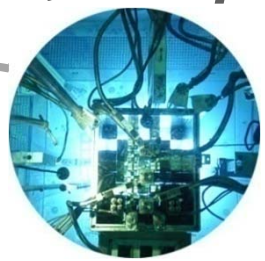
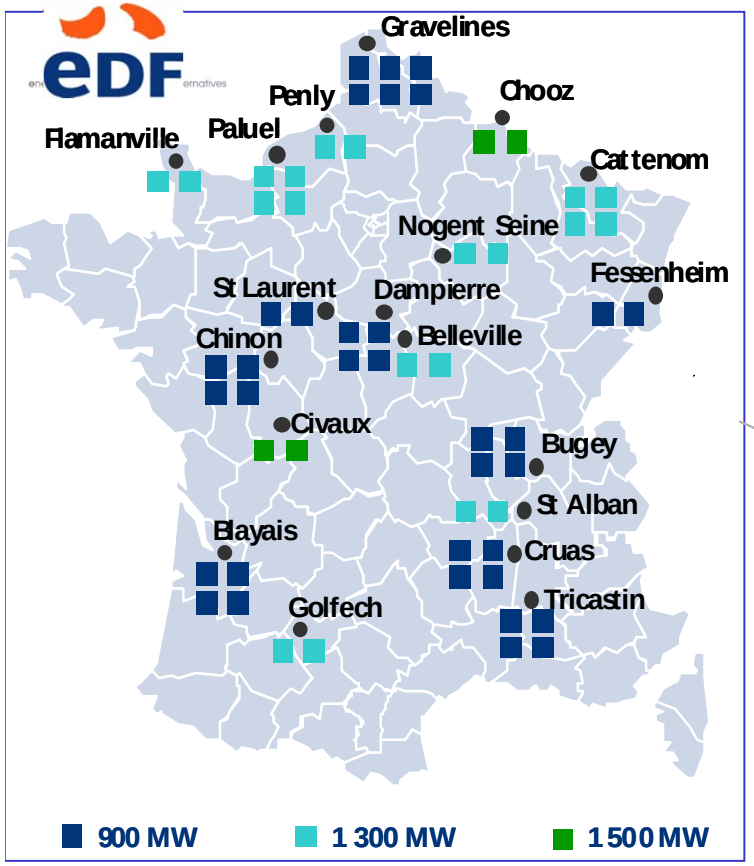
# New Framework for Nuclear Energy Policy Planning Council
## TOKYO, 24 April 2012



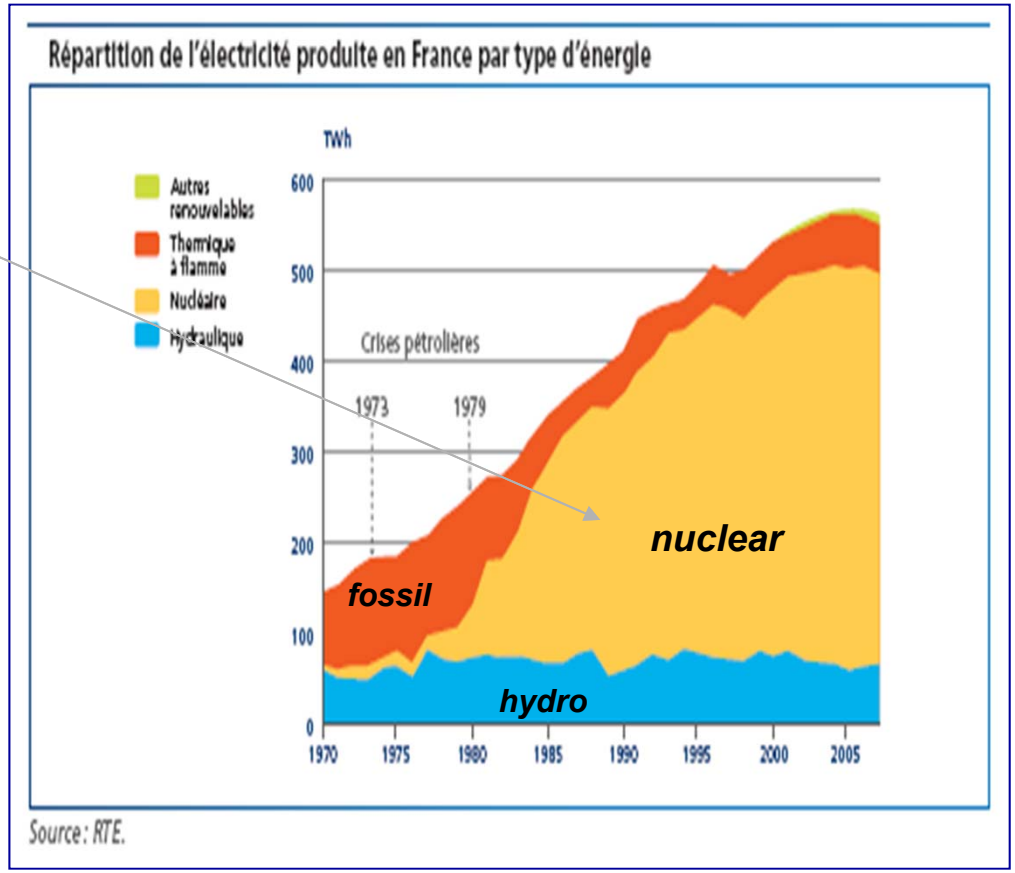
# NUCLEAR FUEL CYCLE BACK-END: FRENCH POLICY

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

# FRENCH ELECTRICITY




***Nuclear > 75 % of electricity generation***
***Low-carbon energy mix : # 4g CO2 per kwh***




***-58 LWR units***
***-63 GWe***
***->410 TWh per year***

# NUCLEAR ENERGY : FRENCH POLICY
## *1 – REGULATORY FRAMEWORK*

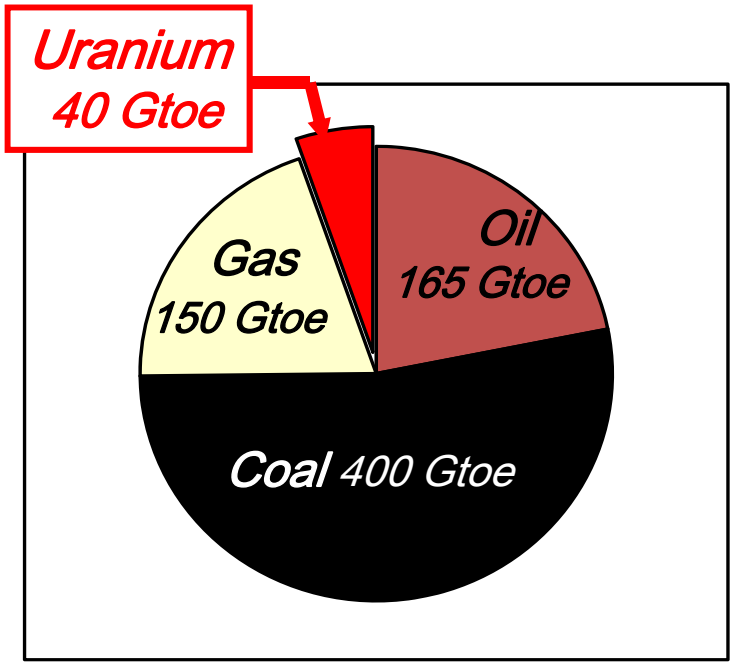
- **2005 ACT *about* ENERGY POLICY:**
  - **national self-sufficiency *(security of supply);***
  - **large access to energy *(competitive price);***
  - **environmental preservation *(decrease CO2);***
    - ***nuclear energy , a pillar;***
    - ***R&D for future generation nuclear systems.***
- **2006 ACT about TRANSPARENCY & INFORMATION**
  - **independent Safety Authority;**
  - **High Committee for transparency & information;**
- **2006 ACT *about* NUCLEAR MATERIALS & WASTE**
    - ***recycle (decrease waste amounts);***
    - ***geological repository for final waste.***

# NUCLEAR ENERGY : FRENCH POLICY
## *2 – RECENT HIGHLIGHTS*

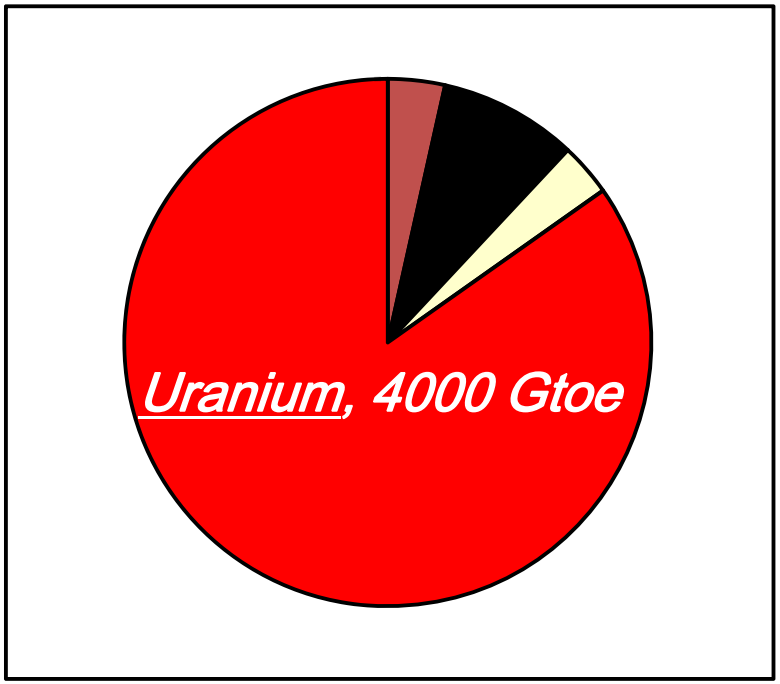
- **2012 *(january): « COUR DES COMPTES »* REPORT about *nuclear energy costs:***
  - **french electricity cost :**
    ***40% lower / other EU countries;***
  - **no « hidden costs »;**
  - **uncertainties about decommissioning costs:**
    ***a low incidence on global costs;***
  - ***the main point :* NPPs life-time extension *(> 40 y***
    ***(if not: huge investments needed).***

