IAEA/JAEA INTERNATIONAL WORKSHOP

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NUCLEAR ENERGY IN THE 21th CENTURY:

MAIN TRENDS AND POSSIBLE SCENARIOS IN FRANCE

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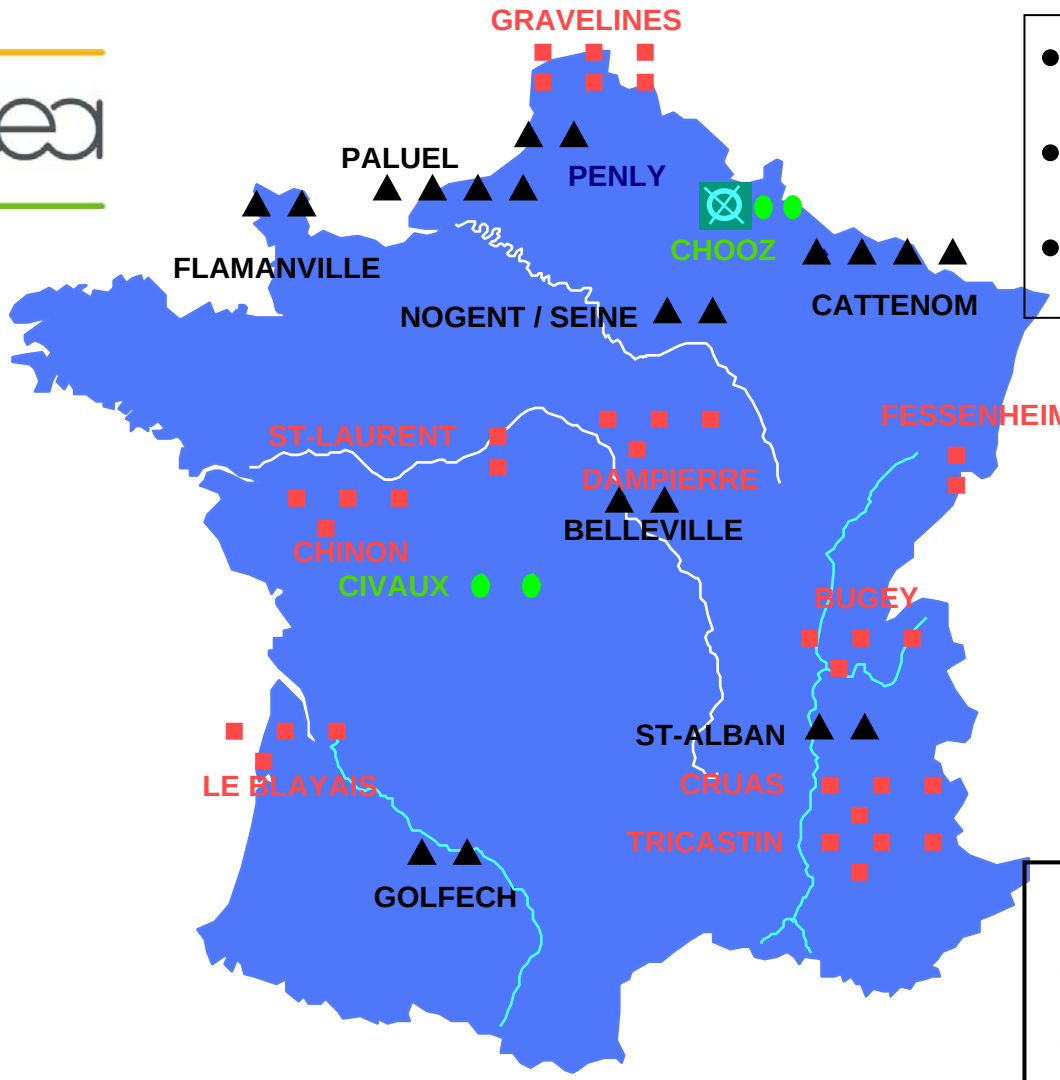
NUCLEAR POWER PLANTS in FRANCE



- 34 900 MWe units ■
- 20 1300 MWe units ▲
- 4 1500 MWe units ●

58 units

63 GWe installed

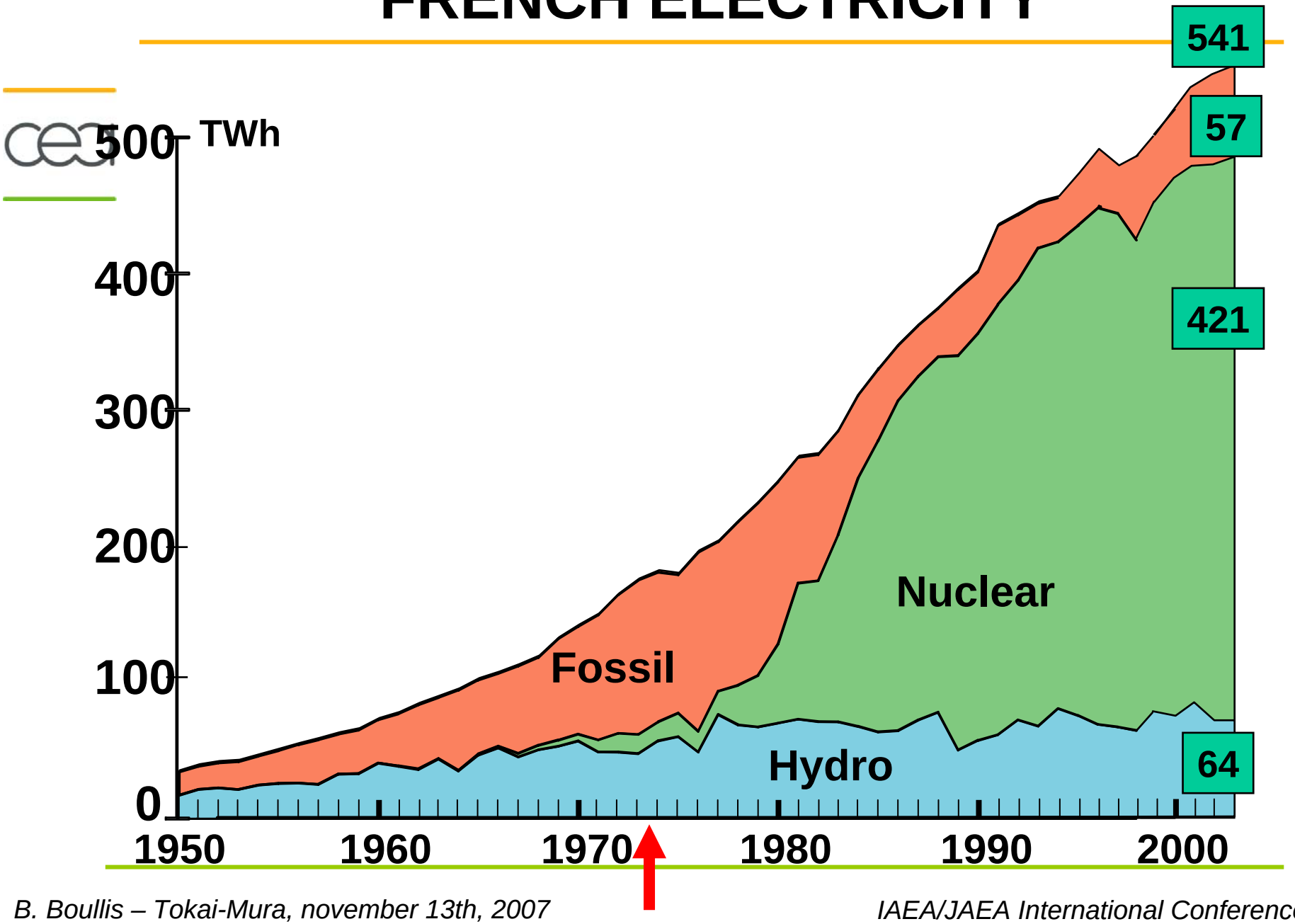
415 net TWh in 2004

Connection to the grid :

