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TRANSMUTATION SCENARIOS IMPACTS ON ADVANCED NUCLEAR CYCLES

> FABRICATION

> REPROCESSING

> TRANSPORTATION

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CONTEXT and OBJECTIVES of the STUDY

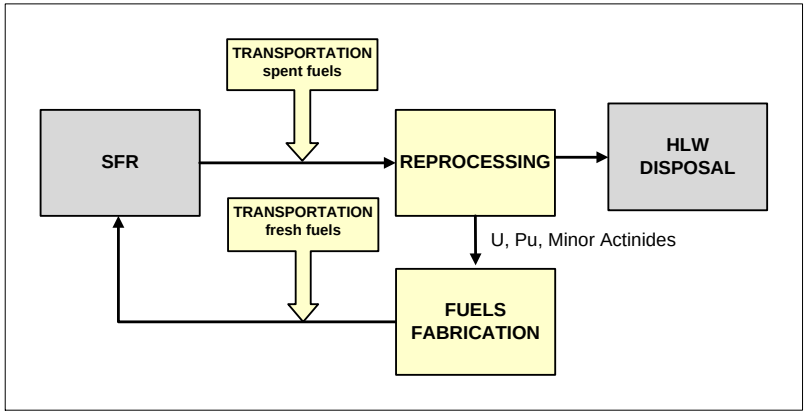
Study in the frame of the French Act for waste management

Different minor actinides transmutation scenarios have been considered

- ❑ Including transition from current French fleet towards a total closed cycle with Sodium Fast Reactors

  (installed capacity 60 GWe, annual production 400 TWh)
- ❑ Transmutation of MA (Am, Np, Cm) or Am alone

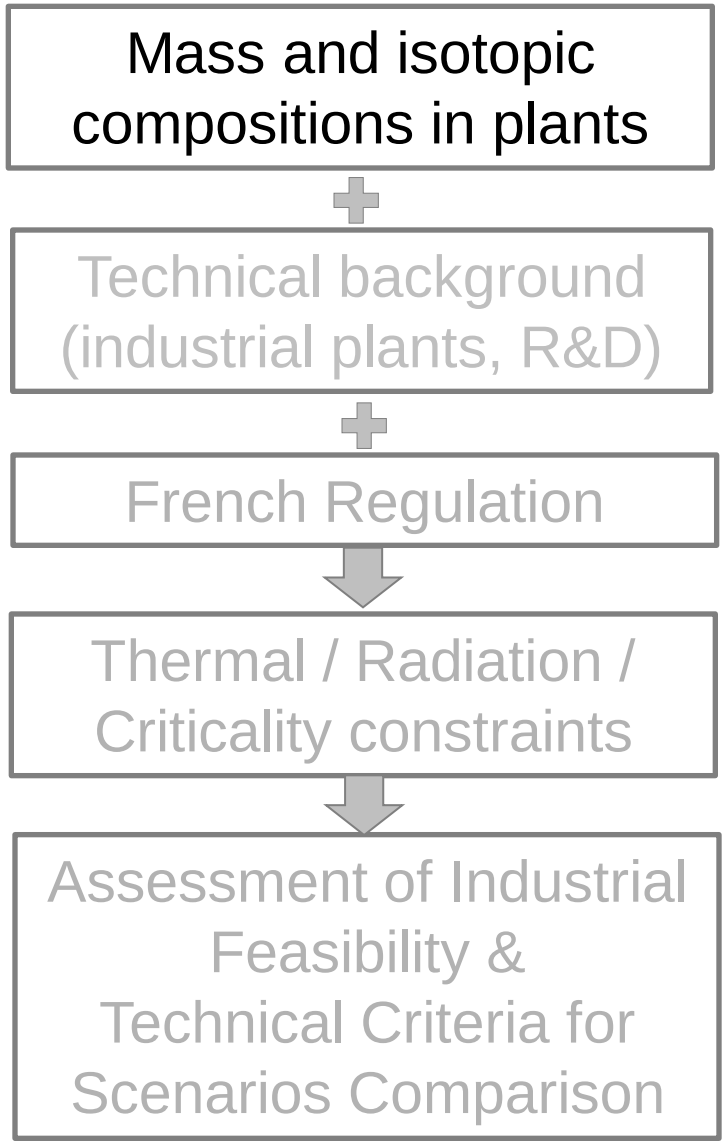
Transmutation options require advanced nuclear cycles with intent to extract MA, to produce new fuels



