STUDY OF MINOR ACTINIDES TRANSMUTATION IN SODIUM FAST REACTOR DEPLETED URANIUM RADIAL BLANKET

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Outline

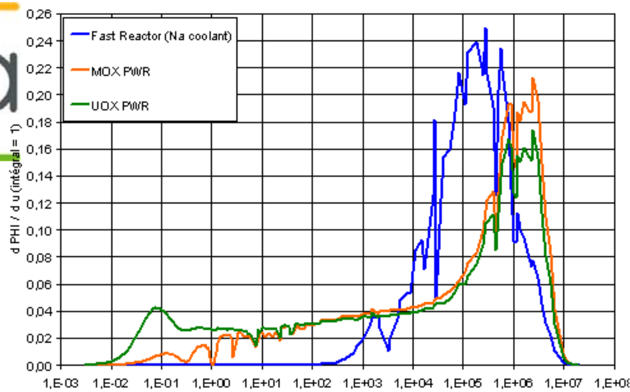
- ***Introduction and recall***
- ***Transmutation Ways***
- ***Heterogeneous transmutation in SFR***
- ***Neutronic and thermal hydraulic design***
- ***Performances of MA depleted uranium radial blanket***
  - ***10% of MA content***
  - ***40% of MA content***
- ***Conclusion, future work***

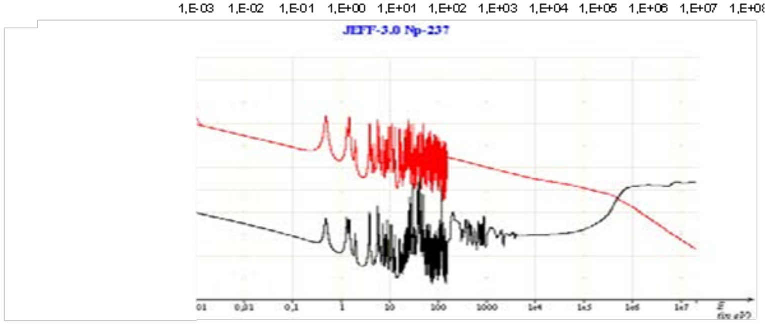
*The purpose of minor actinides and long lived fission products **transmutation** is to reduce the **decay heat** and the **potential long term radiotoxicity** of the long-lived nuclear waste.*

On the reactor physic point of view:

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

Introduction and recall (2/2): interest of fast spectrum





Reactor	PWR		FR	
Burn Up	60 GWd/t		140 GWd/t	
Flux level	2.5 10^{14} n/cm²/s		3.4 10^{15} n/cm²/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

