Prospects for the use of SNF reprocessing products in Light Water Reactors

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New AREVA Ambition
Be a leader in nuclear materials to serve the industry worldwide

- Unique position with proven technologies backed by innovation capabilities
- International presence with solid partnerships
- Operating resilience, with a backlog equivalent to ~8 years of revenue
- Improved profitability through an ambitious performance plan
- Strengthened cash generation thanks to a renewed industrial base and plants capable of operating on a very large scale

Upcoming challenges and drivers for utilities and national waste management agencies

Challenges

Avoid **saturation** and **safely manage interim storage**

Develop safe and optimal **final disposal solution**

Minimize **environmental impact and footprint**

Enhance **public acceptance**

Guarantee **non-proliferation, security, safeguards**

Drivers

Preserve **natural resources**

Increase **energy independence**

Optimize cost of safe and long-term used fuel management

Minimize waste to be disposed of

New AREVA
Flexible cycle solution

Logistics

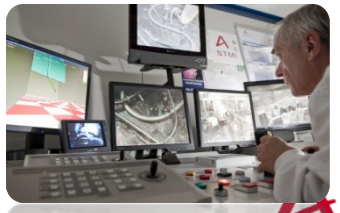
- **Used fuel transport fleet available**
- **Over 3000 transports per year worldwide**
- **Major Dry storage player in Europe**
- **Innovative waste treatment and storage solution**

Shared Recycling facility

- **40 years of industrial experience**
- **Over 32,000tHM of reprocessed used fuel for 9 countries**
- **Used fuel from NPP and Research Reactors**

D&D and waste management

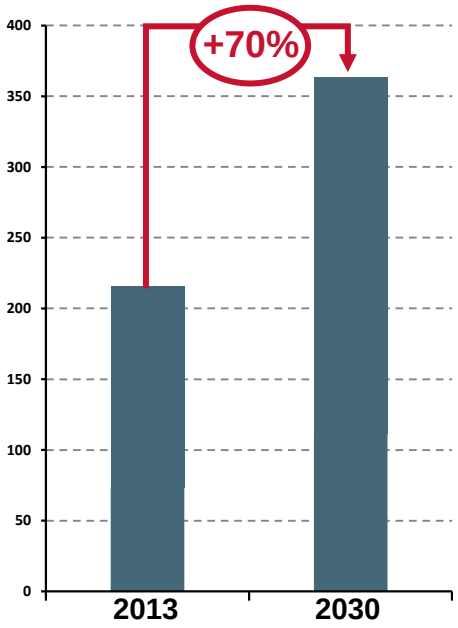
- **Active player in Europe for Dismantling of both NPP and Research Reactor**
- **Unique know-how on large and flexible scope acquired both as an operator and a supplier**



New AREVA addressing utilities' back-end challenges for more than 40 years

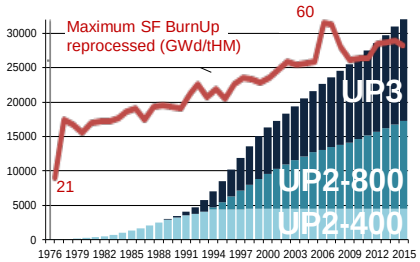
A worldwide challenge → One platform, Three generations of UNF managed → A proven solution able to adapt to new requirements → An solution shared worldwide

Total discharge from LWR



La Hague

~33,000 tHM reprocessed

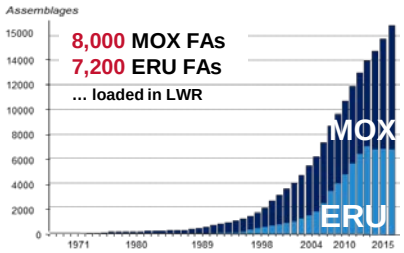


Reprocessing capacity enlarged to RTRs and FNRs' FAs

Used fuel from abroad reprocessed:

Melox

~2,600 tHM of MOX manufactured



[Pu/U+Pu] in MOX fuel : from ~5% to ~10%

Reactors licensed for MOX (20 + 24 in France) :

Recycling is a proven industrial solution with more than 40 years of experience

MOX fuel used since 1972 with a perfect safety track record

MOX fuel used in 40+ reactors worldwide (10% of world's LWRs)

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Closed Cycle noticeable feature: Waste management

