT*



ANDRA, french waste management agency

- CIGEO Licence application: *2015*
- CIGEO Operation: *from 2025*



underground repository
clay, (- 500m)

ILW

HLW (glass canisters)

CURRENT RECYCLING STRATEGY : *THE RATIONALE*

- **saving uranium resources**
(#10% of French nuclear electricity from MOX fuels);
 - **safe & secure ultimate waste without plutonium**;
(volume , heat load, radiotoxicity decreased)
 - **mastering the growth of plutonium inventory**
(Pu flux adequacy : Pu from processing= Pu refueled)
 - **the plutonium available for future use is concentrated in MOX spent fuels**
-
- **an already large industrial experience ,
operated under international safeguards**
(#30 000 tons reprocessed, # 1800 tons MOX)

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2 - TRENDS & OPTIONS FOR THE FUTURE

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NUCLEAR ENERGY IN FRANCE

2005 : FRENCH ACT ABOUT ENERGY

(Nuclear Energy : research on advanced systems)

2006 : FRENCH ACT about SUSTAINABLE MANAGEMENT OF NUCLEAR MATERIALS & WASTE

- recycle (decrease waste amounts);
- retrievable geological repository for final waste

2014 : PUBLIC DEBATE ON “CIGEO” (HLW repository)

*(main issues: reversibility to be precised by law,
a “pilot” phase before industrial full operation)*

2014 : PUBIC DEBATE ABOUT “ENERGY TRANSITION”

*(Act to be discussed at the French Parliament
“ a new energy model for France”)*

MAIN CONCLUSIONS OF THE REPORT ISSUED BY CEA (12-2012):



Closing Pu and U Cycle, the very first condition
for a sustainable management of nuclear materials

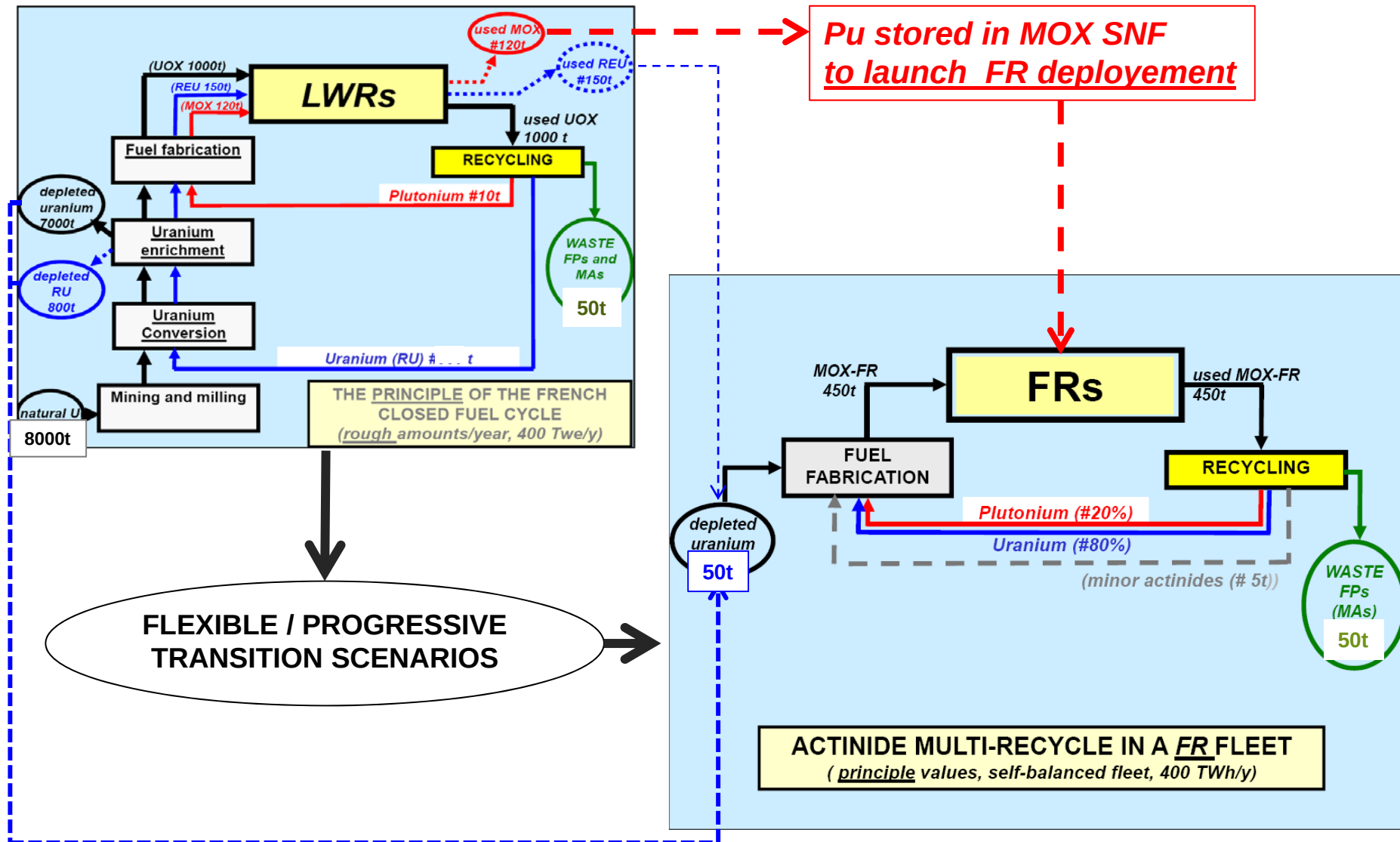
Two main guidelines:

(1) Systematic recycle of U and Pu

(2) fast neutron reactors

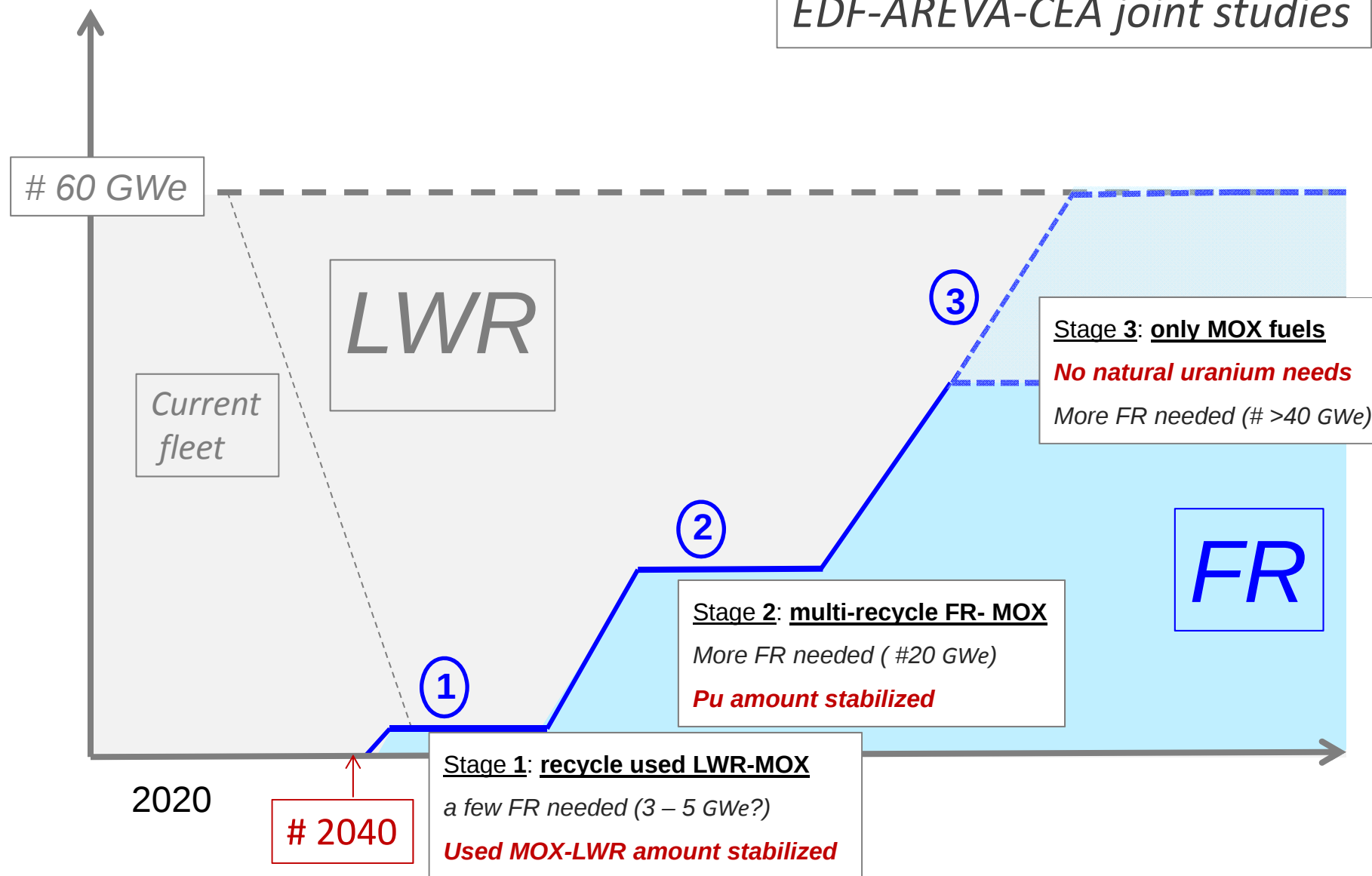
- . to burn and take advantage of plutonium amounts in spent fuels (avoiding the growth of important un-used stockpiles);
- . to decrease minor actinide amounts in final waste
- . to allow a drastic extension of ^{238}U valorization