- ***2012 (february): « ENERGIES 2050 » REPORT***
  - **low energetic dependence, a priority;**
  - **nuclear and renewable.**

# FOSSIL FUELS POTENTIAL RESERVES




Uranium use
in current reactors




Uranium use
in 4th generation reactors

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

# *THE « FRENCH » NUCLEAR FUEL CYCLE*

energie atomique • energies alternatives

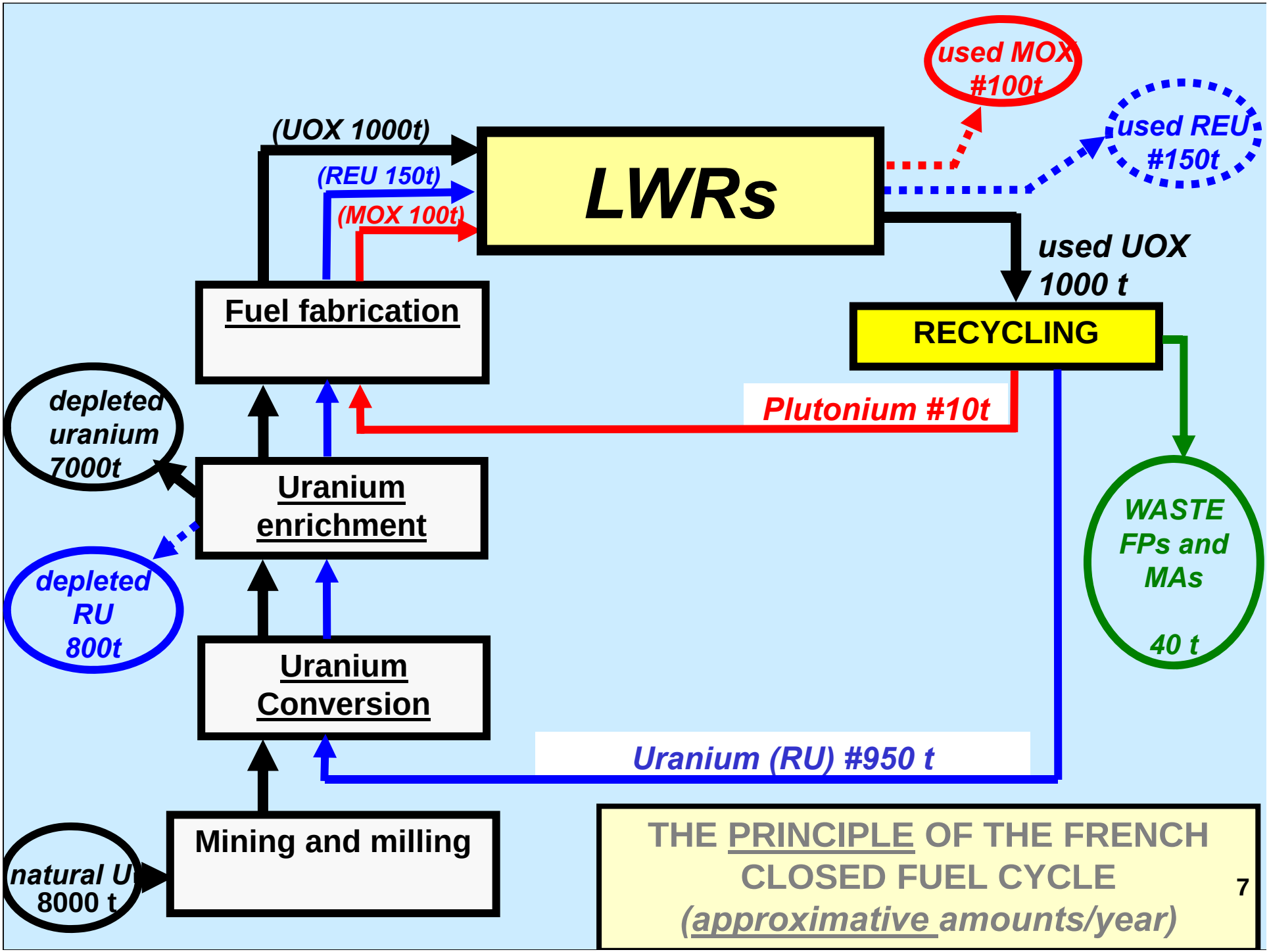
- ***~ 1200 tons spent fuel*** **unloaded each year**

**A « <u>CLOSED</u> » FUEL CYCLE :**

***- UOX SPENT FUEL PROCESSED***

***- U RECYCLED ( 4 REACTORS)***

***- Pu RECYCLED (22 REACTORS)***


used MOX
#100t
used REU
#150t
(UOX 1000t)
(REU 150t)
(MOX 100t)
LWRs
used UOX
1000 t
Fuel fabrication
RECYCLING
depleted
uranium
7000t
Plutonium #10t
Uranium
enrichment
WASTE
FPs and
MAs
40 t
depleted
RU
800t
Uranium
Conversion
Uranium (RU) #950 t
natural U
8000 t
Mining and milling
THE PRINCIPLE OF THE FRENCH
CLOSED FUEL CYCLE
(approximative amounts/year)