Encapsulation of Fission Products

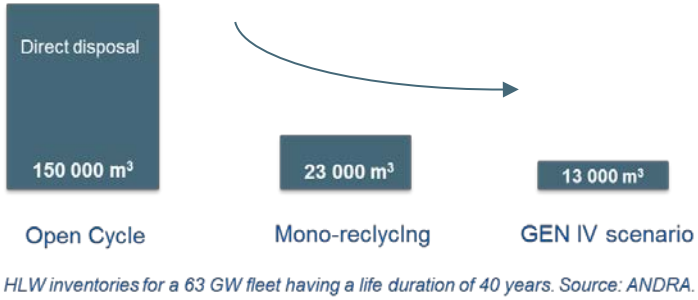
Compactage of structural pieces (hulls and end-pieces)

Cimentation of waste arising from operations in specifically designed matrices

Standard waste form of vitrified and compacted waste suitable for transport, storage and final disposal in 10 countries:

Decades of R&D for continuous reduction of waste and radioactive releases:

- **Volume reduction of primary and secondary waste**
- **Waste segregation at the source, further reducing expensive treatment and disposal**
- **Reduction of releases**
- **Reduction of personnel exposure**

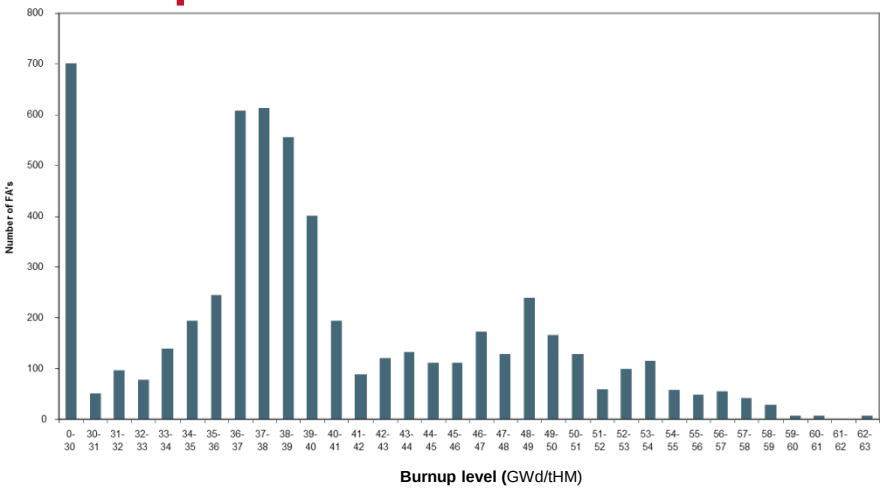


HLW inventories for a 63 GW fleet having a life duration of 40 years. Source: ANDRA.

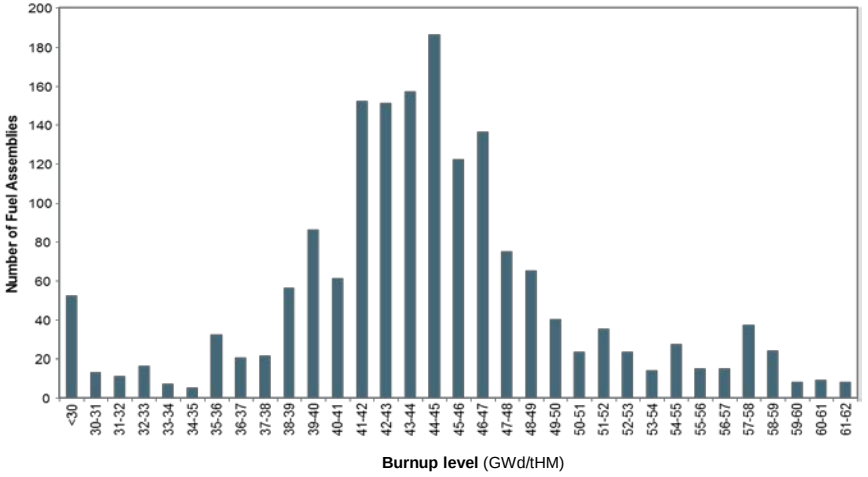
Reduction of the HLW disposal zone by a factor of 4 in France

Recycled Fuel Performance in LWRs: AREVA's performances have been enhanced to reach energy equivalence with UOx

- **MOX burnup Performance:**
  - **1972: 1st MOX loading**
  - **2007: MOX Parity (EDF)**
    Shift forward from 36-38 to 50 GWd/t
  - **Maximum achieved burnups: 62.2 GWd/t PWR**
    58.0 GWd/t BWR