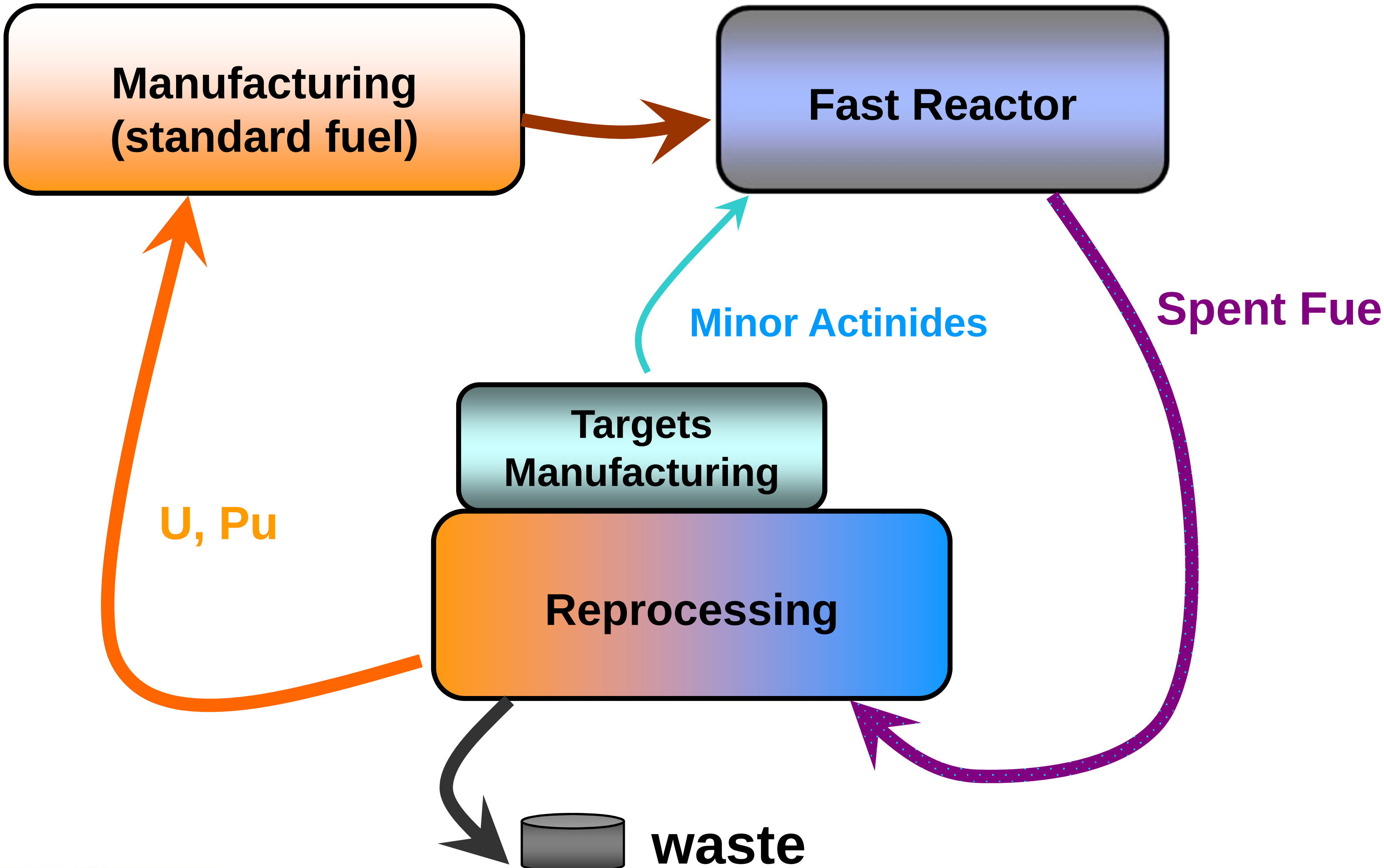
Fast neutron reactors offer greater flexibility and ensure a transmutation performance which is far superior than that of PWRs.

Transmutation ways in fast reactor

- **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

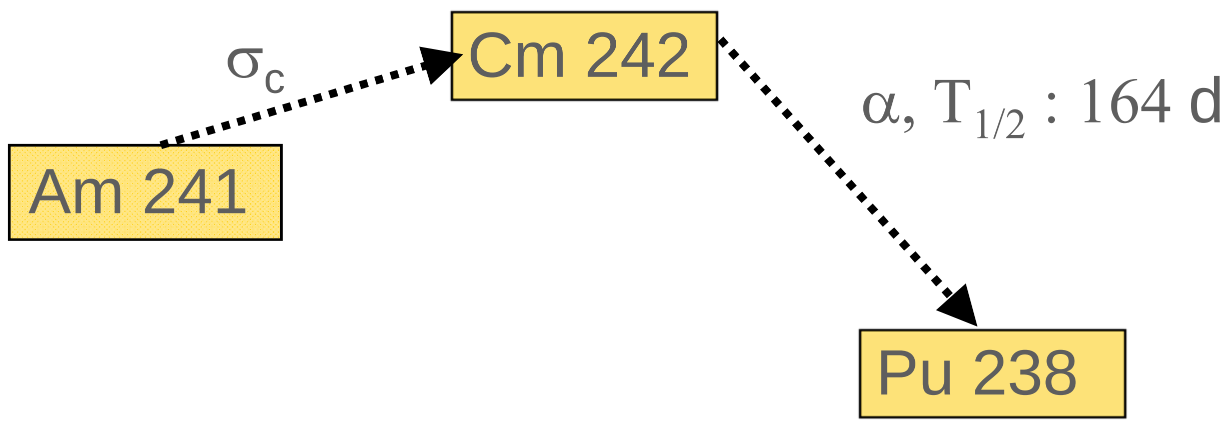
Heterogeneous way (multirecycling)



