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Panel 3

Future nuclear cycle systems and technology enhancing proliferation resistance

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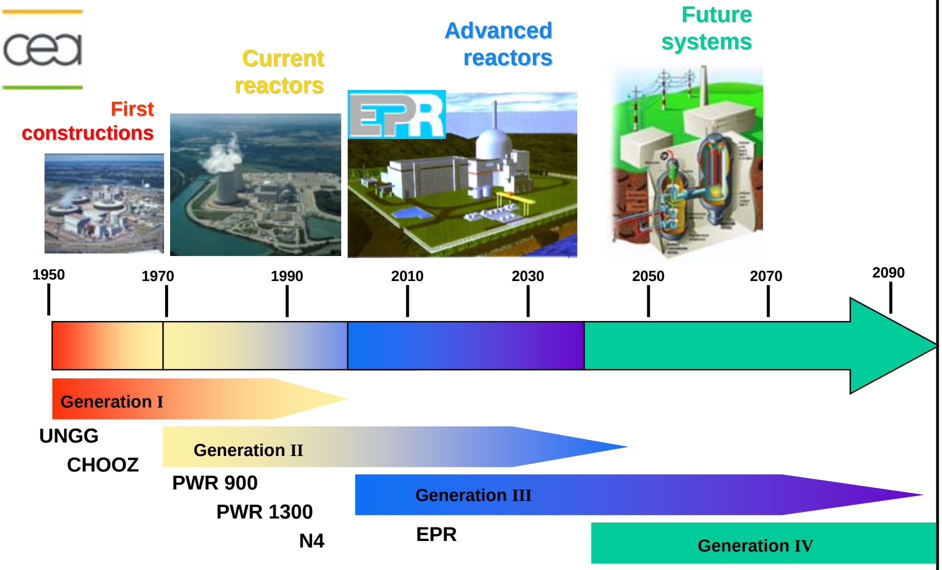
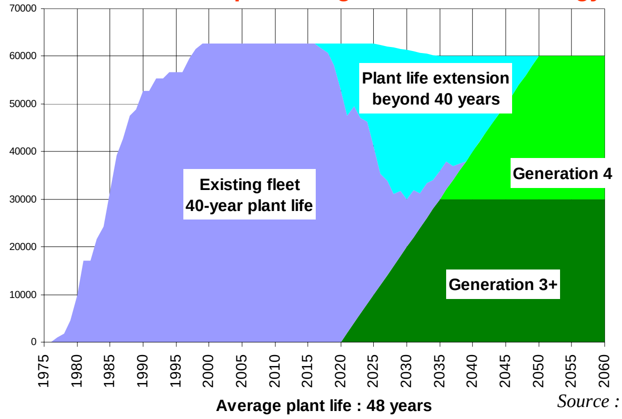
The schedule of nuclear generations



Transition scenarios between generations

- Major role of LWRs in the 21st century
  - Current Gen II LWRs : life time extension
  - Gen III/III+ : replacement of existing LWRs → to be decided in 2015;
    will be in operation until the end of the 21st century
- A transition step awaiting future nuclear energy systems



Source : EDF, ENC 2002

Concepts selection

The French preference:
<u>the "closed cycle, fast neutrons" option</u>

✓ **Top-ranked in sustainability**
- *management of actinides & waste*
- *efficient conversion of fertile uranium*

✓ **Good rating in safety, economics, <u>proliferation resistance</u> & physical protection**

✓ **Two missions : electricity production & waste management**

French R&D strategy for future nuclear energy systems

1 – Development of fast reactors with closed fuel cycles, along 2 tracks:

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

→ ***Industrial deployment around 2040***

2 –Hydrogen production and very high temperature process heat supply to the industry

- Very High Temperature Reactor (VHTR)
- Water splitting processes

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

A prototype reactor in 2020

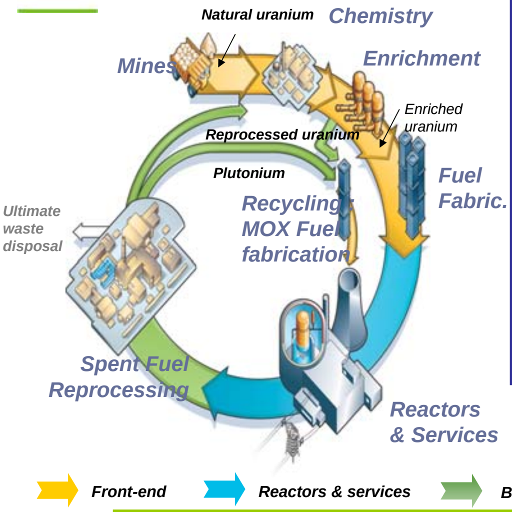
President Chirac statement *(January 2006)*:

« A number of countries are working on future generation reactors, to become operational in 2030-2040, which will produce less waste and will make a better use of fissile materials.
I have decided to launch, starting today, the design work by CEA of a prototype of the 4th generation reactor, which will be commissioned in 2020.

