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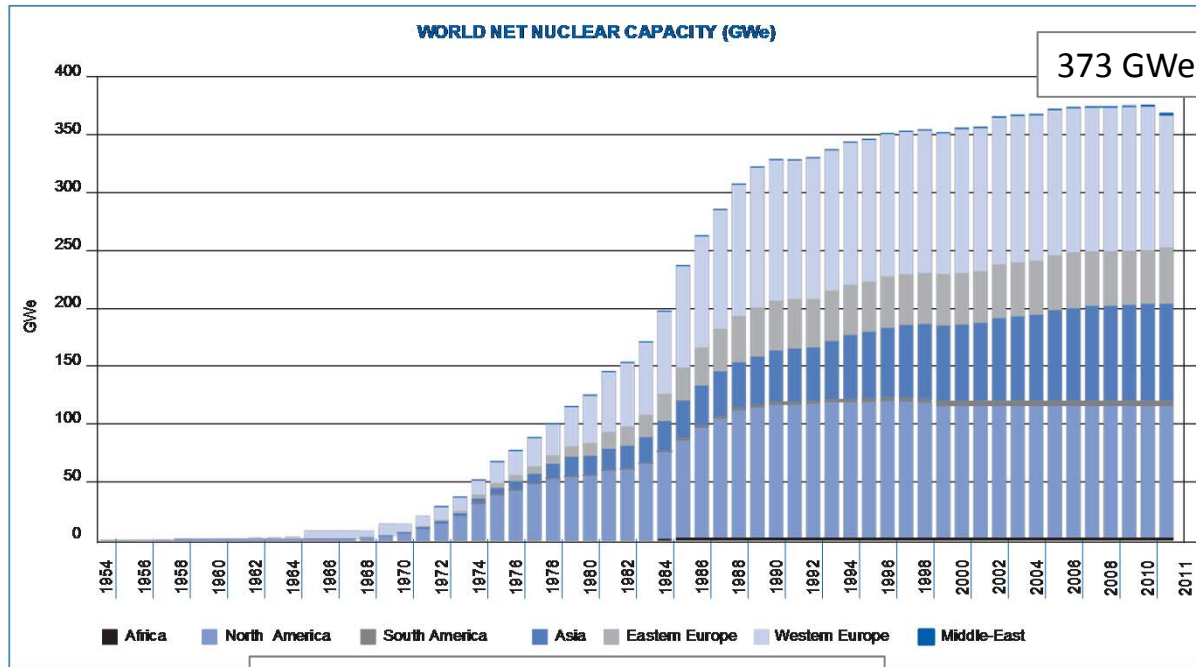
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**THE FRENCH PROGRAM
FOR A *SUSTAINABLE MANAGEMENT*
OF NUCLEAR MATERIALS AND WASTE**

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

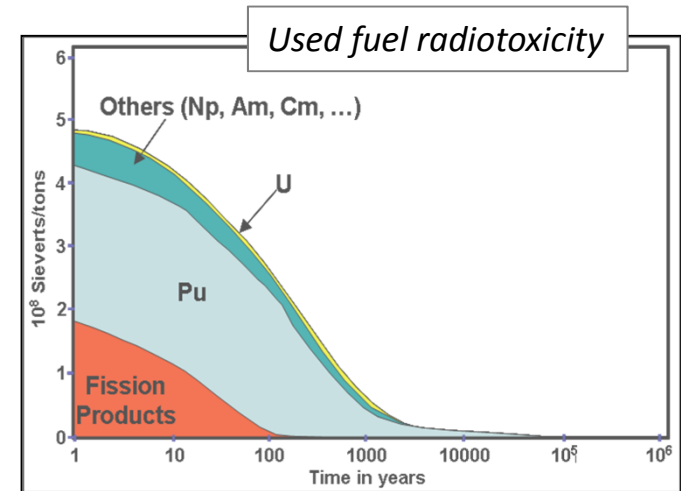


Au 31/

> 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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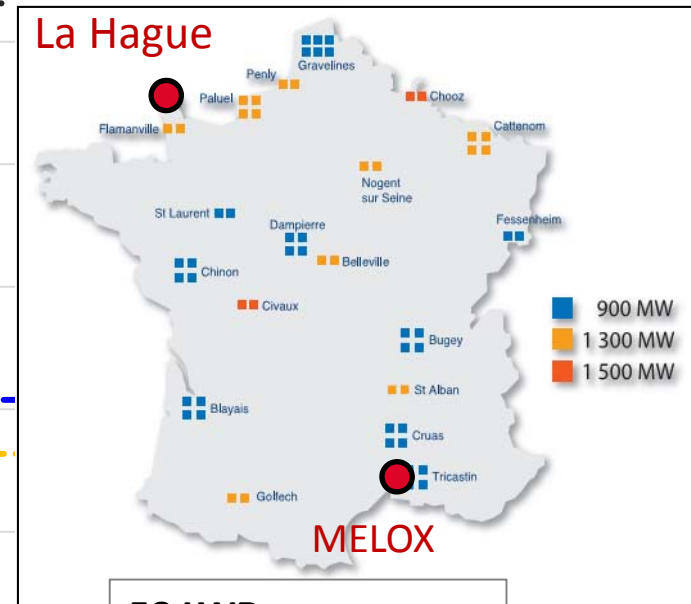
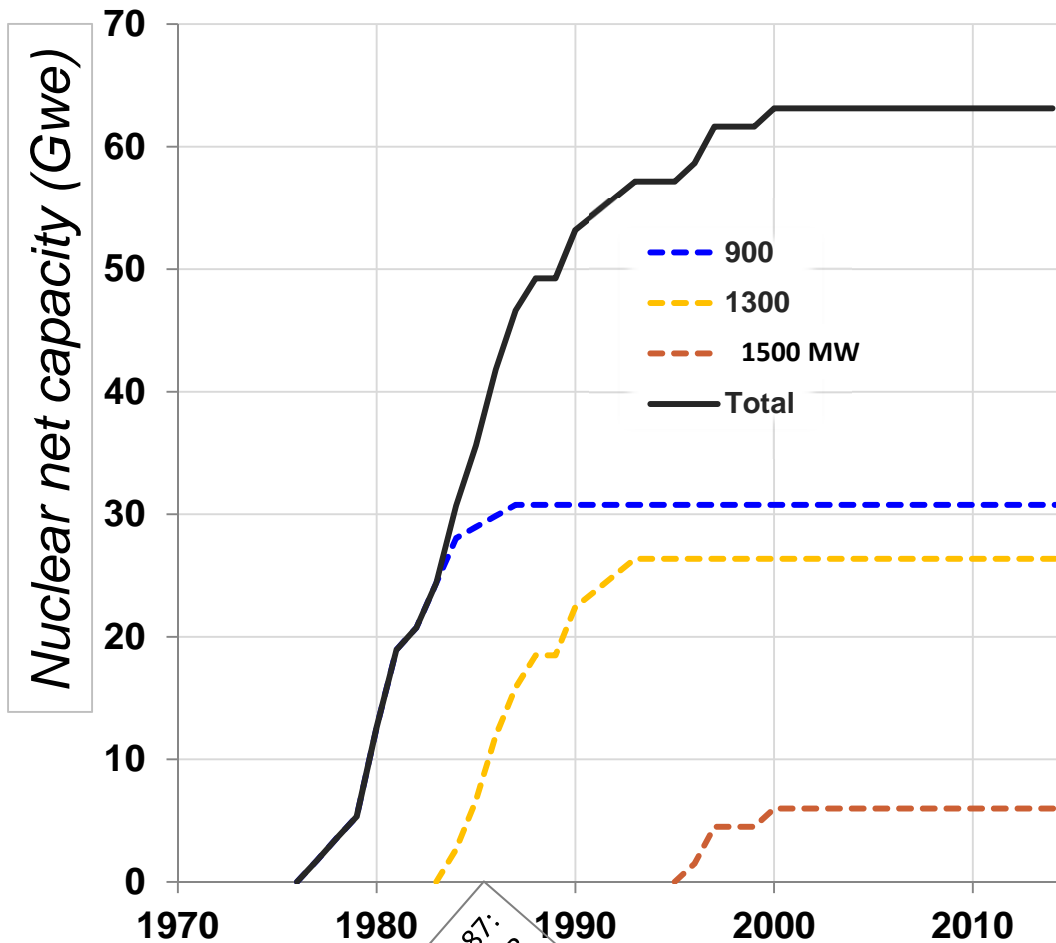


