The Nuclear Fuel Cycle: key to Generation IV Nuclear Energy Systems' Sustainability and transition from LWRs

1 – Significance of closed fuel cycle for future Nuclear Energy Systems
2 – Plans in France for fuel cycle transition from PWRs to Fast Reactors
3 – International technology roadmap for Actinide recycling optimization and phased industrial deployment aligned with that of Gen III & IV reactors

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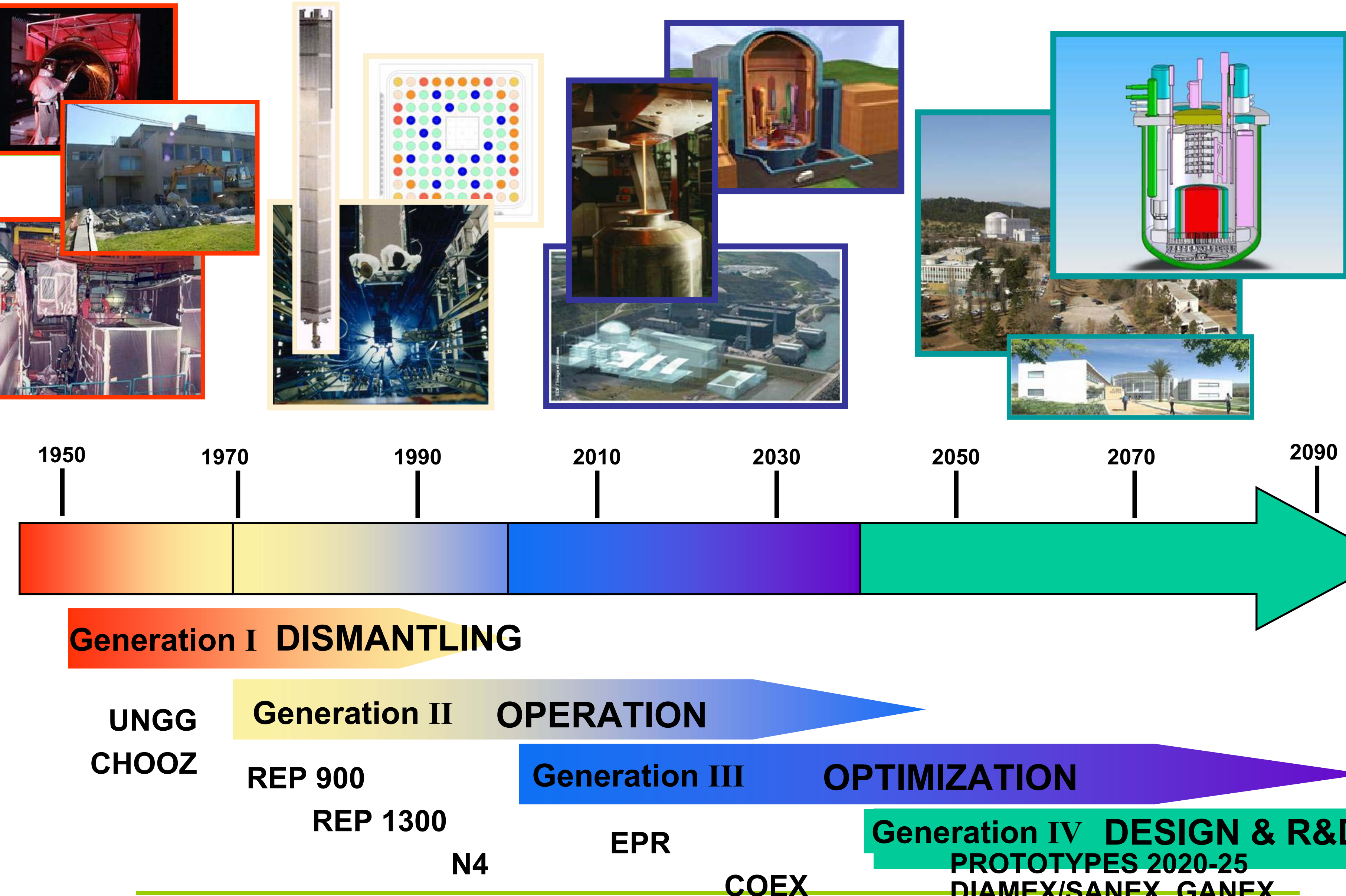
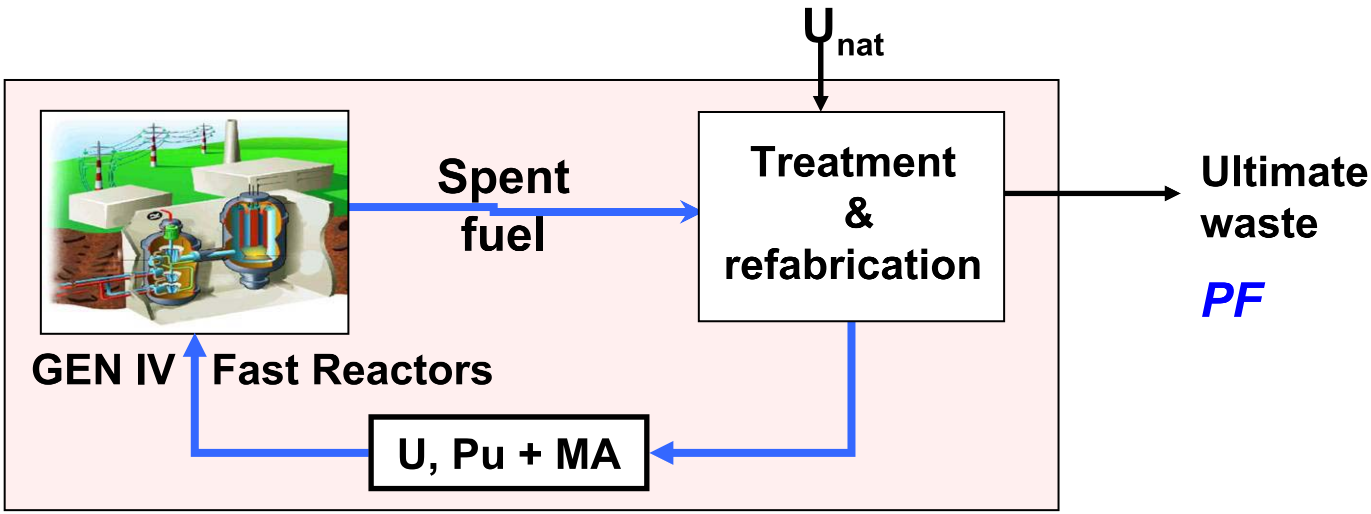
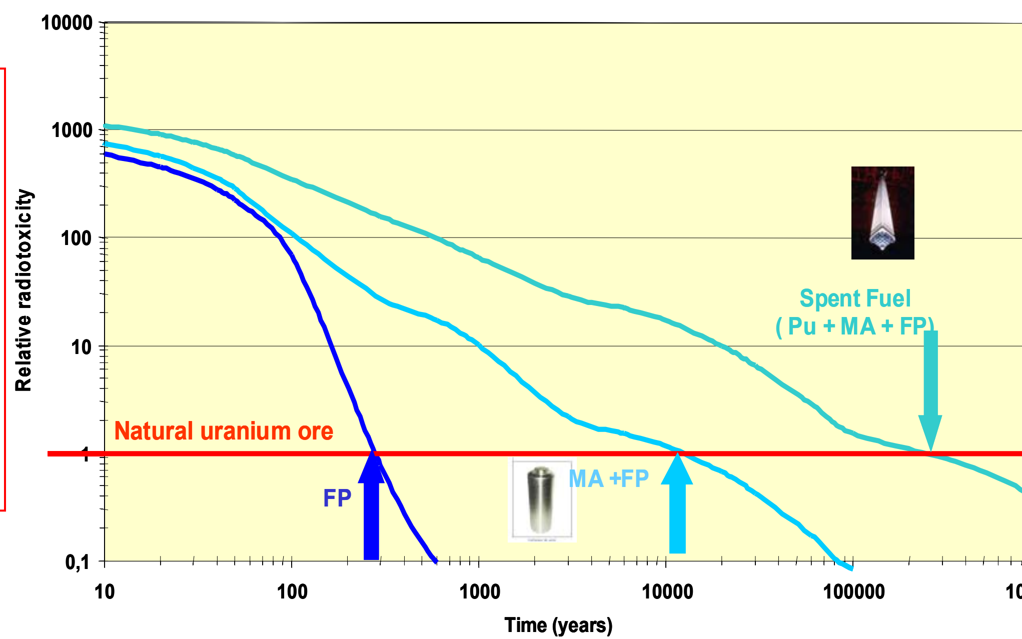
Generations of Nuclear Power Systems