Minor Actinides transmutation in SFR depleted uranium radial blanket

- To reduce the decay heat and potential radiotoxicity of glasses
- In a fast neutron reactor, a substantial neutron flux escapes from the core and can be used to transmutation and/or Pu production
- With UO2 matrix, MA targets follow the spent standard fuel flow at the reprocessing plant
- Less impact on reactivity coefficient (void effect, Doppler, neutrons delay)
- No impact on core management, irradiation time could be optimized for transmutation criteria

- This special case is very promising:
  - It allows to load high amount of MA with only small impact on the core behavior
  - The high level of MA produce degraded Pu (non-proliferation concerns) and increase the breeding gain



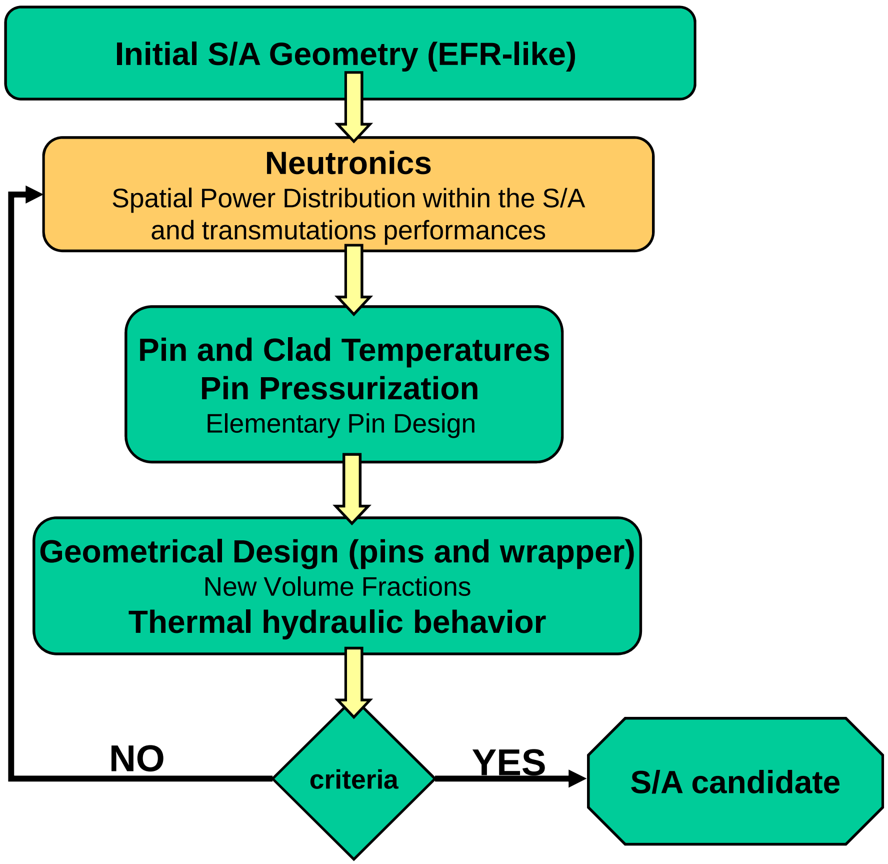
  - It challenges dedicated systems for transmutation with only some “small” changes of GEN-IV SFR design

- Two cases have been investigated:

  - A challenging UO2 blanket assembly with 40% MA:
    - High amount of Actinides leading to high consumption
    - The system need only a fraction of the FR fleet with those blankets to ensure MA equilibrium (production=consumption)

  - A more realistic UO2 blanket assembly with 10% MA:
    - Closer to traditional blanket given rise to lower consumption but for the whole fleet