# RECYCLING TECHNOLOGIES : DECADES R&D!

***high yields…***

SPENT FUEL

$HNO_3$

TBP

U

Pu

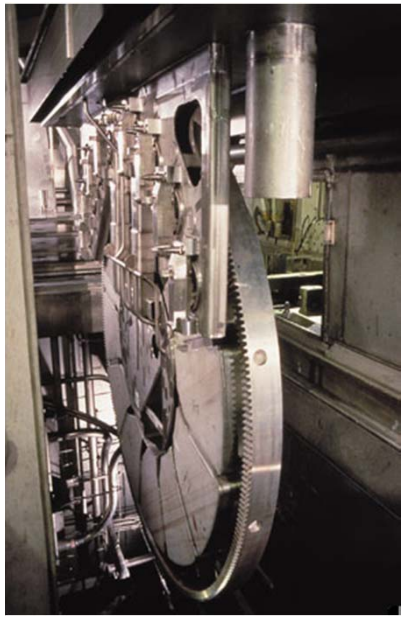
DISSOLUTION

U, Pu, FPs,MAs *solution*

EXTRACTION

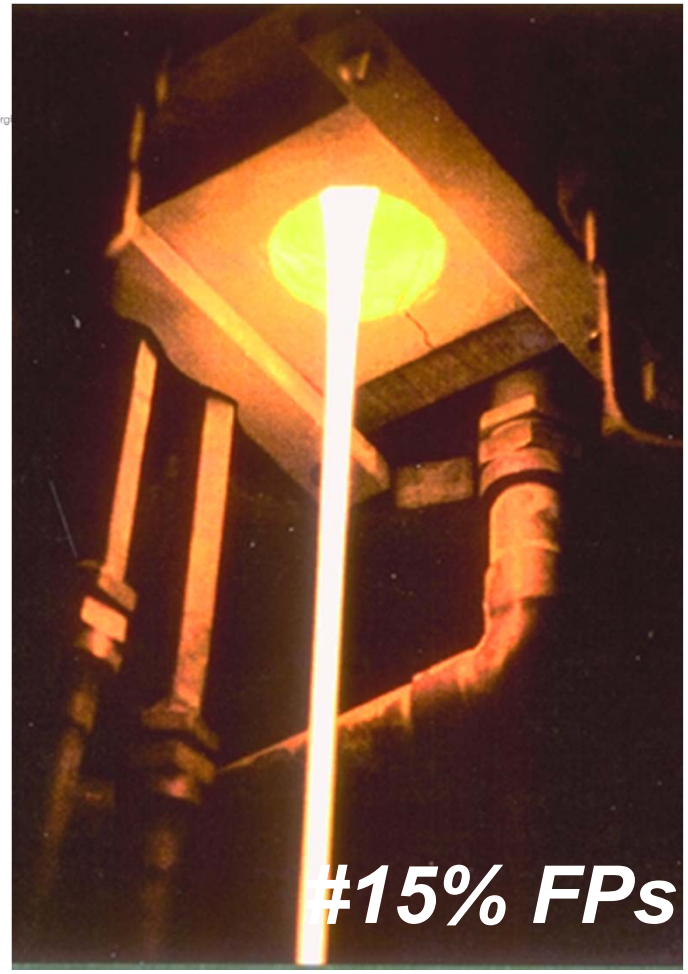
HULLS

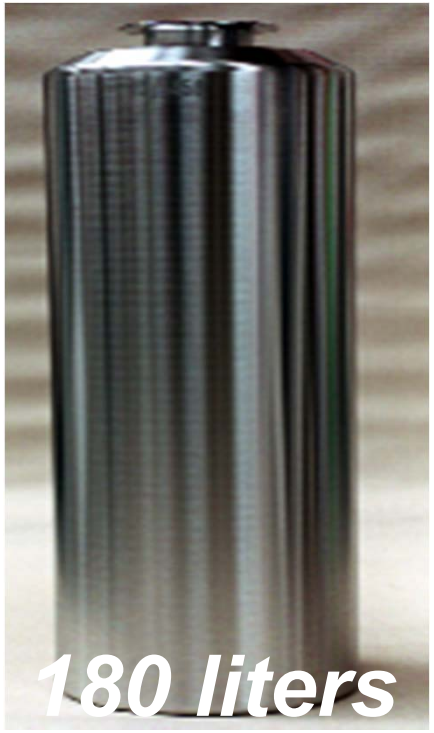
FPs, MAs

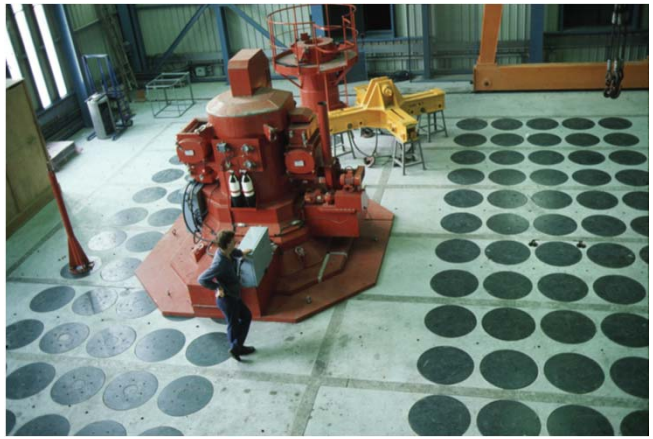


***…technological waste low amounts***

# FINAL WASTE VITRIFICATION

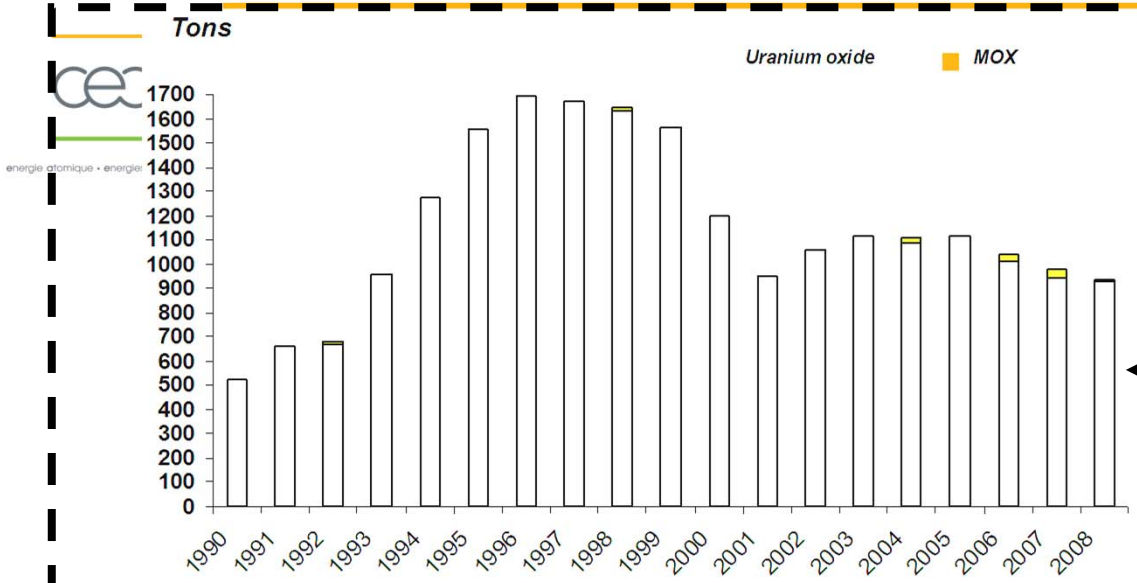


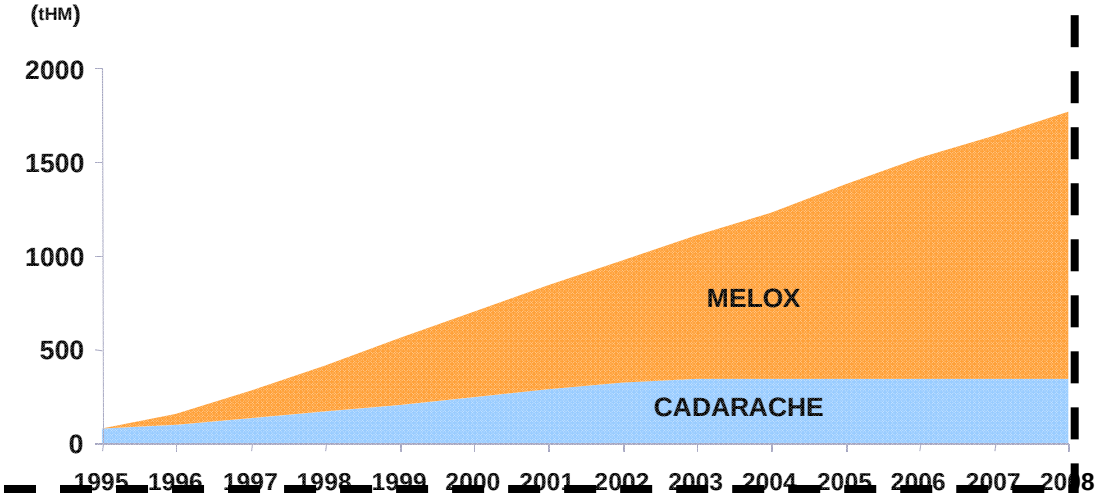
**# 10-15 glass canisters /reactor /per year**

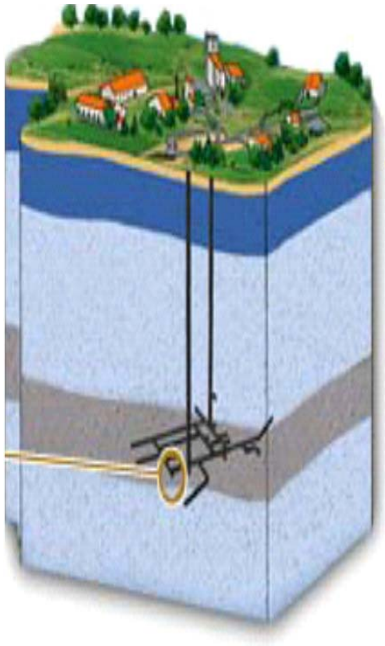
# SPENT FUEL RECYCLING IN FRANCE




***La Hague plant (tons/year)***

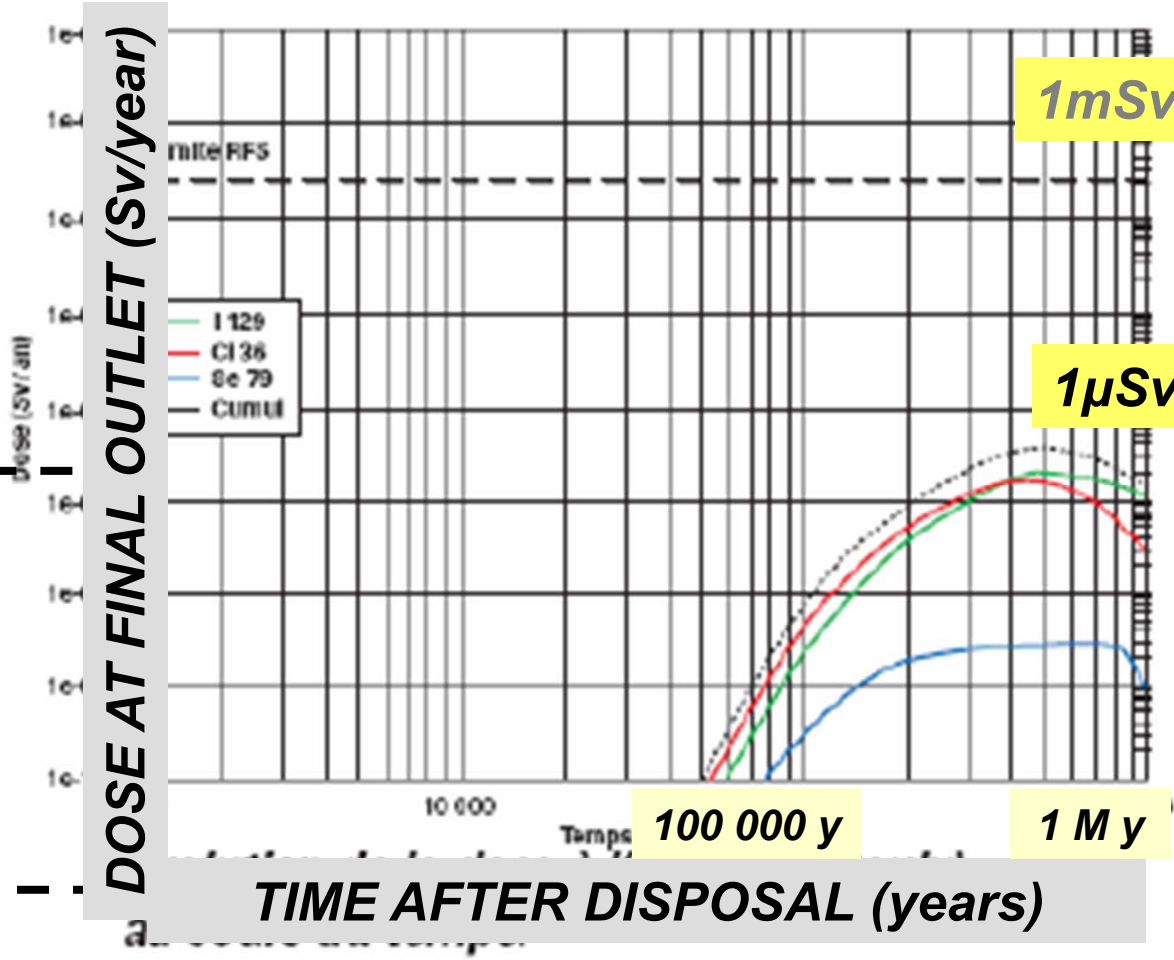
***MOX fuel fabrication (cumulative tons)***