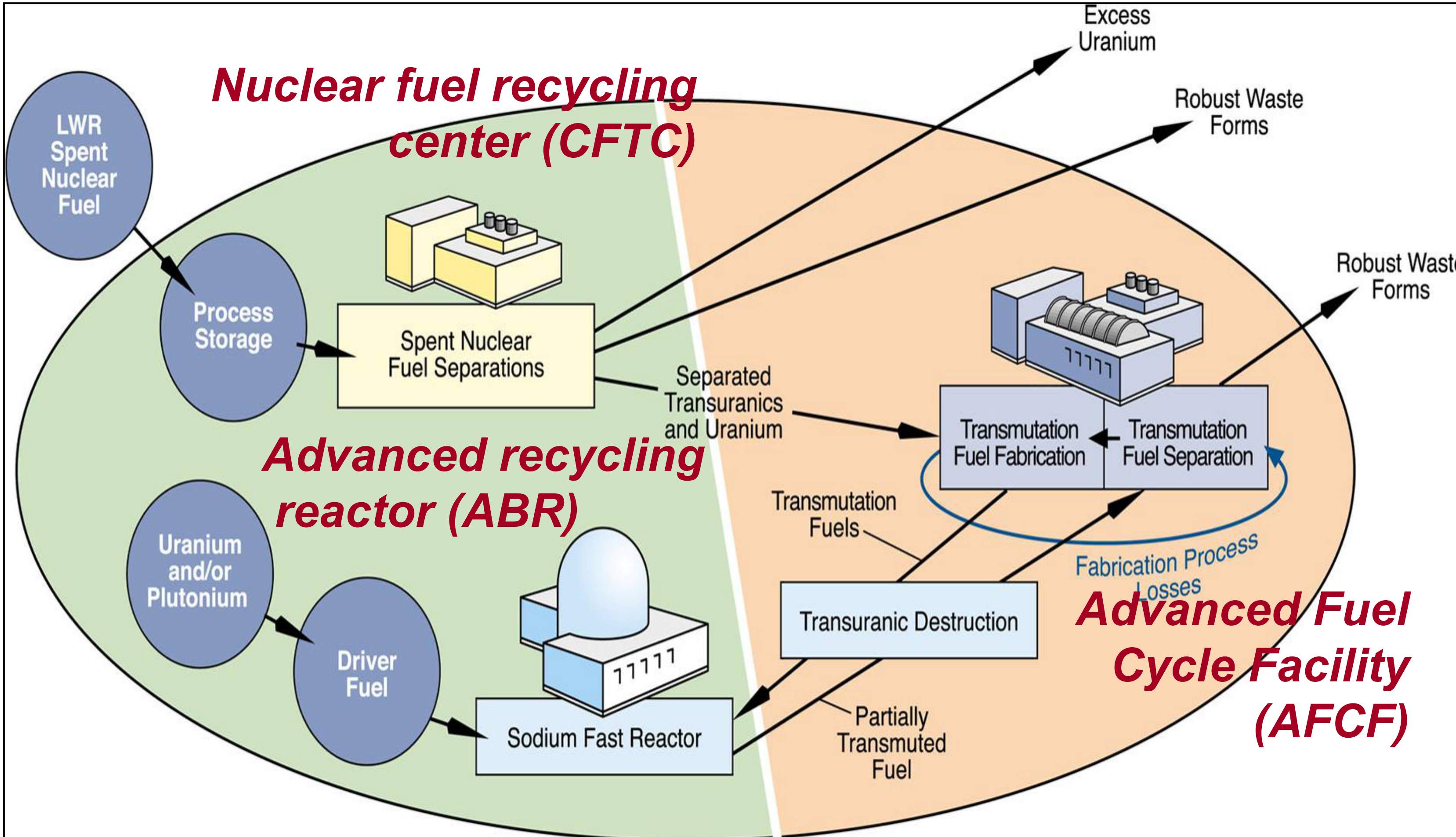
Gen IV Vision of closed fuel cycle: integral & homogeneous recycling of actinides



- **Minimization of HLLL ultimate waste:**
  - *Very small amount*
  - *Radiotoxicity ~ that of initial Uranium after a few centuries*
- **Optimum use of U_{nat}**