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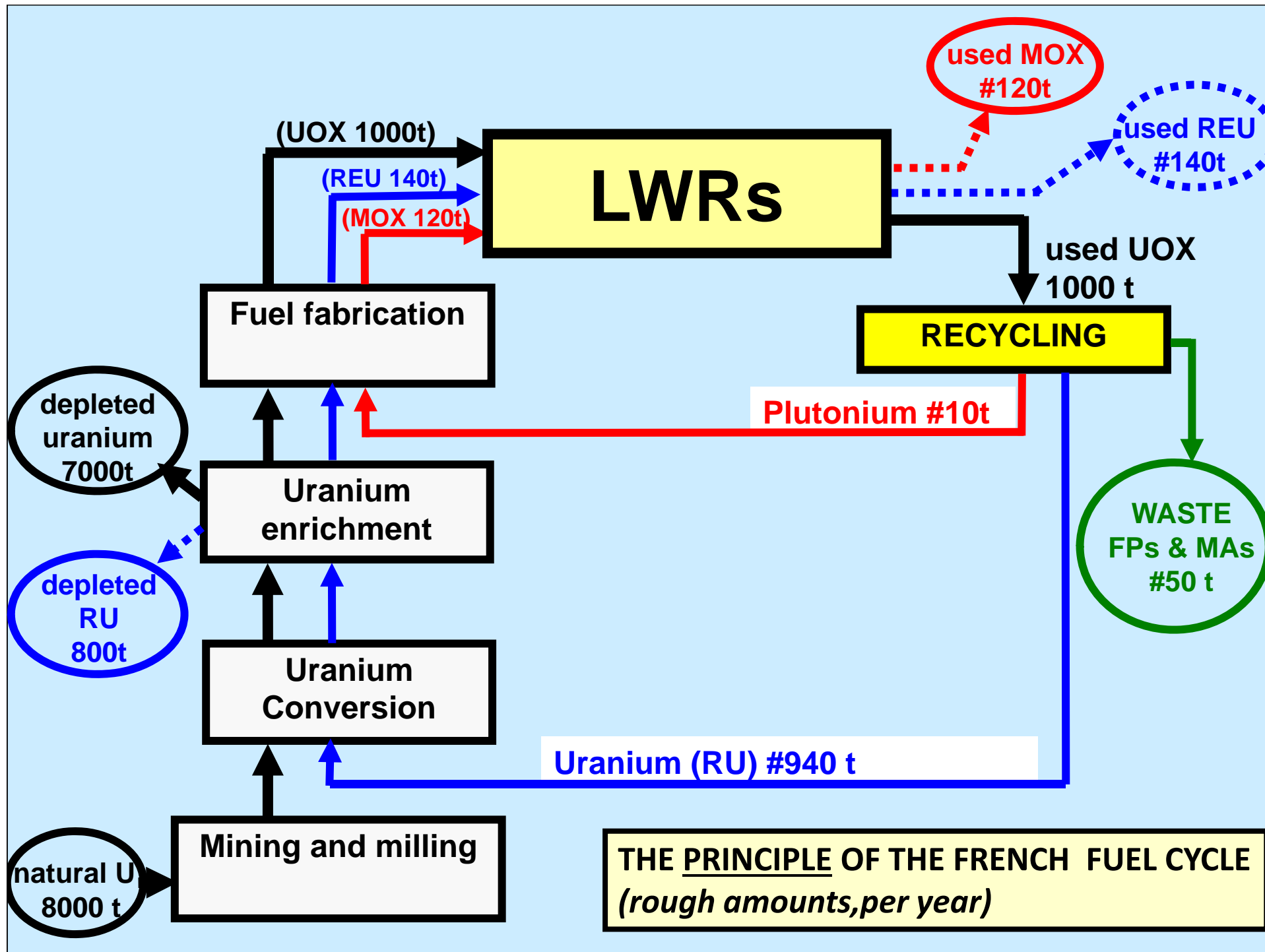
1 - THE CURRENT FRENCH NUCLEAR FUEL CYCLE