FROM CURRENT FUEL CYCLE... TO FUTURE FAST REACTORS FUEL CYCLES



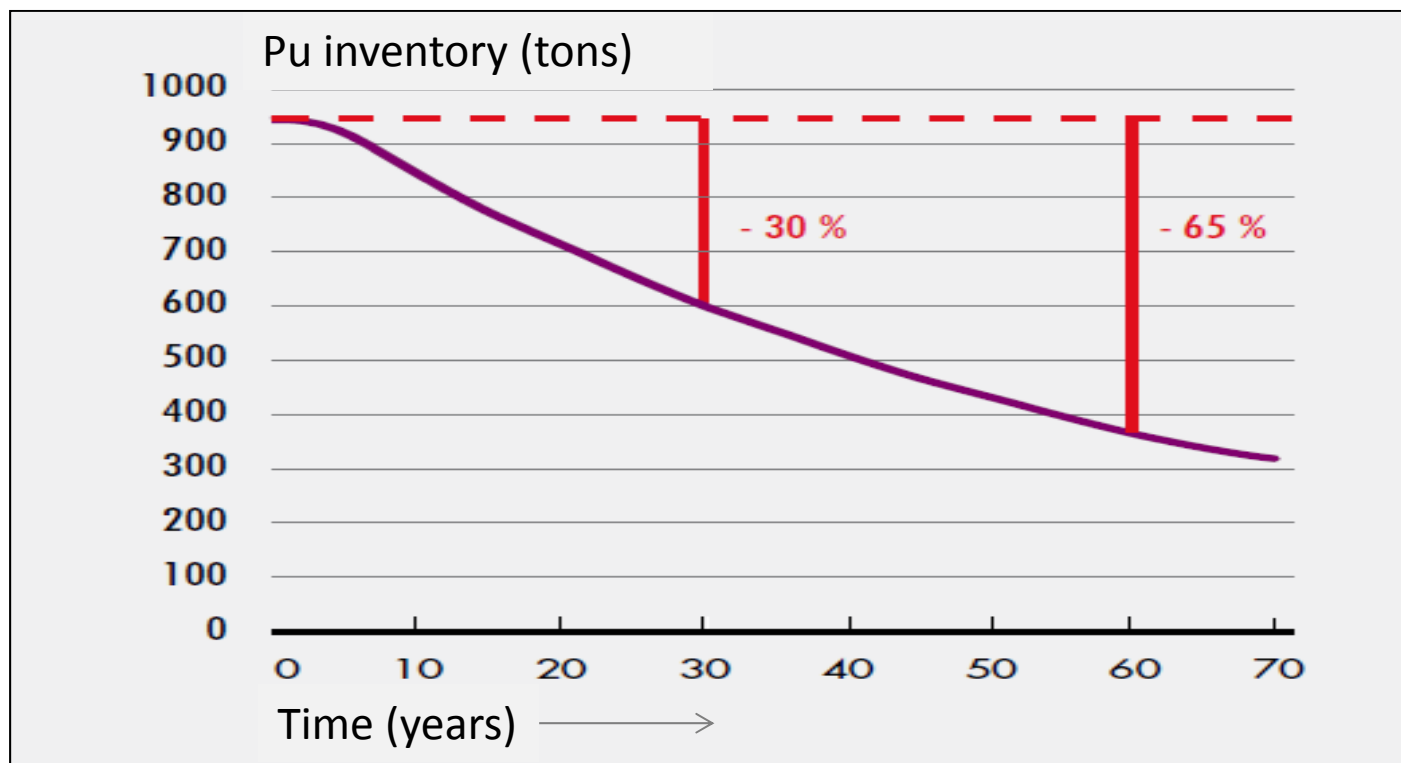
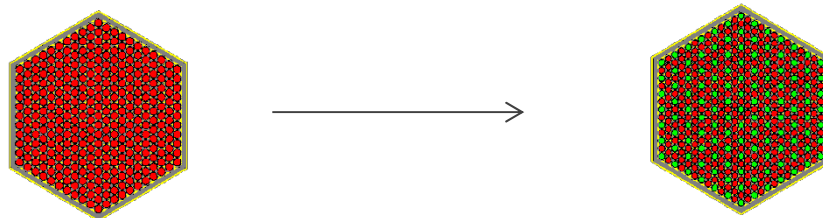
FR REACTORS DEPLOYMENT: CURRENT SCENARIO STUDIES