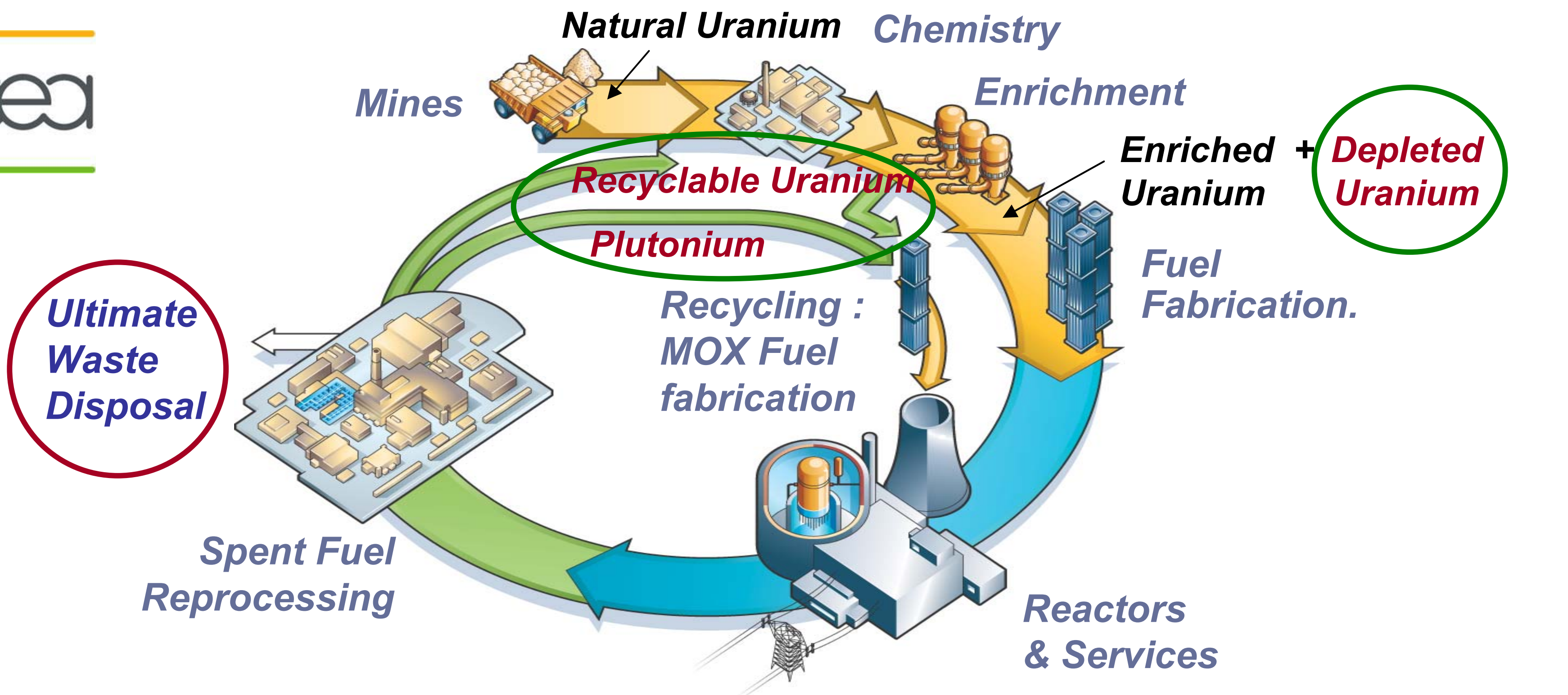
GNEP: 3 Supporting Facilities for its Initial Operation



Industry led

DOE Lab led, NRC, Universities, Industry, International Partners

Uranium & Plutonium recycling… an industrial reality today

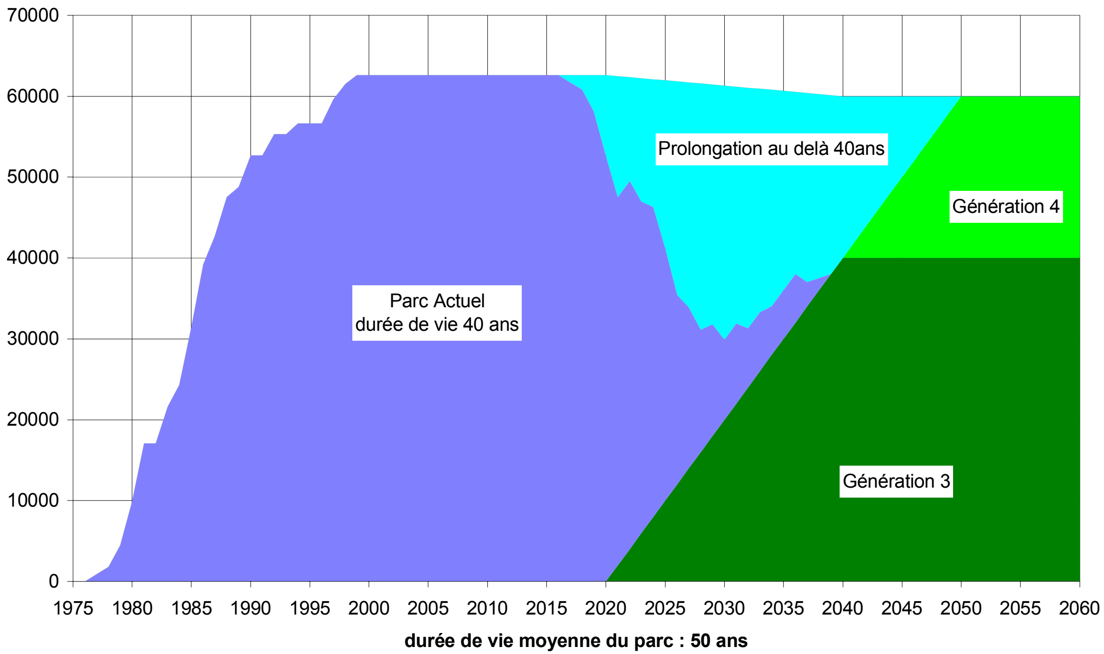


Front-End Sector → Reactors & Services Sector → Back-End Sector

- ✓ **More than 25 years of industrial experience in France**
- ✓ **58 PWRs → 415 TWh in 2004**
- ✓ **1100 Mt_{HM} /yr of spent fuel discharged from the French PWRs**
- ✓ **Up to 1 600 Mt_{HM} /yr of spent fuel reprocessed *(domestic + foreign)***
- ✓ **So far: ~ 20 000 Mt_{HM} spent fuel treated and > 1200 Mt_{HM} MOX fuel recycled**