– Unit 1 *(Fessenheim 1)* : 1977

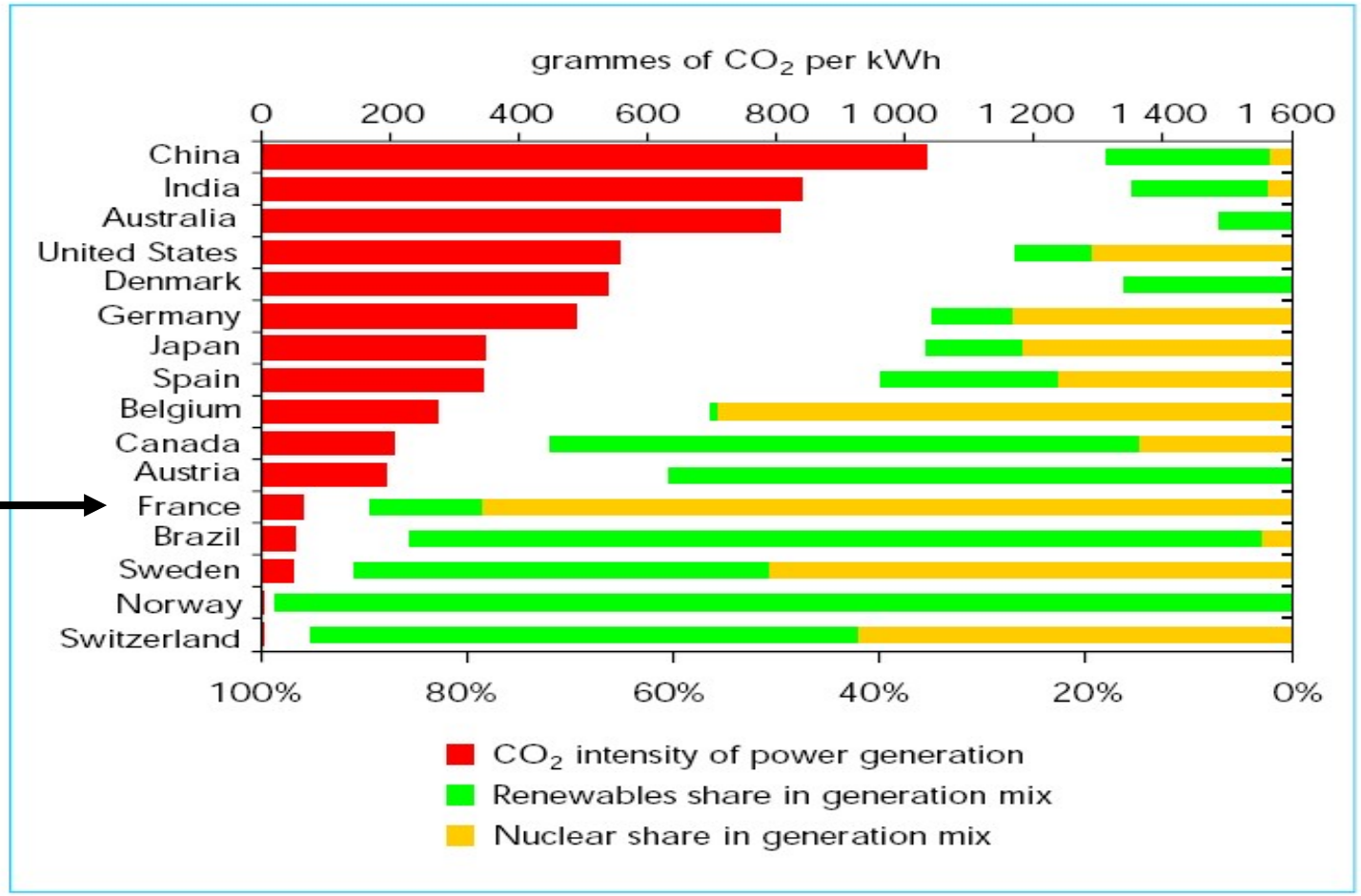
– Unit 58 (Civaux 2) : 1999

FRENCH ELECTRICITY



CO2 RELEASE AND ELECTRICITY GENERATION

Figure 13.1: **Power Sector CO_2 Emissions per kWh and Shares of Nuclear Power and Renewables in Selected Countries, 2004**



Source AIE 2006

NUCLEAR ENERGY IN FRANCE

- **58 LWRs *(and PHENIX !)***
- **>75 % ELECTRICITY SUPPLY**

- **A « CLOSED » FUEL CYCLE :**
  - ***UOX SPENT FUEL REPROCESSED***
  - ***U RECYCLED (2 REACTORS)***
  - ***Pu RECYCLED (20 REACTORS) (from 1987)***

SPENT FUEL REPROCESSING AND RECYCLING

LA HAGUE

UP2-UP3 PLANTS

up to 1600t/y *(F+others)*

>20 000 t processed

MARCOULE

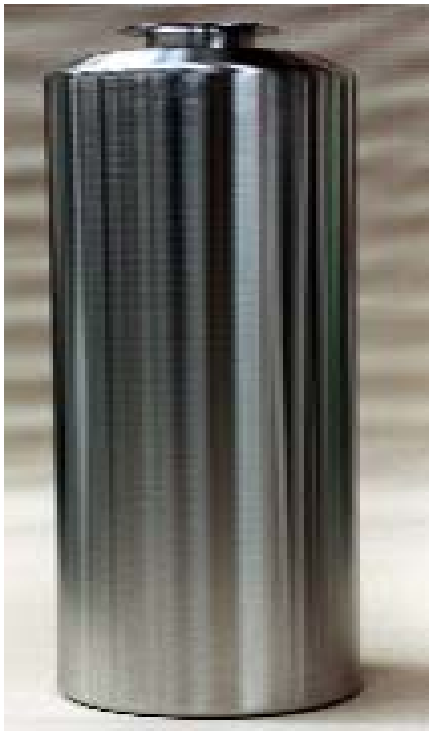
MELOX PLANT

100t/Y *(220 fuel assemblies)*

>1200t manufactured

> 10.000 GLASS CANISTERS

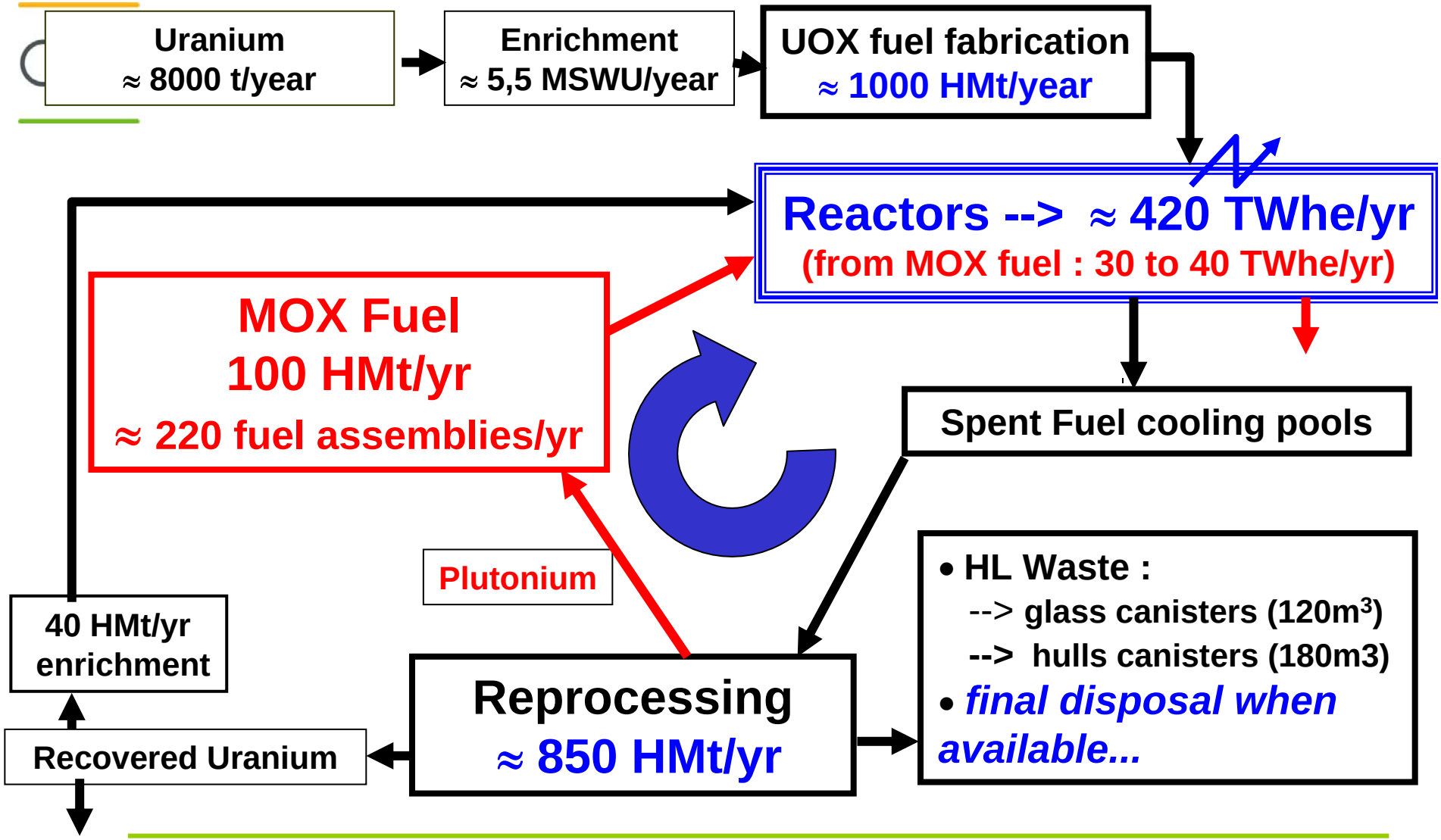
15% FPs oxides



180 liters

Hulls (compacted)