EDF-AREVA-CEA joint studies



PU STOCKPILES RESORPTION : *FR FLEXIBILITY*

THE « BURNER » MODE with FAST REACTORS (CAPRA initiative, 80's)

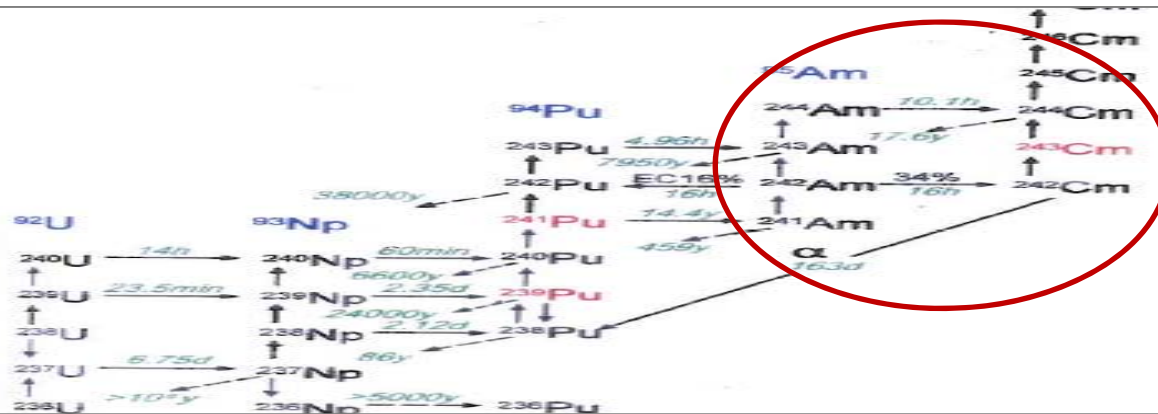


MINOR ACTINIDES TRANSMUTATION: *DRIVERS...*

Minor actinide removal could provide

an optimization of final waste management:

- ***by decreasing waste long-term radiotoxicity***
- ***by decreasing the repository footprint (Am recycle mainly)***



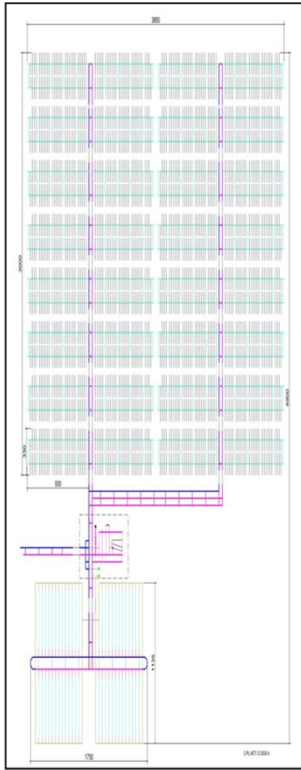
Fast neutron reactors incentives:

- **MA production : 3 -5 times lower in FR (vs. LWR)**
- **MA transmutation : possibly quantitative in FR**
(MA multi-recycle)

MINOR ACTINIDES TRANSMUTATION: *DRIVERS...*

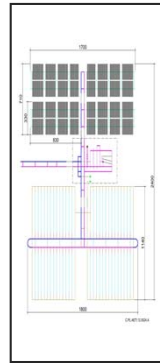
[Andra-CEA 2012]