Scenario for the renewal of power reactors in France *(EDF)*

- **Major role of LWRs over the 21st century**
  - Operating PWRs *(Gen II):* lifetime extension (> 40 years)
  - Gen III/III+ PWRs: relacement of current PWRs around 2015 – Operation over most of the 21st century
- **~2040 – Transition from PWRs to Gen IV Fast neutron systems**



Source: EDF and Nuclear Energy in the Long Term Dec 2004

R&D Strategy of France for Future Nuclear Systems

Approved by the Ministers of Research and Industry on March 17, 2005

1 - Development of Fast Reactors with a closed fuel cycle:

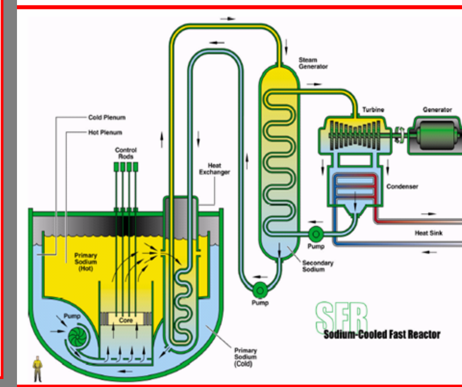
- *Sodium Fast Reactor (SFR)*
- *Gas Fast Reactor (GFR)*
- *New processes for spent fuel treatment and recycling*

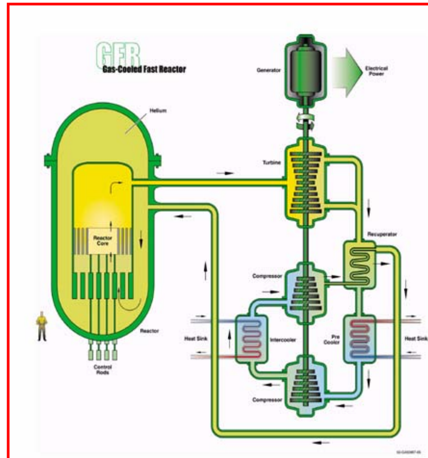
2 - Nuclear hydrogen production and high temperature process heat supply to the industry:

- *Very High Temperature Reactor (VHTR)*
- *Process heat, water splitting processes for hydrogen, synthesis of hydrocarbon fuels…*

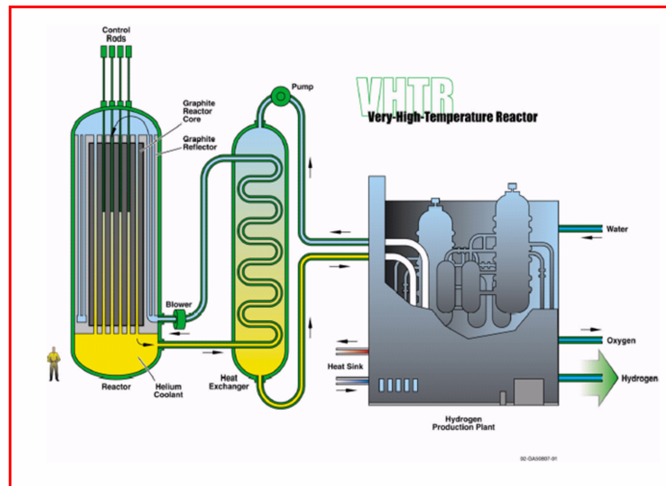
3 - Innovations for LWRs *(Fuel, Systems…)*

Sodium Fast Reactor





Gas Fast reactor



Very High Temperature Reactor

January & June 2006 breaking news

➢ January 6, 2006:

✓ Decision to launch design studies of a GenIV prototype reactor to be put in service by 2020

✓ Creation of an Authority of Nuclear Safety and Transparency

➢ June 28, 2006:

✓ Promulgation of a bill on a sustainable management of radioactive materials and waste

✓ Explicit link between Partitioning & Transmutation and advanced recycling modes in Gen IV Fast Reactors

✓ Have in *2012 an assessment* of industrial prospects of candidate fast reactor types and put a *prototype into operation by the end of 2020* ».

French R&D Strategy on Fast Reactors revisited in 2006

2nd Atomic Energy Committee meeting on December 20, 2006

→ **Two types of *New Generation Fast Reactors* in parallel**

1 – Sodium Fast Reactor, reference type for a Prototype in 2020

→ *Initiative of CEA and coordination with industrial partners*

→ *Search for significant innovations*

2 – Gas Fast Reactor, alternative Fast Reactor type

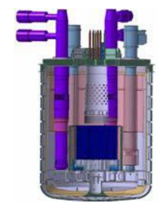
→ *Active collaboration in Europe towards a technology demo reactor?*

Confirmation of design features

Selection of technologies

Innovation Scoping studies
(reviews of *innovative features*)

Integration, Confirmation of selected technologies
(design reviews)



2007 — **2009** — **2012** — **2015** — **2020**

Point design studies to assess candidate innovations

Reference Concept of selected reactor + alternative

Launch of preliminary and detailed detailed design studies, PSAR, Qualification R&D, Construction

