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OVERVIEW ON HOMOGENEOUS AND HETEROGENEOUS TRANSMUTATION IN A FRENCH NEW SFR:

REACTOR AND FUEL CYCLE IMPACT

F. Varaine[1], L. Buiron[1], L. Boucher[1], D. Verrier[2]

1 Atomic Energy Commission, Nuclear Energy Division, Reactor Studies Department

2 AREVA NP

France

Outline

- ***Introduction and context***
- ***Transmutation ways in SFR***
- ***A French SFR Design***
- ***Input data (scenario approach)***
- ***Reactor and fuel cycle impact***
- ***Conclusion, future work***

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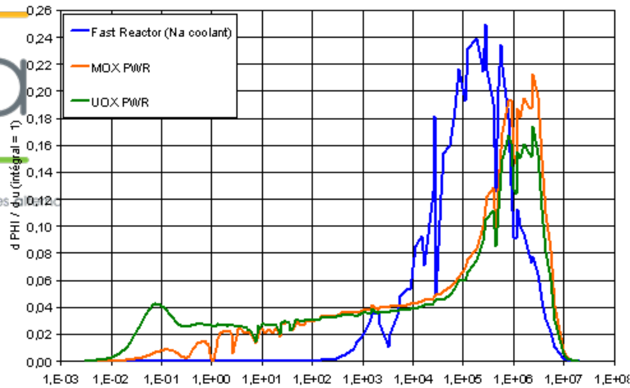
*The purpose of minor actinides and long lived fission products **transmutation** is to reduce the **heat decay** and the **potential radiotoxicity** of the long-lived nuclear waste.*

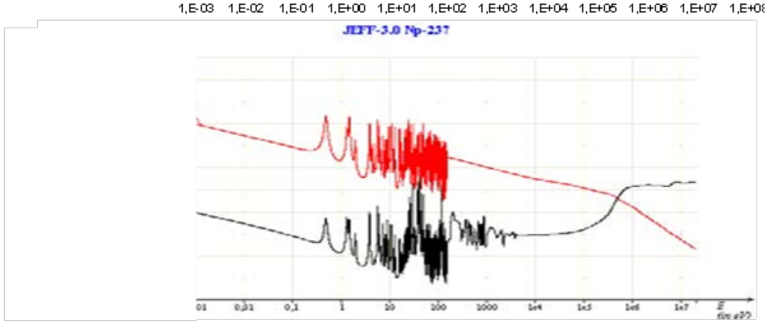
The scientific feasibility of long-lived waste transmutation was studied since several years by the scientific community (including at CEA).

On the reactor physic point of view:

- *capture has to be avoided: generates another actinide and moves the problem*
- *fission must be reached.*

Transmutation physic





Reactor	PWR		FR	
Burn Up	60 GWd/t		140 GWd/t	
Flux level	2.5 10^{14} n/cm^2/s		3.4 10^{15} n/cm^2/s	
Irradiation time	1500 EFPD		1700 EFPD	
Fission (F) and Disappearance (D) rate	D (%)	F (%)	D (%)	F (%)
Np237	46	4	63	24
Am241	70	10	69	24
Am243	65	6	63	15
Cm244	44	16	50	27

Isotope	Thermal spectrum (PWR-UOX)			epithermal spectrum (PWR-MOX)			Fast spectrum (Na coolant)		
	σ_f	σ_c	α	σ_f	σ_c	α	σ_f	σ_c	α
^{237}Np	0,52	33	63	0.6	18	30	0,32	1,7	5,3
^{238}Np	134	13,6	0,1	38.5	4	0,1	3,6	0,2	0,05
^{241}Am	1,1	110	100	0.8	35.6	44,5	0,27	2,0	7,4
^{242}Am	159	301	1,9				3,2	0,6	0,19
^{242m}Am	595	137	0,23	126.6	27.5	0,2	3,3	0,6	0,18
^{243}Am	0,44	49	111	0.5	31.7	63,4	0,21	1,8	8,6
^{242}Cm	1,14	4,5	3,9	0.96	3.45	3,6	0,58	1,0	1,7
^{243}Cm	88	14	0,16	43.1	7.32	0,2	7,2	1,0	0,14
^{244}Cm	1,0	16	16	1	13.1	13,1	0,42	0,6	1,4
^{245}Cm	116	17	0,15	33.9	5.4	0,2	5,1	0,9	0,18

Fast neutron reactors offer greater flexibility and ensure a transmutation performance which is far superior than that of PWRs.

French context

In France transmutation in nuclear reactor has been studied since 1991 in the framework of the first French Act relative to the sustainable management of radioactive materials and waste. This first stage was closed in 2006 after 15 years of research. Main conclusions for the transmutation point of view were:

French context

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- The Long lived Fission Product transmutation is not efficient in nuclear reactor.
- Transmutation is preferable in fast spectrum, and not efficient in PWR.
- A global scenario approach is needed to evaluate all impacts.

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In 2006 a new act was voted by the French parliament. Studies relating to such wastes are prosecuted under the three following complementary areas:

- The separation and transmutation of long-lived radioactive elements. The corresponding studies and research are conducted in conjunction with those carried out on new generations of nuclear reactors to dispose of, in 2012, an assessment of industrial perspectives and to operate a prototype facility before December 31, 2020.
- *The reversible disposal in deep geological formations.*
- *Interim storage.*