1500 ha total, among which **1175 ha**
HAVL, 7 Mm3 excavated



no transmutation

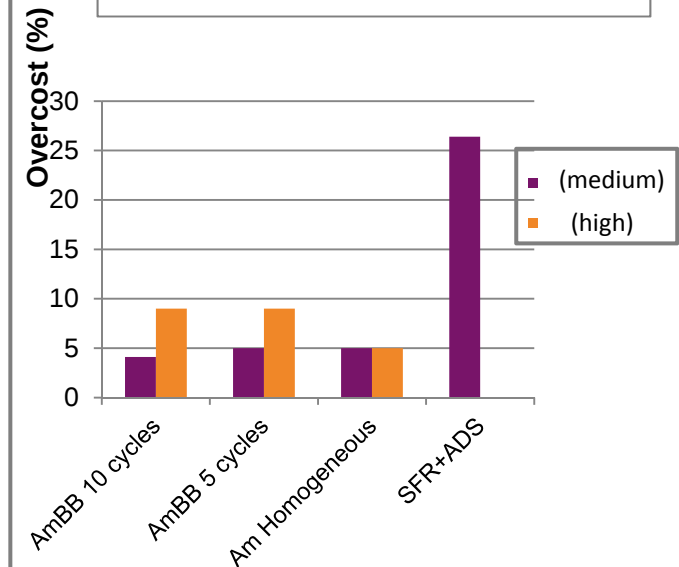
430 ha total, among which **120 ha HAVL**,
3 Mm3 excavated



MA transmutation

REPOSITORY FOOTPRINT
(cooling phase 120 y)

LEVELIZED COST OF ELECTRICITY (LCOE) :
TRANSMUTATION OVERCOST ESTIMATE



EDF / AREVA / CEA , 2012

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3 – ADVANCED RECYCLING TECHNOLOGIES : THE FRENCH R&D PROGRAM

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FAST NEUTRON REACTORS : *OPTIONS*

- Sodium Fast Reactor, the reference option :
[ASTRID, the technology demonstrator]
 - maturity, and possible further improvements (safety, operability, economics)
 - developed with industrial and international partners