TODAY FRENCH CLOSED FUEL CYCLE



A CONTRIBUTION TO SUSTAINABILITY

The closed fuel cycle strategy, along with reprocessing and MOX recycling, enables today, with existing facilities *:*

- **Reduction / stabilization of spent fuel quantity** :

  7 UO2 spent fuel → 1 MOX spent fuel

- **Vitrification of high level nuclear waste :**
  - *a safe and long-lasting confinement, an international standart*
  - *a reduced volume: around 1200 m3 today, and up to 5000 m3 in 2030*

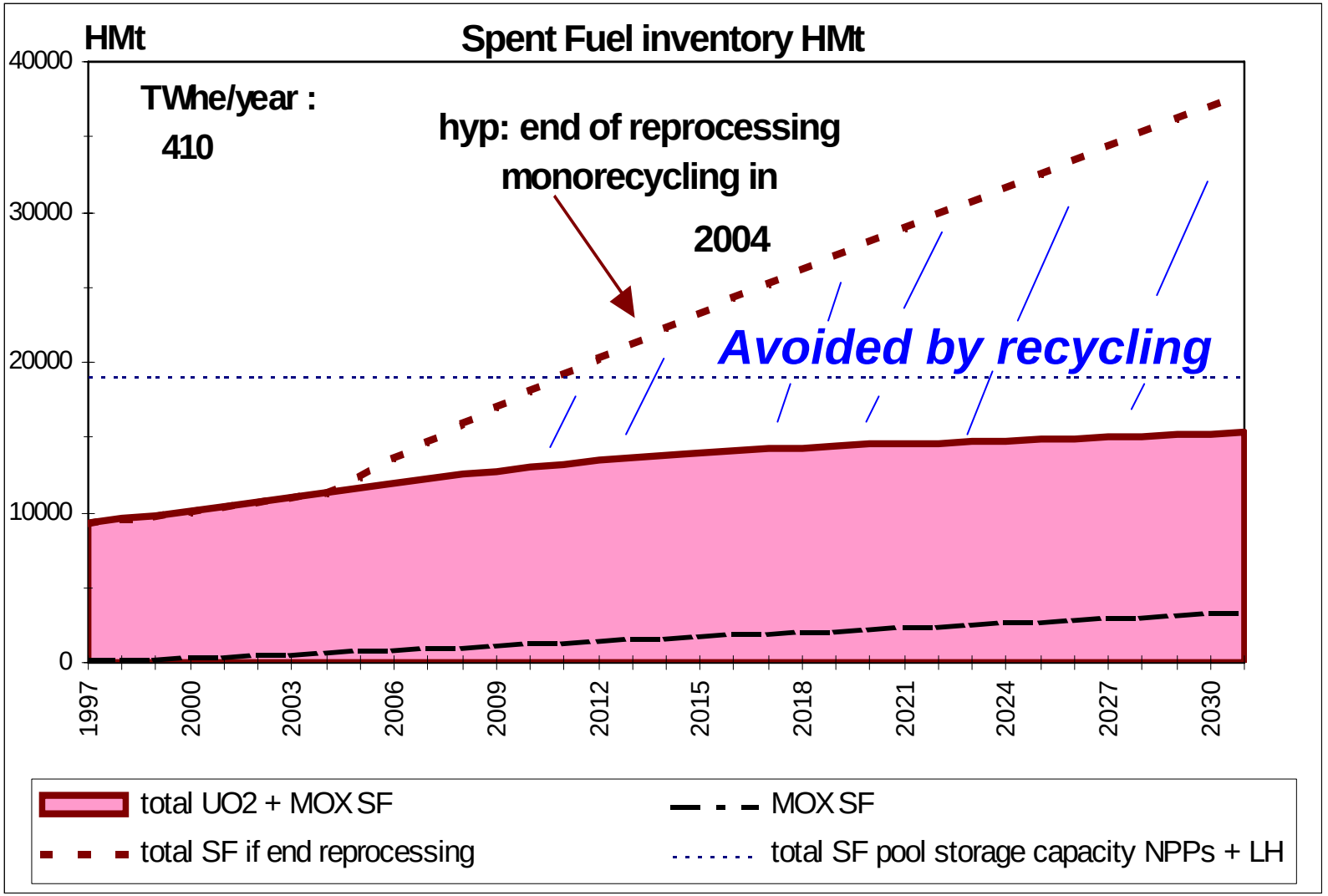
- **Recycling of plutonium and recovered uranium**

  30% Pu is consumed, produces up to 40 TWh/yr (up to 10% production)

- **Preservation of long term energy resources**

  concentration of Pu in MOX spent fuel under a reduced volume, leaves open the possibility to reuse Pu in the future

SPENT FUEL INTERIM STORAGE



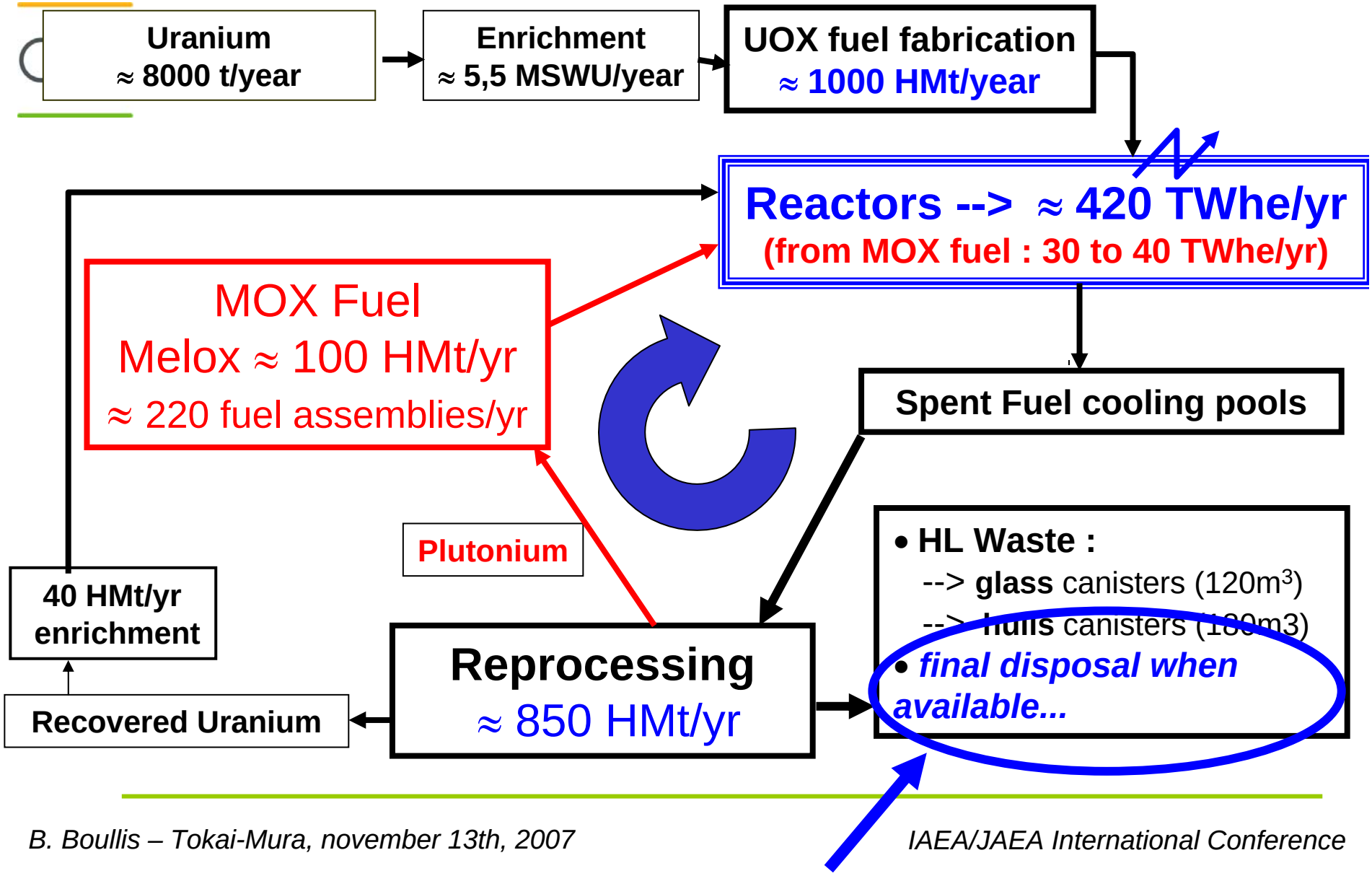
A FIRST TRACK FOR THE FUTURE:

RECYCLE PLUTONIUM INTO GEN3 LWRs !