We will naturally welcome industrial or international partners who would like to get involved… »

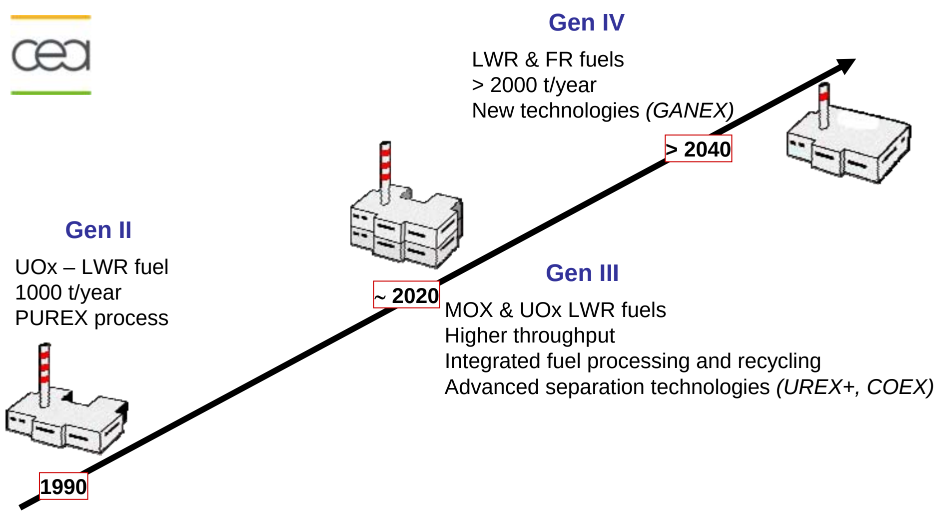
It clearly means fast reactors for sustainability
Sodium has advantages due to French experience
New concept to improve economy and safety
Minor actinides recycling in a progressive approach

Closing the fuel cycle… an industrial reality



- **More than 25 years of unequalled experience in France :**
- **58 PWRs → 451 net TWh (2005)**
- **Until now: ~ 20 000 Mt_{HM} spent fuel reprocessed and more than 1200 Mt_{HM} MOX fuel recycled**
- **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)**

The next generations of reprocessing facilities



The closed fuel cycle : a path forward

In the short term

- **Mono-recycling of plutonium in existing light water reactors:**
  - **to limit the growth of plutonium inventory,**
  - **to allow the management of ultimate waste from uranium spent fuels,**
  - **to concentrate in MOX spent fuels the plutonium available for future deployment of fast reactors**

  - **existing industrial reprocessing plants,**
  - **an already large experience with MOX fuels,**
  - **plants operated under international safeguards.**

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The closed fuel cycle : a path forward

In the near future

- **Improvements with Gen III light water reactors:**
  - **more flexibility for the use of MOX fuels,**
  - **possibility of reducing the plutonium inventory if the deployment of fast reactors is delayed.**

- **Demonstration of the potential of fast reactors:**
  - **for burning plutonium and other actinides,**
  - **Phenix and Superphenix experience,**
  - **a full scale demonstration in Monju…**

- **Design of Gen III industrial plants for treatment and recycling:**
  - **the only end-product should be a reactor fuel**

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The closed fuel cycle : a path forward

In the longer term

- <u>Deployment of Gen IV fast reactors:</u>
  - initially fueled with plutonium and minor actinides coming from the treatment of MOX spent fuels,
  - breeding gain adjusted according to the needs of nuclear energy

- <u>Industrial implementation of the global actinide recycling:</u>
  - no more separated elements (plutonium or others),
  - ultimate waste containing essentially fission products,
  - transportations limited to highly radioactive fuels

- <u>Safeguards measures mainly oriented towards:</u>
  - the accountancy of fuels,
  - the supervision of treatment processes

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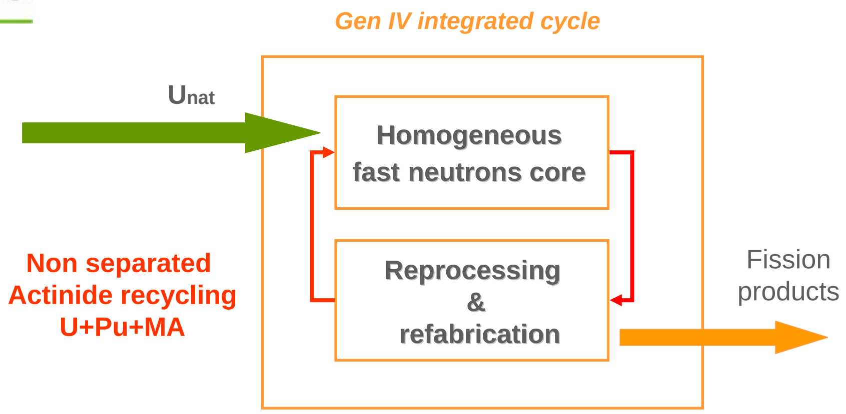
Integrated recycling & proliferation resistance