RAPSODIE
1967 - 1983



PHENIX
1973 - 2010



SUPERPHENIX
1985 - 1998



EFR
1988-1998



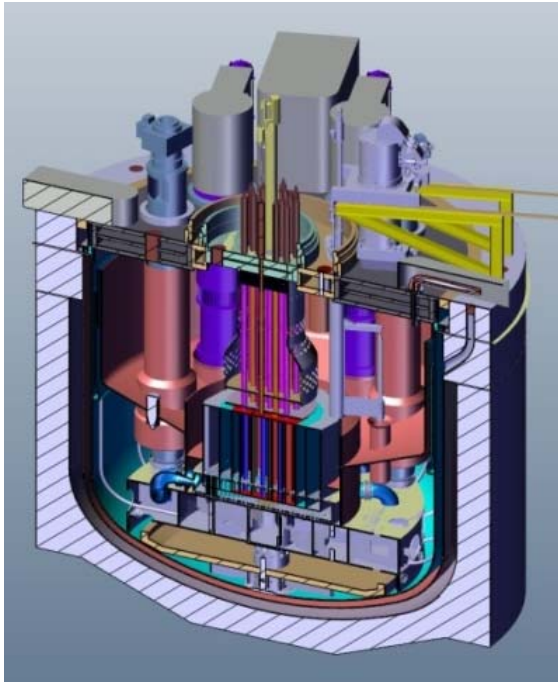
ASTRID



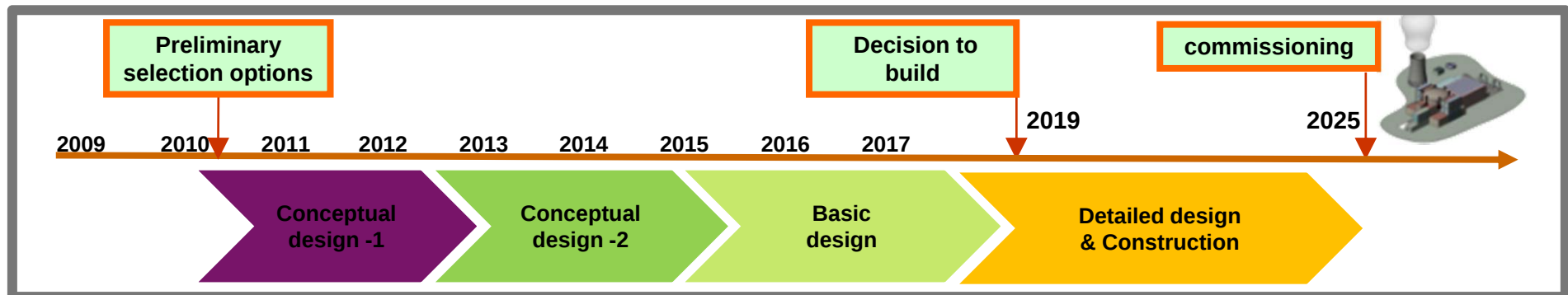
Commercial reactor

- Gas-cooled Fast Reactor, a long-term option:
 - attractive potentialities but heavy challenges...

THE ASTRID PROGRAM



- 600 Mwe , « pool » type
- oxyde fuel, transmutation capabilities
- Innovative design:
 - self-sustainable safer core
 - core catcher, residual heat removal
 - power conversion system

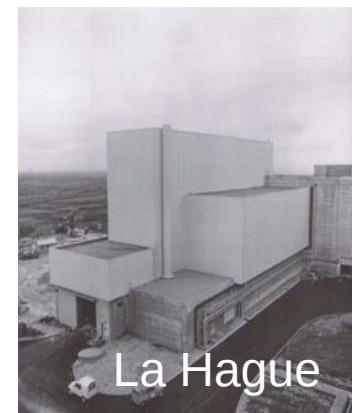
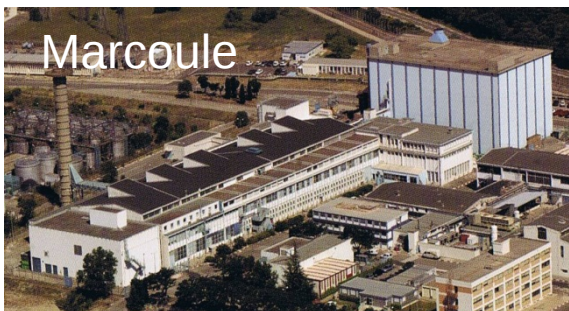


PLUTONIUM MULTIRECYCLE :

1 – PROCESSING USED FUELS

- **CURRENT RECYCLING TECHNOLOGIES:**
a robust basis for oxide fuels recycle!

- **ADAPTATION TO FAST REACTOR FUELS**
(# 25 tons FR-MOX already recycled)