- **ERU burnup Performance:**
  - **1983: 1st ERU loading**
  - **Maximum achieved burnups: 61.5 GWd/t for PWR**
    58.3 GWd/t for BWR



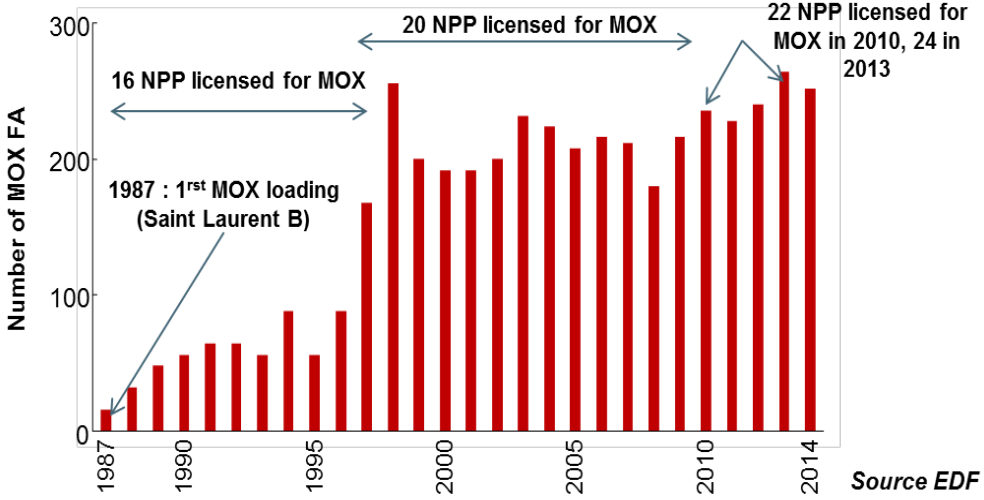
MOX fuel use in French nuclear power plants

EDF's achievements:

- 24 EDF 900MW-PWRs MOX-licensed– 22 units loaded with MOX (+1 in 2018 ; +1 in 2019)
- 4,500 MOX FAs loaded in EDF 900MW reactors (⇔ 120t of Pu) since 1987

10% of EDF uranium saved per year
19,000t since 1987

Prevented storage of 36,000 used fuel
~18,000tHM+

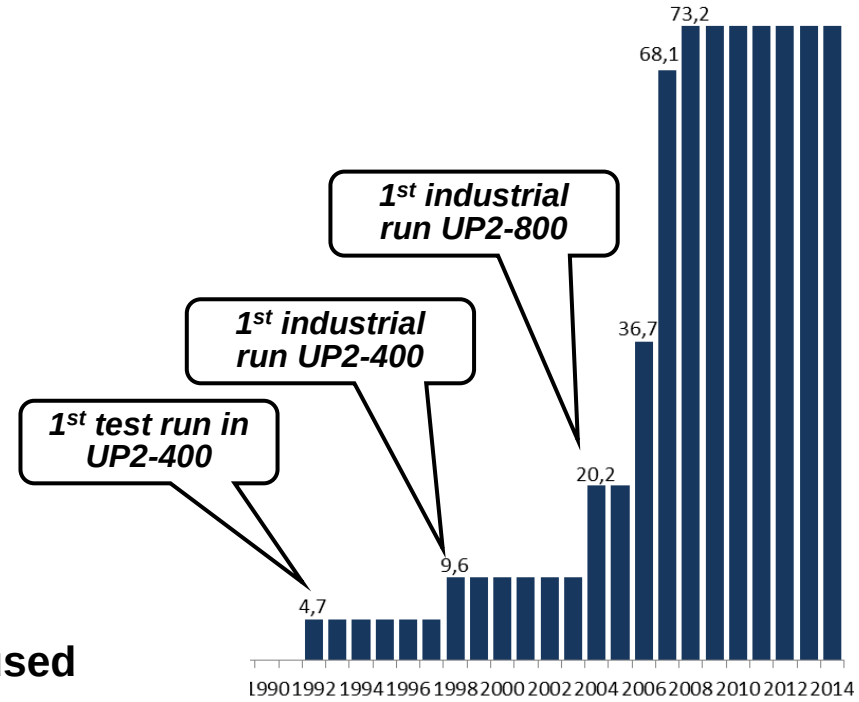


Resource Savings:

- Discharged UOX fuels are processed
- Pu is recycled in MOX fuel:
  - ~1,000 tHM from spent UOX fuels give 10 t of Pu to produce 120 t of MOX
  - MOX FAs fabrication similar to UOX, major differences in radioprotection arrangements