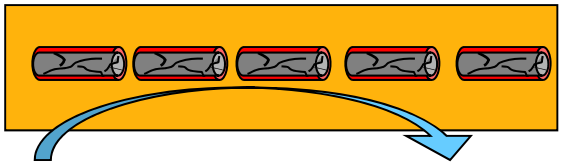




# GLASS CANISTERS DISPOSAL

*(ANDRA, « CLAY REPORT », 2005)*



***steady state :***
***#1 µm/1000 years,***

# CURRENT RECYCLING STRATEGY :

## *THE RATIONALE*

- **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**
  *( #25 000 tons reprocessed, # 2000 tons MOX)*
- **suitable option for Generation III reactors**

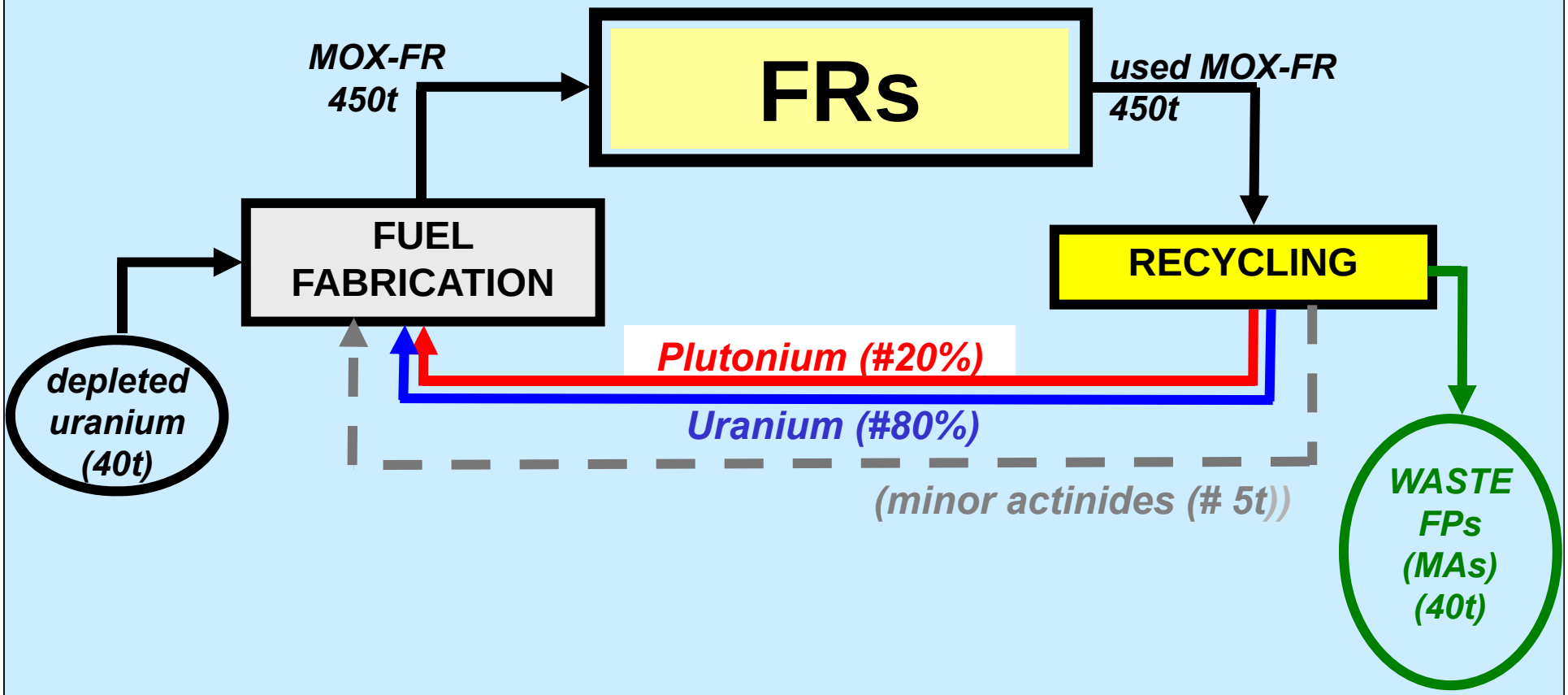
# LONG TERM *SUSTAINABLE* NUCLEAR SYSTEMS

***(1)RECYCLE, (2) IN FAST NEUTRON REACTORS…***

- ***efficient burning of plutonium,***
- ***full use of uranium,***
- ***potentialities for improving waste management ,***
- ***no enrichment needs***

***A progressive deployment?***

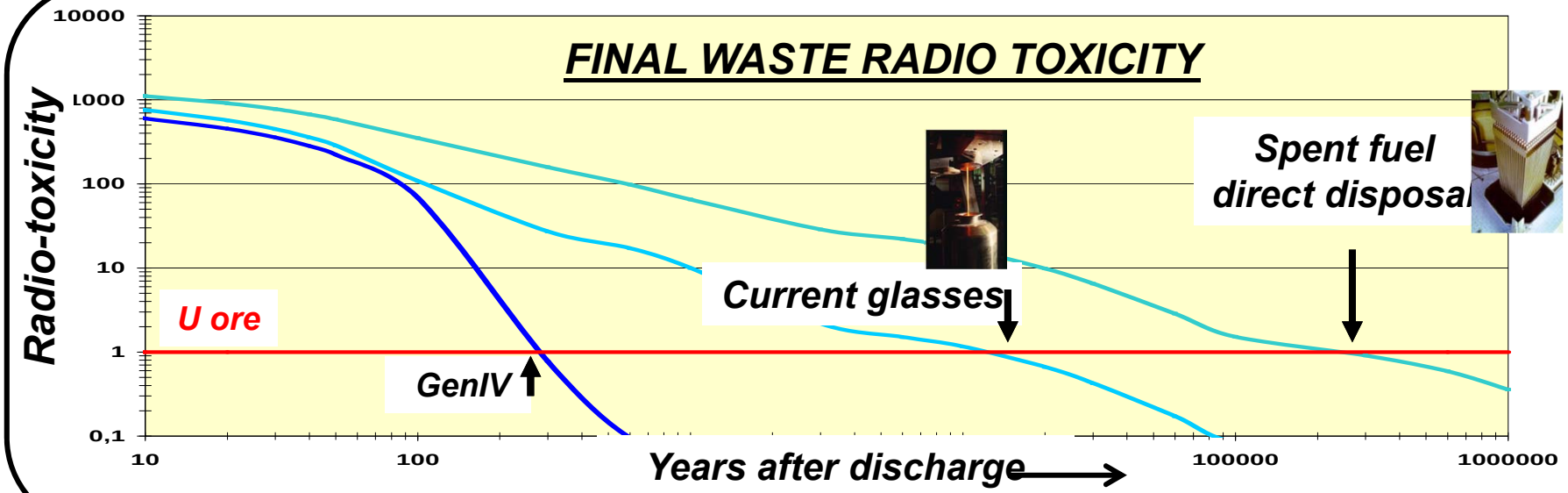
- ***initially fueled with plutonium coming from spent MOX***
- ***FR/LWR deployment could be adjusted in the future*** *(according to energy needs)*
- ***able to recycle more -in a later step -*** *(transmutation of "minor actinides"… )*



