FUEL CYCLE STRATEGY FROM THE OPERATOR POINT OF VIEW BY EDF

Sino-French Seminar

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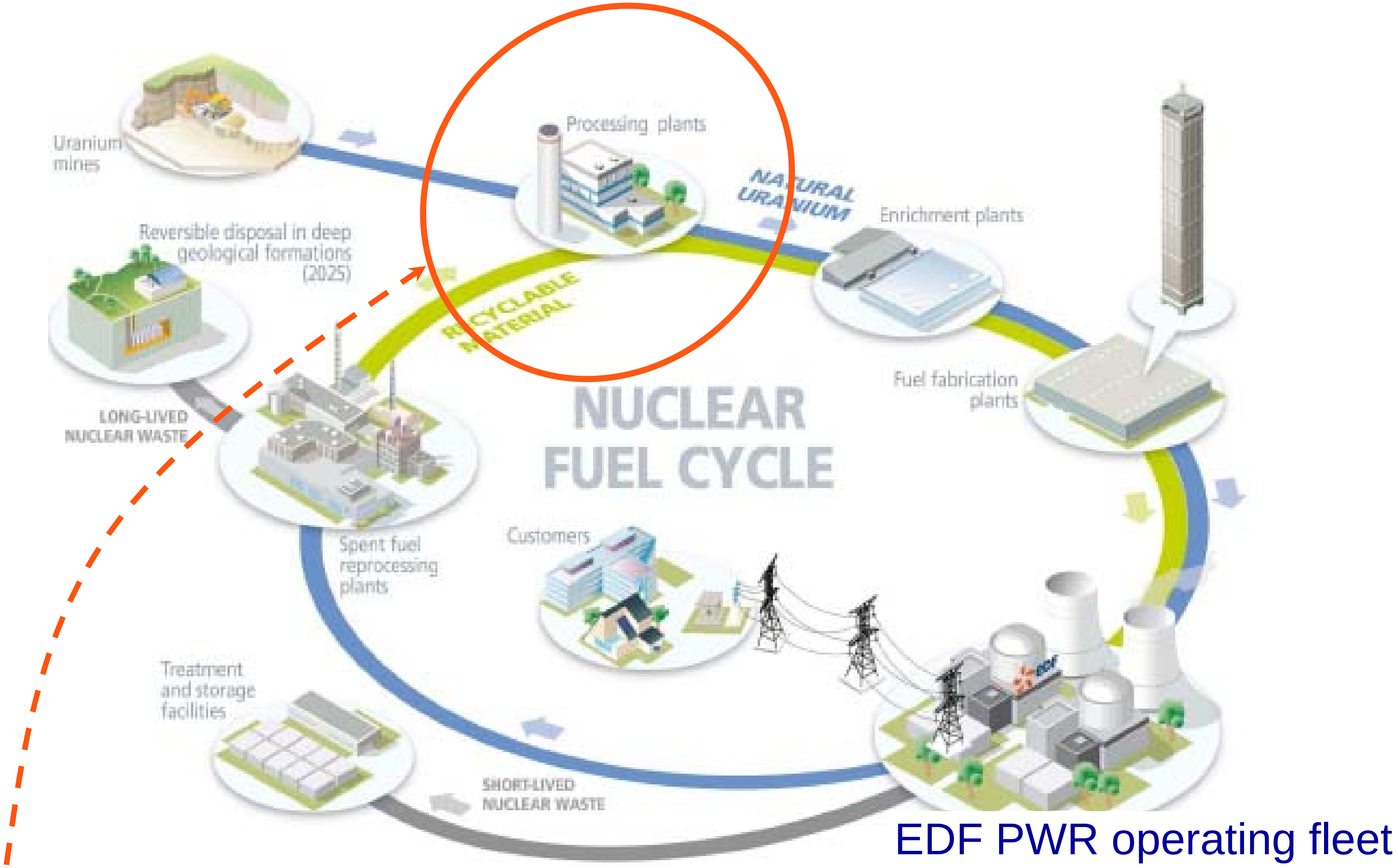
INTRODUCTION