Used MOX Recycling

- **70 tons processed within 4 campaigns**
- **Wide range of used MOX fuel**
- **Throughput 2t/day demonstrated**
- **All exit product within specifications**
- **Pu reused in MOX Fuel**
- **The whole supply chain is validated for used MOX recycling**



Industrial MOX recycling is already a reality

NPP adaptation required for MOX fuel use

NPP

- **Adaptation of reactivity control devices : addition of RCCAs; boron concentration increase, due to higher energy neutron spectrum (higher Pu content)**
- **New core management**
- **Fuel building adaptations:**
  - Reinforcement of cranes (hardware + software) : capacity, reliability, safety
  - Fresh MOX direct storage under water in fuel pit
  - Reinforced safeguards during MOX handling (cameras)
- **Operators' training** (fuel handling, core monitoring)
- **Used MOX fuel transport after 3 to 4 years cooling time** (slower decrease of decay heat)

Logistics

- **Fresh MOX fuel transport in specific cask**
- **Used MOX fuel can be transported in standard used fuel cask**

MX8, for fresh MOX fuel transport

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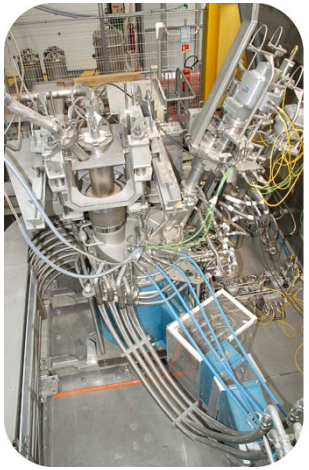
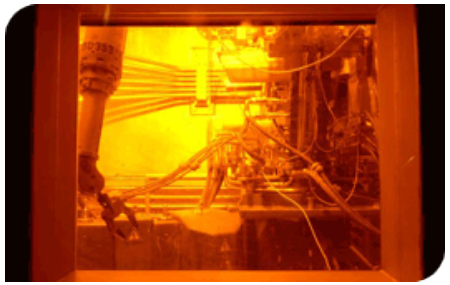
Going Forward…
Expanding capabilities of existing industrial plants

- **Vitrification of a wider range of product (UMo…)**
  - **Cold Crucible Melter vitrification technology**

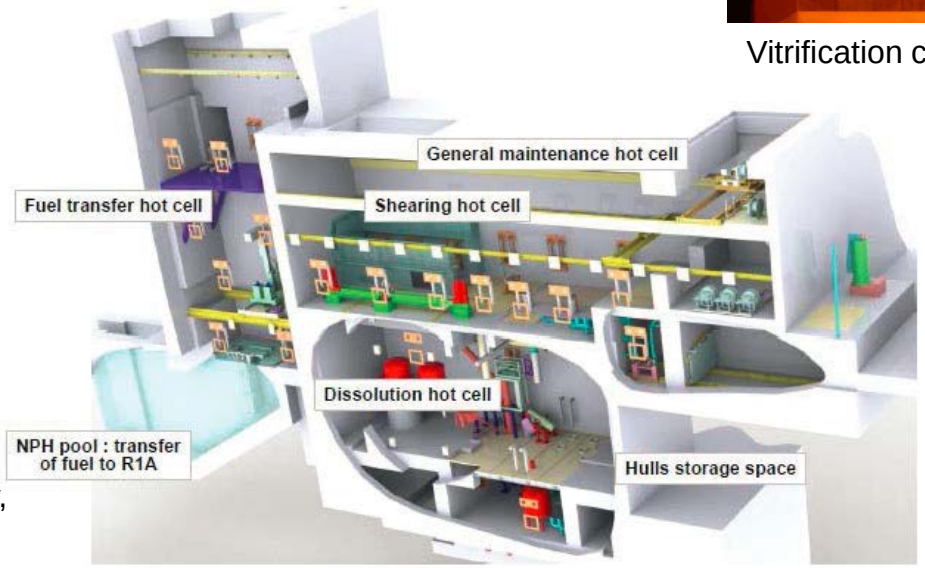


Vitrification cell constructed at the Beaumont-Hague Research Hall (HRB)



Vitrification cell, La Hague

- **Recycling additional types of fuels TCP project**
  - **Research reactor fuels**
  - **MOX fuels from LWR and FR**
  - **Special material**