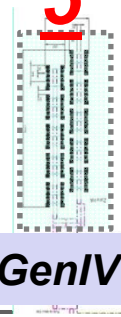

## ACTINIDE MULTI-RECYCLE IN A *FR* FLEET

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

# 4th GENERATION SYSTEMS : WASTE…

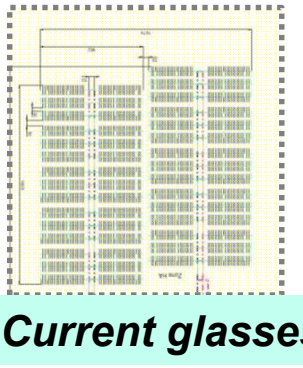



## HIGHLY ACTIVE WASTE REPOSITORY FOOTPRINT



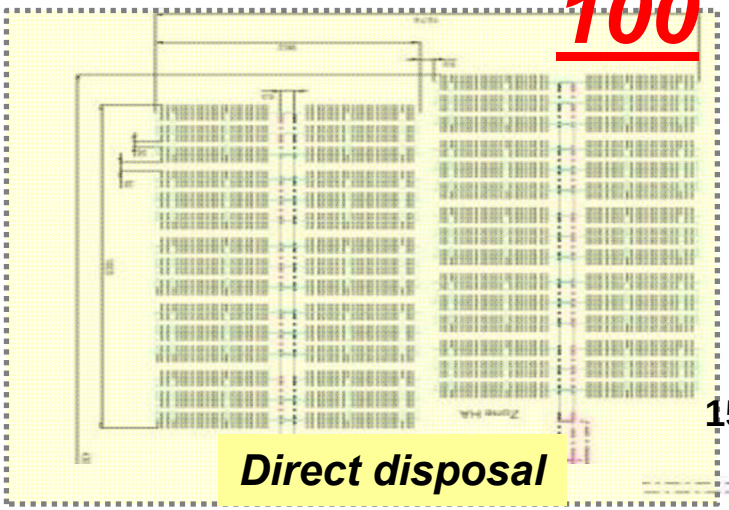
5

GenIV



30

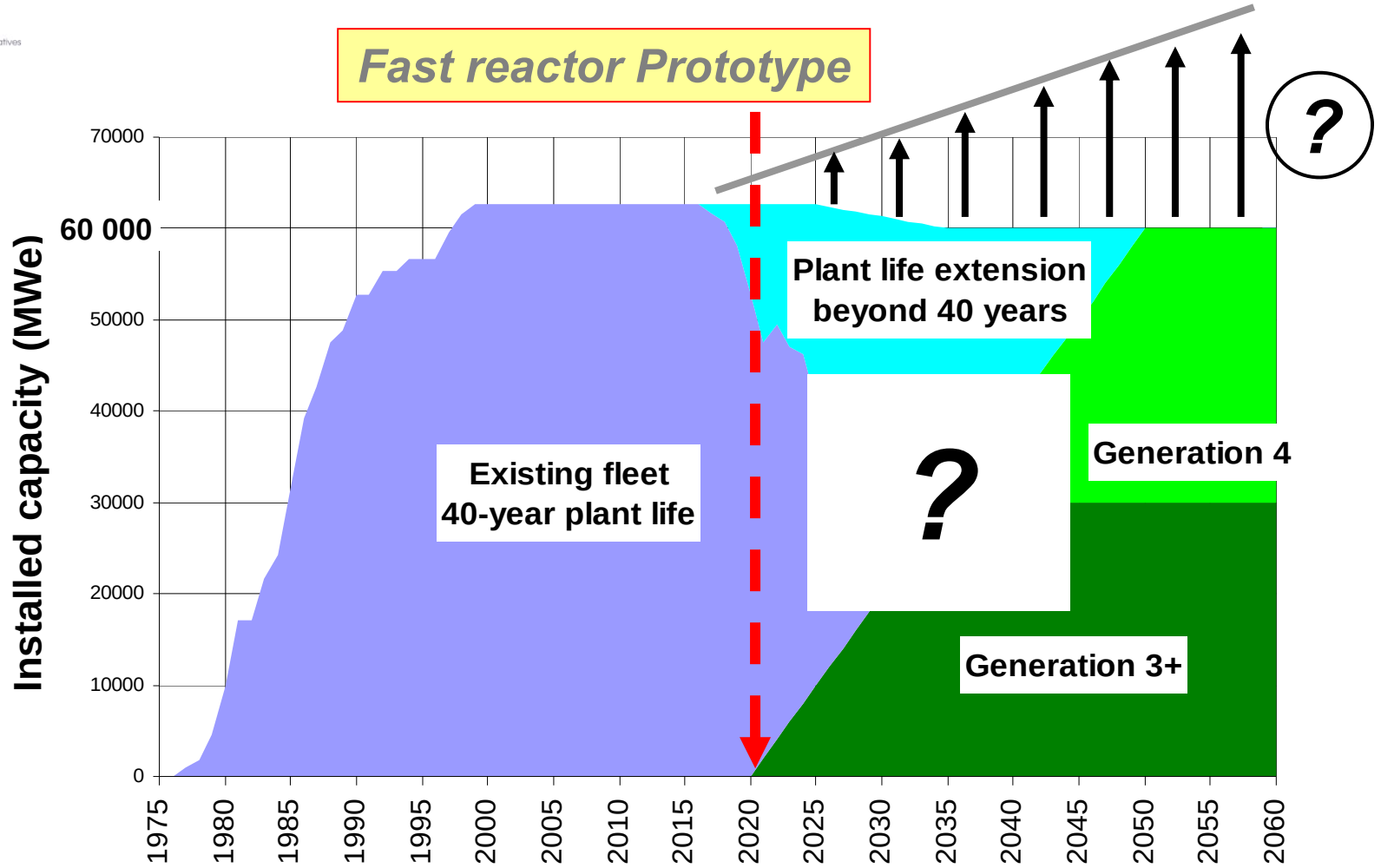
Current glasses



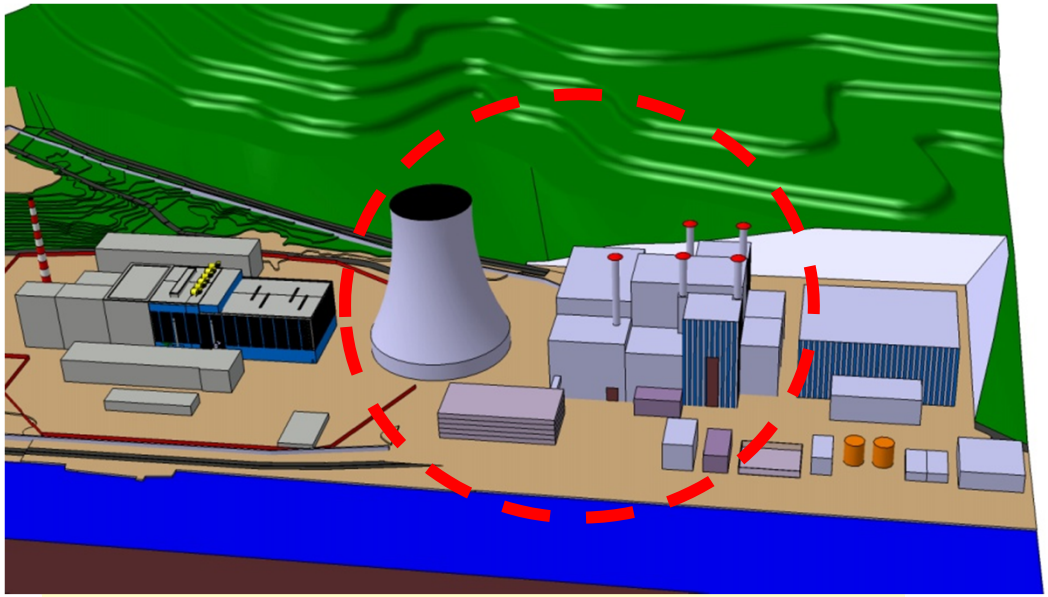
100

Direct disposal

# FROM LWRs TO FRs…A SCHEMATIC PATHWAY

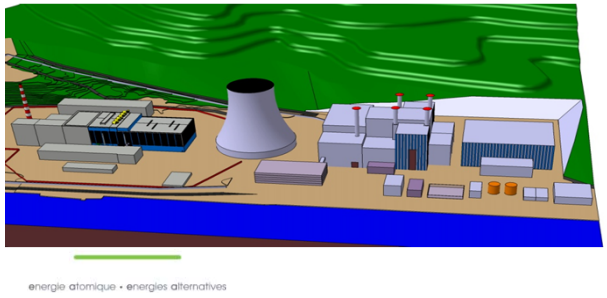


# THE ASTRID FAST REACTOR PROTOTYPE



***sodium-cooled***
***#600 Mwe***

***« Advanced Sodium-cooled Technological Reactor for Industrial Demonstration »***




# ASTRID PROTOTYPE Schedule

*Preliminary choice of options*

*Decision to continue*

*Decision to build*

*Fuel loading*

*ASTRID*

2009 2010 2011 2012 2013 2014 2015 2016 2017

*Conceptual design -1*

*Conceptual design -2*

*Basic design*

*Detailed design & Construction*

*Facilities*

*Position Report on minor actinides partitioning and transmutation*

*Core manufacturing workshop (AFC)*

*MA bearing fuels fabrication facility (ALFA)*

# JAPAN / FRANCE PARTNERSHIP

- **FRANCE AND JAPAN :**
  - **R&D PARTNERSHIP FOR DECADES !**
    - **JAEA & CEA *JOINT PROGRAMS***
    - ***LARGE SCALE EXPERIMENTS***
    - ***STAFF EXCHANGE***
  - **DRIVERS AND GOALS**
    - ***A CLOSED FUEL CYCLE***
    - ***FAST REACTORS IN PERSPECTIVE***
- **MONJU REACTOR, A KEY-TOOL !**
  - ***ESSENTIAL FOR 4th GENERATION SYSTEMS R&D***
  - ***REINFORCED INTEREST SINCE PHENIX REACTOR SHUT DOWN.***