Design features of the **Prototype**

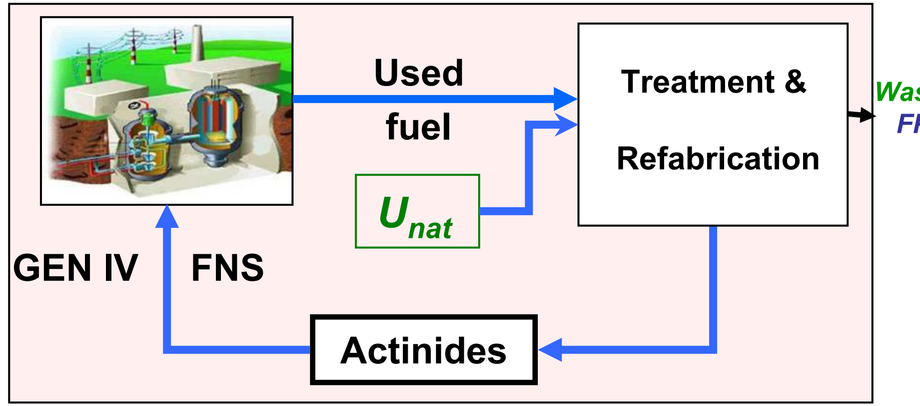
Decision to build

Options to close the fuel cycle of Fast Reactors

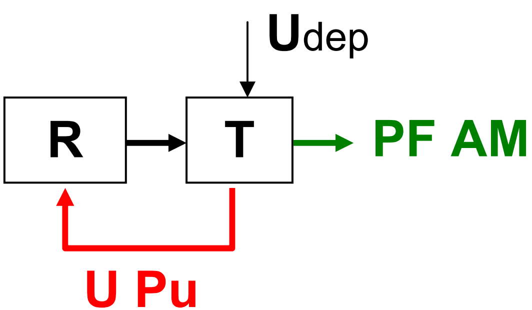
→ Resource saving

→ Waste minimization

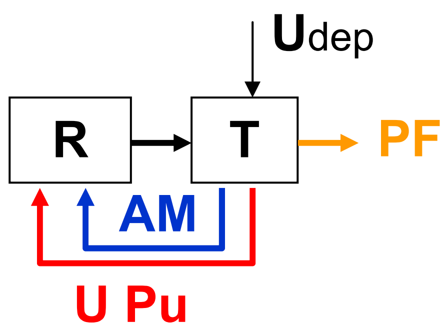
→ Non-proliferation



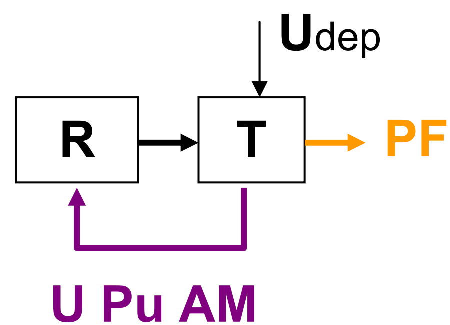
- Develop international non-proliferation standards to allow for diverse fuel cycle processes
- Keep all options open as they could be deployed in sequence



Recycling U Pu only



Heterogeneous recycling



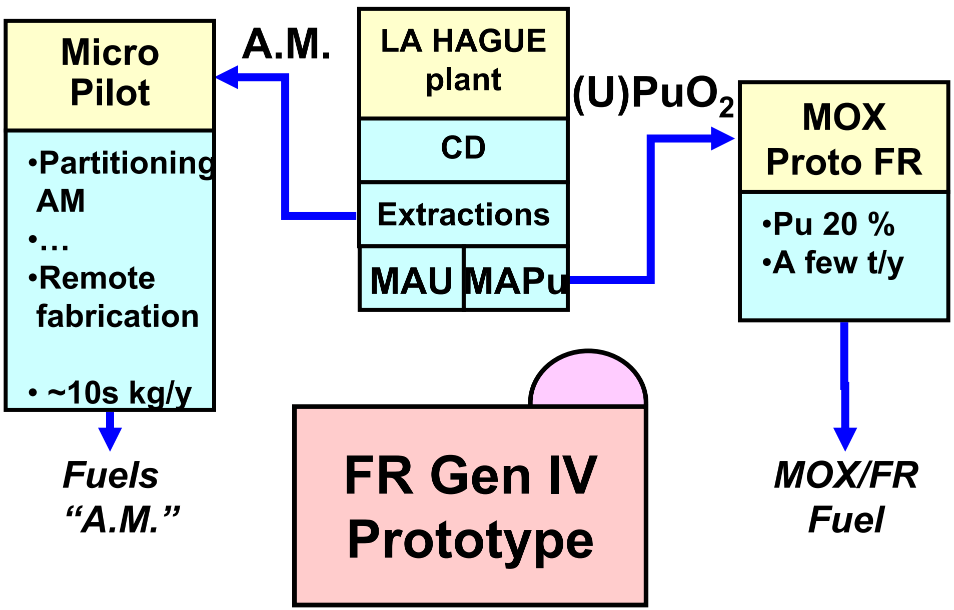
Homogeneous recycling (GenIV)

2020 Prototype and fuel cycle pilot plants at La Hague

A demonstration of Partitioning & Transmutation and key technologies for sustainable nuclear energy

- **Prototype 2020**
  - 250-600 MWe
  - **Breeding ratio ~ 1**
  - **Multiple Pu recycling & Recycling Demos (AM)**

- **Advanced fuels and fuel cycle processes**
- **Innovations for a new generation of competitive FRs**
- **Enabling technology innovations** *(materials, power conversion)*



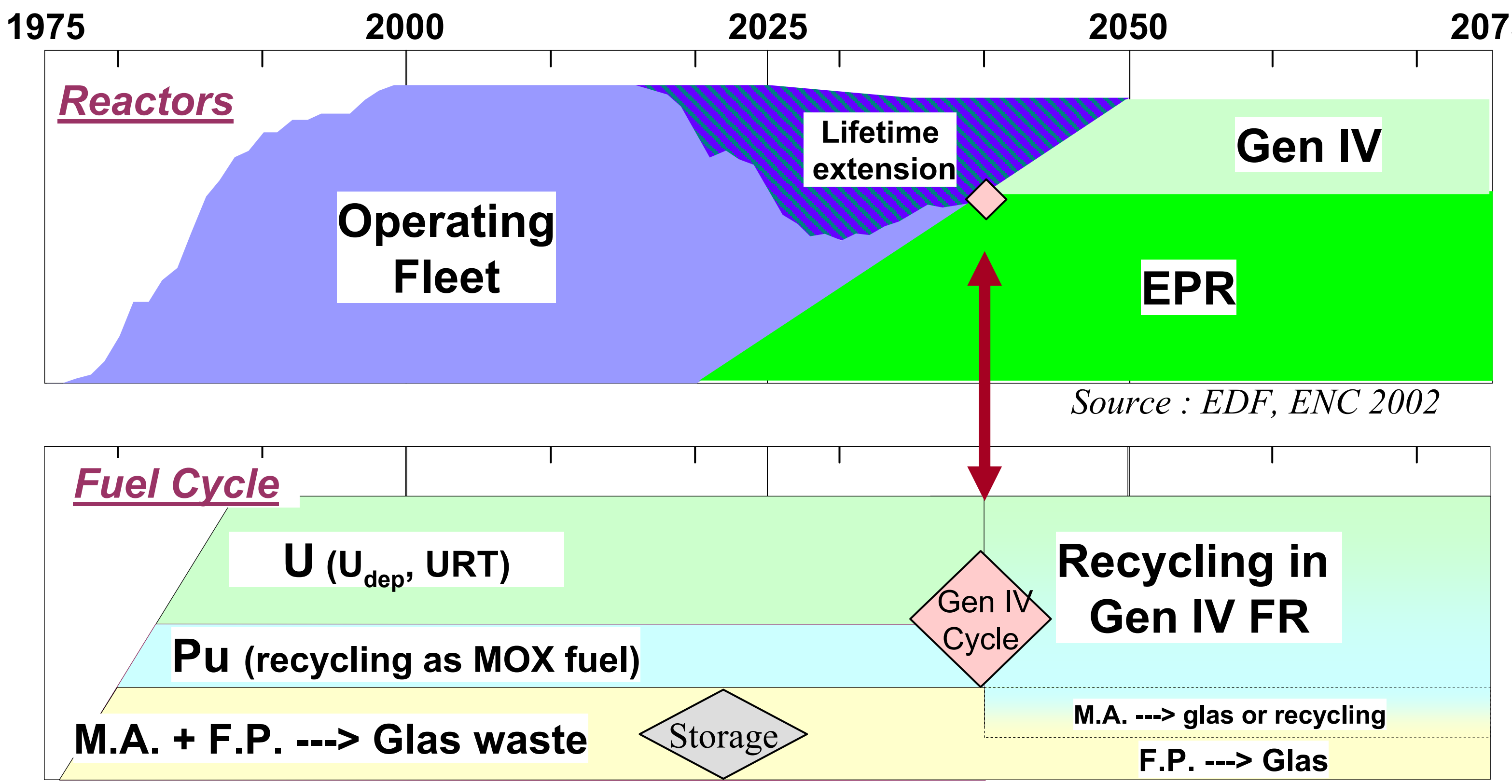
- **Two pilot plants on the site of La Hague (~2017):**
  - Fuel fabrication $(U,Pu)O_2$ *(a few tonnes/y)*
    - *(COEX)*
  - AM bearing micro-pilot plant *(~10s kg/y)*
    - *GANEX → $(MA,U,Pu)O_2$*
  - *- Diamex-Sanex → $(MA,U)O_2$*
- **Sustained R&D for decision making in 2012**