Transmutation ways in fast reactor

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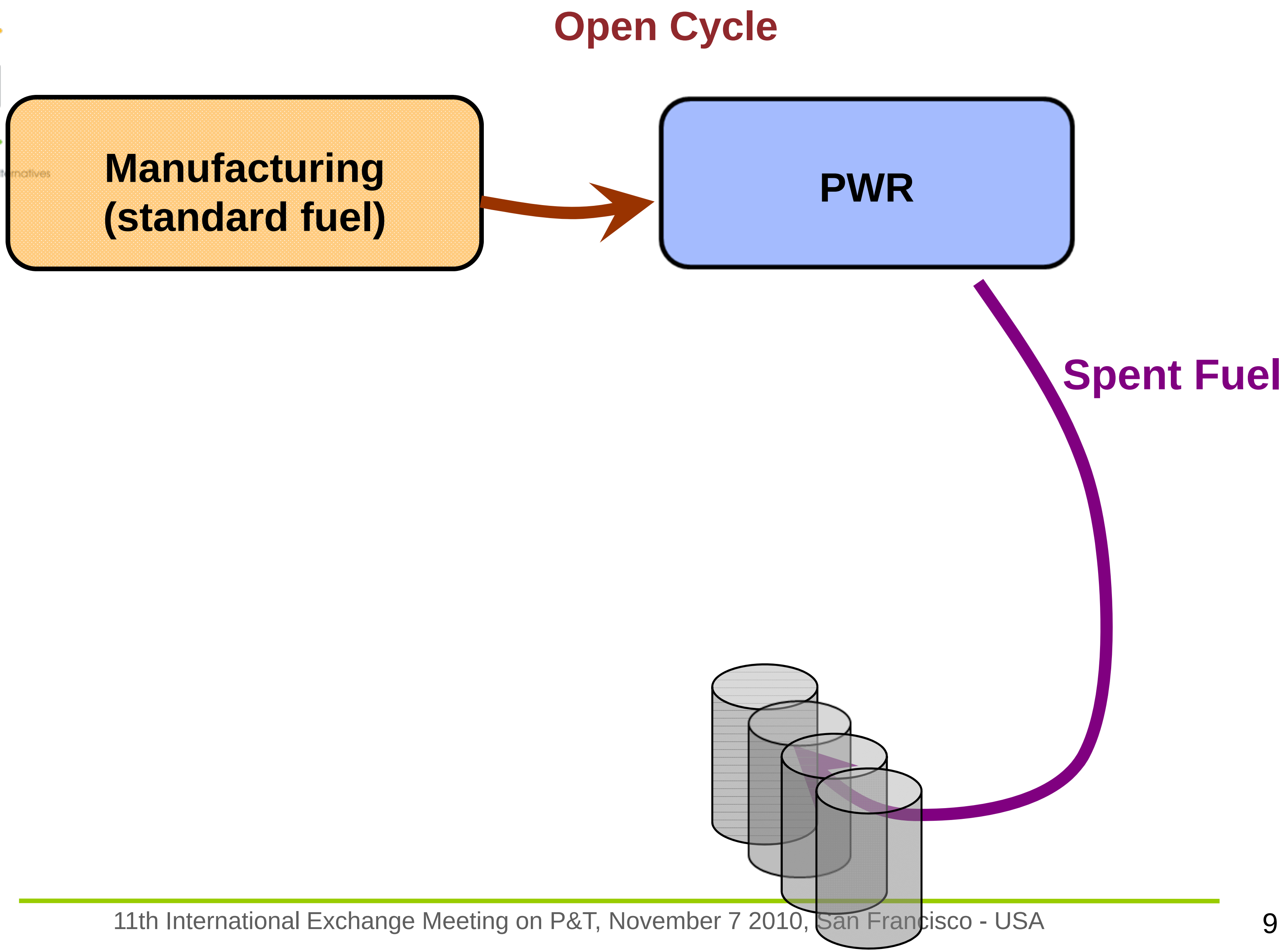
- **Two ways for transmutation are possible :**
  - The homogeneous mode where the minor actinides to be transmuted are directly mixed with "standard" fuel of the reactor,
  - The heterogeneous way for which the actinides to be transmuted are separated from the fuel itself, in limited number of S/A (targets) devoted to actinides transmutation.

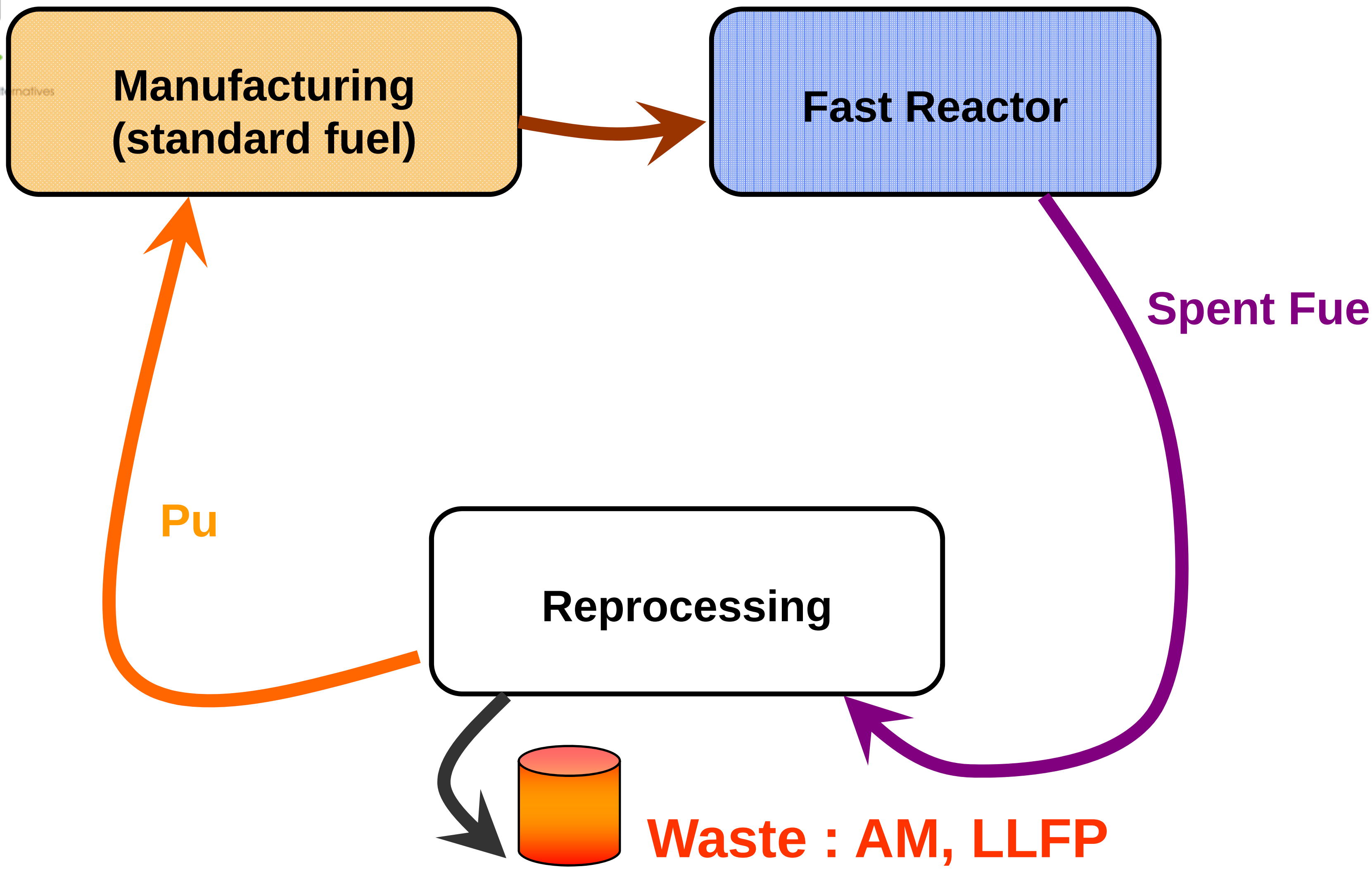
- **With two associated ways for actinides management :**
  - The multi- recycling : in this case whole or part of minor actinides and plutonium at the end of each reactor cycle is sent back in the following cycle. In that way, only reprocessing losses go to the waste,
  - The once-through way : in this case the minor actinides are transmuted in targets where very high burn up is reached