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THE FRENCH NUCLEAR FLEET



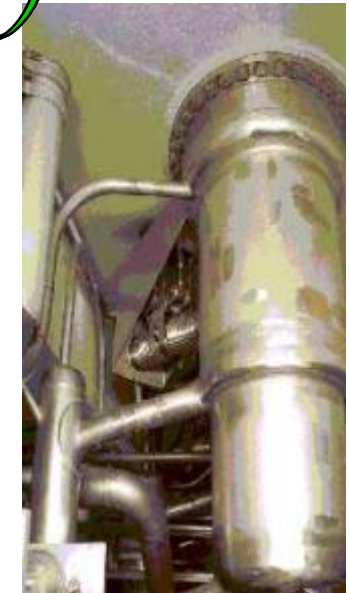
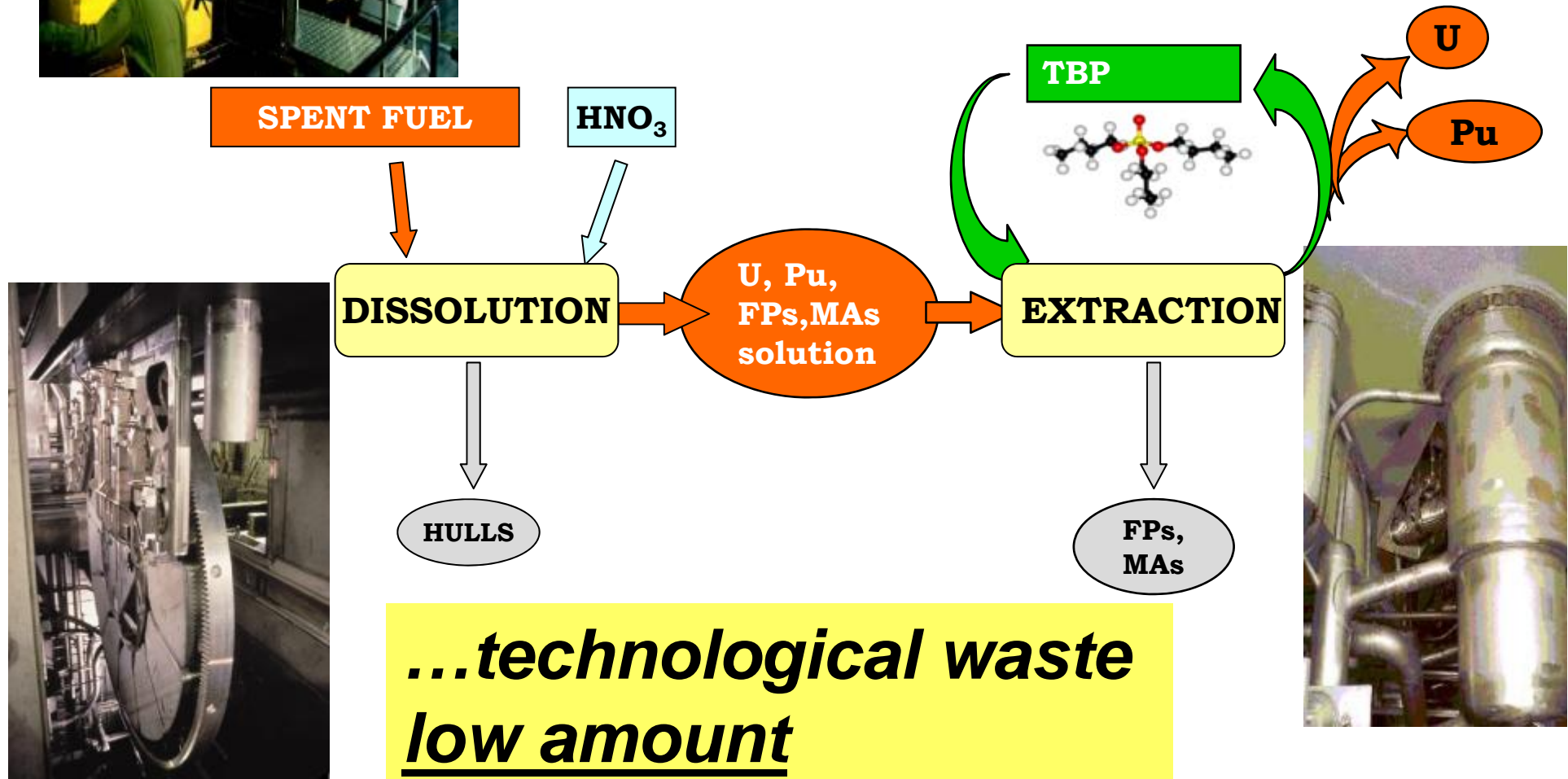
58 LWR
24 licenced for MOX
4 licenced for REU



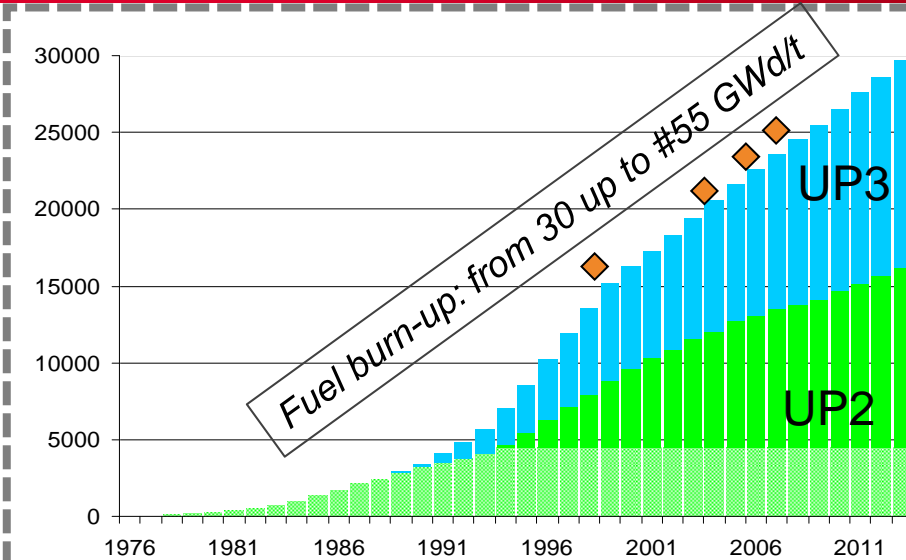
RECYCLING TECHNOLOGIES : DECADES R&D !



high yields...



USED FUEL RECYCLING IN FRANCE



La Hague plant
(UNF tons)



> 30 000 tons
processed

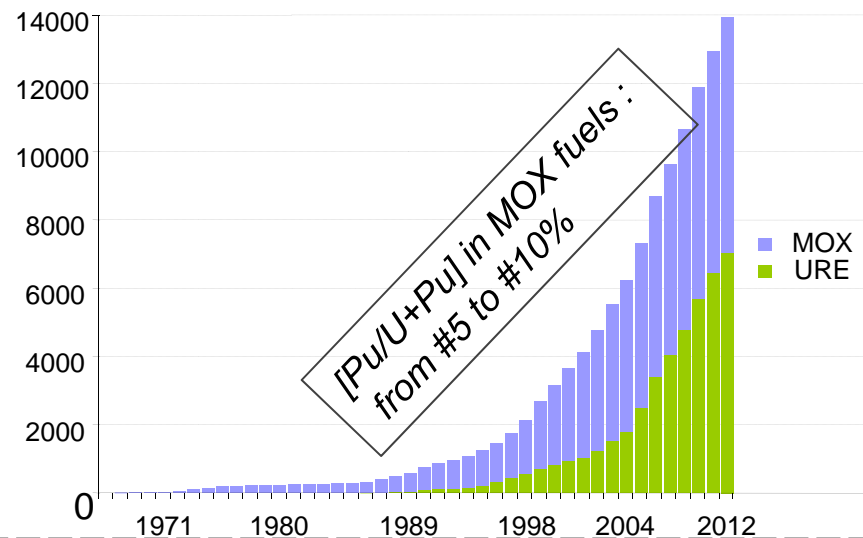
◆ Used MOX fuel
(#70 tons processed)