- **Necessity *to avoid spent fuel accumulation* when worldwide *« nuclear renaissance »* is there!**

- **Today's technology as an efficient basis, possibly improved by *uranium-plutonium co-management***
  (COEX process, no « pure plutonium stream »)

TODAY FRENCH CLOSED FUEL CYCLE



HALL WASTE : THE 1991 FRENCH ACT

30, december, 1991

- **3 RESEARCH THEMATICS :**

  – ***partitionning & transmutation of LLRNs ;***

  – ***deep repository ;***

  – ***confinment & interim storage.***

- ***2006 : a public debate, and a new bill***

THE 2006 FRENCH ACT

28, june, 2006

➡ **ENOUNCES PRINCIPLES :**

– ***RECYCLE (reprocess)***

to decrease waste amount & toxicity

– ***RETRIEVABLE GEOLOGICAL REPOSITORY***

the reference option for ultimate waste management.

THE 2006 FRENCH ACT …

28, june, 2006

➡ **PRECISES A « ROADMAP » :**

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

PRESENTATION OF THE 2006 FRENCH ACT

"With this text, the Government doesn't propose to you a definitive solution to the question of radwaste management; he proposes to take time enough to implement (step by step) the solution …."

François LOOS, Minister for Industry
French Parliament, 6 april 2006

NUCLEAR ENERGY IN FRANCE:
TRENDS FOR THE FUTURE

A « CLOSED FUEL CYCLE » !

- **WITH *CURRENT GEN II LWRs***
- **THEN WITH *GEN III EPRs***

GENERATION III ADVANCED REACTORS

A new generation of reactors

taking advantage of the large experience acquired in the operation of Gen II plants (LWRs mainly)

- **a main objective: new improvements in safety while improving economic competitiveness**

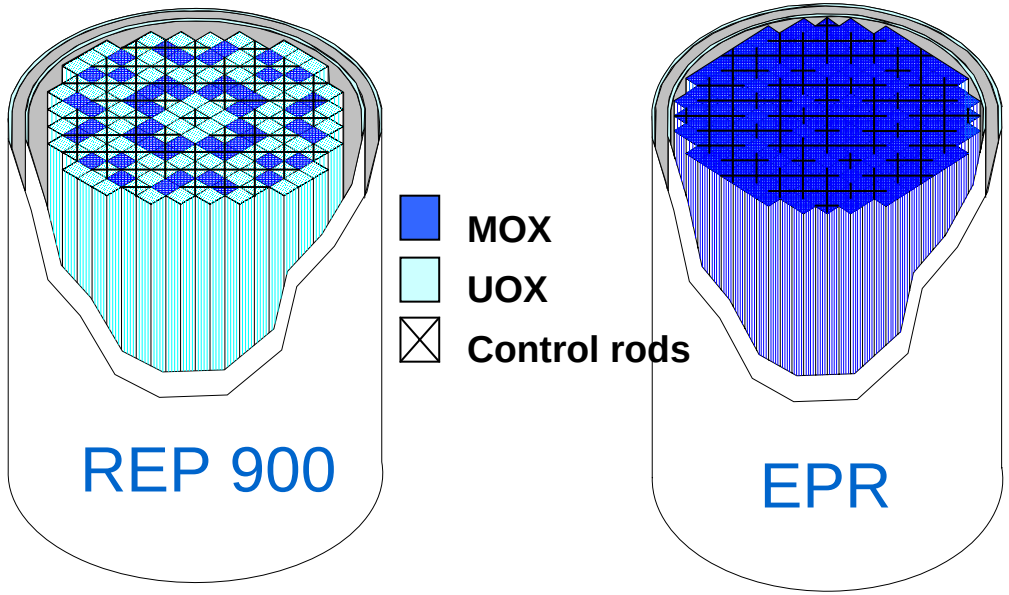
- ***Mitigation of severe accident consequence, major goal***

FLAMANVILLE 3 : EPR in FRANCE

site permit <u>april 2007</u>, operation by <u>2012</u>

Gen III REACTORS FEATURES

Gen III reactors such as EPR may help to reduce the plutonium inventory



Capacity to load up to 100% MOX Core

Plutonium annual balance (Kg Pu/year)

REP 900 UO_2 : + 200

REP 900 MOX : 0

EPR 100% MOX : - 670

An enhanced capacity to burn Plutonium

MAIN CRITERIA FOR FUTURE NUCLEAR SYSTEMS

(1) COSTS

(2) SAFETY

(3) « SUSTAINABILITY » :