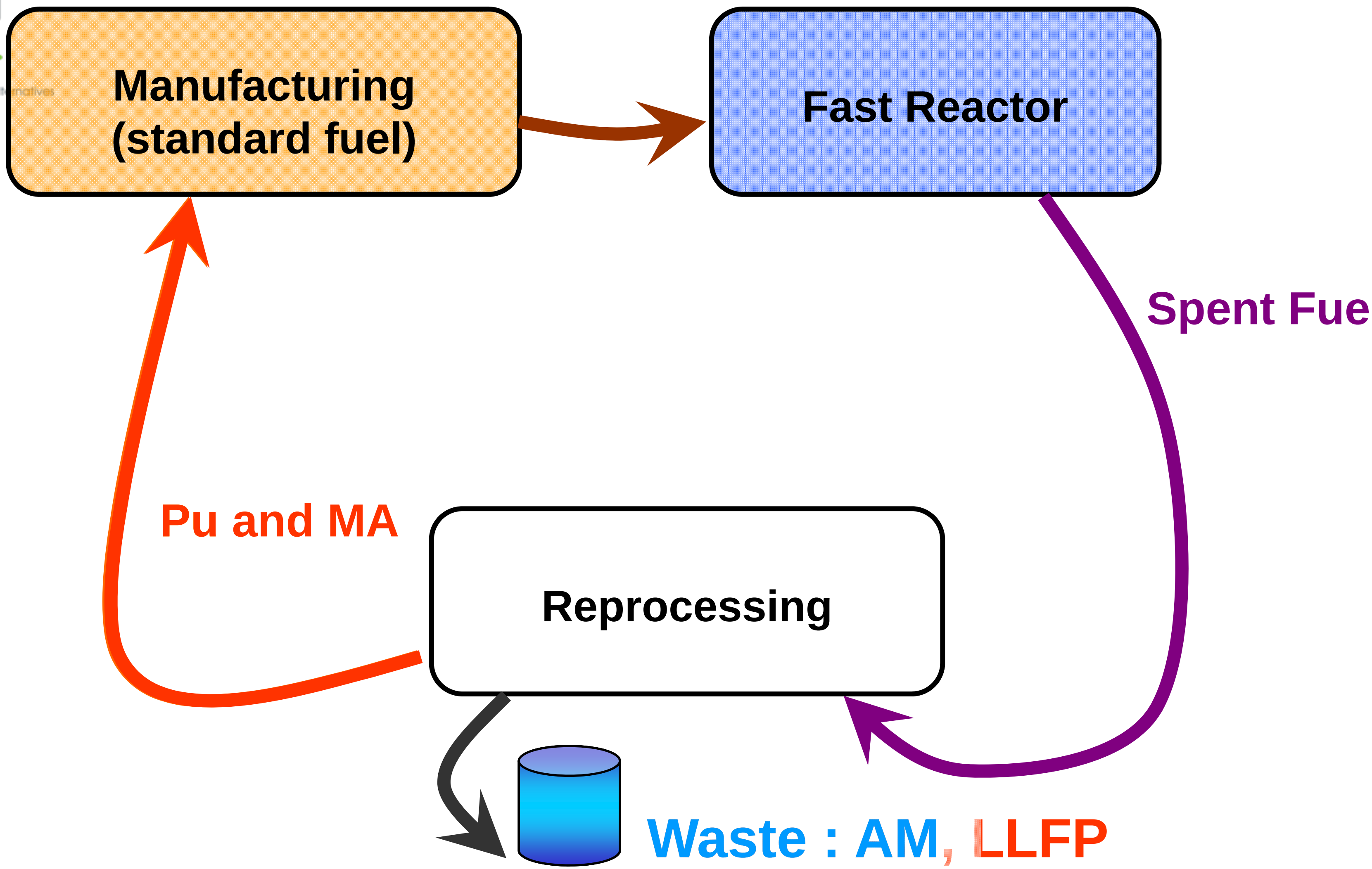
Open Cycle
Manufacturing
(standard fuel)
PWR
Spent Fuel