- **EDF is operating a large fleet in France since 1963**
  - 58 Pressurized Water Reactors (PWR), operating since 1978
    - 3 loops series, 900 MWe, 34 units
    - 4 loops series, 1300 MWe, 20 units
    - 4 loops series, 1450 MWe, 4 units
  - 9 units stopped
    - 6 Natural Uranium Graphite Gaz (UNGGR), operating between 1963 and 1976
    - 1 Heavy Water Reactor (HWR), operating between 1967 and 1979
    - 1 PWR, operating from 1967 to 1991
    - 1 Fast Breeder Reactor (FBR), 1200 MWe, operating between 1986 and 1998
  - 1 unit in construction : EPR 1600 MWe

- **EDF is operating NPP in United Kindom**
  - 15 reactors
  - Construction projects : 2 EPR 1600 MWe

FUEL CYCLE STRATEGY – GENERAL ORIENTATION



Reprocessing of French used fuel is at the early stage of a long term strategy in order to:

- maintain independence from the demand for uranium
- prepare a fast breeder reactors program

FUEL CYCLE STRATEGY – GENERAL ORIENTATION

- **Major Technical Stakes for reprocessing fuel**
  - To separate valuables (U, Pu) from actinides and fission products
  - To store and condition products
  - To manufacture the recycled fuel (mixed oxides MOX, uranium oxide made with enriched reprocessed uranium ERU) meeting the safety requirements:
    - During fabrication, transportation
    - Producing the energy in the reactor core
    - In back end of the cycle

- **CEA (atomic energy agency), AREVA (former Cogema and Framatome) and EDF work together on these topics since the 80's, supported by many industrials and under control of the French Safety Authority**
  along with a long experience in common, undergoing however some evolutions:
  - in CEA and AREVA organisations
  - as ANDRA creation (national agency for radioactive waste management) in 1991 replacing a subset of CEA

FUEL CYCLE STRATEGY – REGULATION FRAMEWORK

- **Environmental impacts of nuclear energy have to be anticipated and formally accepted by the public:**
  - Commitments are national, framed by laws
  - Responsibilities are endorsed by radio nuclides producers as EDF
- **French Environment Code supplemented by Act 2006 frames long-lives radioactive waste management**
  - A major goal: ''Reducing the quantity and noxiousness of radioactive waste is the end aim particularly of the processing of spent fuel and the processing and drumming of radioactive waste''
  - Many rules aiming health protection, nuclear safety, reducing the burden on future generations, preparation of repository for long-lived waste, responsibilities, transparency
- **European Directive 2011/70 on "responsible and safe management'' of spent fuel and waste is in line with French laws. It prescribes:**
  - '' The generation of radioactive waste shall be kept to the minimum which is reasonably practicable, both in terms of activity and volume, by means of appropriate design measures and of operating and decommissioning practices, including the recycling and reuse of materials''
  - Rules to implement in the European states