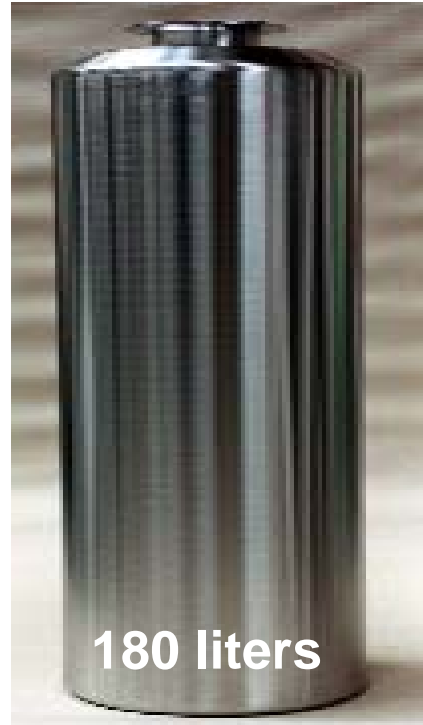
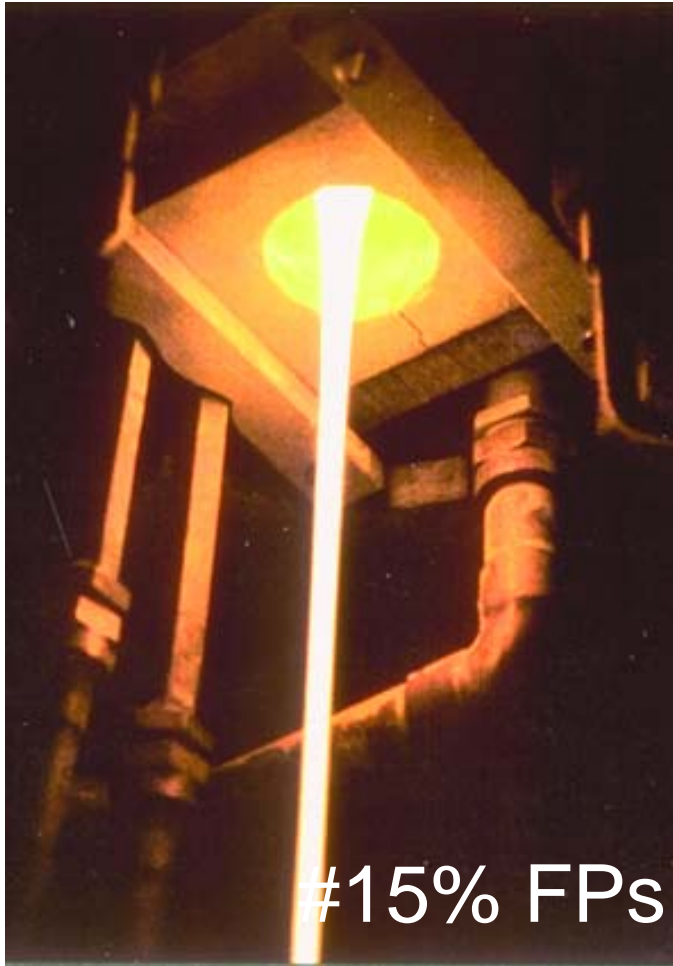
MOX & REU Fuels
(sub-assemblies)

1800 tons MOX fuel manufactured

Assemblies



FINAL WASTE VITRIFICATION



17 000 glass canisters produced

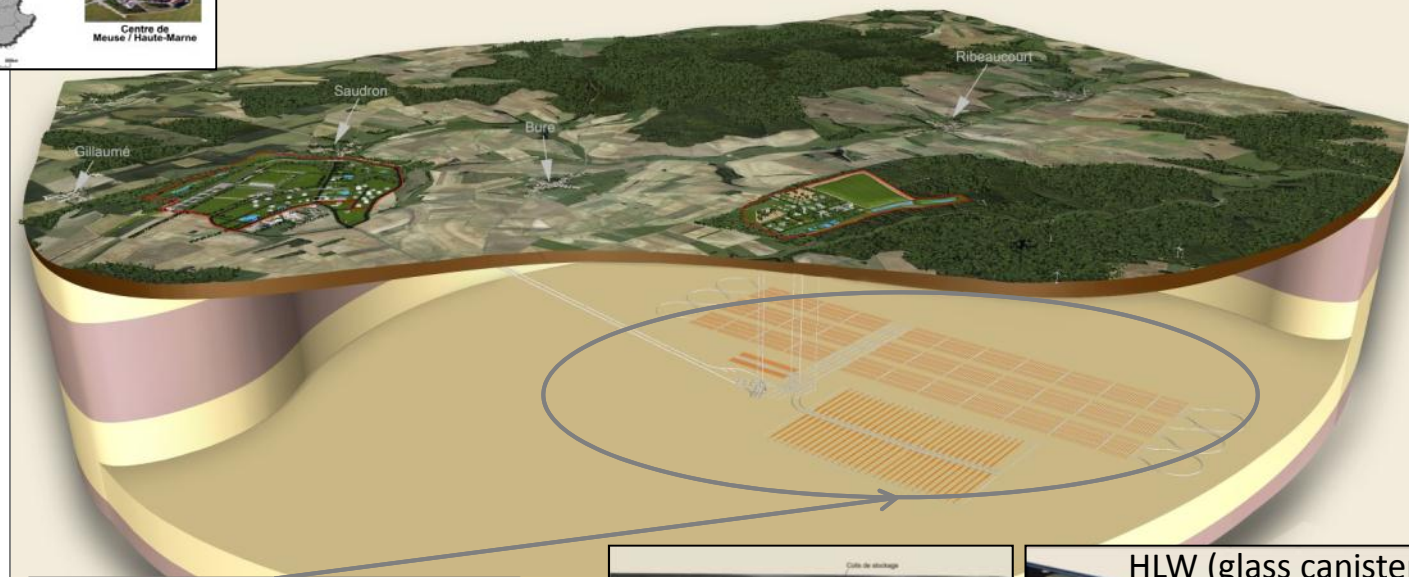
10-15 glass canisters /reactor /per year

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

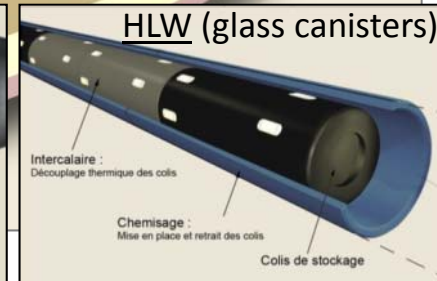
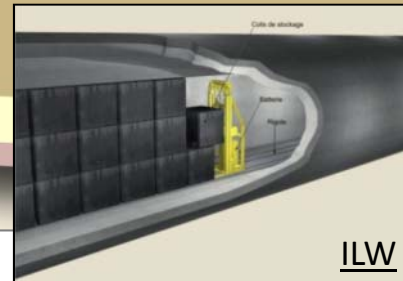
ANDRA, french waste management agency