Transmutation scheme

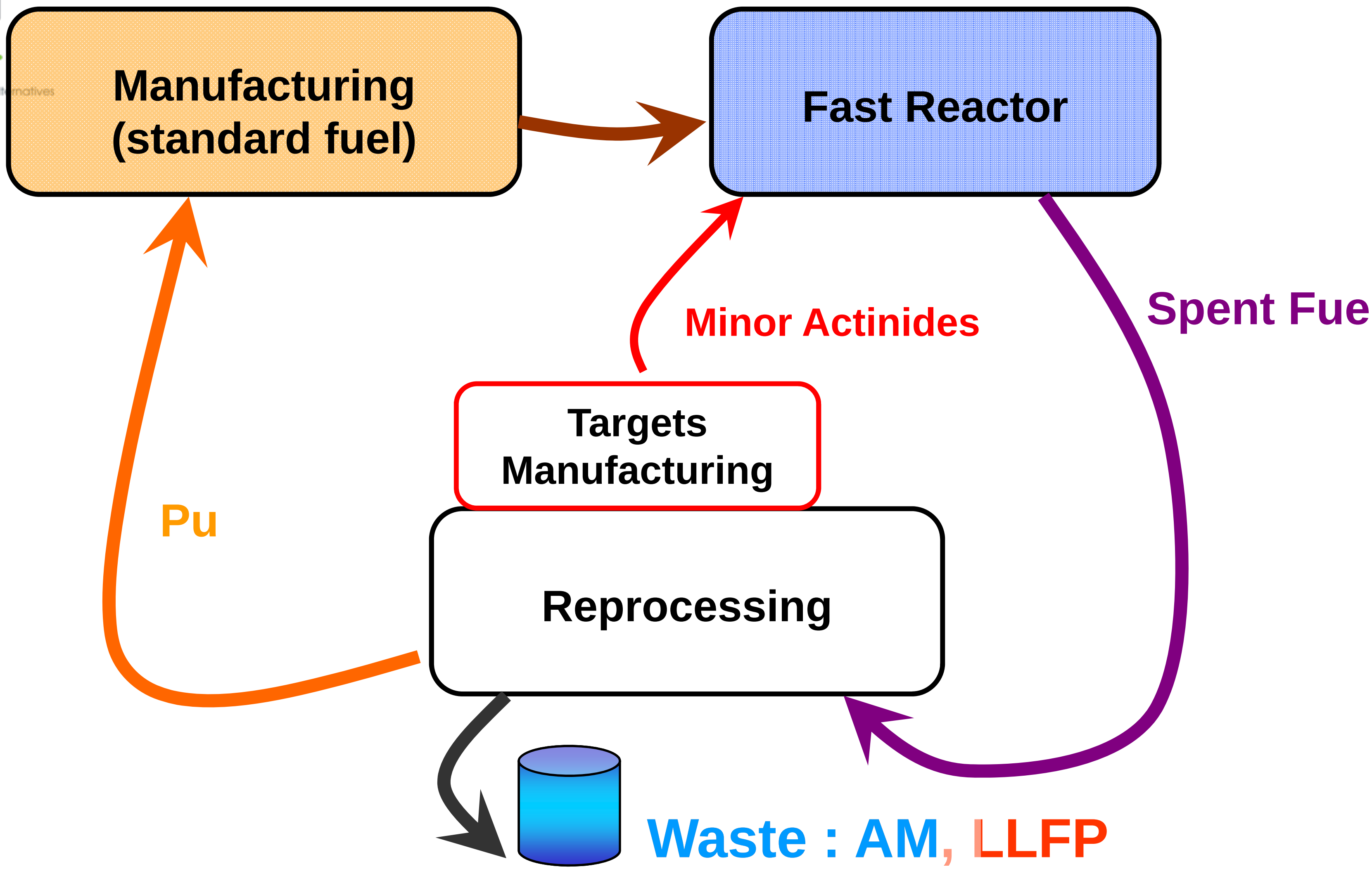
Pu Recycling (multirecycling)



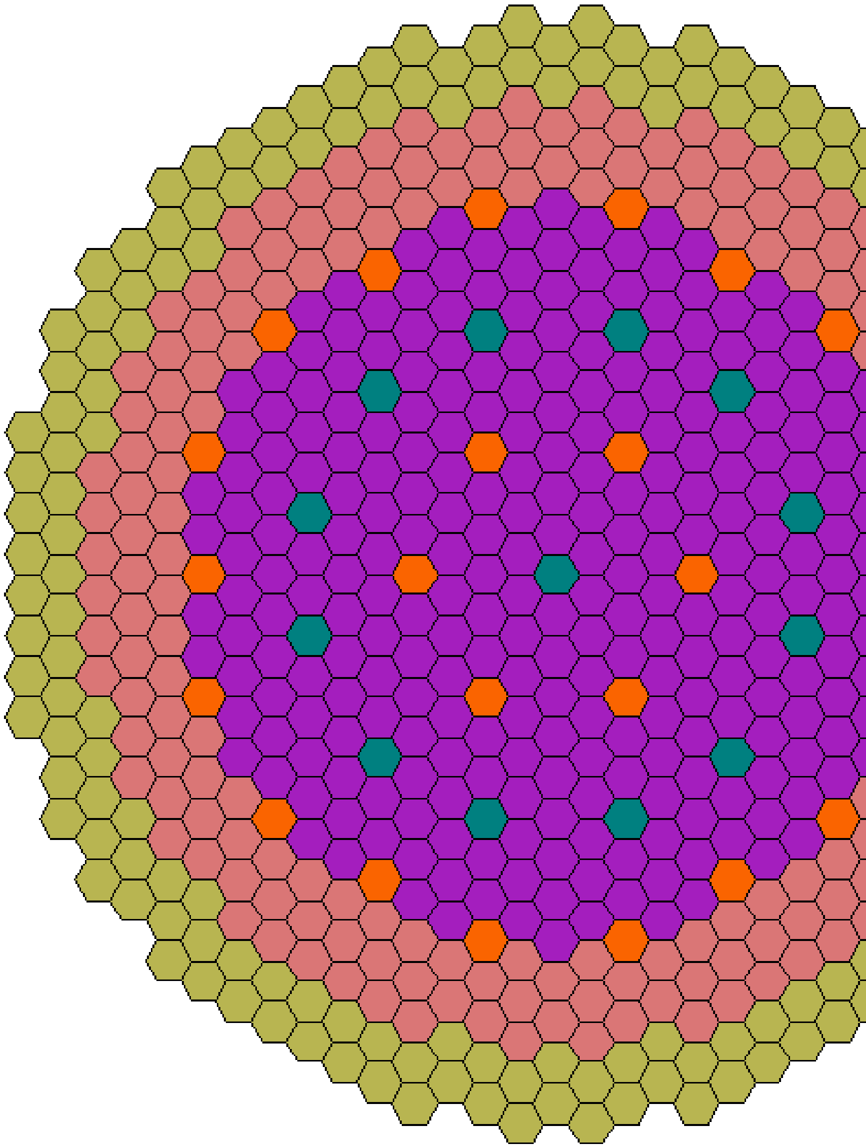
MA Homogeneous multirecycling



Heterogeneous way (multirecycling)