cle

energie atomique • energies alternatives

# ANNEX:
## *ADDITIONAL SLIDES*

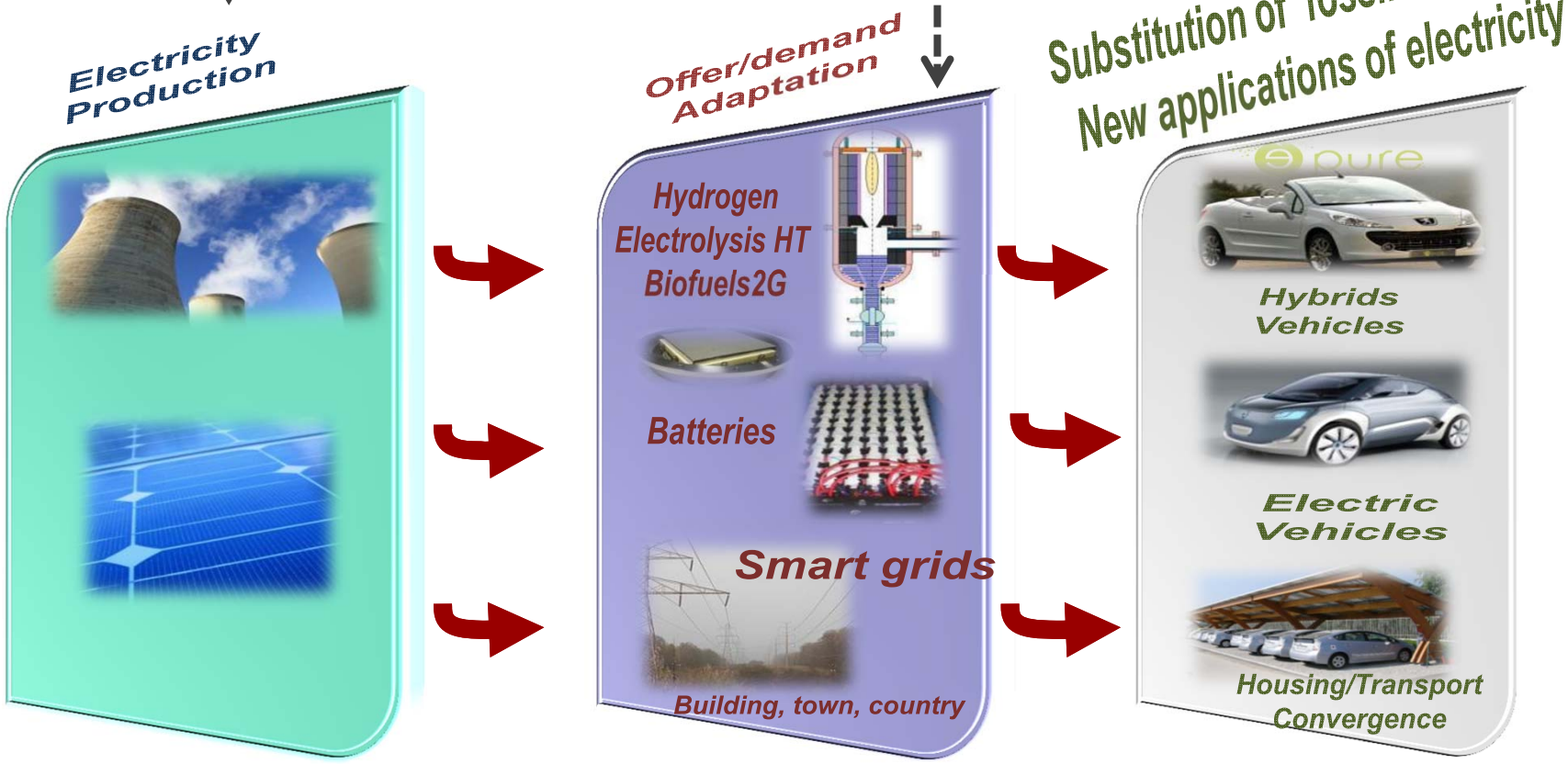
# NUCLEAR ENERGY , AN ENERGY FOR FUTURE…

A POSSIBLE SYNERGISTIC DEVELOPMENT
OF NUCLEAR (BASE LOAD) & RENEWABLES

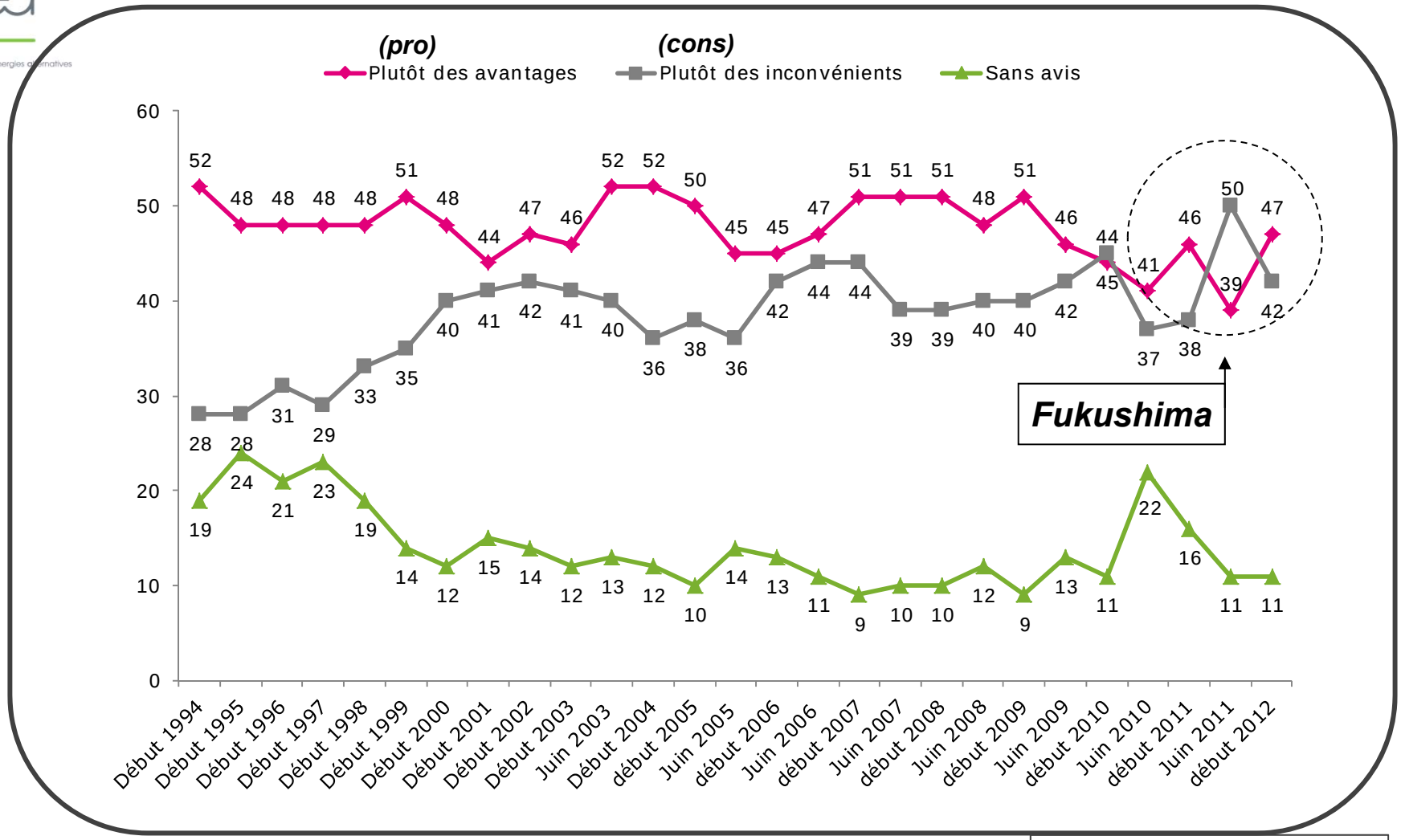
NEW APPROACHES,
NEW APPLICATIONS…

energie atomique • energies alternatives

DEVELOPMENT OF
ENERGY STORAGE CAPABILITIES
AND « INTELLIGENT TECHNOLOGIES »