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



**underground repository
clay, (- 500m)**



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**

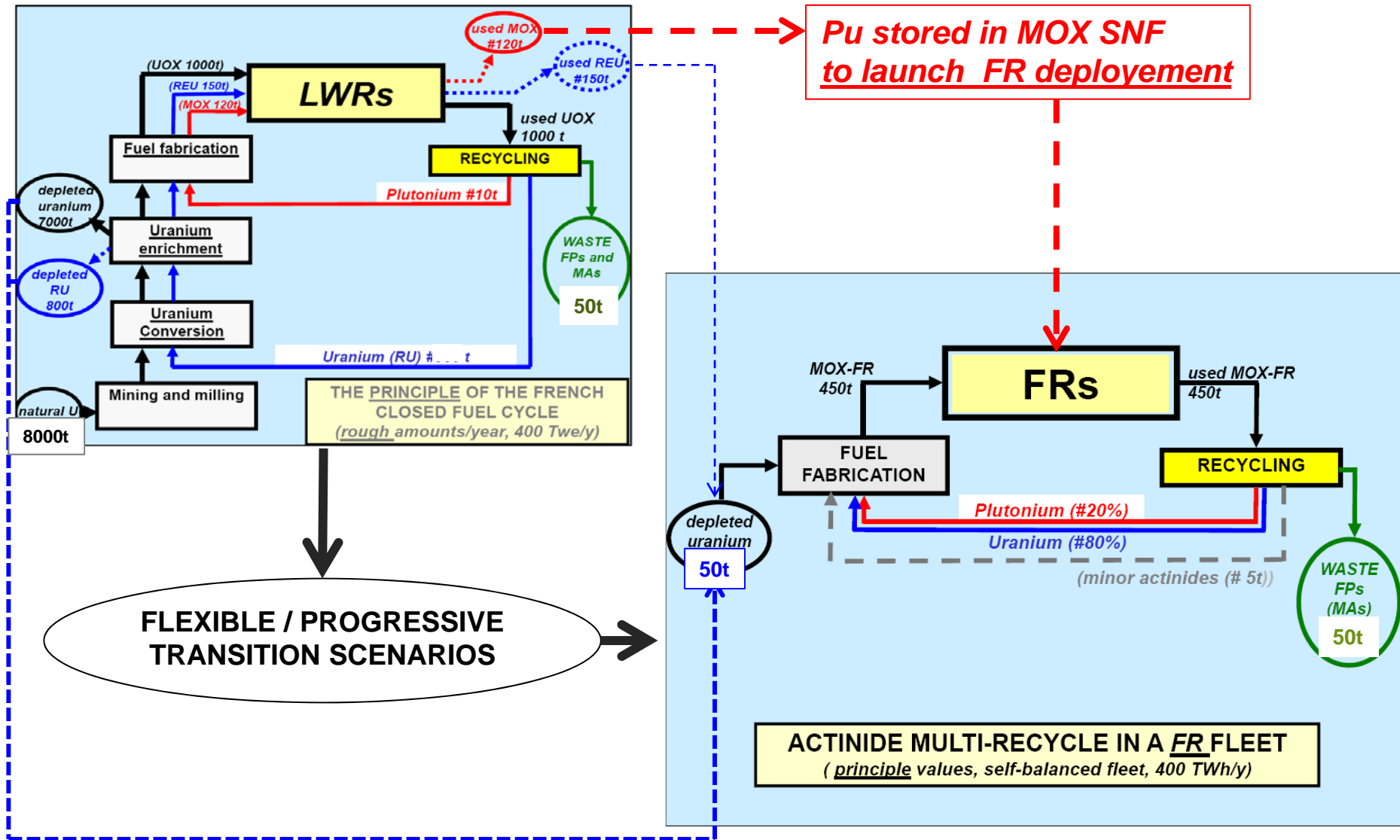
Two main guidelines:

(1) Systematic recycle of U and Pu

(2) fast neutron reactors

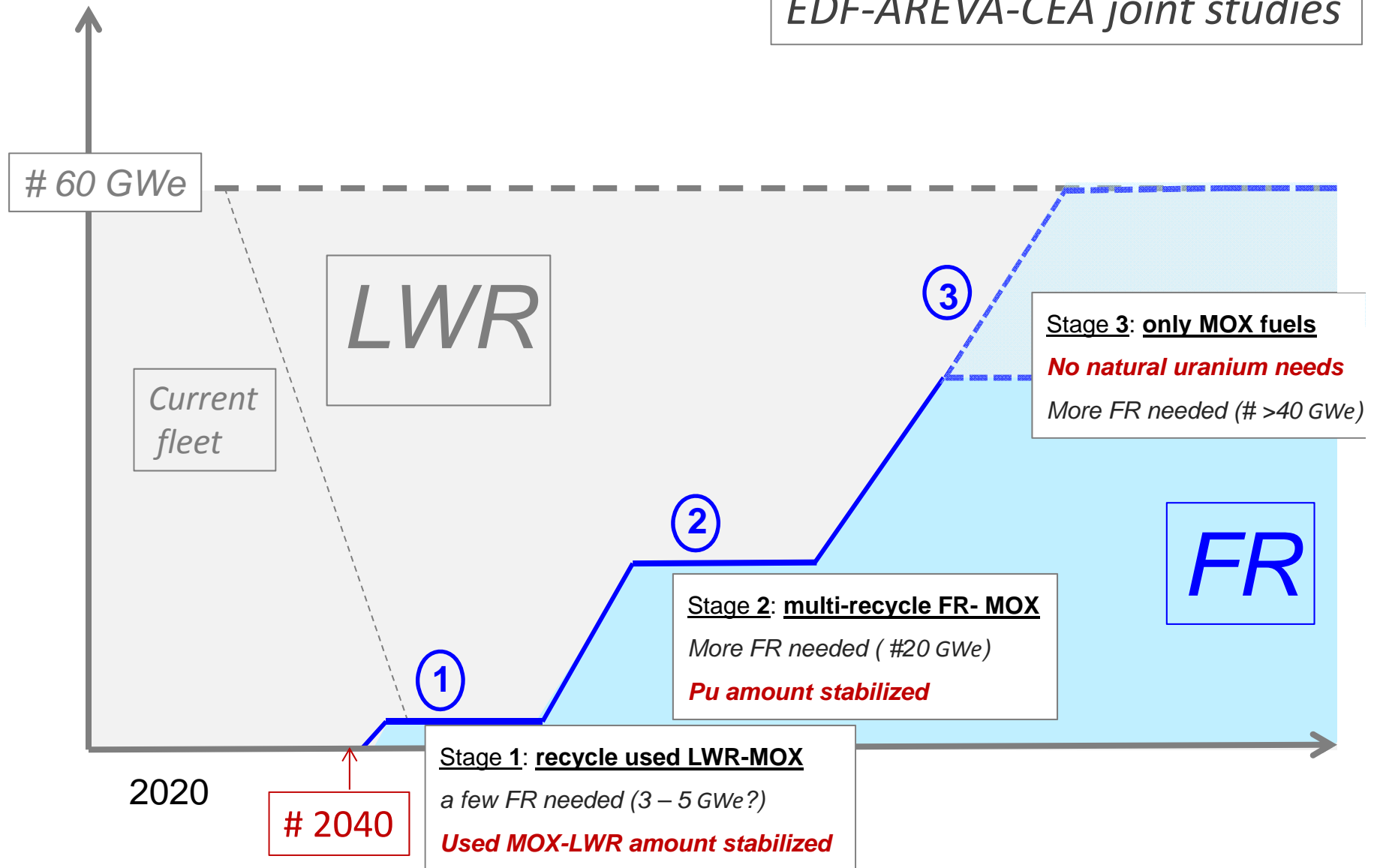
- . to burn and take advantage of plutonium amounts in spent fuels (avoiding the growth of important un-used stockpiles);
- . to decrease minor actinide amounts in final waste
- . to allow a drastic extension of ^{238}U valorization