SFR characteristics



Core power (MWth)	3600
Core electric power (MWe)	1500
Core batches	5
Mass of Pu (t)	12.5
Mass of equivalent Pu (t)	8.1
Mass of U+Pu+Am (t)	74
Average Pu mass content (%vol)	15.8
Core diameter (m)	4.9
Core height (m)	1
Core volume (m3)	17.4
Fuel residence time (EFPD)	2050
Average burn-up (GWd/t)	99
Maximum burn-up (GWd/t)	139
Maximum neutron dose (dpa)	148
Power density (W/cm3)	207
Maximum linear power (W/cm)	420
Sodium void reactivity ($)	4.9
Internal breeding gain	+0.04

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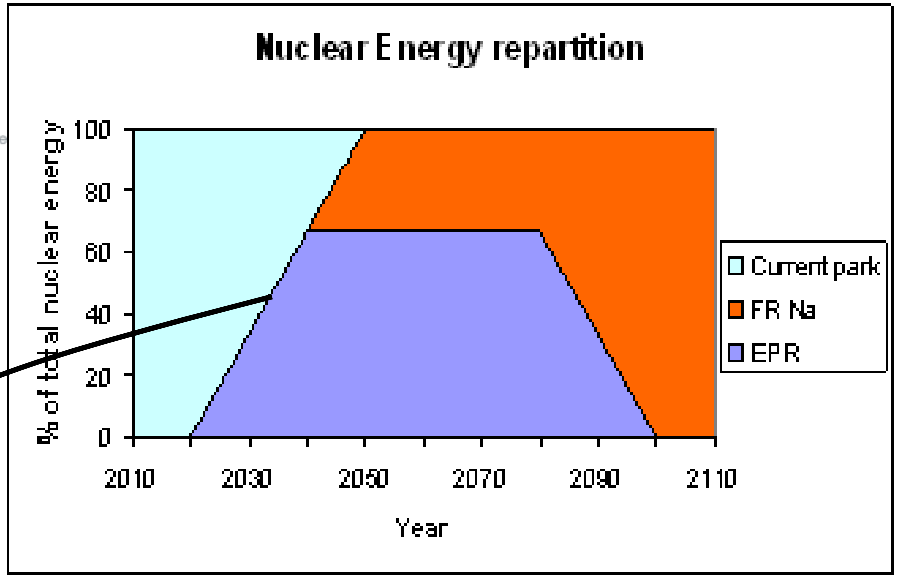
. Based on French context and needs



The current nuclear park is replaced

between 2020 and 2050 by a mixed nuclear park: of Generation III EPR reactors and 33% of Generation IV SFR.

Data and hypothesis

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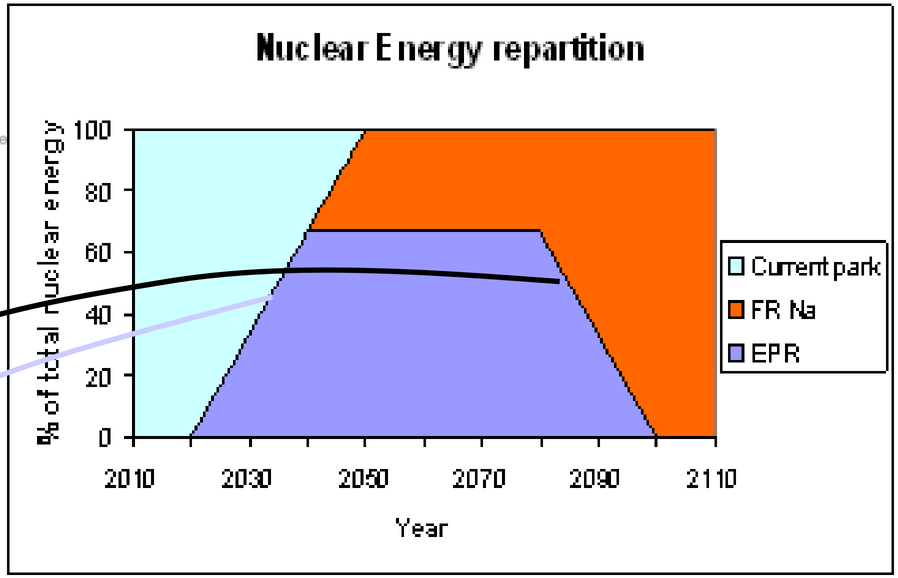

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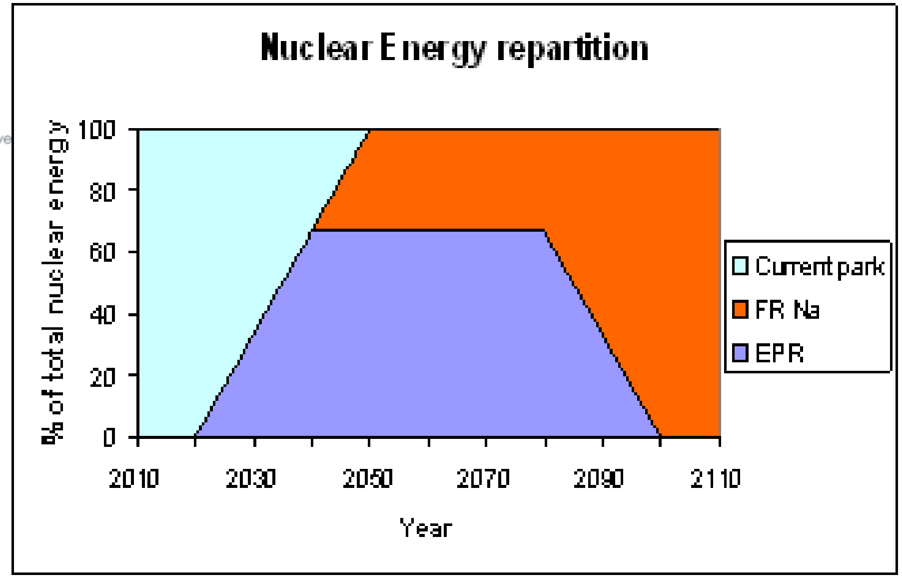