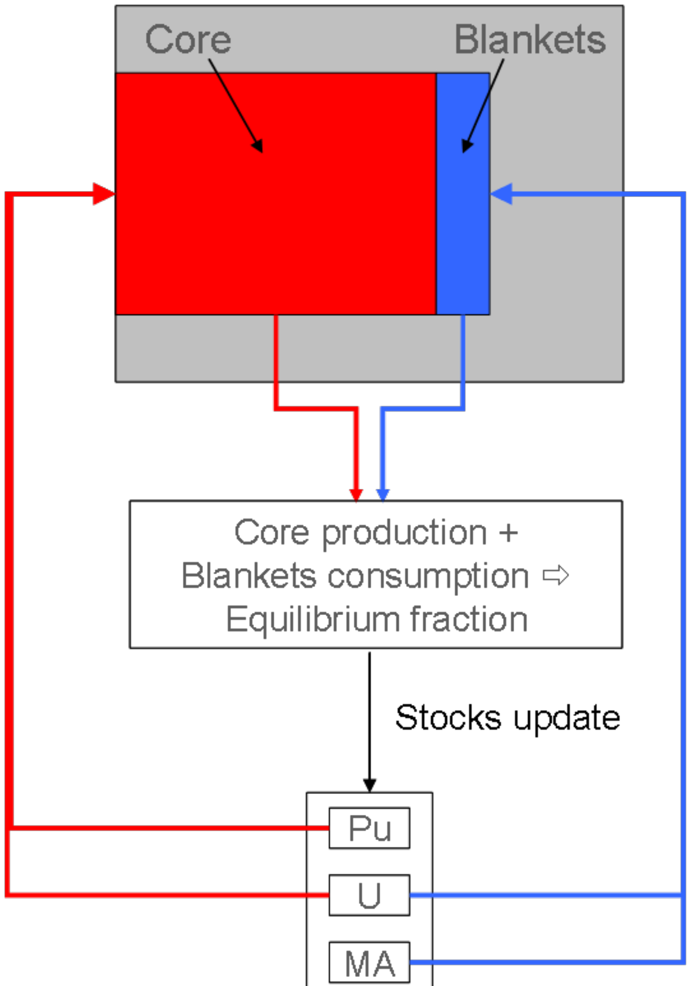
Methodology for design



- The design of such system need a multi-discipline process to deal with the arising technological problem due to MA transmutation :
  - Neutronic: irradiated fuel characteristics (depletion, power distribution…)
  - Mechanic: pressurization (huge helium production)
  - Thermal hydraulic: fuel and pin temperatures
- Starting from a first image of GEN-IV like SFR core designed by CEA, we performed an iterative design process involving the multi-discipline criteria

Multirecycling : core / blanket coupled equilibrium (ERANOS)