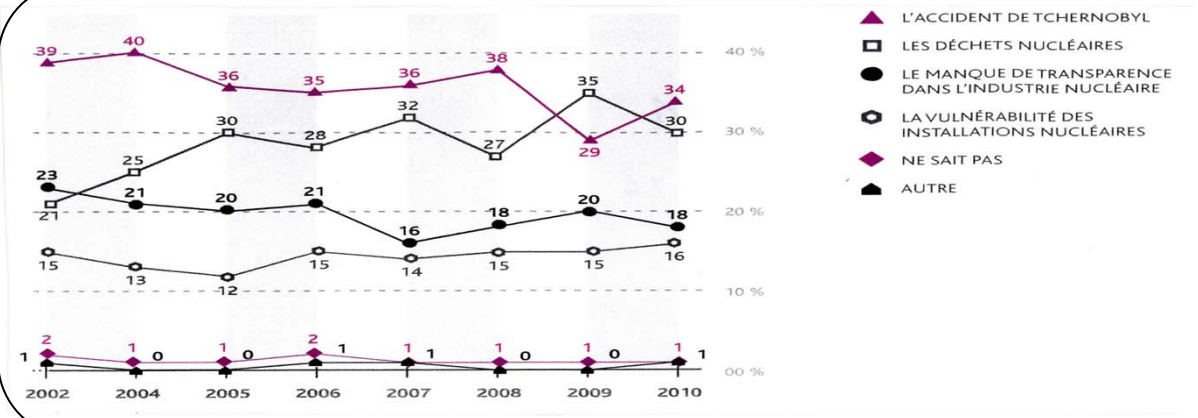


# FRENCH PUBLIC OPINION ABOUT NUCLEAR



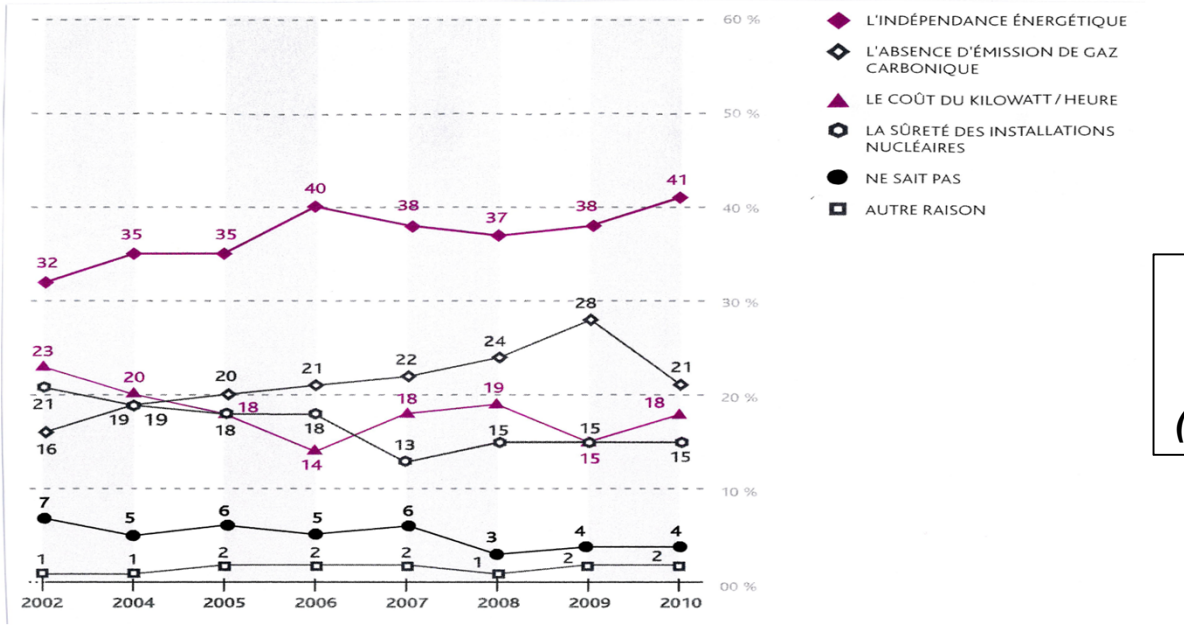

*Ministery of energy, DGEC*

# NUCLEAR ENERGY : *POINTS…*




***NUCLEAR ENERGY:***
***<u>WHY NO?</u>***

***( IRSN, 2010 barometer)***




***NUCLEAR ENERGY:***
***<u>WHY ?</u>***

***( IRSN, 2010 barometer)***

# THE 2006 FRENCH ACT
## (RW & nuclear materials management)


➧ **PRINCIPLES** :

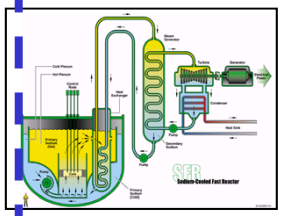
- ***RECYCLE (reprocess)***
  ***to decrease waste amount & toxicity***
- ***RETRIEVABLE GEOLOGICAL REPOSITORY,***
  ***for ultimate waste***

➧ **A « ROADMAP » :**

- ***2012 : assess the industrial potentialities***
  ***of advanced recycling options in 4th generation systems***
  ***(prototype 2020)***
- ***2015 : repository defined***
  ***(operation by 2025)***

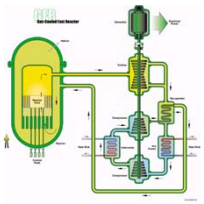
# FAST REACTORS DEVELOPMENT : *FRENCH STRATEGY*

- **Sodium Fast Reactor, the reference option :**
  ***ASTRID, the prototype***



- **maturity, possible further improvments** ***(safety, operability, economics)***
- **commercial level 2040**
- **developped with industrial and international partners**

- ***Gas-cooled Fast Reactor, a long-term option:***
  ***( ALLEGRO, experimental-scale project)***



- ***attractive potentialities but heavy challenges (materials, fuel, safety)***
- ***in Europe?***

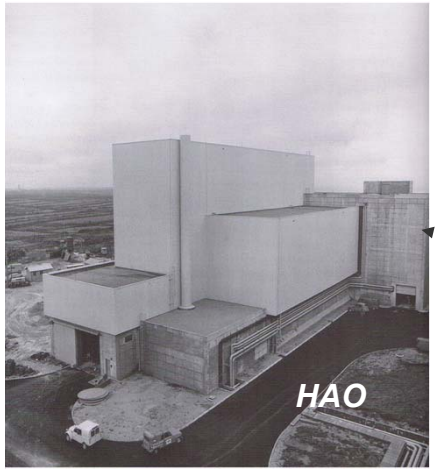
# FAST REACTORS OXIDE FUELS FABRICATION

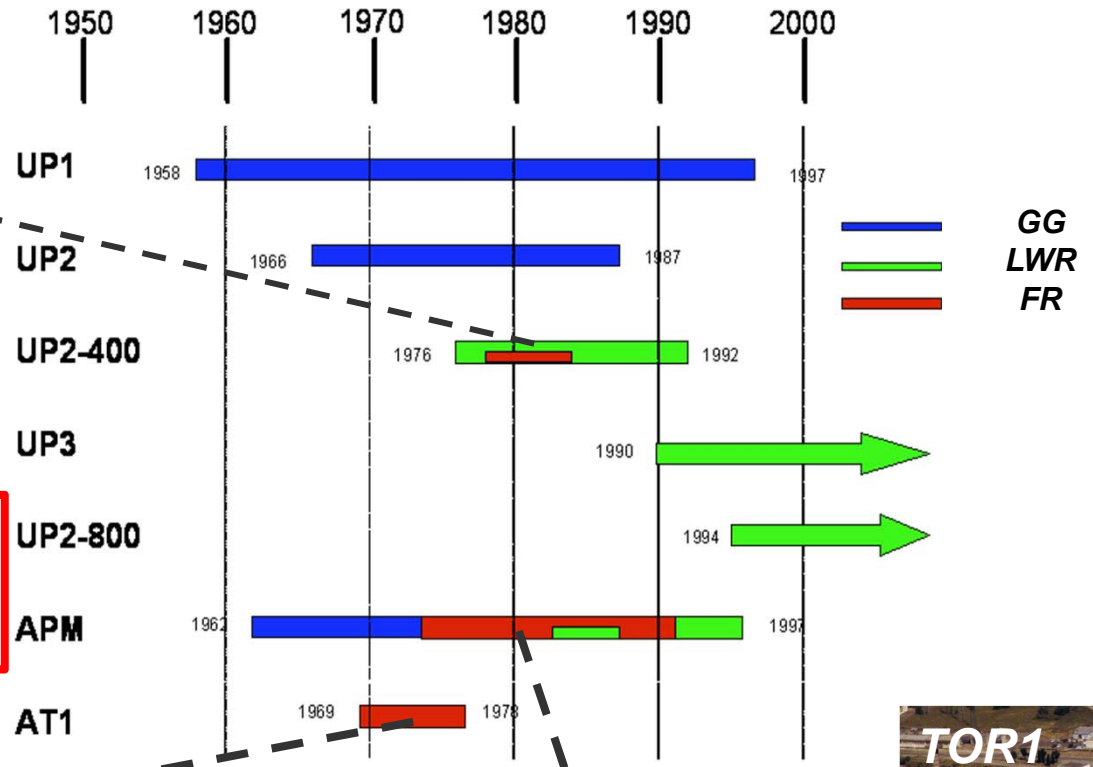



## OXYDE SFR FUELS FABRICATION1963 - 1999

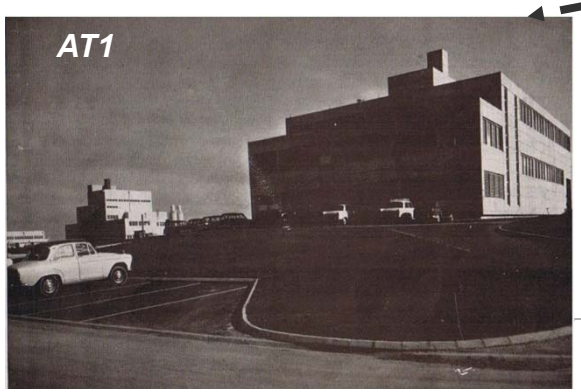
| Réacteurs | Nb. d'aiguilles | Nb. de pastilles (millions) | Pastilles ($t_{ML}$) | Masse Pu (t) |
|---|---|---|---|---|
| Rapsodie | 28 536 | 1 | 1,2 | 0,35 |
| Phénix | 180 941 | 12,6 | 32,4 | 8,2 |
| Super-Phénix | 208 396 | 16,9 | 71,2 | 12,7 |
| PFR (GB) | 9 555 | 0,7 | 1,6 | 0,54 |
| Total | 427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