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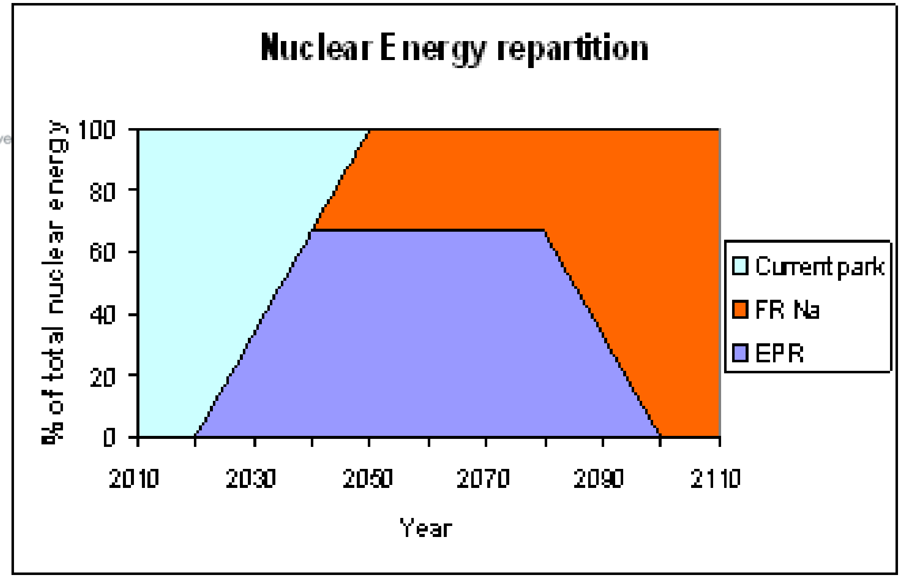

	Am	M.A
Np237		16.86
Am241	66.67	60.62
Am242		0.24
Am243	33.33	15.7
Cm242		0.02
Cm243		0.07
Cm244		5.14
Cm245		1.26
Cm246		0.09

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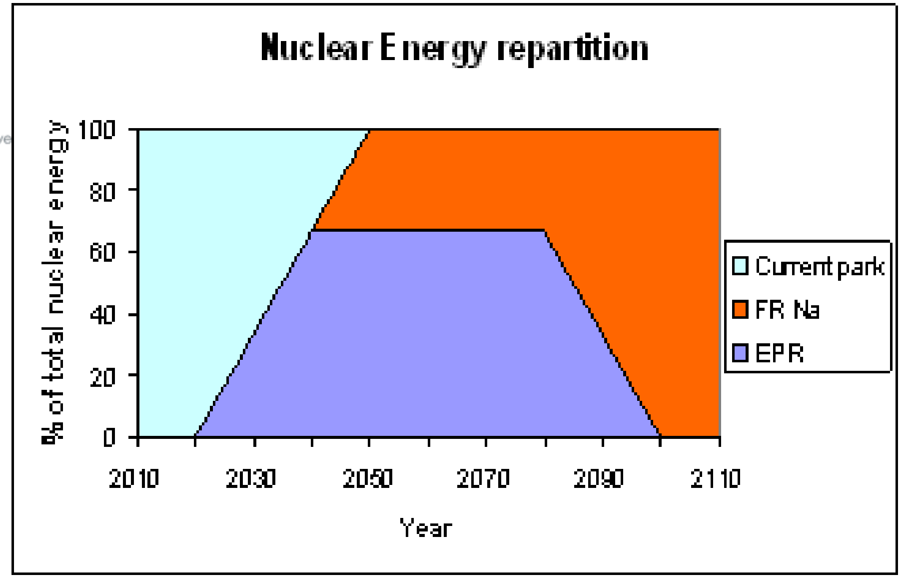

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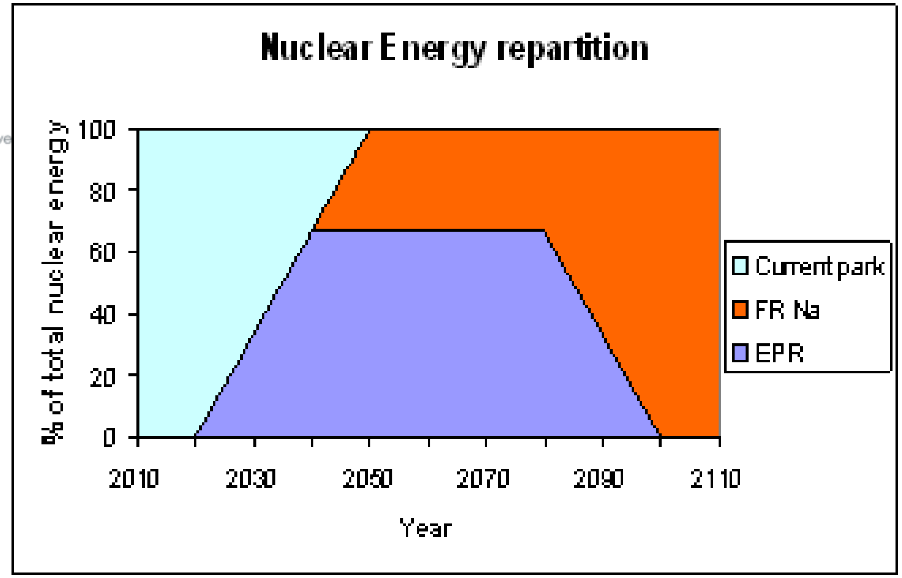