- Core Pu oxide
- Radial Blankets U and MA oxide



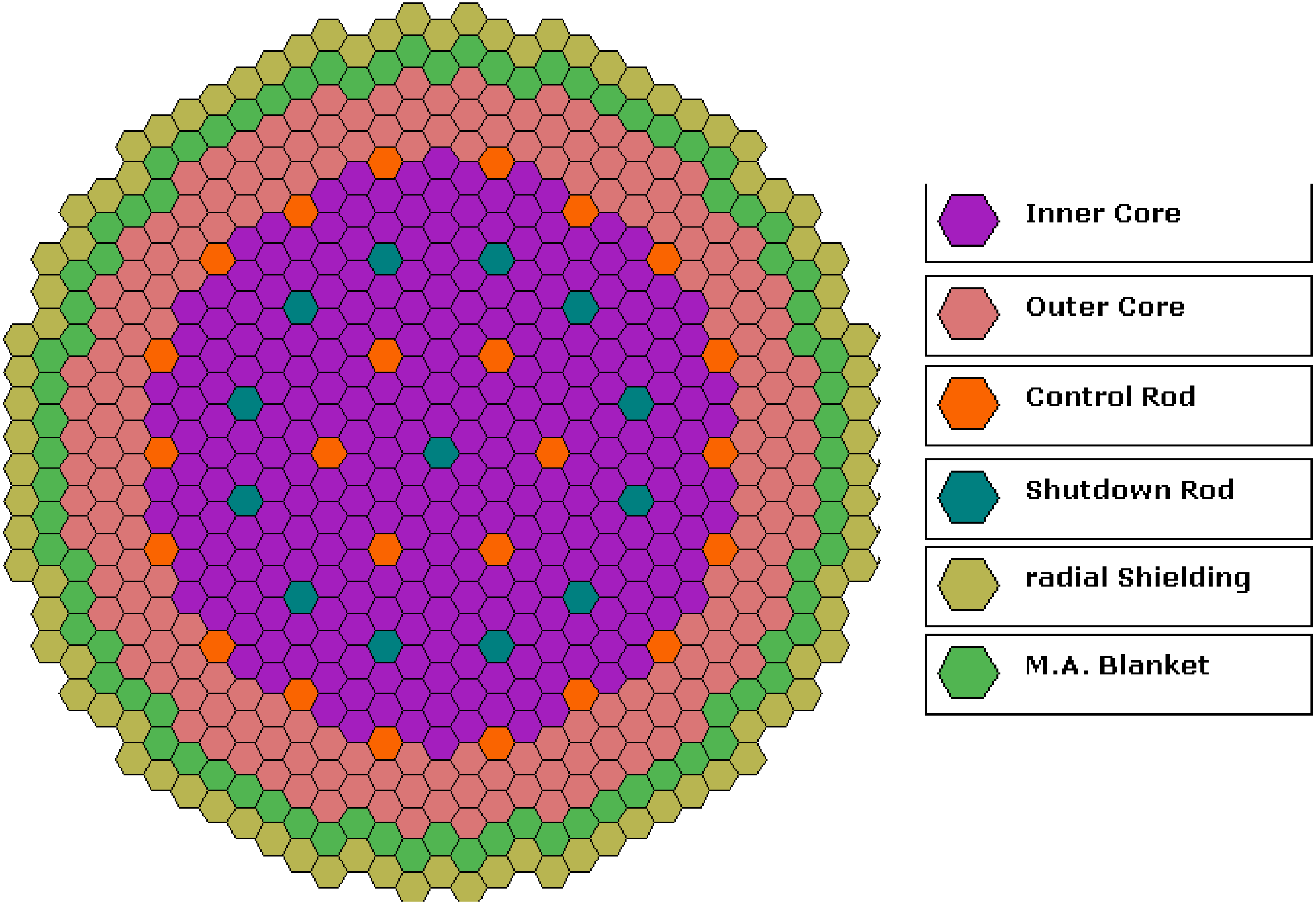
Fraction to get MA equilibrium:

production in the core (whole fleet)
=
destruction in the blankets (some reactors)

Calculation hypothesis:
- Time life : 2050 efpd (Core) / 4100 efpd (Blanket)
- Assembly revolving at 2050 jepp
- Coupled Pu/MA multirecycling
- Cooling time : 3 years
- Starting point : year 2035 french stock configuration (UOX and MOX spent fuel)

	Np	Am	Cm
Minor Actinides	17%	76%	7%

SFR core layout with MA blanket



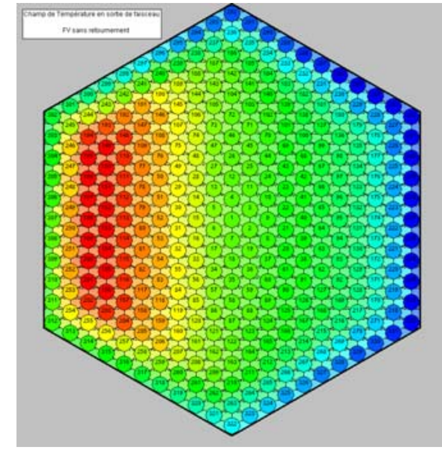
CEA SFR Core

Parameter	EFR type	SFR 2007 with MA Blanket
Radius (cm)	202	232
Active Height (cm)	100	100
Pu mass (t)	7.7	10.8
Volumic power (W/cm3)	300	220
Fuel time life (efpd)	1525	2050
Blanket assemblies	78	84
HM (kg) in one blanket assembly	121 (UO2)	138 / 145 (UO2+MA)