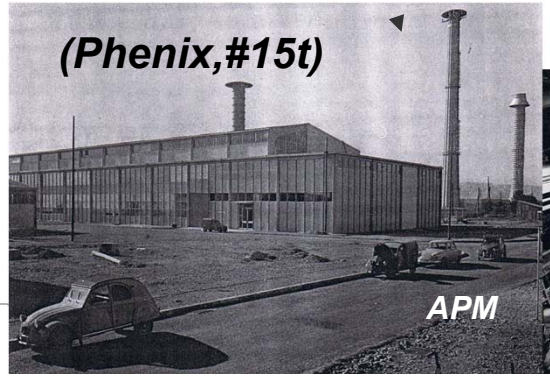
# FR FUEL REPROCESSING IN FRANCE



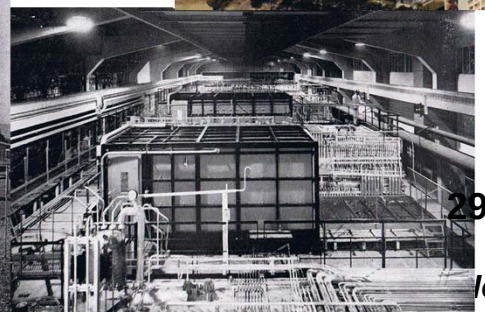




***# 25 tons***
***FR fuel reprocessed***

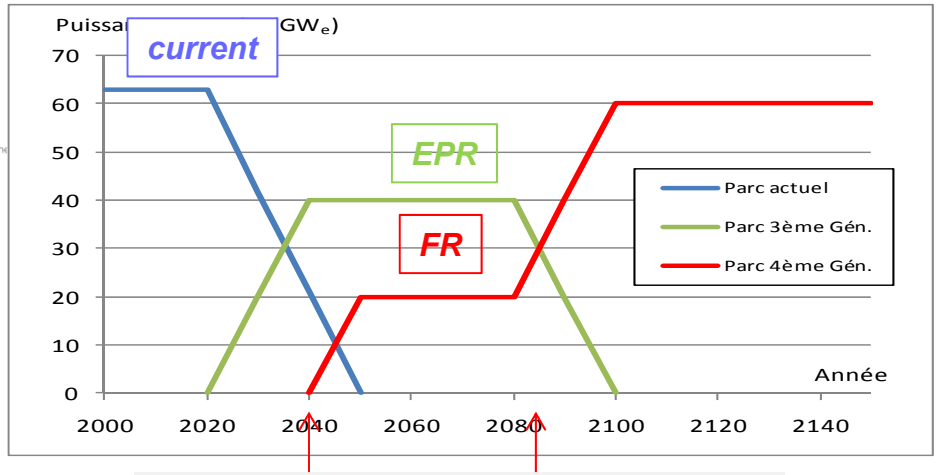


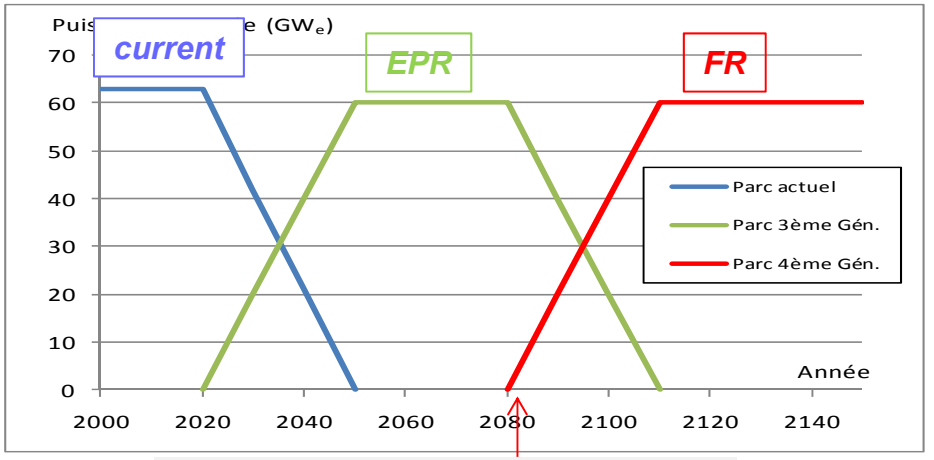




# SCENARIOS FOR FR DEPLOYMENT

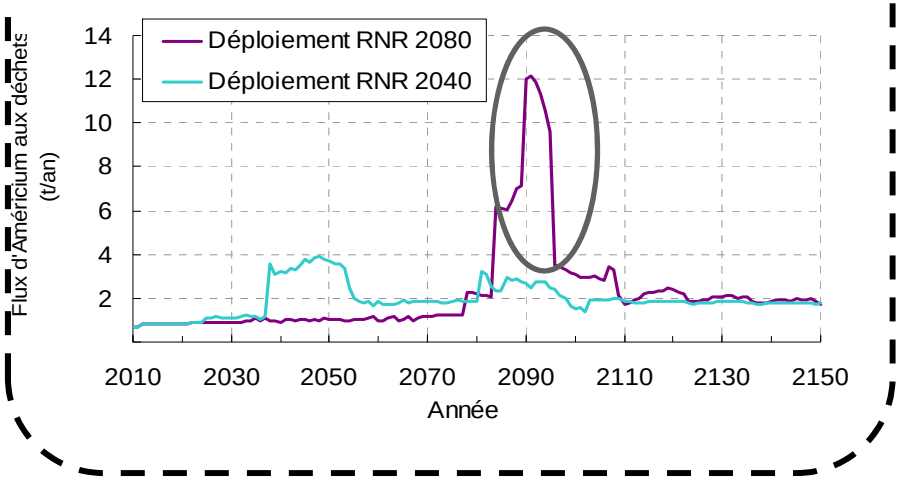



« 2 steps » FR deployment

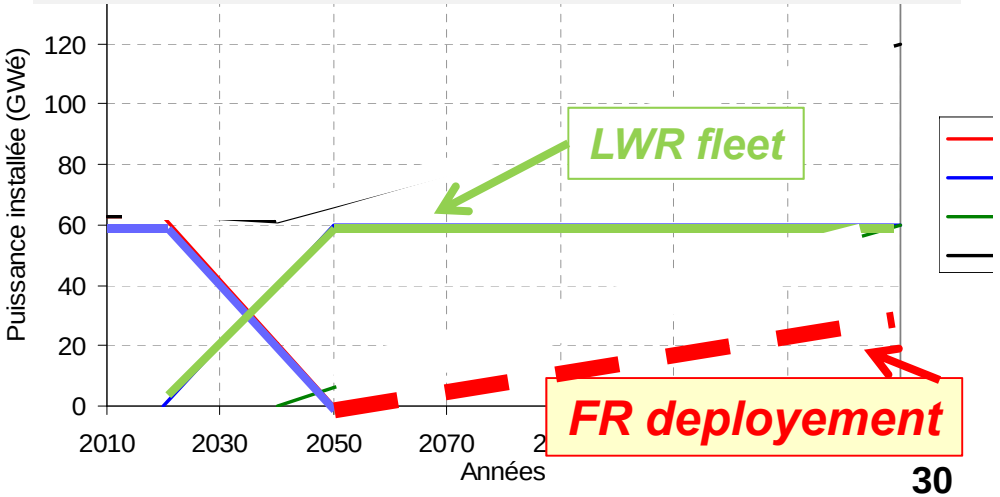



delayed FR deployment

## Americium to waste



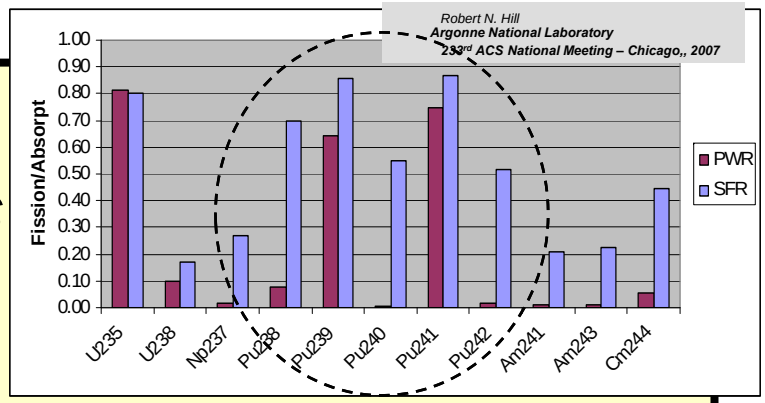

## Progressive / flexible FR deployment



# 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)***

# 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***

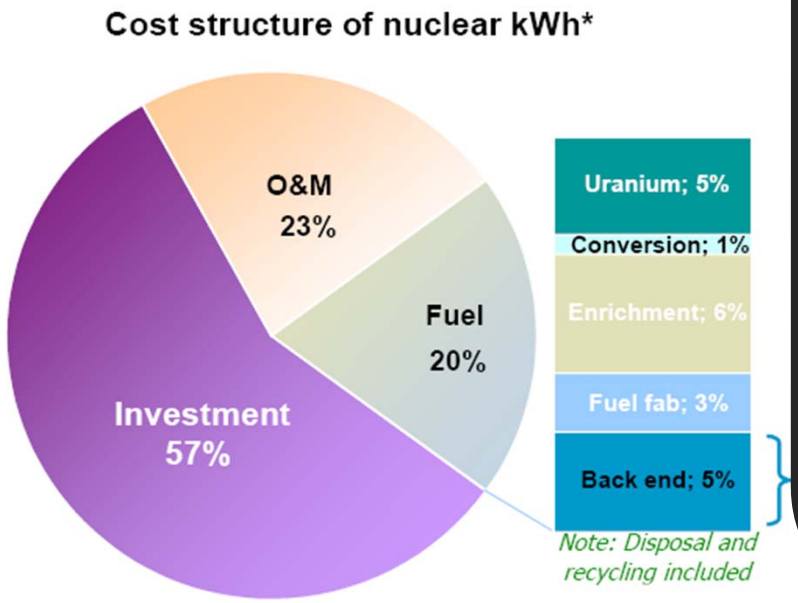
**after 6 months : *8.5***

**5 years : *14***

**20 years : *25***

**50 years : *32***

# FUEL CYCLE ECONOMICS




***•Fuel costs represent about ~20% of the total cost of generating electricity with nuclear energy.***

***•Back-End costs (either open or closed cycle) represent about 5% of the total cost of electricity generation.***

***Direct Disposal and Recycling economics are comparable.***

** Source: OECD/AEN 2002 "Trends in the Nuclear Fuel Cycle: Economic, Environmental and Social Aspects"*

- **Nuclear energy is competitive, with or without recycling.**
- **And recycling reduces the exposure to uncertainties (disposal), which is the main issue of the back end.**