Fast Reactors and New Fuel Cycle Plant in France ~2040

2040: - Deployment of Fast neutron systems *(SFR or GFR)*

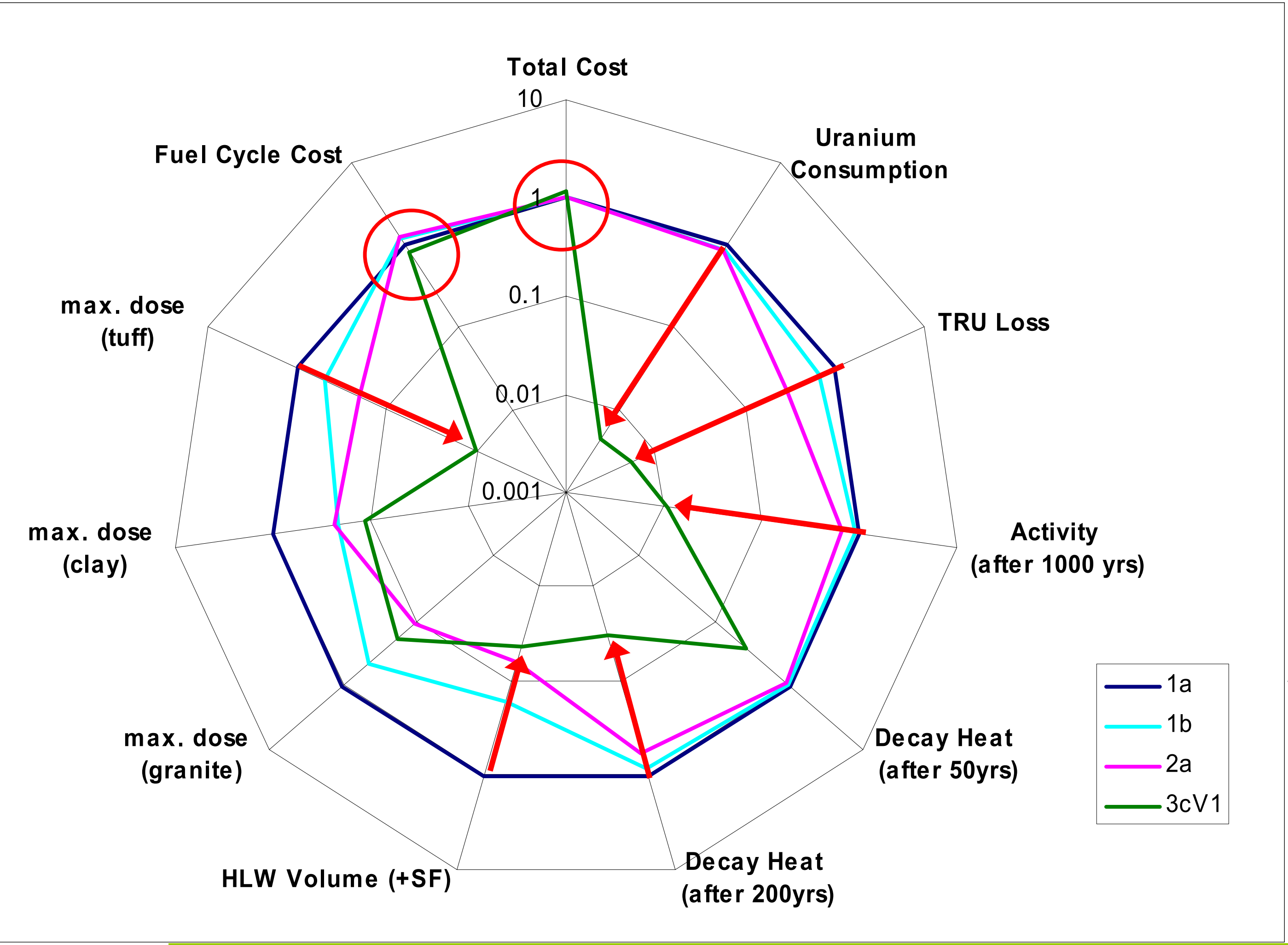
- New spent fuel treatment plant – 2 options:

- ✓ ***U-Pu recycling and MA to waste or interim storage***
- ✓ ***U-Pu-MA integral recycling (Ganex)***



NEA assessment of closed Fuel Cycles (ENC 2005)