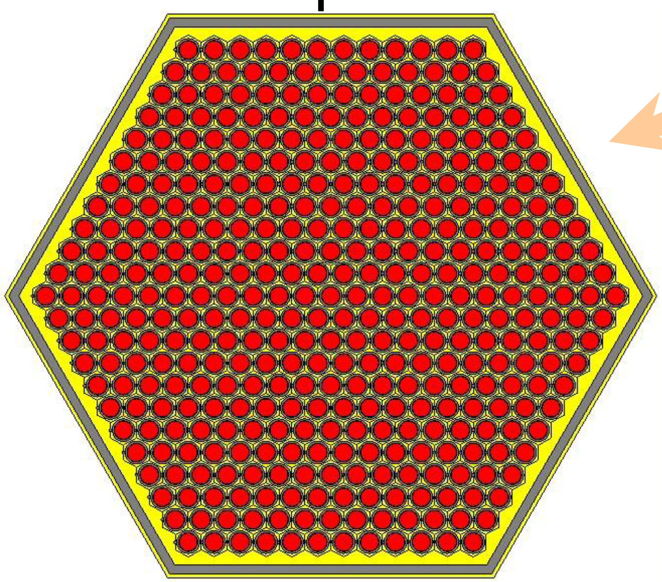
Blanket Assembly design

- Results of the iterative process:

Blanket S/A	EFR type	SFR 40%	SFR 10%
HM ratio	40.97 %	37.09 %	40.31 %
Structure ratio	21.24 %	23.84 %	21.0 %
Sodium ratio	27.21 %	31.00 %	27.2 %



397 pins



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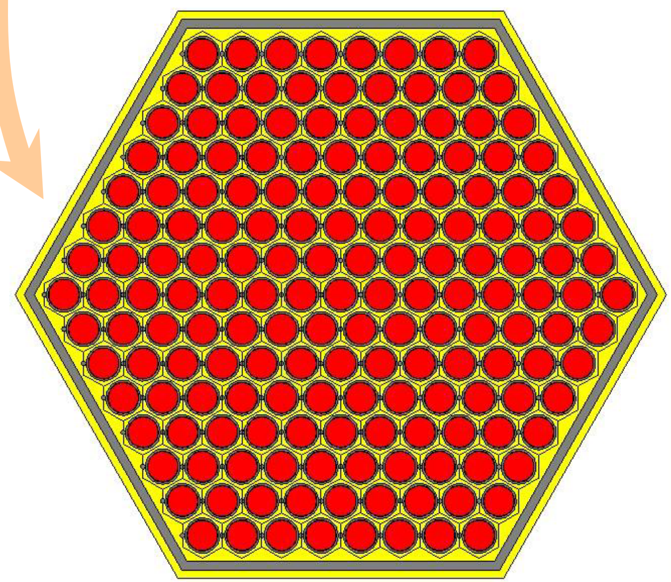


Transmutation performances (equilibrium)

Concept	40% MA		10% MA	
Masse inventory (kg) (BOL and EOL) per SA	Charged	Discharged	Charged	Discharged
U	79.0	71.2	130.9	118.3
Pu	0.0	17.4	0.0	12.6
Np	9.0	5.1	2.6	1.5
Am	35.8	18.5	9.8	5.0
Cm	8.0	7.6	2.2	2.1
H. N.	131.8	119.9	145.5	139.5
Transmutation Rate	40.9%		41.1%	
MA consumption	-12 kg/TWeh		-3.5 kg/TWeh	

Isotopic content of the reprocessed plutonium produced in the radial blankets

isotope	40% MA	10 % MA
Pu238	46	23
Pu239	39	65
Pu240	15	12

Equilibrium results

Radial Blanket (MA content)	40%	10%
Maximum damage rate (DPA)	112	79
Pu238/Pu240 part in reprocessed Pu(%)	46/15	23/12
Breeding gain	0.18	0.11
MA Transmutation rate (%)	40.9	41.1
MA consumption (kg/TWhe)	-12.7	-3.5
Fresh fuel thermal power (kW)	21	5
TCT Max (GWj/t)	119	57
Fraction of SFR with MA blanket (%)	23	88
Fabrication (nb SA/year) *	~50	~200
MA loaded mass/SA (kg)	52.7	14.6