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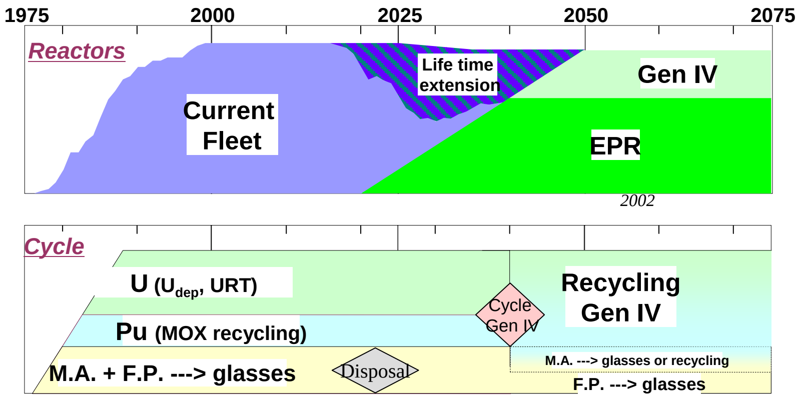
Transition scenarios between generations

- Major role of LWRs in the 21st century
  - Current PWRs (Gen II): life time extension (> 40 years)
  - Gen III/III+ PWRs : current PWRs replacement around 2015 – Operation during 21st century
- A transition scenario between LWRs and Fast Neutrons Systems



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Non-proliferation strategy

A systemic approach

1. **To adopt a comprehensive non-proliferation strategy**
2. **To achieve a global optimization of the future systems (fuel cycle and reactor technologies)**
3. **To implement measures from early design stages to operation**
4. **To take benefit from the experience with safety methodology**
5. **To take advantage of new technologies**
6. **To share the approach internationally**

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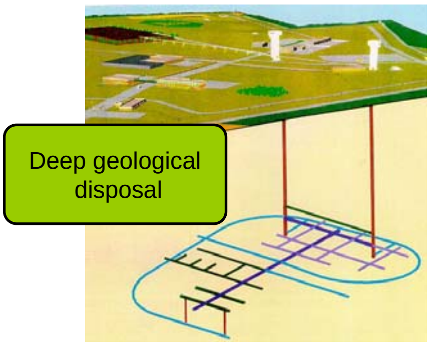
Fuel cycle and proliferation resistance

➢ Classical PUREX/MOX strategy

- **Risk of proliferation associated to current industrial treatment and recycling is <u>not underestimated</u> today (meets IAEA / Euratom controls and requirements)**
- **Pu from LWR spent fuel is not attractive for making a nuclear head.**
- **There are easier approaches than diversion of spent fuel to proliferating activities (HEU, enrichment technologies, diversion of neutron sources…)**
- **Plutonium recycling is preferable to direct disposal of spent fuel elements in repositories likely to eventually become “plutonium mines”**
- **Recycling plutonium without delay limits separated stocks to the minimum required for the fuel management**
- **Up to now, no malevolent use of nuclear materials has come from commercial treatment and recycling**
- **Implementation by national companies**

Non proliferation : to burn or to bury

• Closed cycle (vs once-through and spent fuel geological disposal) : a better option to recycle and burn Pu (under today’s IAEA control) than to leave « Pu mines » to future generations



Fuel cycle options for enhanced proliferation resistance

Identify technical solutions to meet these requirements

1. Attractiveness
   - increased fuel burn-up
   - recycling without separation of plutonium
   - recycling with the extraction of fission products only (« dirty fuel - clean waste concept »)

2. Accessibility, physical protection
   - integrated cycle
   - detection techniques and controls
   - minimization of transports

3. Safeguardability

   IAEA safeguards, Euratom controls

Technical features enhancing proliferation resistance

- **Decreasing the enrichment needs**
- **Avoiding the build-up of a "plutonium mine"**
- **Thanks to recycling, fissile material can be kept within proper safeguards**
- **A new target : "no isolated plutonium"**

Three categories of reactors for R&D

- « Material testing reactors » : MTR

- pool reactors : for irradiation purpose

JHR 2014

- Experimental reactors (anticipating new systems)