. rational use of natural resources

. waste minimization

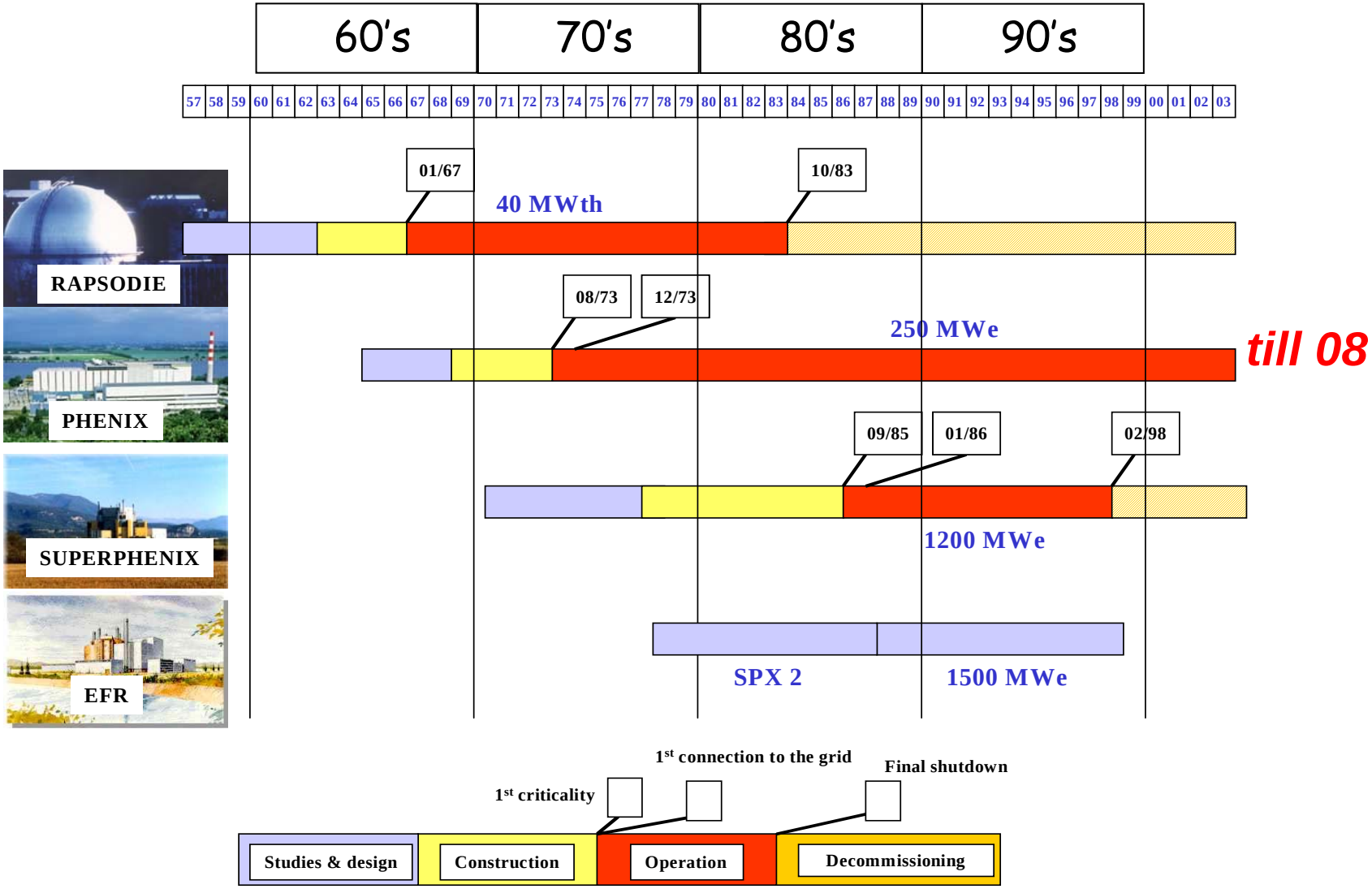
. resistance vs. proliferation risks

NUCLEAR ENERGY IN FRANCE:
TRENDS FOR THE FUTURE

A « CLOSED FUEL CYCLE » !

- **WITH *CURRENT GEN II LWRs***
- **THEN WITH *GEN III EPRs* (1st Unit, 2012)**
- **THEN WITH *GEN IV FAST REACTORS*:**
  - ***Uranium & plutonium (fuel resource extended)***
  - ***Americium, Neptunium, Curium ? (radiotoxicity decreased, …)***

FAST REACTORS PROJECTS



FROM GENERATION III *TO GENERATION IV*

- **LWRs: many advantages,**
  but can't satisfy alone sustainability.

- **Sustainability requires fast neutron systems**
  - ***to efficiently burn plutonium, and fully use uranium***
  - ***to reduce efficiently long-term radiotoxicity*.**

- **new concepts at industrial maturity :**
  two or three decades
  (Gen III deployement & operation)

- **Plutonium stored in spent LWR- MOX fuels could allow *around 2040* the progressive start-up of several fast reactors.**

FRENCH PRESIDENT, 6 january, 2006

« …many countries think to the next generation of nuclear reactors, for 2030-2040, which will produce less waste and will use in a better way fissile materials .

I decided to launch now the design, by the CEA teams, of a prototype of such a reactor, which will be commissionned by 2020.

We will cooperate, obviously, with industrial and international partners who would propose to join us in this project… »

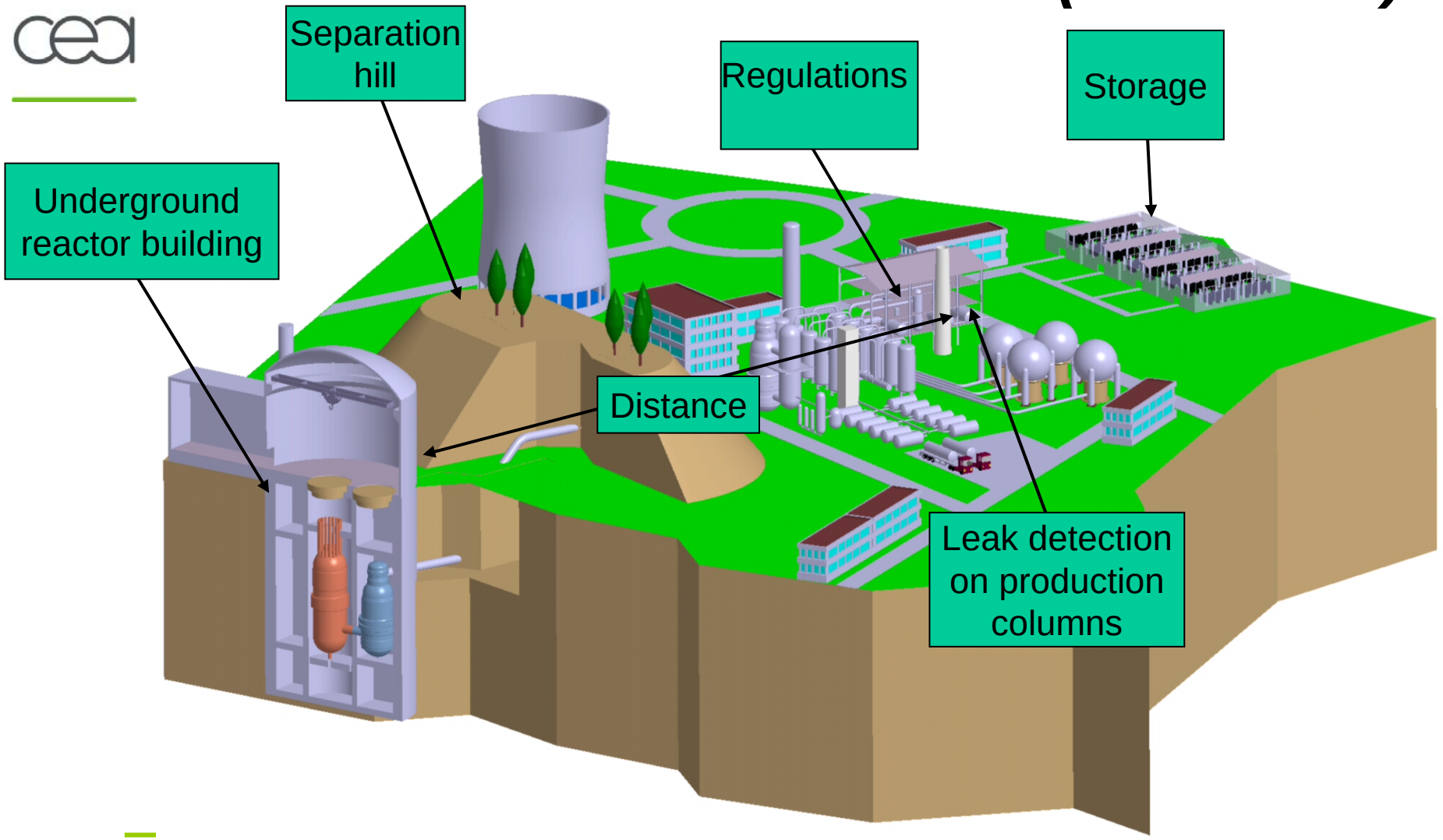
NUCLEAR ENERGY IN FRANCE:
TRENDS FOR THE FUTURE

A « CLOSED FUEL CYCLE » !

- **WITH *CURRENT GEN II LWRs***
  (today 22 years old in average)
- **THEN WITH *GEN III EPRs***
  (1st Unit, 2012)
- **THEN WITH *GEN IV FAST REACTORS***
  (transition from 2040?)