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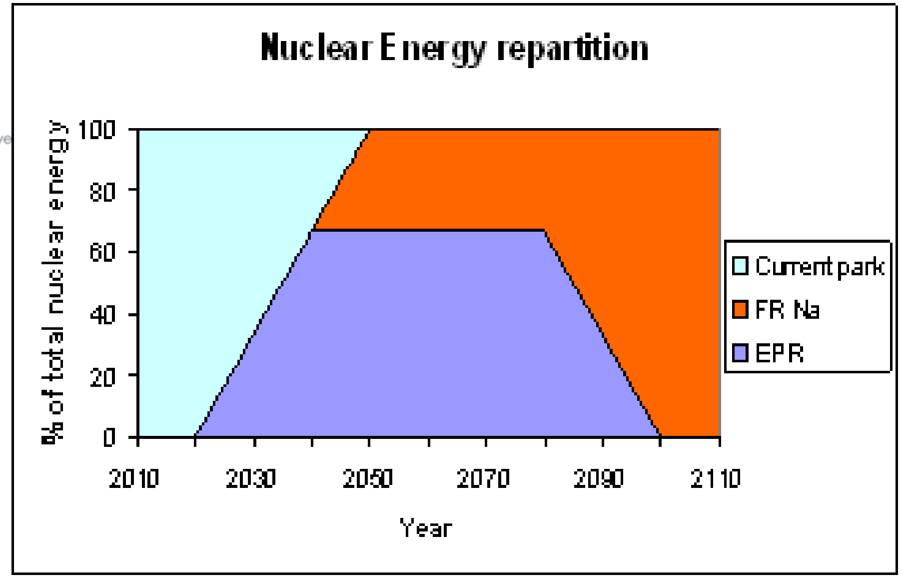

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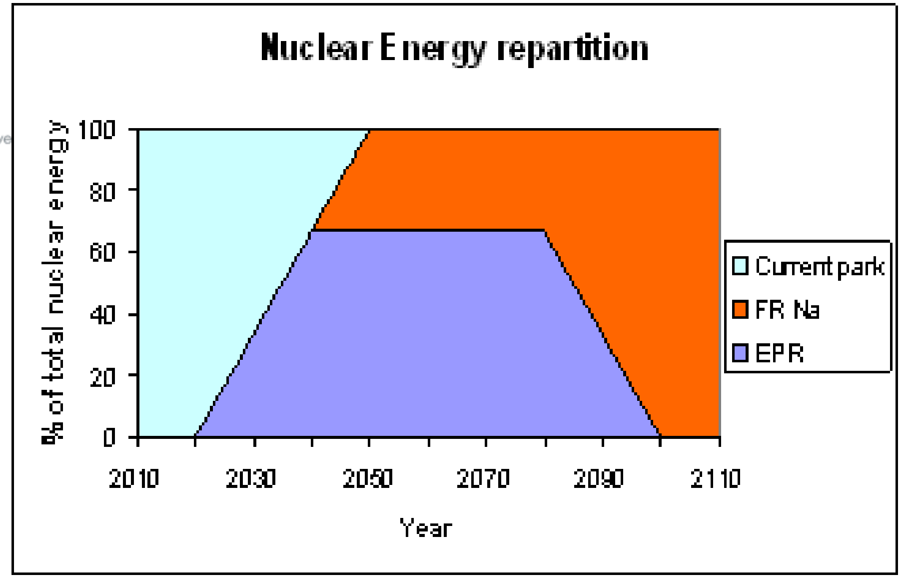

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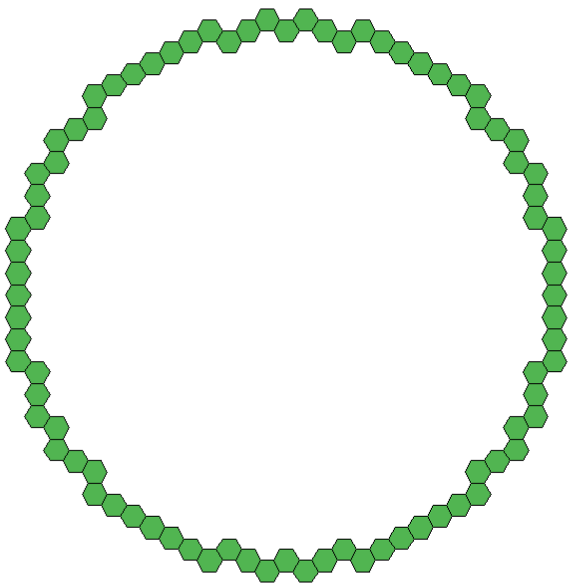
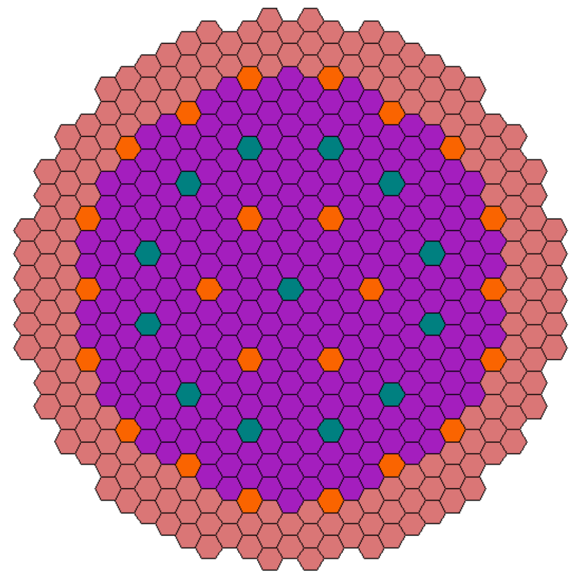
Heterogeneous

- *1 or 2 rows of 20% MABB (~80 S/A)*



Homogeneous

- *Whole core at 3,9% MA content (~400 S/A)*



Transmutation performances

Mode	Homogeneous		Heterogeneous	
Case	3.2% Am	3.9% MA	20% Am	20% MA
Charged mass (kg)				
Np	0	618	0	411
Am	2429	2258	2438	1866
Cm	0	67	0	160
M.A	2429	2943	2438	2437
Discharged mass (kg)				
Np	43	335	20	265
Am	1435	1312	1493	1101
Cm	390	281	242	223
M.A	1867	1927	1755	1589

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Mode	Homogeneous		Heterogeneous	
Case	3.2% Am	3.9% MA	20% Am	20% MA
Transmutation rate (%) at EOL				
M.A	-23.1	-34.2	-28	-34.8
Mass balance (kg/TWhe) at EOL				
Np	+0.60	-3.97	+0.14	-1.02
Am	-13.93	-13.26	-6.62	-5.36
Cm	+5.46	2.99	+1.7	+0.44
M.A	-7.87	-14.24	-4.79	-5.94