TCP project, in R1 facility, La Hague

Going Forward…
Enhancing MOX fuel fabrication and design performance

Gen III
design & performance

- Pu quality: degradation from increased UO2 discharge exposure
- Pu content: higher from increased Core management cycle length
- Ratio of MOX core adaptable for some designs : up to 100% for EPR

R&D
for performance

- Optimization of fuel design for increased performance
- Matrix evolution with CHROMOX: MOX doped with Chromium

MELOX
capacities

- Commissioning of a new powder blending unit
- A 28.5 M€ investment to secure multi-customer production capacity
- Adaptation to higher Pu content and degraded plutonium quality

Going Forward…

Plutonium multi-recycling in LWRs

Fuel concept

Pu multi-recycling

- **Fuel concepts identified in the 90's:**
  - **MIX: MOX with enriched UO2 matrix**
  - **Corail: Fuel assemblies with both MOX and UO2 rods**
- **Development of those concepts:**
  - **Multi-recycling of Pu in LWRs, offering flexibilities to switch to future technically and economically robust advanced cycle with FRs**
  - **Similar performances to UO2 without major impact on NPP design, safety demonstration and operations**
  - **High Pu content to optimise the supply chain and concentrate Pu recycling in a limited part of the fleet**
  - **Industrial deployment could start from 2030**

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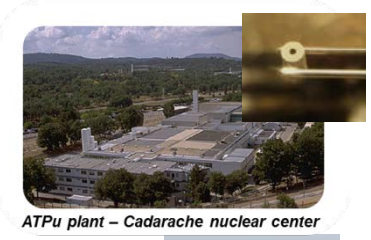
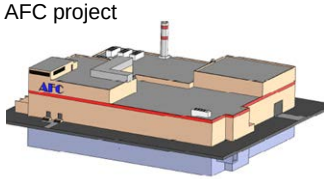
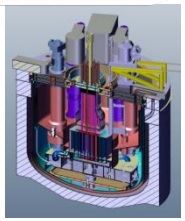
Preparing the future
Plutonium multirecycling

- **Generation IV sodium-cooled reactors is our reference option:**
  - **Experience of FR MOX fabrication at ATPu, Cadarache, for Phenix and Superphenix reactors from 1964**
  - **GEN(IV) - ASTRID project led by CEA:**
    - The project is currently in design phases, with industrial and international cooperation *(Japan, notably).*
    - Manufacturing of pellets at Melox
    - AFC project manufacturing plant for Astrid fuel

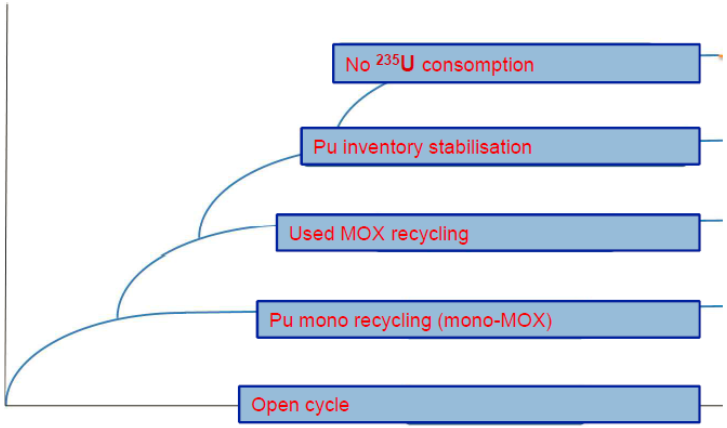

ATPu plant – Cadarache nuclear center

AFC project




Astrid Reactor

- **FR development for Waste reduction and natural resources management: Scenario studies to explore options : step by step SFR deployment**