- **IMPROVEMENT OF TECHNOLOGIES**

Recently : *UPu co-management*
cold crucible melter vitrification

Tomorrow : *single-cycle, redox-free process?*

PLUTONIUM MULTIRECYCLE : 2 – FUEL FABRICATION TECHNOLOGIES

POWDER METALLURGY, the reference option for FR-MOX fuels

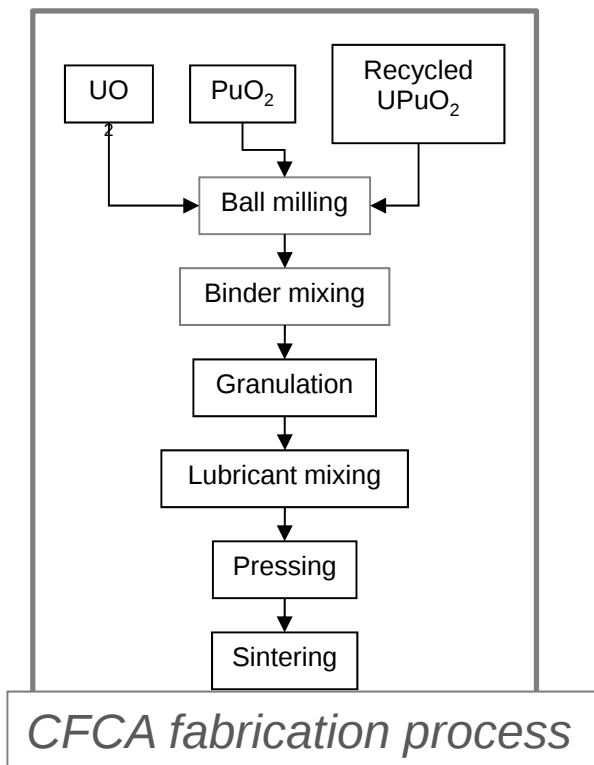
- A SIGNIFICANT EXPERIENCE

France: CFCA , Cadarache

Japan: PFPP, Tokai

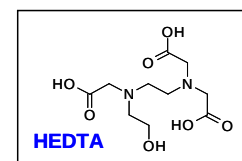
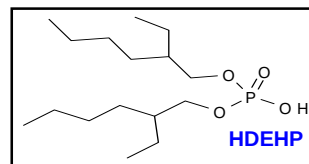
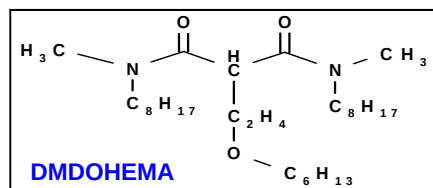
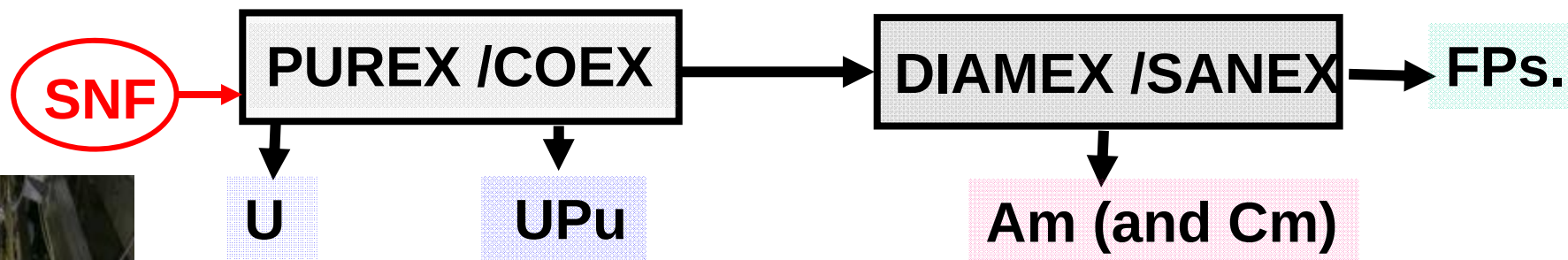
SFR fuel fabrication, CFCA, from 1963

Réacteurs	Nb of pins	Nb of pellets (millions)	Pellets (t _{HM})	Pu (t _{HM})
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



- TO BE ADAPTED (Pu from LWR-MOX)
- TO BE IMPROVED (innovative precursors)

MINOR ACTINIDE P&T



MA recovery innovative processes
have been successfully experimented, at lab-scale
[SANEX 2005, GANEX 2008, EXAm 2010] (kgs, genuine SNF)

**R&D goals: optimize and pilot-scale approach
separation, MA-bearing fuels fabrication, transmutation:
a long way to reach industrial maturity**

« en résumé... »

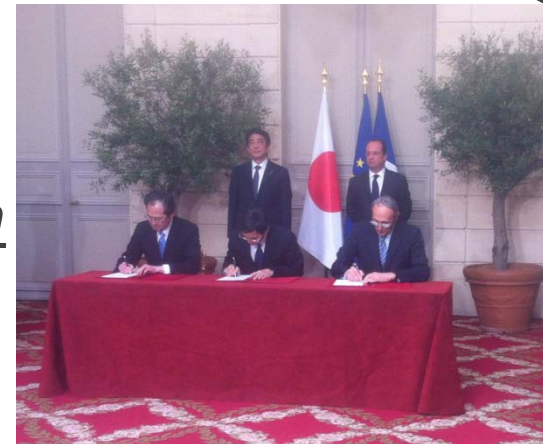
Optimized waste management is a major stake for future nuclear systems: this points recycling options, and fast neutron reactors

Actinide management is key : *plutonium first,*
...then minor actinides (Am notably)
...pursuing a « step by step » approach

CEA has launched the ASTRID program,
an opportunity for large-scale demonstration
an opportunity for international cooperation

- *MONJU, an important tool for experiments*

- *JAPAN / FRANCE cooperation agreement, Paris, May 5th, 2014*



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***THANK YOU
FOR YOUR ATTENTION !***

International Symposium – TOKYO, October 9-10, 2014

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