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



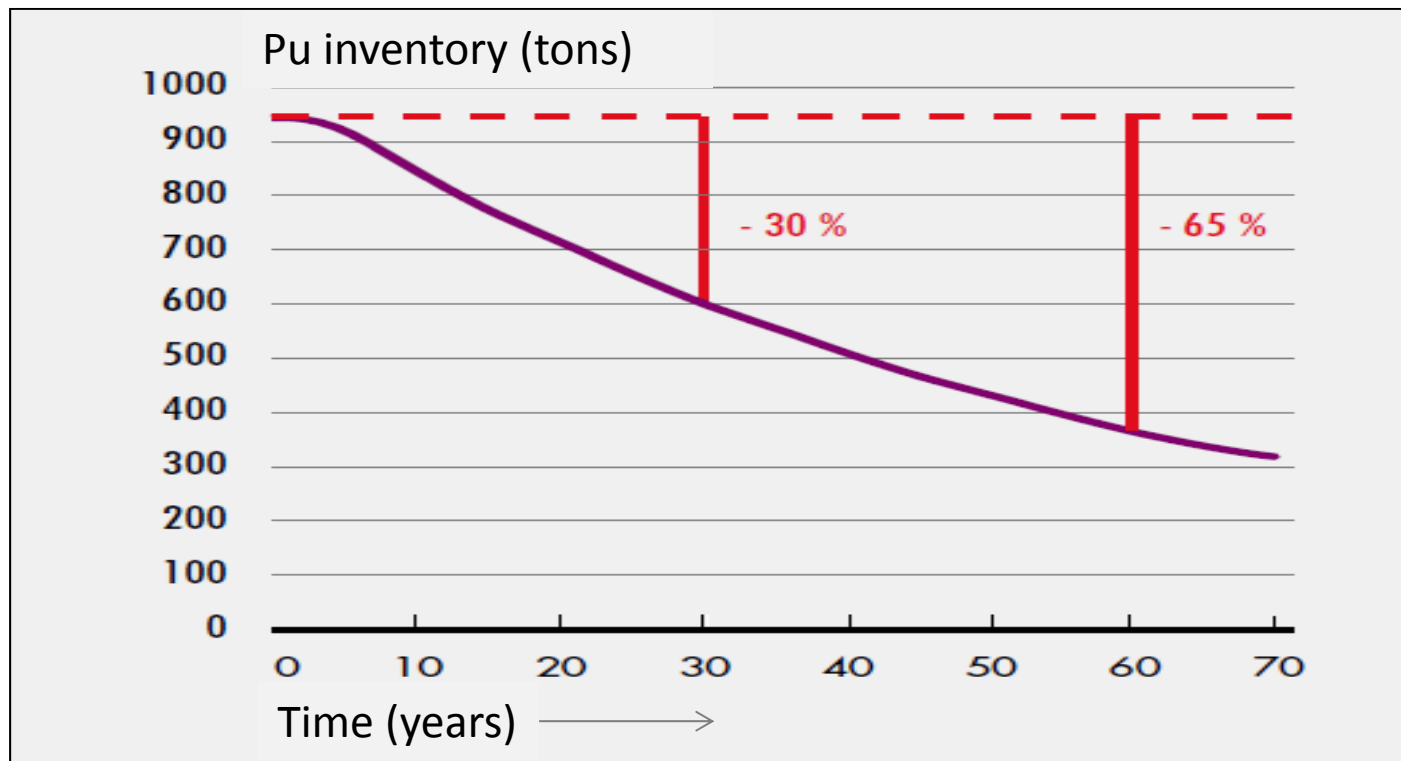
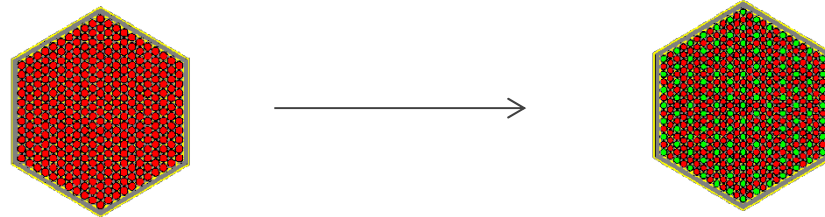
FR REACTORS DEPLOYMENT: CURRENT SCENARIO STUDIES

EDF-AREVA-CEA joint studies



PU STOCKPILES RESORPTION : *FR FLEXIBILITY*

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

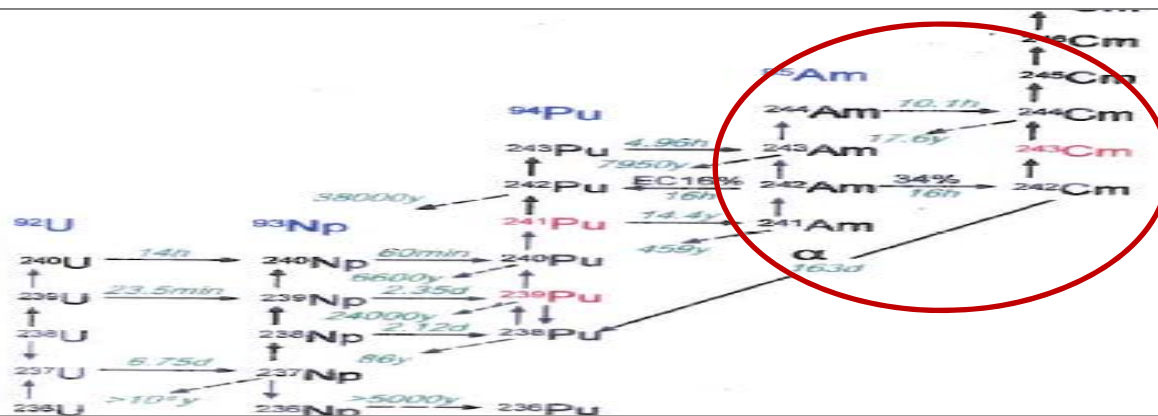


MINOR ACTINIDES TRANSMUTATION: DRIVERS...