Gen IV and P&T impacts



1a: *Once-through cycle as reference.*

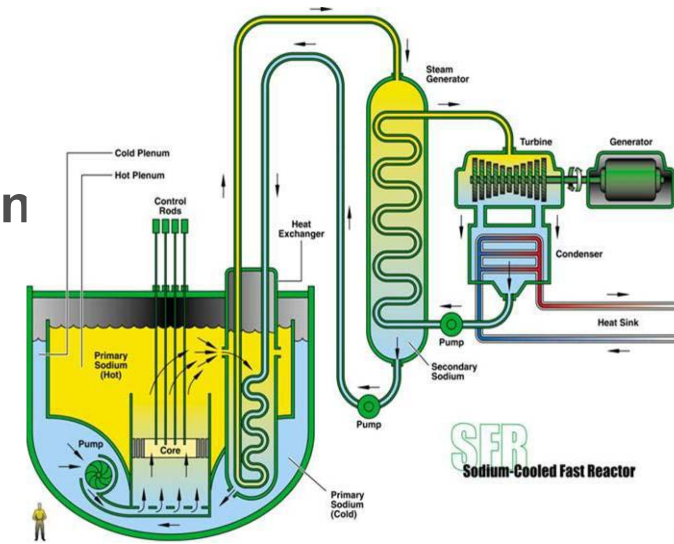
1b: *Full LWR park, Pu re-used once*

2a: *Full LWR park, multiple re-use of Pu*

3cV1: *Full fast reacto park and closed fuel cycle (Gen IV).*

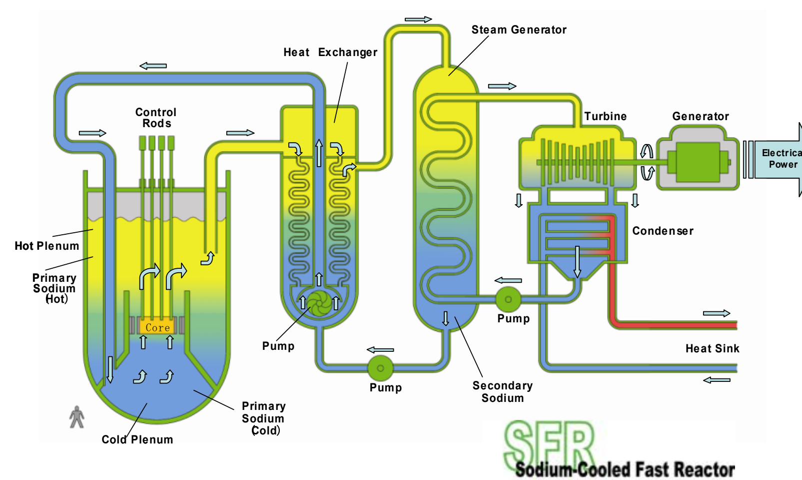
Sodium Fast Reactor *(SFR)*

- **A new generation of sodium cooled Fast Reactors**
- **Reduced investment cost**
  Simplified design, system innovation
  (Pool/Loop design, ISIR – SC CO_2 PCS)
- **Towards a passive safety approach**
- **Integral recycling of actinides**
  Remote fabrication of TRU fuel

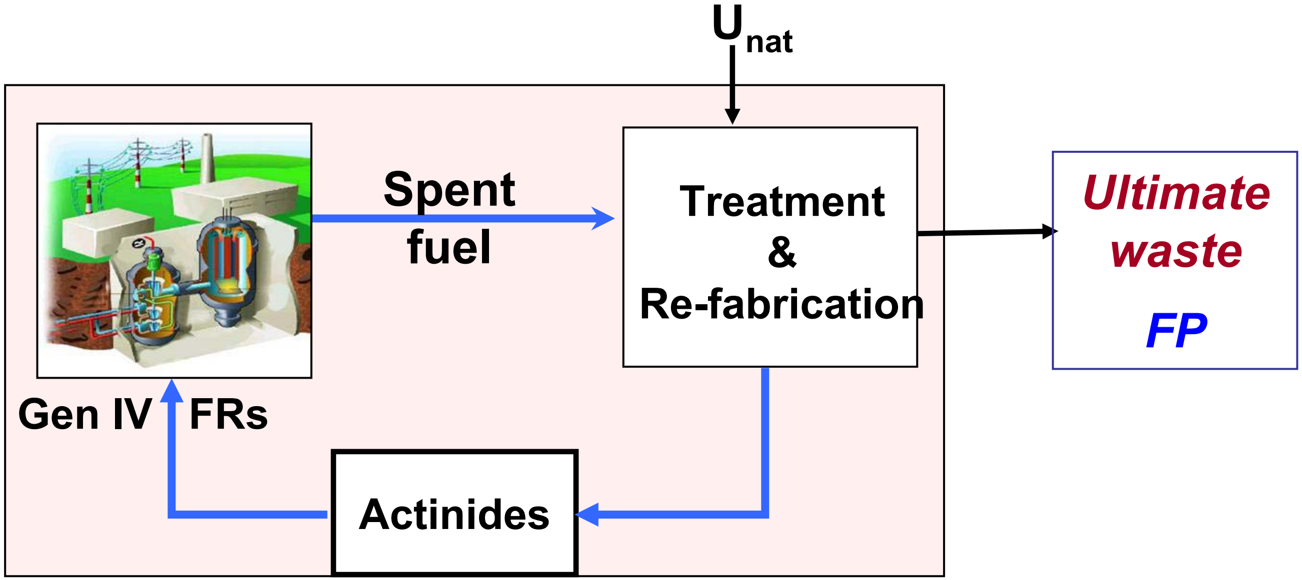


→ 2009: Feasibility – 2015: Performance → 2020+ : Demo SFR *(FR, US, JP…)*

2007
+
Russia
China



Global Actinide Cycle International Demonstration *(GACID)*



Milestones:

2008-12 - Demonstration of the **GANEX** process in Atalante

2015-20 - International Laboratory at La Hague to demonstrate at pilot scale the Grouped Actinide Extraction *(GANEX)* **and the fabrication of Minor Actinide bearing fuels**