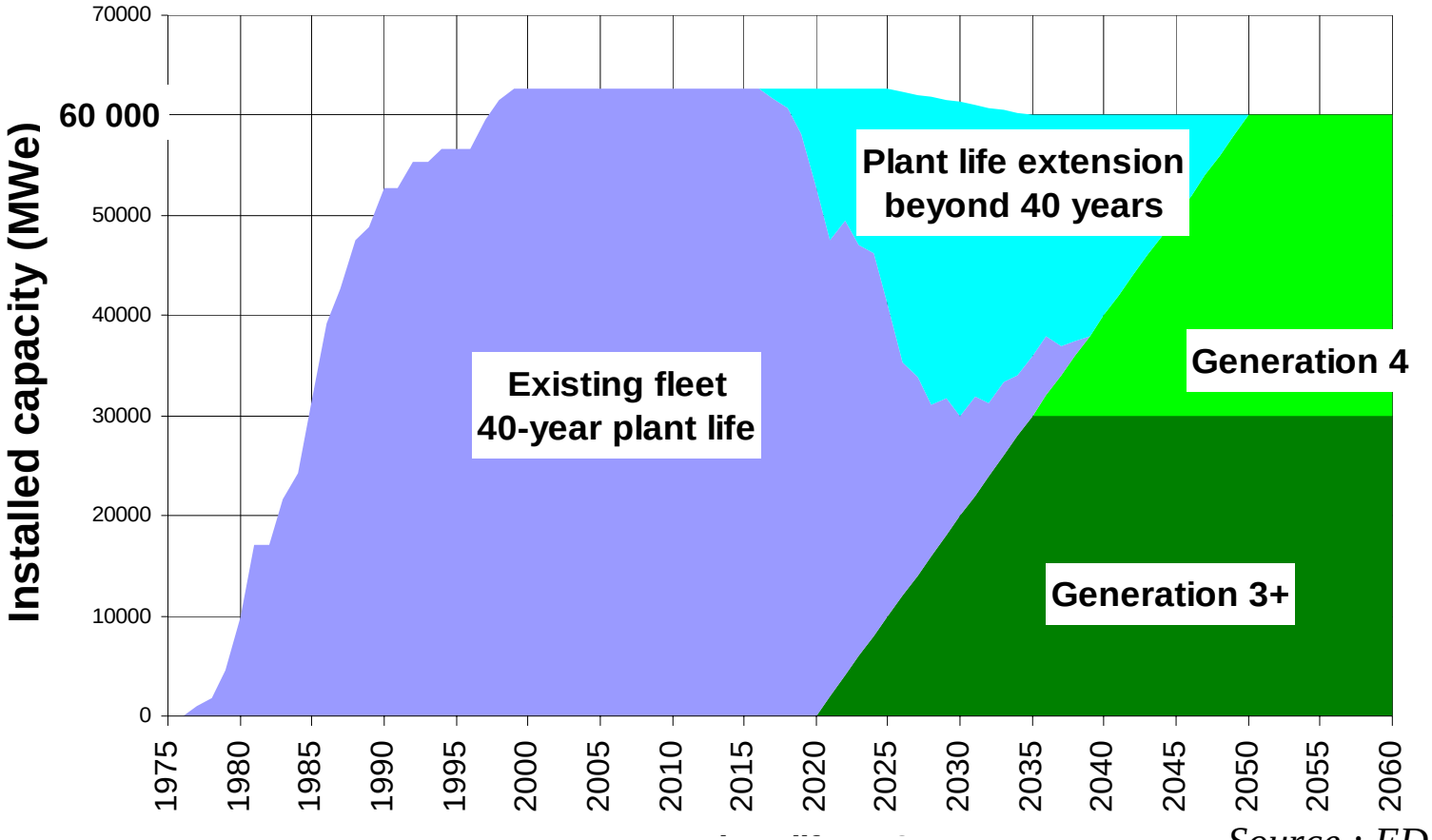
AND HYDROGEN GENERATION ?

(artist view)



Scenario for the renewal of French NPPs

Major role of LWRs over the 21st century



Source : EDF

Scenario for the renewal of French NPPs

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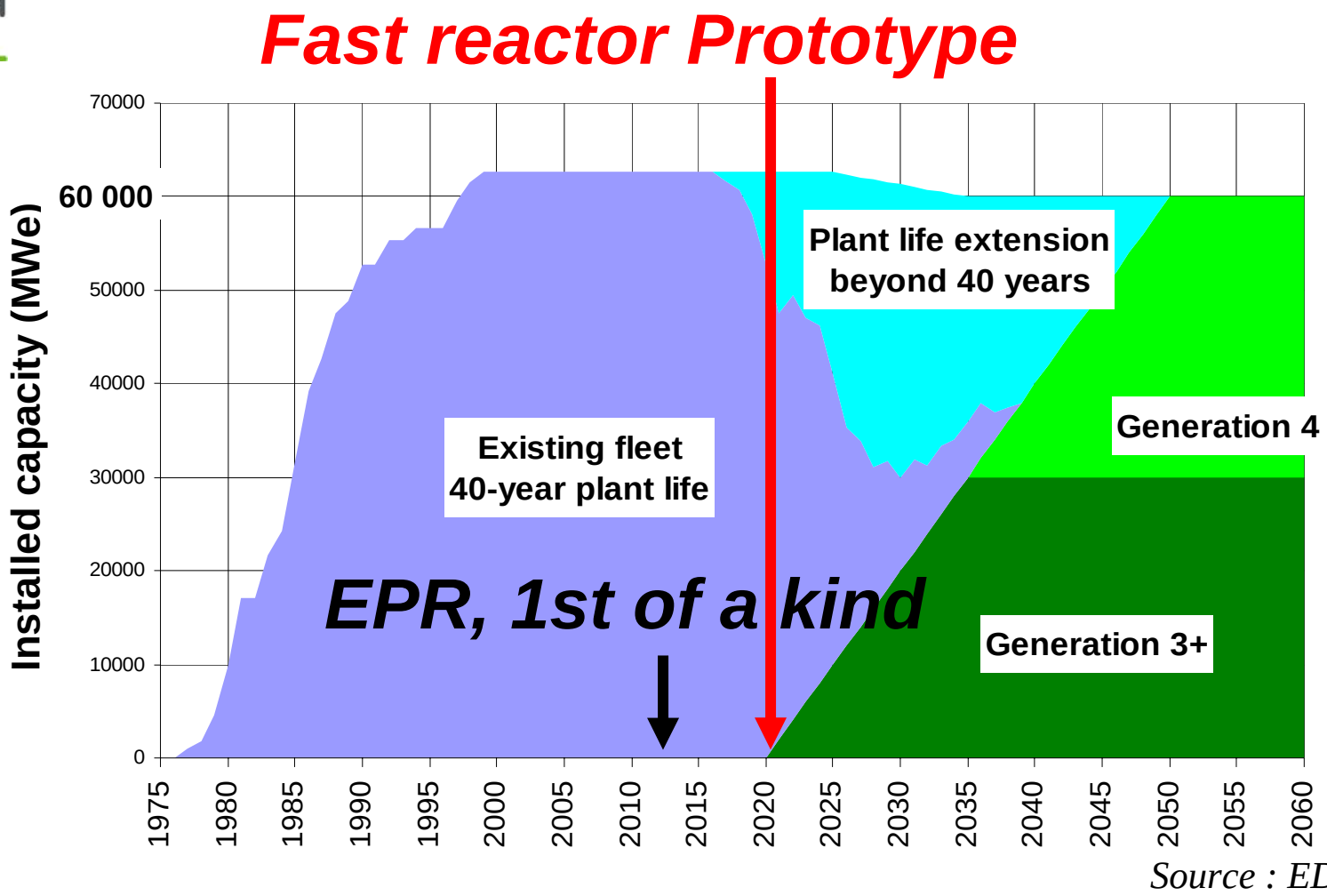


Source : EDF

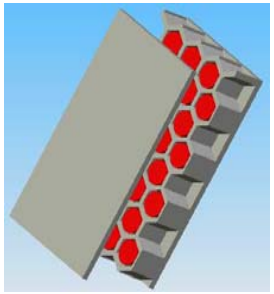
GUIDELINES FOR THE PROTOTYPE…

- ***SFR, the référence option***

  - *near 600 MWe, loops or pool, ..?.*

  - *increased safety ,competitivity, iso-generation, easier in-service inspection …*