Minor actinide removal could provide

an optimization of final waste management:

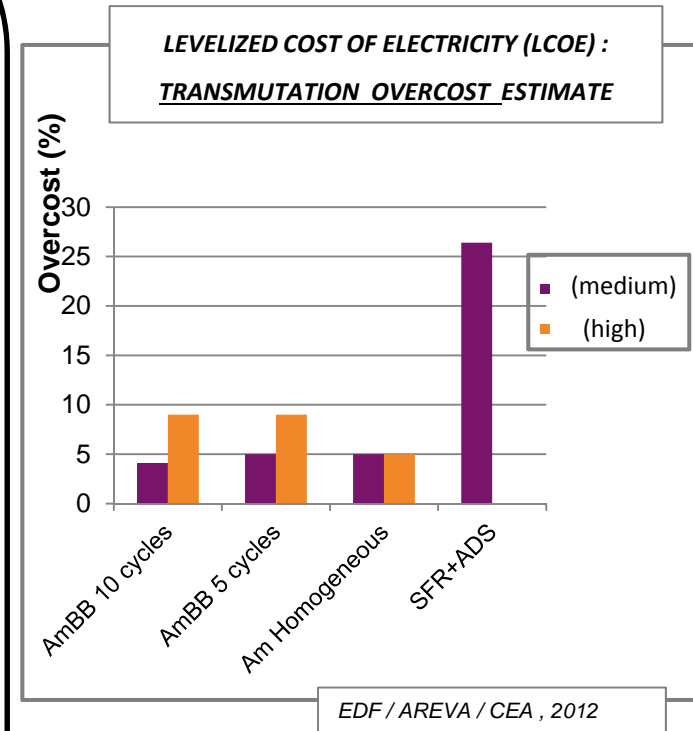
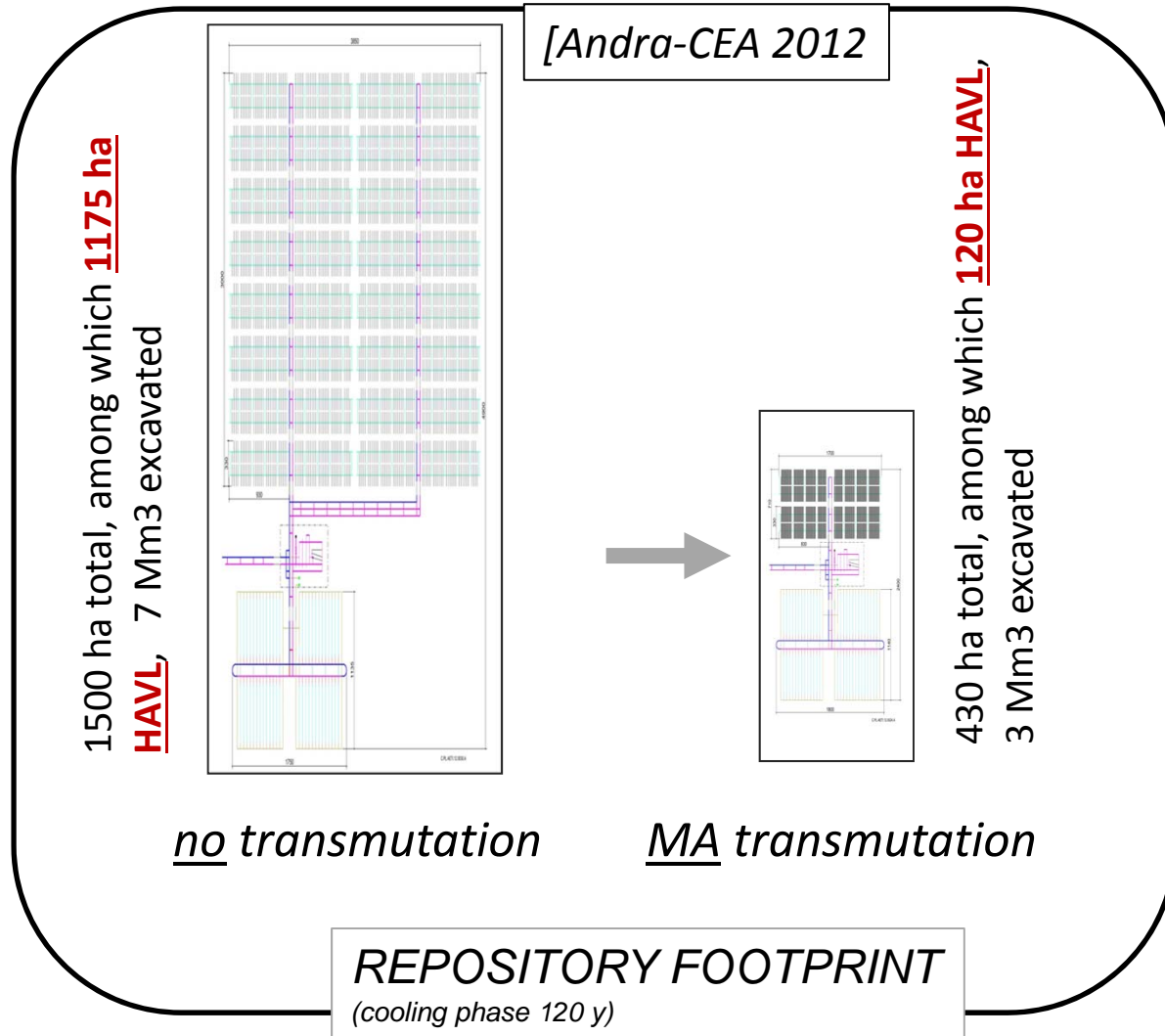
- *by decreasing waste long-term radiotoxicity*
- *by decreasing the repository footprint (Am recycle mainly)*



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...



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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