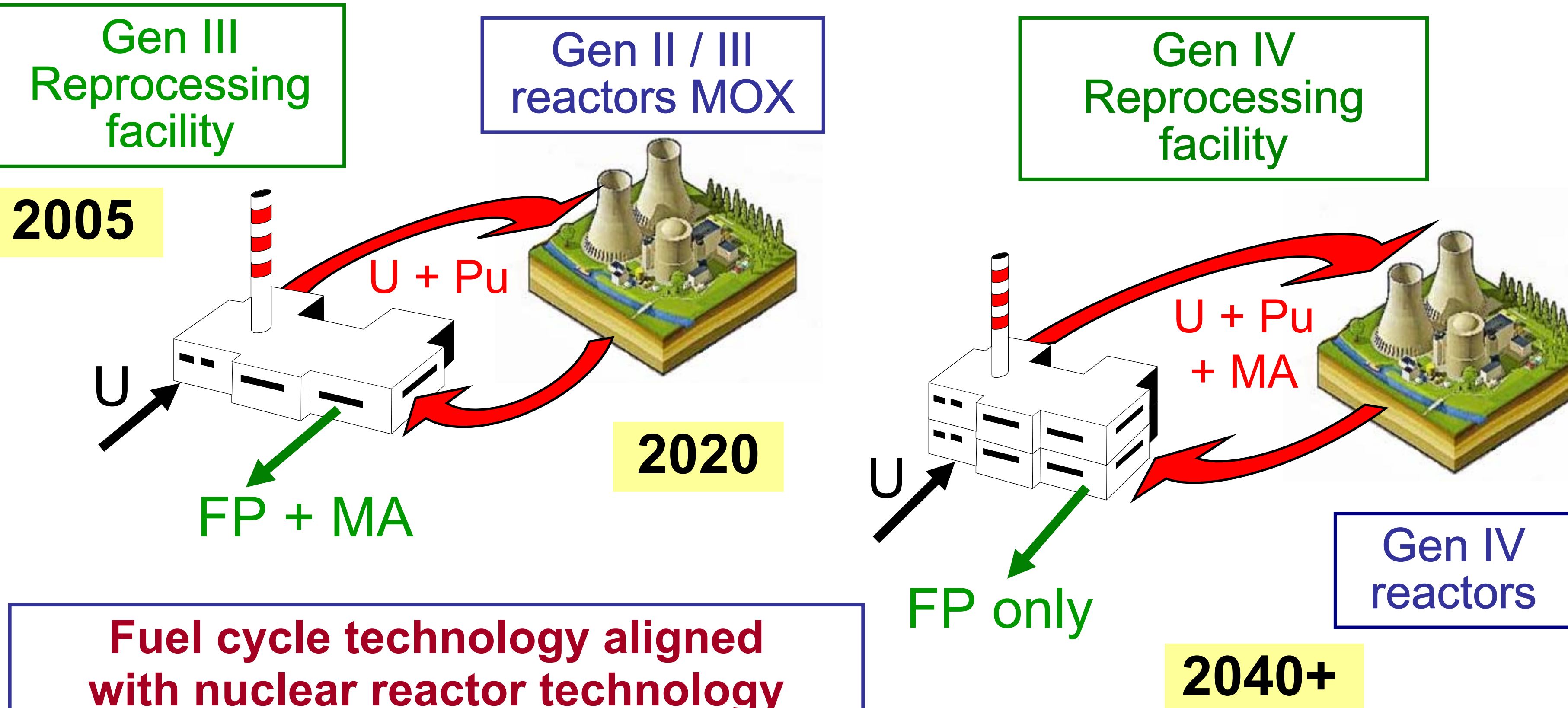
2020-25 - Irradiation experiments in Monju
> 2025 French Sodium Fast Reactor Prototype, ABR in the US…

Collaborations :

Japan *(JAEA)*, USA *(DOE)…* within the framework of Gen IV & GNEP

hased Dvpt of Gen III & IV Reactor & Fuel cycle Technologie

- **Natural resources conservation**
- **Waste minimisation**
- **Proliferation resistance**

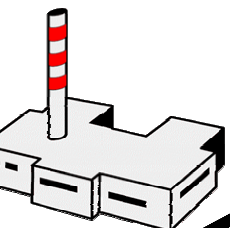


Fuel cycle technology aligned with nuclear reactor technology

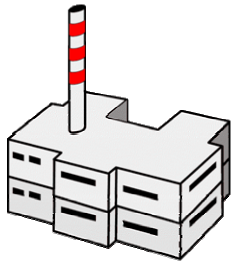
Phased development of recycling technologies

Gen II

UOx – LWR fuel
1000 t/year
PUREX process



1990



Gen III

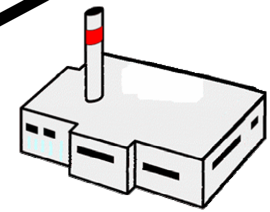
~ 2020

MOX & UOx LWR fuels, Higher throughput
Integrated fuel processing & recycling
Advanced separation technologies
COEX, + Np…

Gen IV

LWR & FR fuels
> 2000 t/year
New technologies
DIAMEX-SANEX, GANEX, UREX+1A, NEXT…

> 2040



Recycling	International	National
Resource utilization	U-Pu	Mgt of MA?
Waste		Waste form
Non proliferation	Standards	Processes

Phased development of Sodium Fast Reactors

Gen IV Systems

Gen IV SFR
…

> 2040

Existing plants

BOR60, FBTR
<1990 Phenix, Monju
BN600, FFTF?...

1990

~ 2020

Proto & Demo Plants

ARR
2020 French Prototype 2020
2025 Japanese Demo

Under construction

CEFR
BN800, PFBR…

Fast reactor	International	National
Ressource ut. & Waste	U-Pu	Breed / Burn Blanket / Fuel
Safety	Standard/Codif	Principle/Techn
Non-prolif, PP	Standard	Technology

Phased development of Fast Nuclear Energy Systems

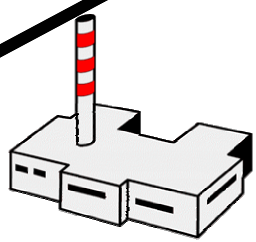
International / National

> 2040

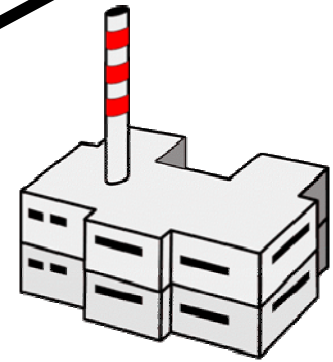
- **Past experience / Time line**
- **Legacy of current nuclear fleet**

~ 2020

1990



- **Safety standards / Codification**
- **Non-proliferation standards**
  + Physical protection, Safeguards…
- **Resource utilization**
- **Waste form**
- **Technology**



Summary and perspectives

- Advanced recycling processes and Fast Reactors are key to a sustainable development of nuclear power: *Resource saving, Waste minimization, Non-proliferation*

- Industrial experience of recycling as well as national plan for more advanced fuel cycle demonstrations are seeds for the international development of optimized recycling modes in fast neutron systems

  → *Key role of Joyo/Monju, US-ARR, French prototype 2020… for demonstrations of global actinide management*

- Crucial need to federate current national initiatives as well as longer term R&D and demonstration program into a consistent international technology roadmap

  → *Enhancing R&D and technology demonstrations,*
  + Progressing towards harmonized international standards
  (safety, non-proliferation, physical protection…)

- Towards a phased development of recycling technologies aligned with that of successive reactor generations (II, III, IV)