- 10 to 100 MW th → fuel type, coolant, safety and control systems.
- with no energy conversion system
- example : Rapsodie (FNR sodium, 40 MWth)

ETDR 2015

- Demonstration Reactors (prototypes)

- fully integrated system with energy conversion,
- scalable up to commercial needs
- technical and economical performances
- front-end and back-end industrial inputs (fuel fabrication, SNF reprocessing, etc...).
- example : Phénix (600 MWth, 250 MWe)

ASFR 2020

PGFR 2025

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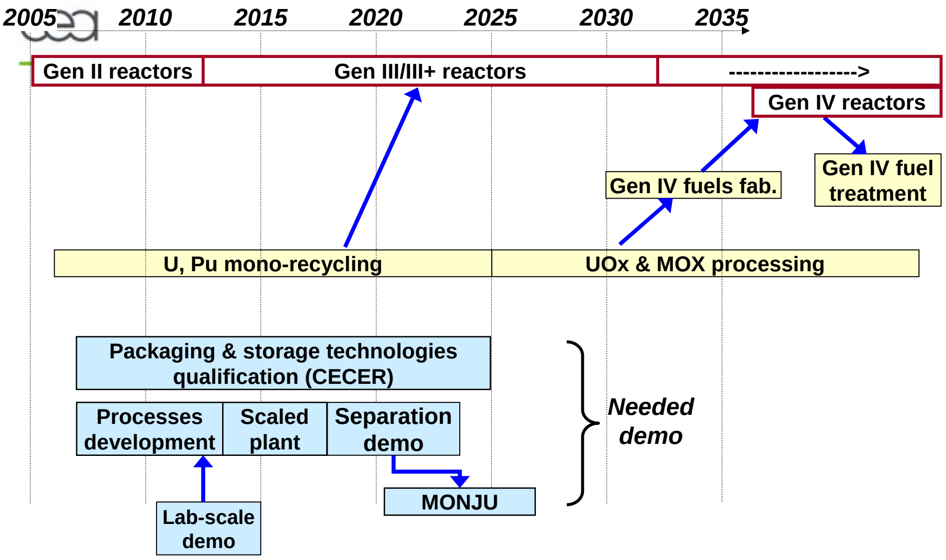
Main technology demonstrations



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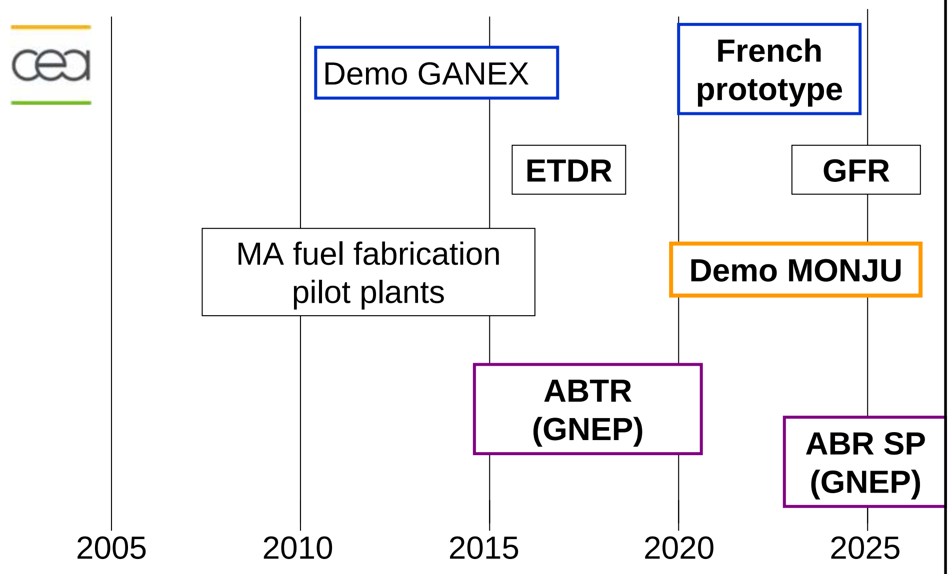
In connexion with progressive steps worldwide



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Conclusion

- One essential condition for a large expansion of nuclear energy is sustainability with the minimization of waste and radiotoxicity as well as the preservation of natural uranium resources and proliferation resistance.
- Closed fuel cycle and fast neutron reactors are the best option to meet the sustainability requirements. The global actinide management fuel cycle shows many assets in this respect and in particular great advantages regarding non-proliferation considerations.
- The capacity to share multilateral R&D programs, with the full support of nations, reinforces the credibility for a sustainable nuclear energy development, in consistency with the statements of the Non Proliferation Treaty (art IV).

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