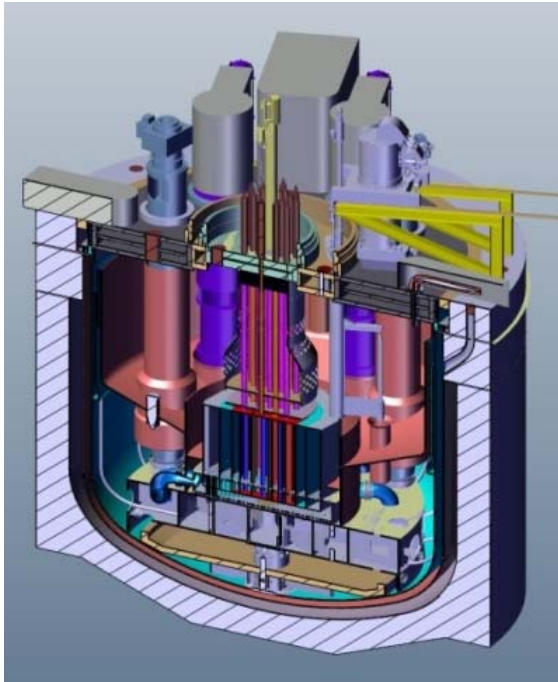
ASTRID



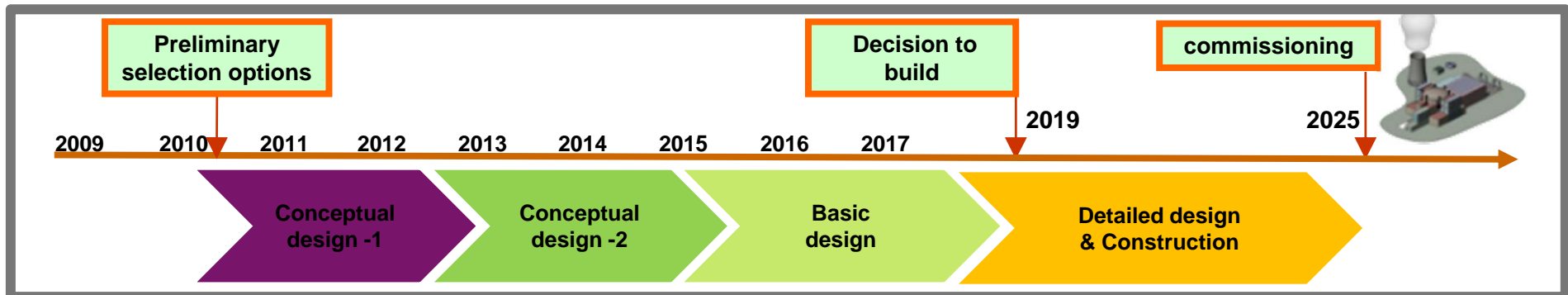
Commercial reactor

- *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

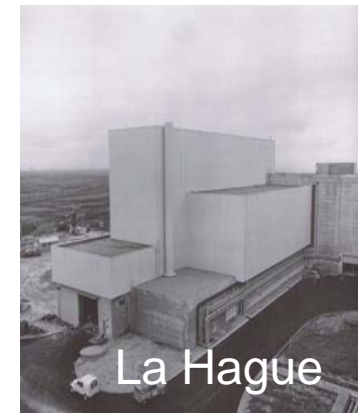
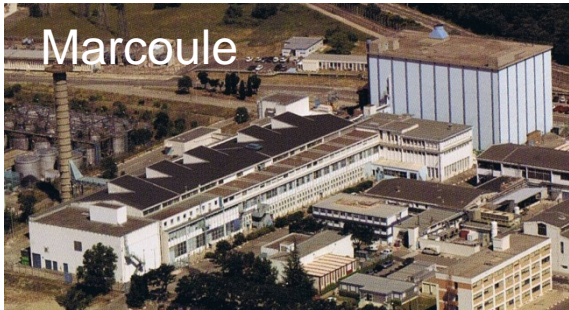


PLUTONIUM MULTIRECYCLE :

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?*

POWDER METALLURGY, the reference option for FR-MOX fuels

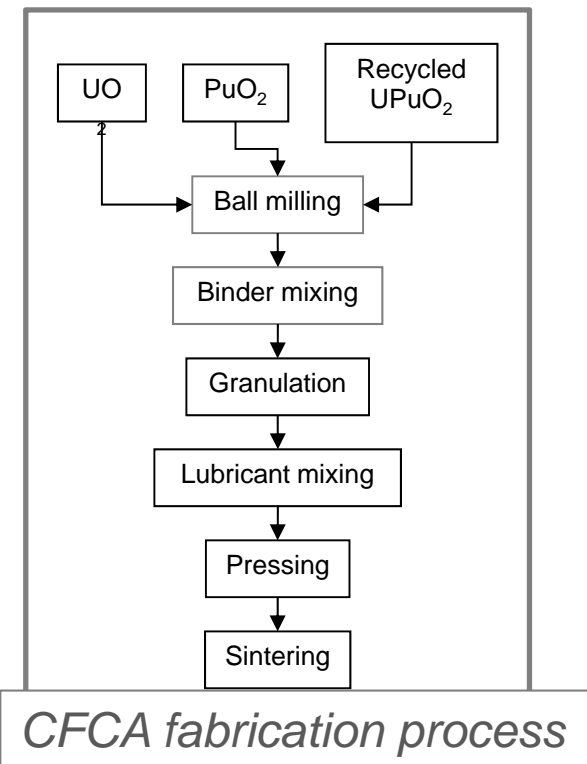
- A SIGNIFICANT EXPERIENCE

France: CFCA , Cadarache

Japan: PFPP, Tokai

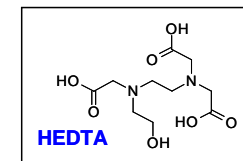
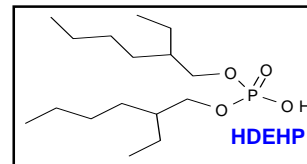
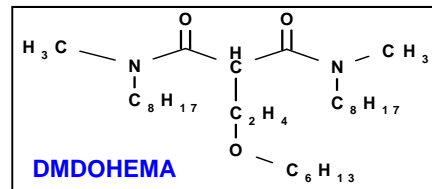
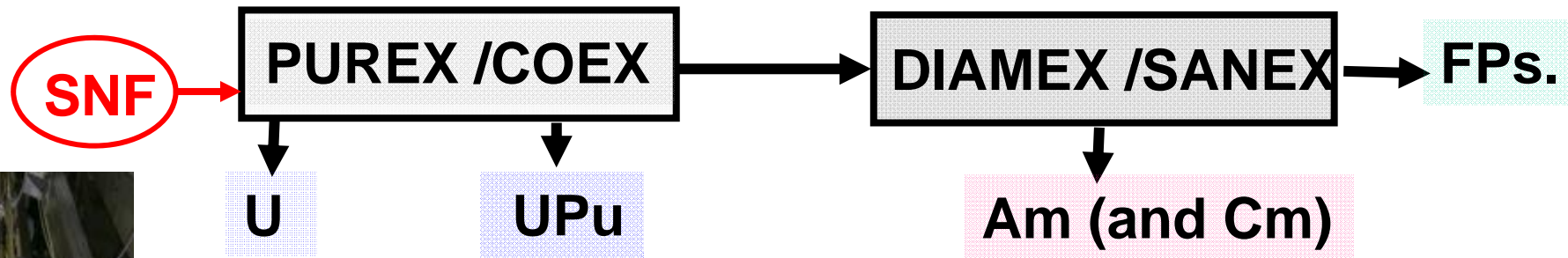
SFR fuel fabrication, CFCA, from 1963

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

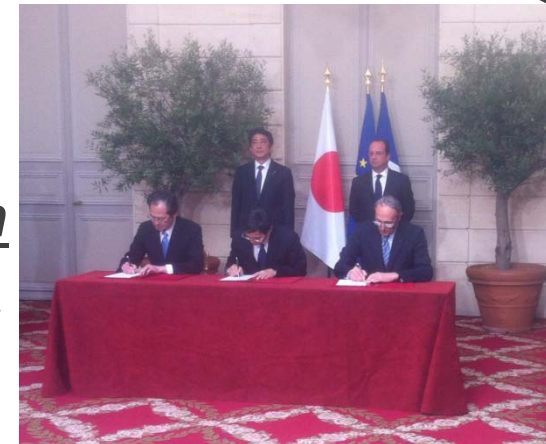
« en résumé... »

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 !***

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