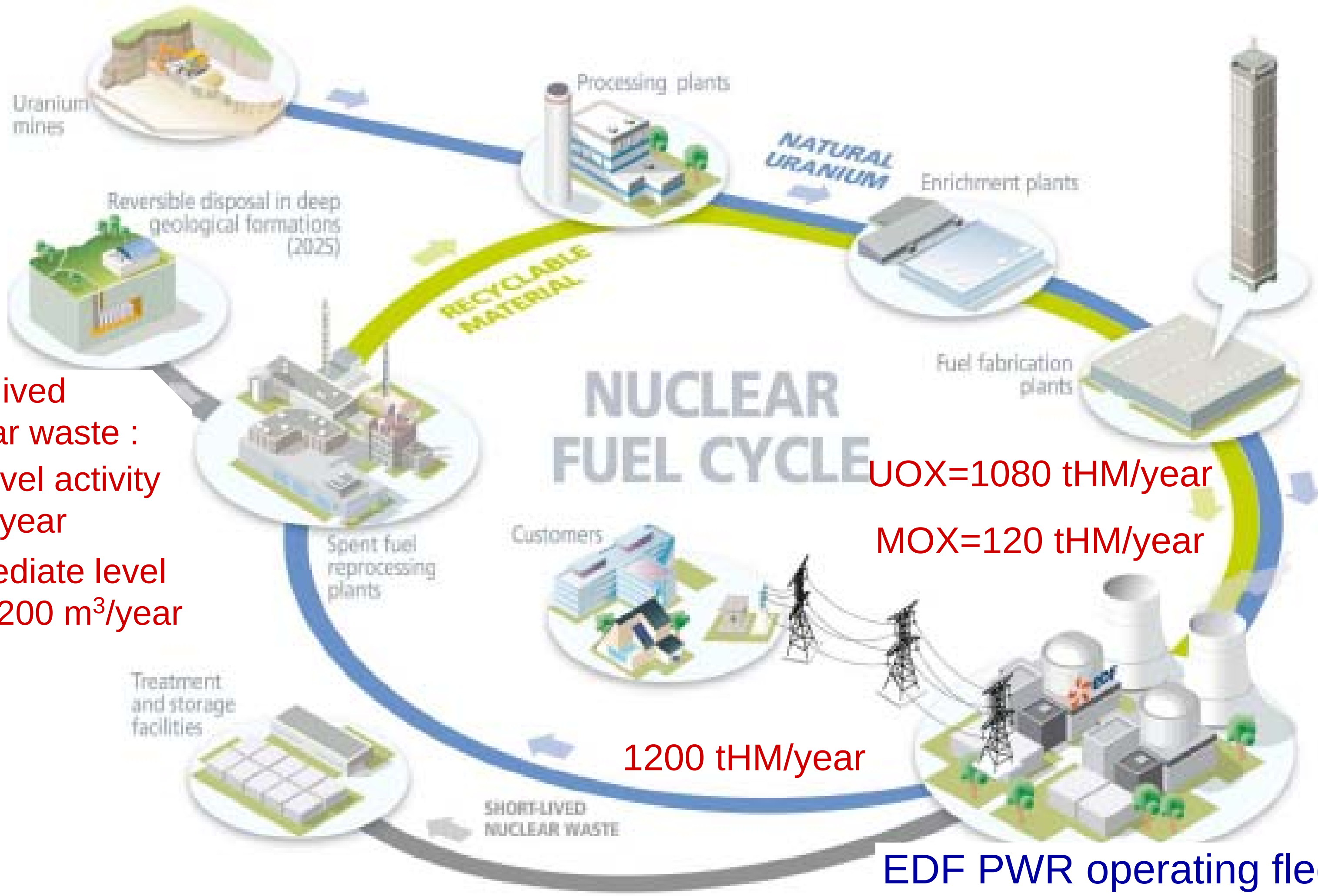
FUEL CYCLE STRATEGY – EDF AREAS OF ACTION

- **Regarding back end fuel cycle, as an Industrial Company in a large regulation framework, EDF has the duties and the missions of mastering and financing long term waste management programs**

- **Mastering:**
  - Design and operate the NPP with safe and reliable fuel, including recycled ones (MOX, EPU): the in-core fuel management types are fitted to reactor specifications, production needs and reprocessing capacities
  - Minimize the volumes of waste and the costs regarding the whole chains
    - Separated Uranium and Plutonium are reserve materials rather than waste
  - Work with ANDRA that is in charge of developing repository for long-lived radioactive waste

- **Financing: all industrial steps of nuclear fuel cycle are followed by EDF in order to**
  - Optimize the contracts on both technical and cost aspects
  - Anticipate changes
  - Make appropriate provisions for the financing of long-term radioactive waste management

FUEL CYCLE - MAJOR QUANTITIES INCURRED



Long-lived nuclear waste :

-High level activity 150 m^3/year

-Intermediate level activity 200 m^3/year

UOX=1080 tHM/year

MOX=120 tHM/year

1200 tHM/year

EDF PWR operating fleet

FUEL CYCLE STRATEGY

French NPP in-core fuel management schemes

Series	Power (MWe)	Number of units	In-core fuel management	Fuel type	Enrichment & Fractioning	Cycle length (months)
CP0 (3 loops)	900	6	CYCLADES	UOX	4.2% per third	16-18
CPY (3 loops)		28	GARANCE ENU	UOX	3.7% per quarter	13
			GARANCE ERU	UOX 100% ERU	3.7% eq. per quarter	13
			Parity MOX	2/3 UOX + 1/3 MOX	3.7% U, 8.65% Pu per quarter	14
P4&P'4 (4 loops)	1,300	20	GEMMES	UOX	4% per third	18
			GALICE	UOX	4.5% per third or quarter	15-21
N4 (4 loops)	1,450	4	ALCADE	UOX	4% per third	17
EPR	1,600	1	EPR ENU	UOX	4.2%	
TOTAL	**63,200**	**58**	Average discharge burn-up > 40 GWd/t			