Purpose of the study : to analyze impacts of transmutation scenarios on fuels cycle

- facilities
- transportation

METHODOLOGY : for each transmutation scenario several steps (1/3)



Transition between current French fleet and SFR deployment with / without transmutation option is carried out with the simulation software COSI

→ Evolution of nuclear fleet and associated facilities over a defined period

→ in our study three plant generations (2 for transition, 1 for equilibrium)

METHODOLOGY : for each transmutation scenario several steps (2/3)

Mass and isotopic compositions in plants

+

Technical background (industrial plants, R&D)

+

French Regulation

Thermal / Radiation / Criticality constraints

Assessment of Industrial Feasibility & Technical Criteria for Scenarios Comparison

Assessment of fuel cycle facilities taking into account **technical background**:

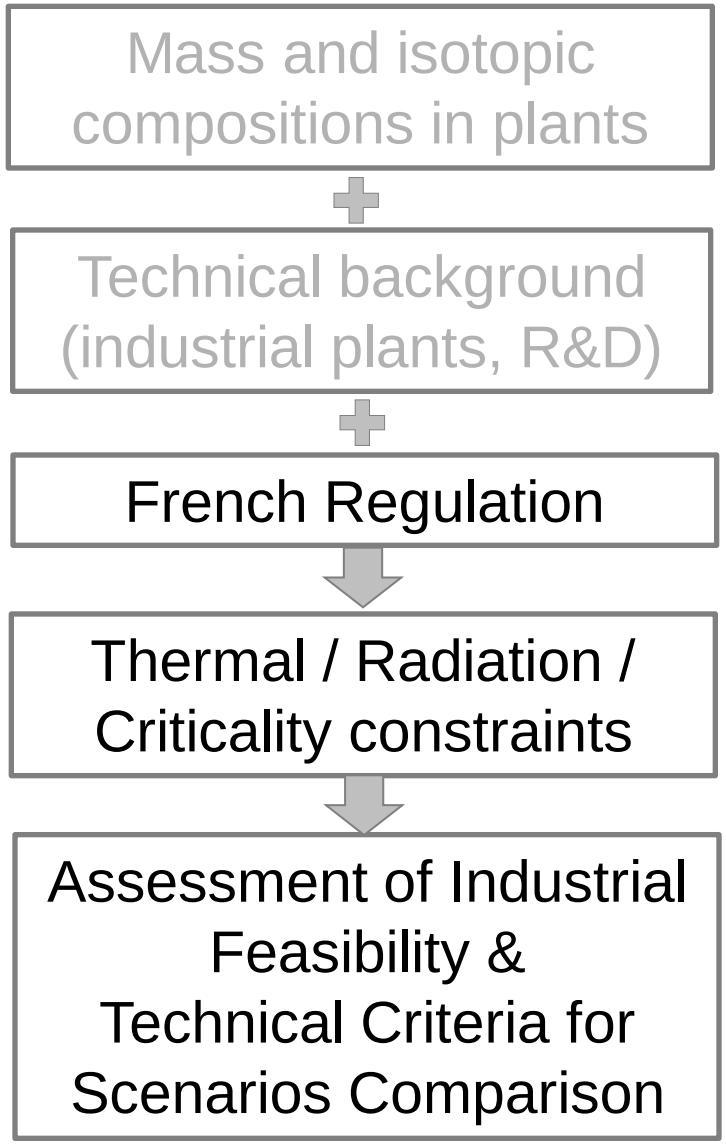
industrial experience from French facilities

MOX Fabrication (MELOX)

La Hague Reprocessing Plants

and R&D results in partitioning (Atalante experiments)

METHODOLOGY : for each transmutation scenario several steps (3/3)



French regulation

For liquid and gaseous releases

For workers occupational exposure

For fuels transportation

Characteristics

of the fresh assemblies to be produced

of spent fuels to be reprocessed are known in terms of **heat release, radiation**

Studies provide information on **industrial feasibility** for each of the MA or Am transmutation options

Scenario studies also include economical assessment and waste disposal analysis

DIFFERENT MA TRANSMUTATION OPTIONS HAVE BEEN ANALYZED

Several differentiated options have been selected:

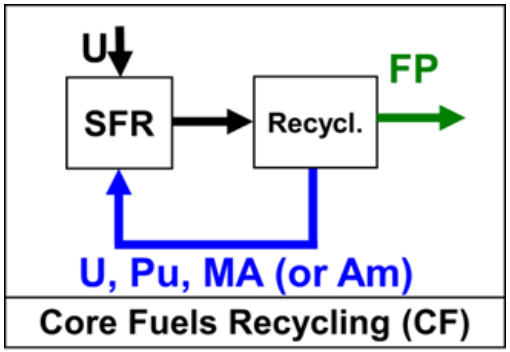
- Recycling of plutonium only

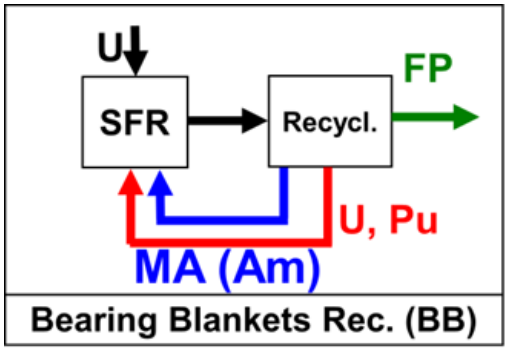
- Recycling of plutonium and transmutation of all or part of the minor actinides in homogeneous mode (core fuels)
  - ✓ of all minor actinides (Am + Np + Cm)
  - ✓ of americium only

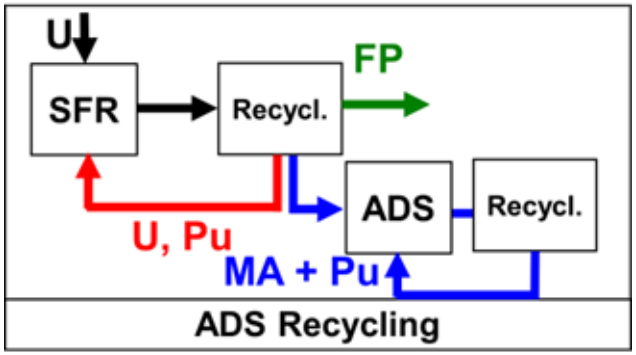
- Recycling of plutonium and transmutation of all or part of the minor actinides in heterogeneous mode (bearing radial blankets)
  - ✓ of all minor actinides (Am + Np + Cm)
  - ✓ of americium only

- Recycling of plutonium in SFR and transmutation of minor actinides in a dedicated ADS stratum

DIFFERENT MA TRANSMUTATION OPTIONS HAVE BEEN ANALYZED







Homogeneous Mode
(Core Fuels Recycling)

(U + Pu + MA)
MA mass content
1.2 % (equilibrium)

or (U+ Pu + Am)
Am mass content
0.9 % (equilibrium)

Heterogeneous Mode
(Bearing Blankets Recycling)

(U + MA)
MA mass content
20 %

or (U + Am)
Am mass content
20 % to 10 % (equilibrium)

in Accelerator Driven System

ADS fuels
CERCER with
73.1 % Pu+MA
54% MA and 46% Pu contents
26.9 % MgO

IMPACTS ON FABRICATION PLANTS
Each transmutation scenario needs specific fuels and fabrication plants

Powder metallurgy process is considered for producing the different fuels

→ *powders preparation* → *pelletizing* → *fuel pins fabrication* → *fuel assembly* →

Differences between plants / scenarios

- Number of objects to be fabricated
- MA contents → constraints on plants design

	Homogeneous Mode		Heterogeneous Mode		In ADS
	Core Fuels Recycling		**Bearing Blankets Recycling**		**ADS Recycling**
Tons.yr^{-1}	450		MOX (SFR) + 29 – 75		MOX (SFR) + 20
Assemblies.yr^{-1}	2 760		MOX (SFR) + 244 – 522		MOX (SFR) + 688
% MA / HM	0.9 – 2.9 Am	1.2 – 3.9 MA	20 or 10 Am	20 MA	54 MA
kW / assembly	0.7 – 2.9 Am	1.6 – 1.8 MA	3.1 – 1.4 Am	9.1 MA	8.3 MA

IMPACTS ON FABRICATION PLANTS
thermal / radiation protection / criticality constraints