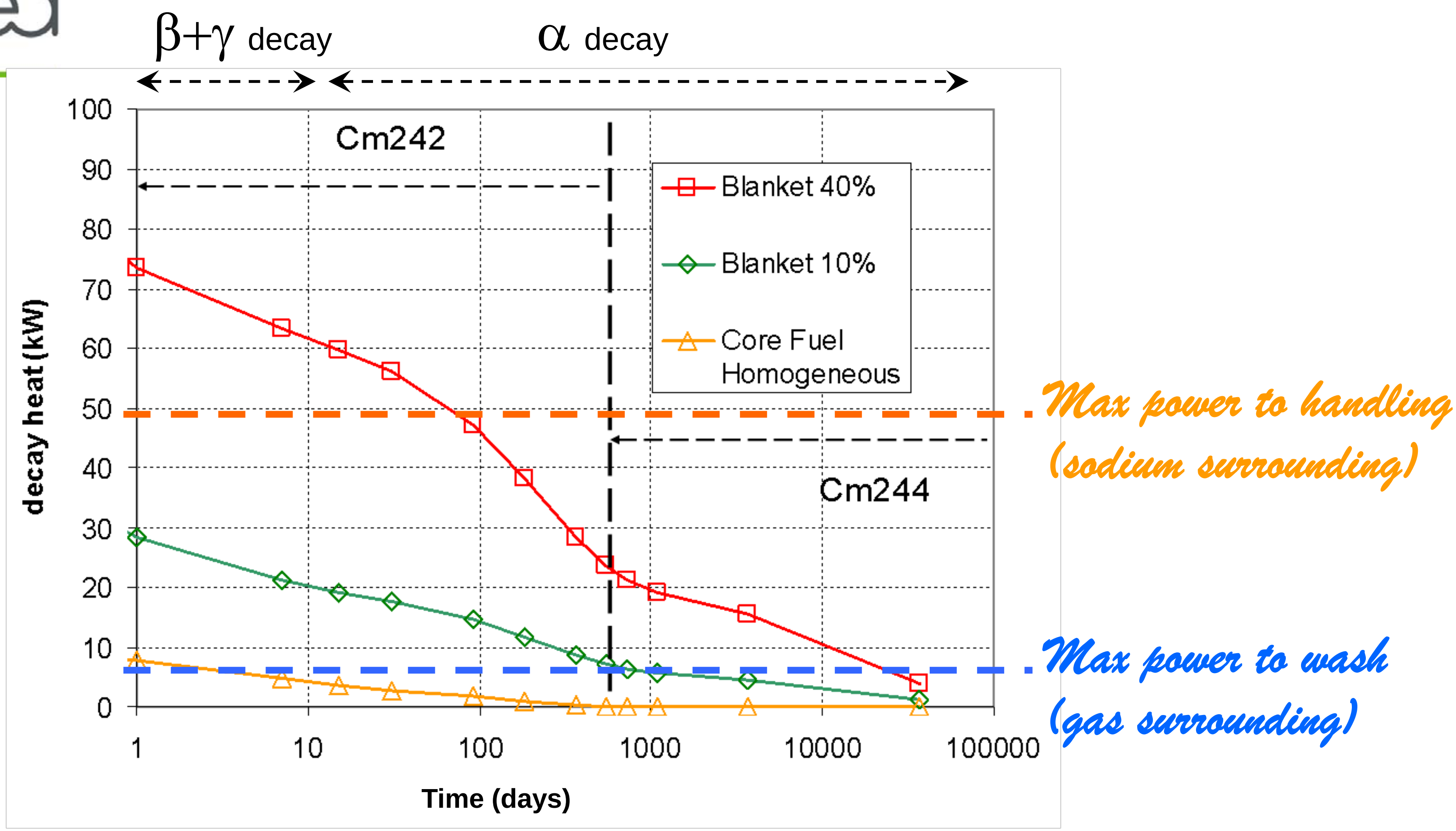
* Exemple for a French fleet (400 TWhe/year)

Thermal power and neutron source for fresh S/A vs standard SFR MOX fuel

	SFR homogeneous recycling (UPu + 0.7% MA)	Radial Blanket 40% MA	Radial Blanket 10 % MA
Thermal Power (kW)	0.7	21.6	5.4
neutron/s	$1.7\ 10^{9}$	$8.0\ 10^{10}$	$1.9\ 10^{10}$
neutron/s vs SFR Pu	X40	X2000	X500