FUEL CYCLE STRATEGY – OPERATING EXPERIENCE

- **The volume of about one annual discharged fuel is reprocessed each year to produce Pu for the manufacture of MOX (Mixed Oxide) fuel:**
  - About 1,000 t of heavy metal from spent fuel give 10 t of Pu to produce 120 t of MOX
  - It is required to reduce interim storage of Pu, because of progressive creation of americium that produces neutron and gamma reducing its quality; so recycling separated Pu is not delayed
  - MOX assemblies fabrication is similar to UOX, major differences are in radioprotection arrangements

- **MOX fuel in French reactors:**
  - 900 MWe CPY model is considered to implement “Parity MOX” in-core management: safety margins equivalent to UOX fuel management are obtained using 4 supplementary rod control assemblies in the core
  - 24 reactors have a licence to use MOX in 2013, under ‘’Parity MOX’’ fuel management
  - Continuous use of MOX is expected on the licensed 24 units

FUEL CYCLE STRATEGY – OPERATING EXPERIENCE

- **MOX fuel and operating features regarding transportation**
  - Special packaging is used for transportation from the manufacture facility to the plants
    - Reinforced radioprotection design including neutron protection
    - Allows under water transfer to the plant pool
  - Special tools to perform under water transfer to the plant pool
  - Adapted surveillance during transportation because of sensitive material Pu
  - Transport are mastered thanks to the skills, equipment and adapted methods

- **MOX fuel and operating experience in the areas of in-core loading and sealing**
  - Loading plans are achieved in accordance with procedures similar for MOX and UOX, without significant difficulties
  - To prevent any change or hazard in core loading, some supplementary UOX assemblies are provisioned and stored on site
  - Very low rate of leakage on MOX fuel as AREVA UOX fuel are noted since years
  - In-core loading and operating with MOX are mastered thanks to skills, equipment and adapted methods
  - no significant difference between the two management modes MOX and UOX regarding operating performance

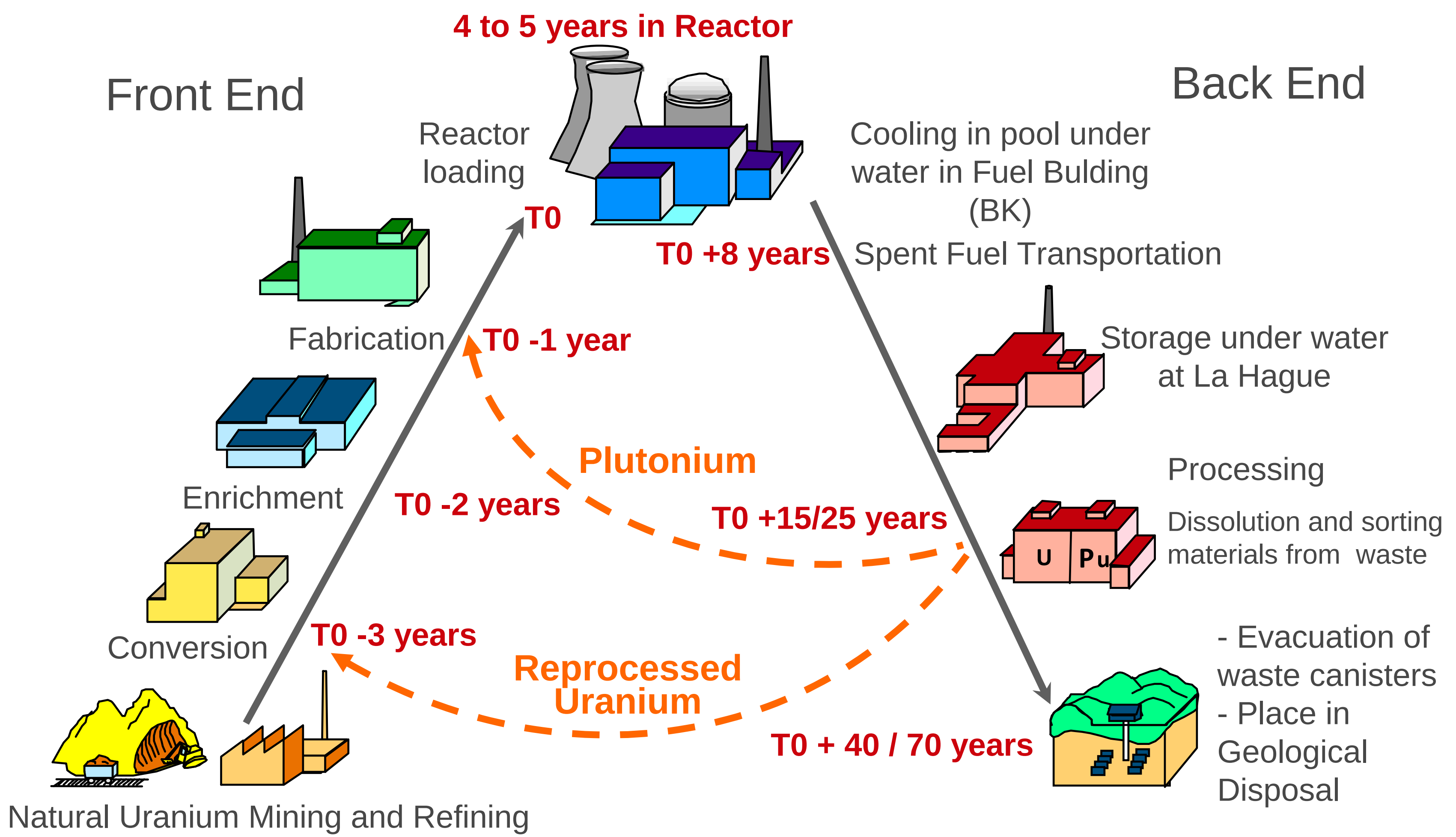
FUEL CYCLE STRATEGY – OPERATING EXPERIENCE