	Homogeneous Mode		Heterogeneous Mode		In ADS
	Core Fuels Recycling		Bearing Blankets Recycling		ADS Recycling
	Am	MA	Am	MA	MA
Thermal (W/kg ox.)	4	9	7	56	160
Neutron radiation (n/s/g ox.) *Max. values/ scenario*	$2{,}5.10^{2}$	$1{,}9.10^{4}$	$9{,}6.10^{2}$	$2{,}1.10^{5}$	$4{,}2.10^{5}$
Gamma radiation (γ/s/g ox.) *Max. values/ scenario*	$1{,}8.10^{9}$	$2{,}6.10^{9}$	$1{,}4.10^{10}$	$1{,}4.10^{10}$	$4{,}2.10^{10}$

Increasing with curium

- **Increasing constraints with curium quantities**
  - / Thermal: Decreasing batch sizes
    Difficulties on assembly line more specifically for ADS fuels and MA-BB
  - / Radiation: Heavier protections (hot cells)
    Glove boxes if no MA transmutation
- **With high curium content**, whole new technology development will be required (more pronounced for ADS option)
- Even with less constraints, **Am recycling** will need R&D for equipment and maintenance qualification

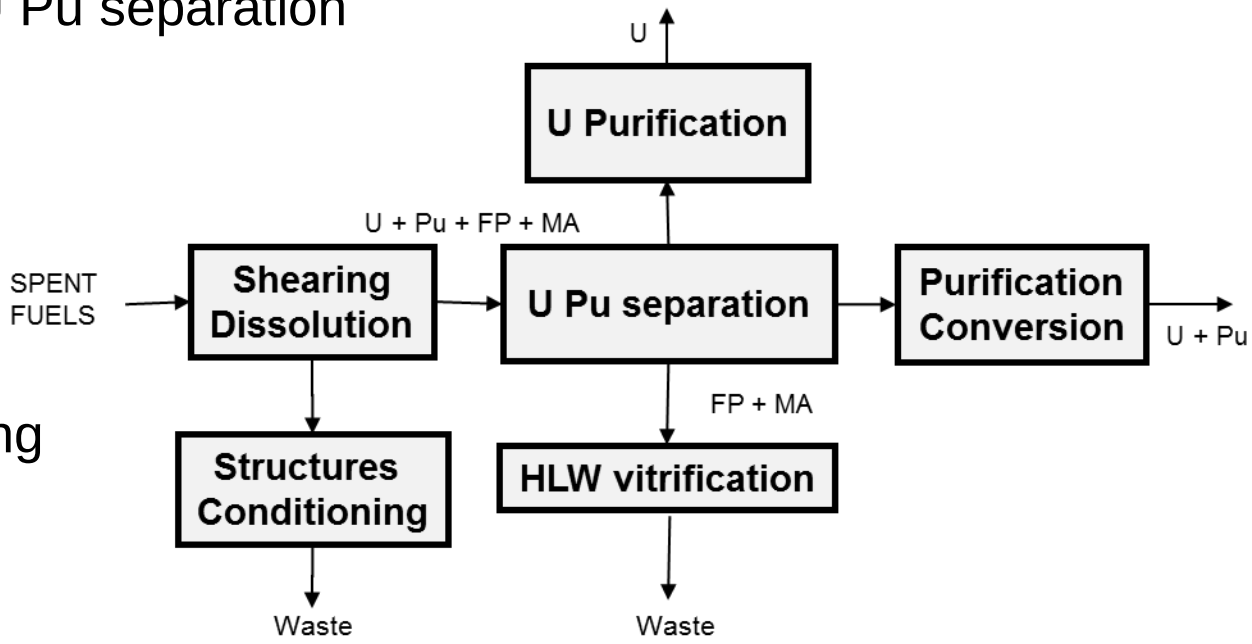
IMPACTS ON REPROCESSING PLANTS
Each transmutation scenario needs specific reprocessing plants

Nearly same capacity: about 450 tons per year

Hydrometallurgy process is considered

Similar functions to U Pu separation

- ✓ Fuel dissolution
- ✓ U purification
- ✓ Fuels metallic structures conditioning
- ✓ High Level Waste Vitrification



Differences in HLW composition

- *Fission Products + MA (no MA transmutation)*
- *Fission Products + Np + Cm (Am transmutation)*
- *Fission Products (MA transmutation)*