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Front end Impact

	Reference		Homogeneous		Heterogeneous	
	12% PWR MOX	Driver SFR Fuel	3.2% Am	3.9% MA	20% Am	20% MA
Power per S/A	1	0,4	0,8	1	2	2
Power per tons	1	1,3	2,5	3,1	7	7
Neutron source per S/A	1	0,4	0,7	19	1,2	58
Neutron source per tons	1	1,3	2,2	57	4	198

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- *The impact of Curium recycling is underlined for both strategies; the neutron source is very high in comparison to driver fuels.*
- *It is needed to establish the appropriate biological protections, shielding and robotic. This problem is more severe for the heterogeneous way.*

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- *The impact of Curium recycling is underlined for both strategies; the neutron source is very high in comparison to driver fuels.*
- *It is needed to establish the appropriate biological protections, shielding and robotic. This problem is more severe for the heterogeneous way.*
- *The power per S/A seems manageable. The transmutation of Am alone seems easier to manage.*
- *We can notice also that the transportation of such fresh S/A with a large amount of MA (including Cm) is not demonstrated yet.*

Back end Impact

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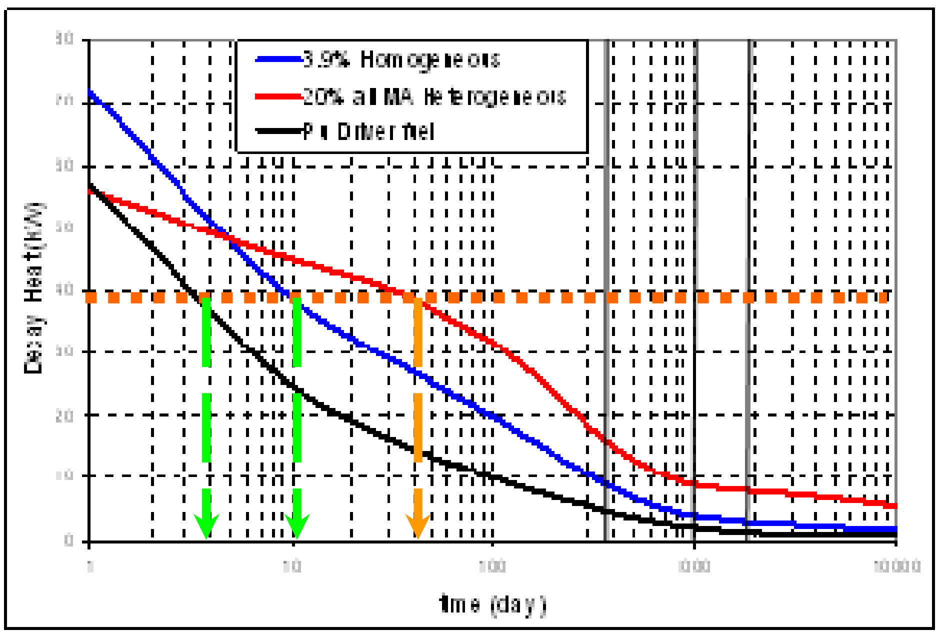

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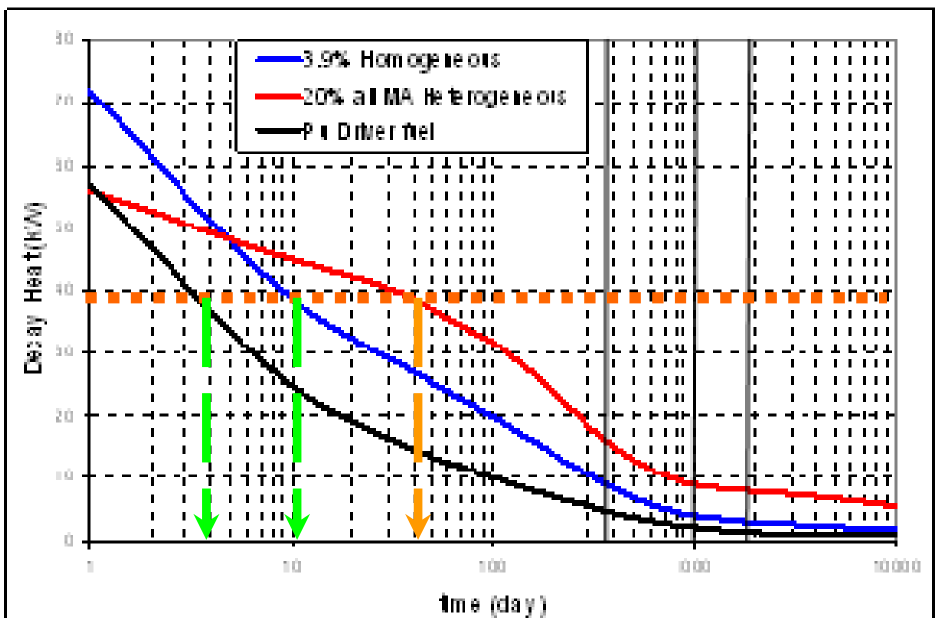

- *The impact on the reactor loading /unloading planning could be investigated to know when this time becomes on critical path.*
- *The waiting time for decreasing the decay heat below 7,5 kW (value authorizing handling in gas and fuel washing) is about 400 days for homogeneous, 2000 days for heterogeneous (200 days for standard fuel)*

Conclusions

- The purpose of this presentation is to remind the whole issue related to the transmutation of minor actinides and does not want a reflection of the technological reality.
- Consideration of transmutation on an industrial scale remains a technological challenge where many locks exist.
- However, both solutions presented here (homogeneous management or heterogeneous management in specific radial blanket) allows net consumption of MA with the drawback of a net Cm production (large in case of Am alone transmutation, slight in case of all MA recycling).
- Due to the high levels of the thermal power, neutron source and the equivalent dose of such S/A, the core management could be affected and specific procedures and/or additional equipments may be needed for the handling of these innovative S/As: Unloading in sodium canisters, interim storage in sodium
- The transmutation of Am alone gives more flexibility and seems easier to implement than all MA management.
- All these impacts will be taken into account for a global evaluation in a nuclear scenario approach to determinate pro and cons of each strategy.