- ***GFR, the main alternative***



  - *access to high temperature applications …*

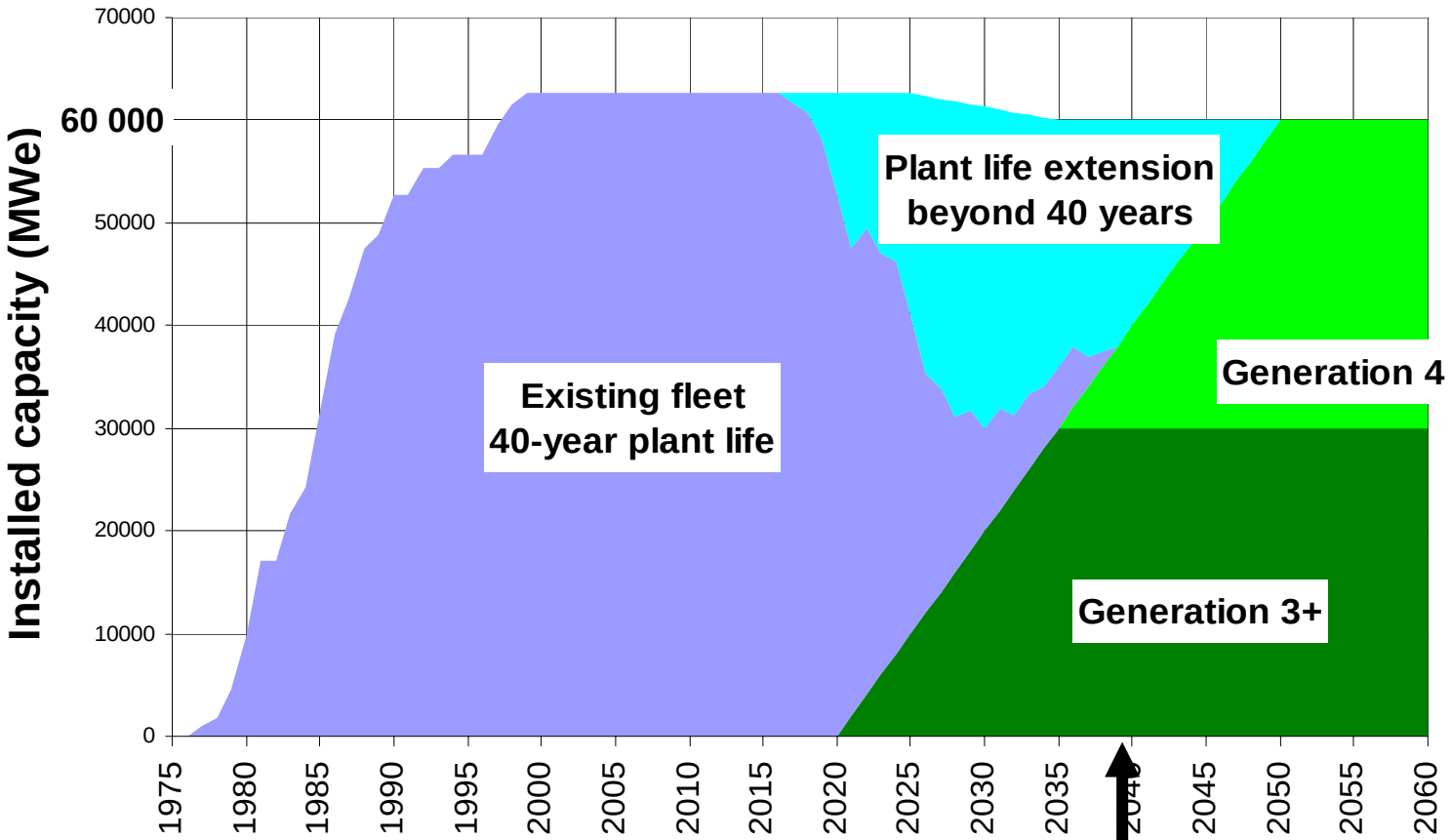
  - *International cooperation, an experimental reactor possibly in Europe (50 MWth)?*