IMPACTS ON REPROCESSING PLANTS

Differences between scenarios: specific functions to extract and convert MA

Specific Functions	Core Fuels Rec.		Bearing-Blankets Rec.		ADS Rec.
	MA	Am	MA	Am	MA
Extraction & Conversion U Pu			x	x	x
Extraction & Conversion U Pu MA	x				
Extraction U Pu, Am & Conversion U Pu Am		x			
Extraction MA & Conversion U MA			x		
Extraction Am & Conversion U Am				x	
Extraction Pu MA & Conversion Pu MA (+ Mg)					x

Core Fuels Rec. / Bearing Blankets Rec.: no important difficulties
ADS Rec.: scientific and technical feasibility of hydrometallurgy process has to be investigated for ADS spent fuels

- Analogy between conversion and fabrication: batch sizes must decrease and protection must be heavier with curium content
- Criticality constraints have been analyzed in preliminary studies: additional analyzes are required for specific functions (for example conversion of product containing curium)

IMPACTS ON FUELS TRANSPORTATION (1/2)

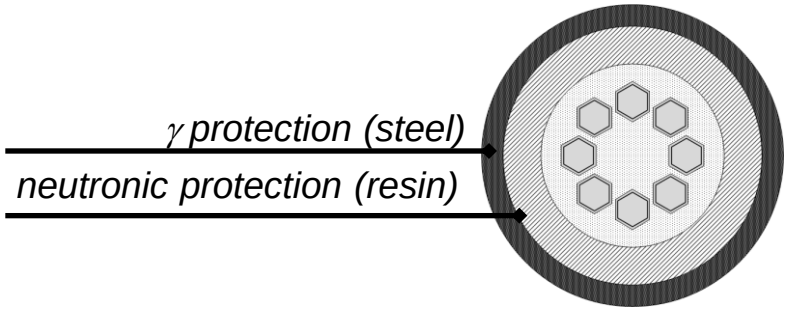
Differences between scenarios

MA contents & number of objects to be fabricated / reprocessed
Thermal / radiation protection / criticality constraints in normal conditions

→ Choice of cask concepts

→ Number of assemblies / cask

Example of cask for fresh fuels



→ Results : number of annual transportation / scenarios

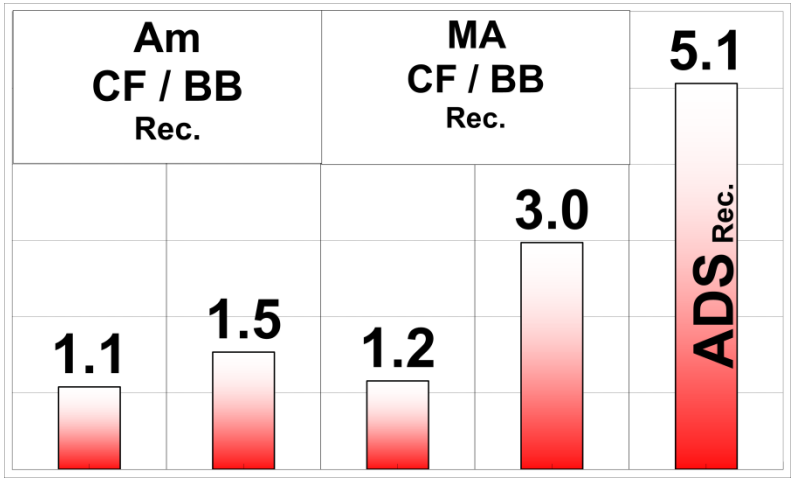
IMPACTS ON FUELS TRANSPORTATION (2/2)

Considering 1 for no transmutation scenario

- Core Fuels Recycling

(Homogeneous Mode)

Nearly identical annual transportation for MA or Am



- Am-Bearing Blankets Recycling

(Heterogeneous Mode) : slight increase

- Increasing transportation with curium quantities

  3 times more transportation for MA-bearing blankets recycling

  5.1 times more for ADS fuels

  because of important heat release requiring dividing fresh fuels and technological innovations development

- Feasibility of transport operations for Am transmutation scenarios (homogeneous, heterogeneous) achievable through few adaptations of the cask
- High uncertainties about the feasibility of transport operations when fuels contain curium (MA-BB and ADS fuels)

CONCLUSIONS

First detailed assessment of **plants** and **transportation** in various transmutation scenarios

In case of curium transmutation

large difficulties and uncertainties requiring whole new technology development (more pronounced for ADS option)

For Am transmutation

more feasible, still to be demonstrated on specific points for industrial extrapolation

Thank you for your attention

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