D 100% MOX – a majority of FR

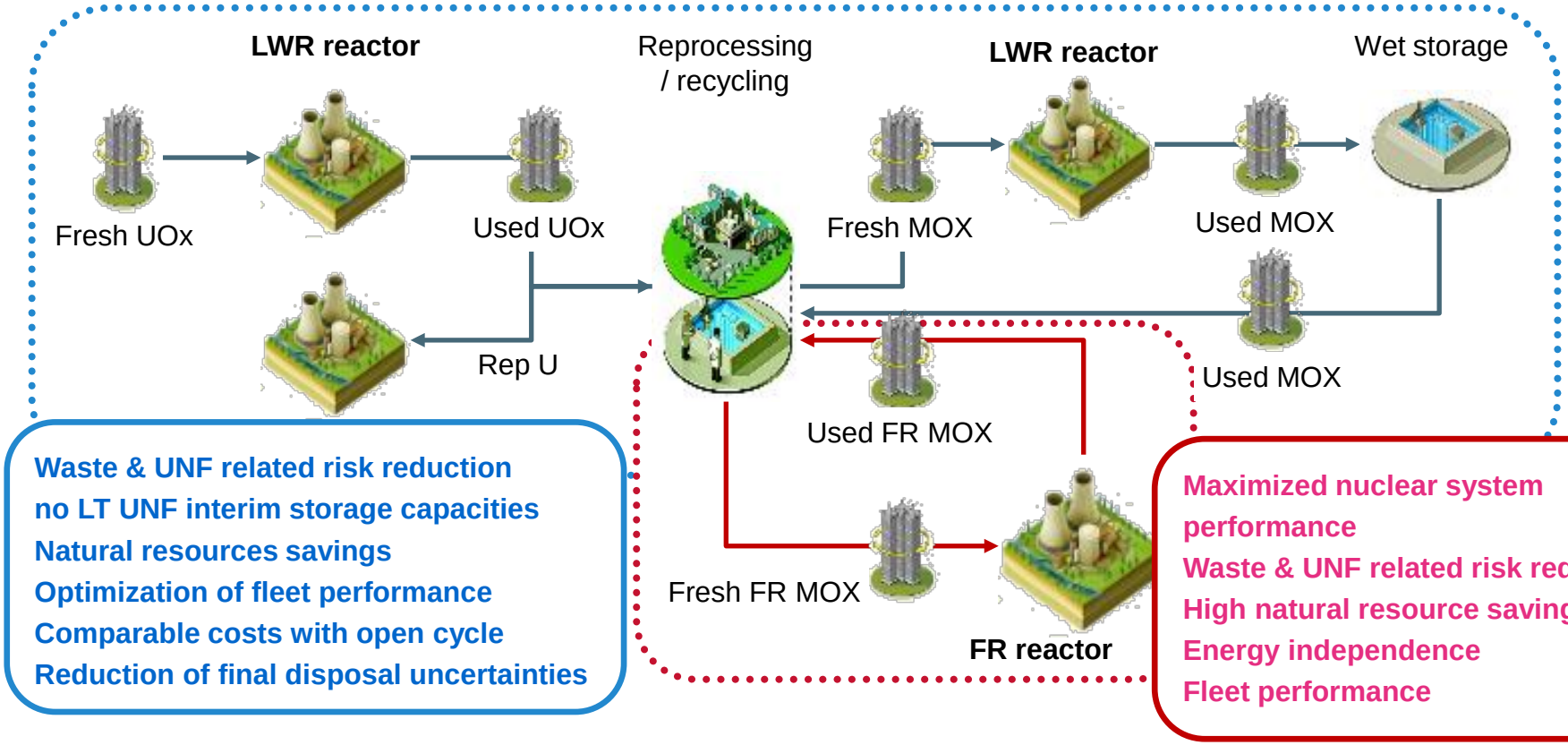
C LWR – FR / UOX-MOX combination

B No LWR MOX accumulation
A few FR (~3000 Mwe)

A No used UOX accumulation
Current situation

O Used UOX accumulation

MOX fuel use in LWR
A flexibility to address progressive deployment of FR



- **Industrial deployment of fast reactors and associated cycle entails uncertainties and may require time**
- **LWR recycling allows for short term reduction of risks and increased flexibility**

In summary

- **The use of MOX and ERU fuel has reached maturity**
- **Both MOX fuel design and supply chain are well mastered and R&D efforts allows for enhancement of their performances to meet utilities requirements**
  - **ensuring MOX energy equivalence with UOX fuel in reactors**
  - **without major impact on reactor design , safety or operations**
- **A LWR mono-recycling strategy**
  - **favors a rapid decrease of total used fuel inventory (one MOX FA instead of 8 UOXFA) resulting in a reliable, optimised and safe solution without IAEA safeguards fissile materials for final waste containment.**
  - **maximises the energy extracted from uranium resources reusing the great energy potential contained in used fuel.**
  - **opens the door to different recycling strategies**
- **A Pu multi-recycling strategy in LWRs allowing stabilization of total UOX + MOX used fuels could be implemented through the development of existing fuel concepts , taking into account that LWR MOX Recycling is already an industrial reality**
- **This proven industrial scale technology combined with constant innovation:**
  - **offers multiple possibilities for optimizing the reuse in LWRs of fissile materials arising from reprocessing.**
  - **This permits major flexibilities to move to future technically and economically robust advanced nuclear systems.**