  - *A « challenging » fuel !*

- ***ADS , in the frame of international programs***

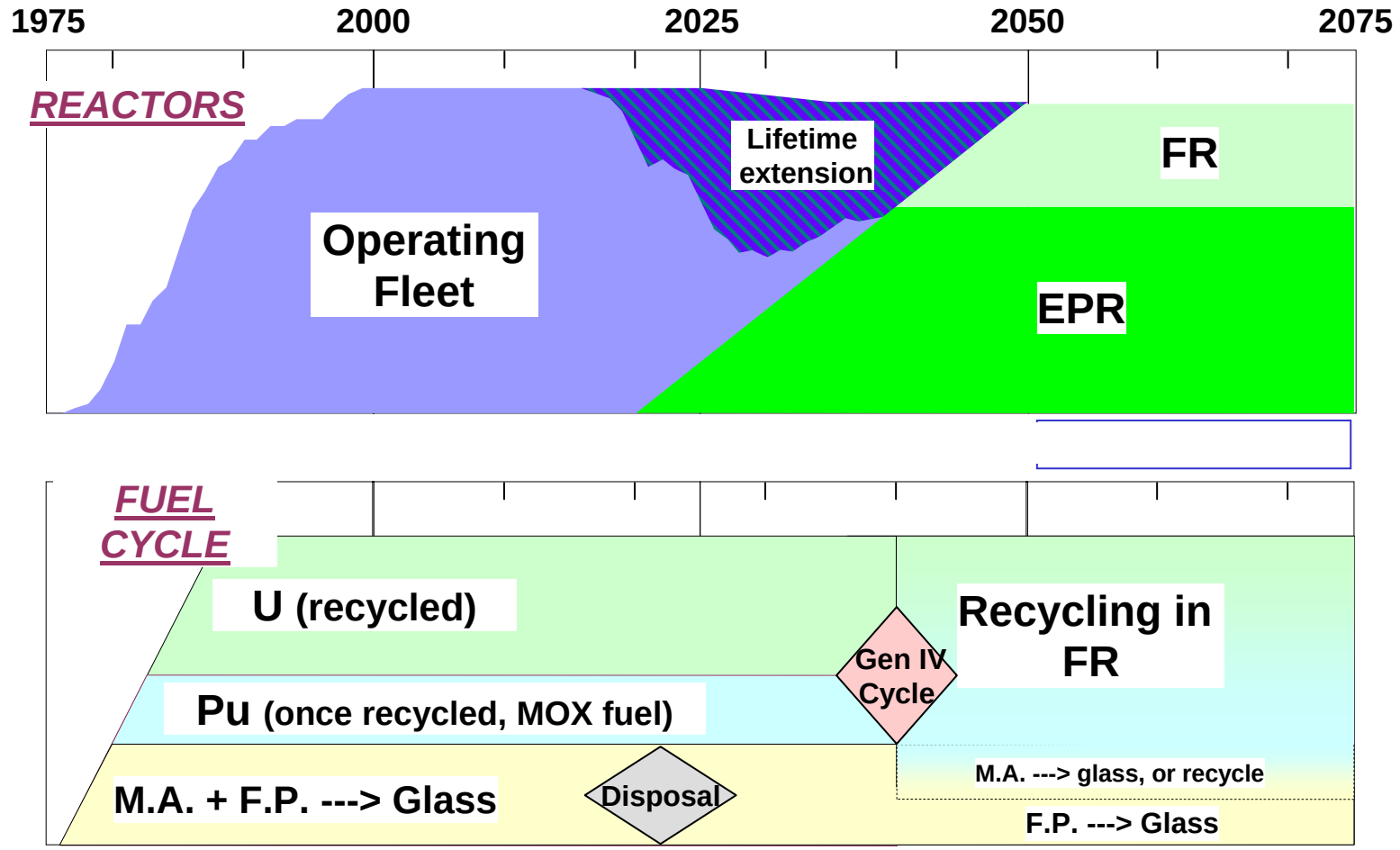
Scenario for the renewal of French NPPs

Major role of LWRs over the 21st century

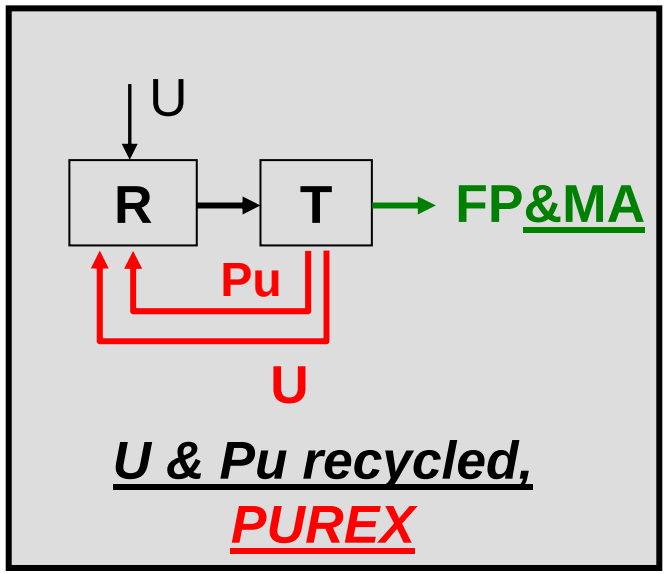


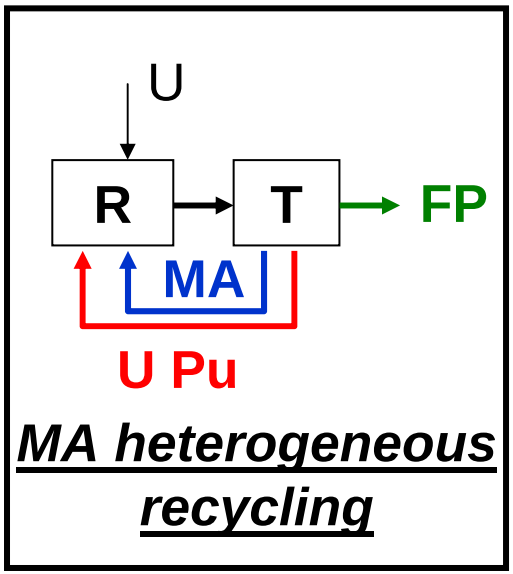
Source : EDF

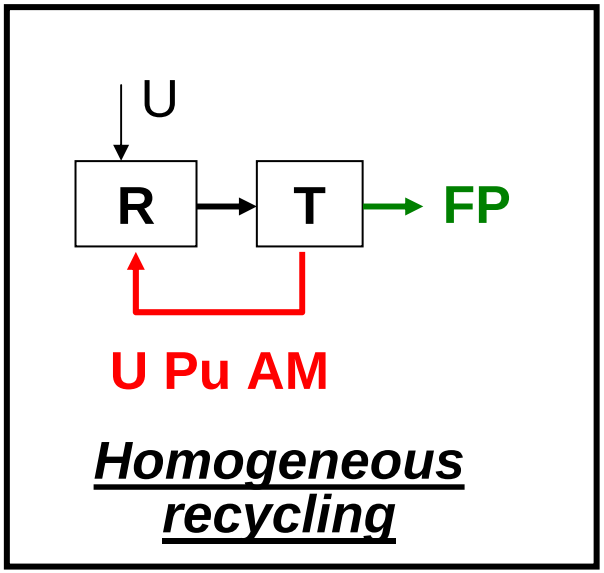
A POSSIBLE SCENARIO IN FRANCE…

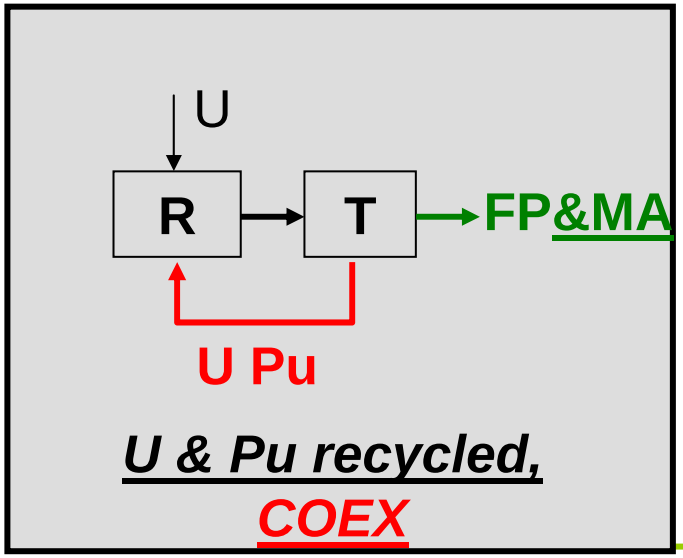


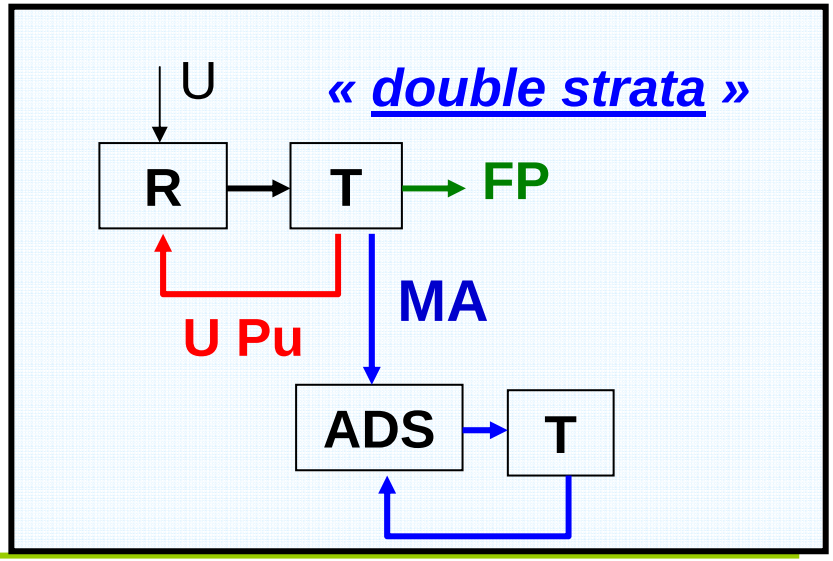
WHICH OPTION FOR THE FUTURE ?











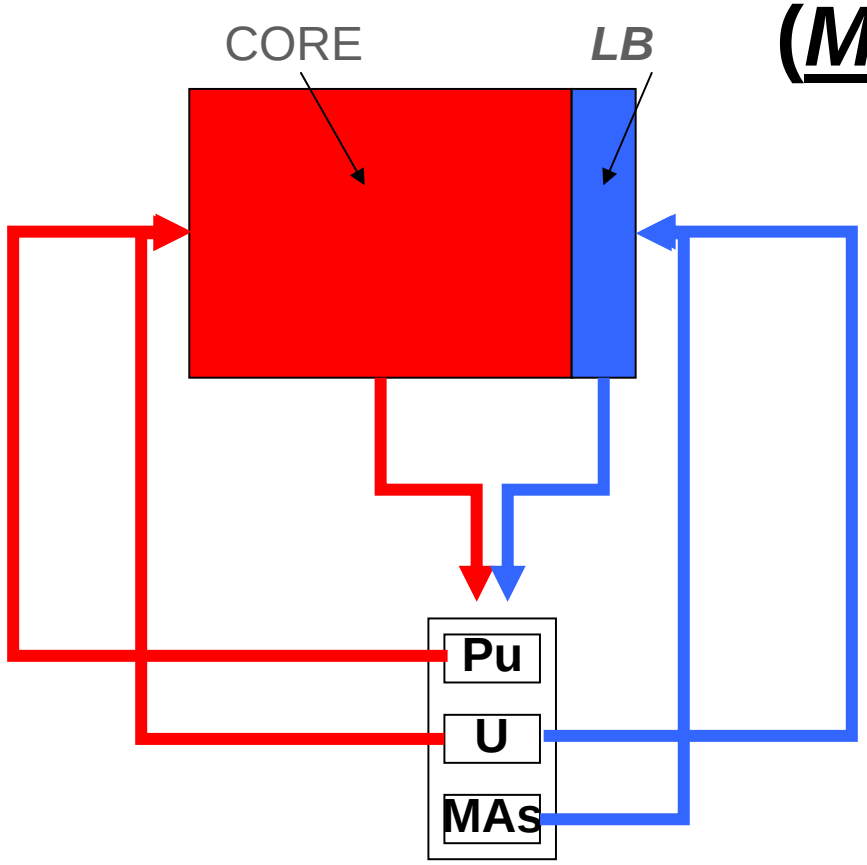
GENERATION IV FUEL CYCLES

CRITERIA TO FIT : *RESOURCE, WASTE , PROLIFERATION-RESISTANCE*

- **SEVERAL OPTIONS,**
  WHICH COULD BE SUCCESSIVELY DEPLOYED
  - **HETEROGENEOUS, HOMOGENEOUS**
  - **AMERICIUM, ALL-ACTINIDE…?**
- **SOLVENT EXTRACTION, INNOVATIVE TECHNOLOGIES ?**

OPTION FOR HETEROGENEOUS MULTI RECYCLE

- **core : $UPuO_2$**
- **“loaded blankets” : $UMAO_2$ (*MA* =Np/Am/Cm)**



NEW FACILITIES AT LA HAGUE ?

SFR / MOX FUEL FABRICATION

(the core of the prototype, tons)

MINOR ACTINIDES PILOT

(experimental pins, MONJU demo, kg)

en résumé…

- TODAY FRENCH LWRs FLEET and CLOSED FUEL CYCLE : an efficient, a mature option
- GENIII REACTORS provide in the next decades a new *optimization step*

  (with optimized technologies for fuel cycle(COEX ?) it could allow a suitable worldwide restart of nuclear energy, avoiding spent fuel accumulation)
- To meet sustainability goals, we need the development of Gen IV systems *including fast reactors*;
- Several fuel cycle options including ,minor actinide recycling ,are still matter of R&D,;
- By 2012, CEA (and partners) will present a project for a fast reactor prototype and related fuel cycle facilities, to be operated by 2020

AS A GENERAL RULE …

AT EACH PERIOD OF *TIME*,

TAKE ADVANTAGE OF THE POTENTIALITIES OF THE *BEST AVAILABLE TECHNOLOGIES !*

GEN III reactors, with appropriate (optimized) technologies for fuel cycle, could allow a suitable worldwide restart of nuclear energy (avoiding spent fuel accumulation), and be used as a "bridge" toward fully sustainable systems