- **Processing spent fuel allows to produce Recycled Fuel based on Enriched Reprocessed Uranium:**
  - Spent fuel contains U235 at 0,75% (compared to 0,71% in natural Uranium) and can be enriched to about 4,1% to allow fabrication of ''Enriched Reprocessed Uranium'' (ERU)
  - ERU is made by the same steps as Enriched Natural Uranium (ENU), using adapted radioprotection arrangements
  - Recycling ERU saves almost the same mass of ENU.

- **The quantity of ERU used depends on balance of costs between the ERU chain and the ENU chain including procurement**
  - 4 reactors from 900 MWe CPY model have been chosen to use ERU and ENU fuel indifferently in GARANCE in-core management
  - Safety margins equivalent to UOX fuel management are obtained using 4 supplementary rod control assembly in the core

- **Operating experience regarding ERU fuel is satisfactory**

NUCLEAR FUEL CYCLE – TIME SCHEDULE



Many items in front end and back end, anticipated and future, added to burn-up level of the fuel assembly, make Fuel Cycle costs.

FUEL CYCLE STRATEGY
PROCESSING INTEREST

- **A solution for conditioning and interim storage on an industrial scale of long-lived waste ...**
  - Recovery of recyclable material U and Pu

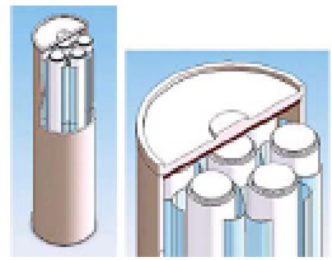
    Present management and available techniques allows to recycle U and Pu to produce 10% to 20% of total nuclear electricity of EDF
  - Radioactive waste management
    - Intermediate level long lived level (ILLL) waste are compacted and packaged
    - High level long lived (HLLL) waste are vitrified

    The standard containers of vitrified residues can be used for long term storage
- **... Supplemented by an emerging solution of repository for long-lived waste (2006 Act and ANDRA mission)**
- **Industrial benchmark and available researches show that these solutions are the safe available ones in order to reduce the volume of waste**

FUEL CYCLE STRATEGY
PROCESSING INTEREST

Spent Fuel Processing reduces long-lived waste volumes

1 Fuel Assembly:
~500 kgU



Without treatment:

1.5 m^3 of HLLL waste conditioned

With treatment:

0.07 m^3 of HLLL waste conditioned and

0.1 m^3 of ILLL waste conditioned

Uranium recovered: 470 kg (94%)

Plutonium recovered: 5 kg (1%)

FUEL CYCLE STRATEGY CONCLUSIONS

- **The different steps of the nuclear fuel cycle are strongly connected**
- **Every stage is involved in technical and economical performance of the nuclear generation**
- **The whole strategy saves nuclear material and allows to reduce the environmental impacts of waste**

Thanks
for
your attention !