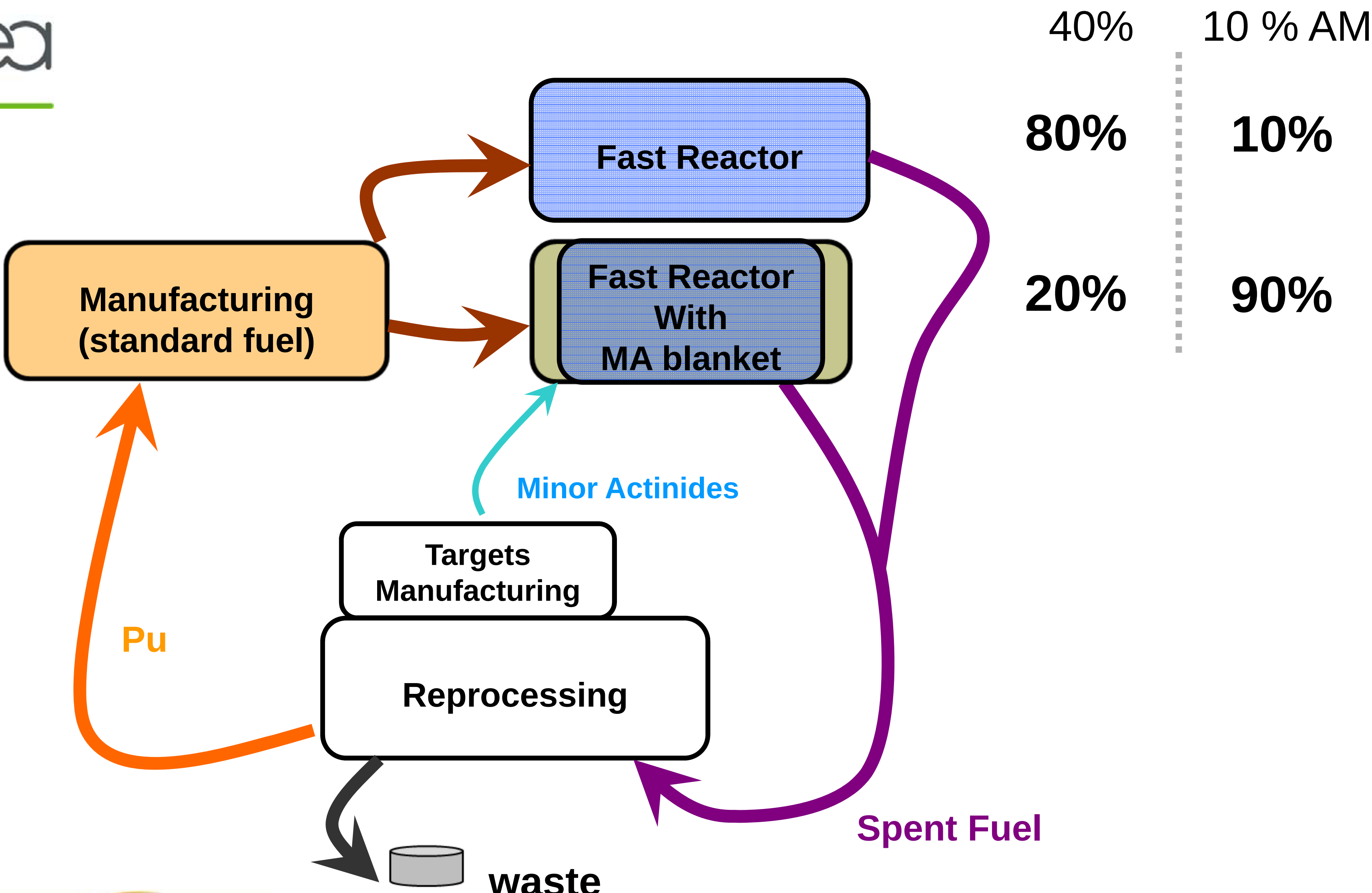
Constraints on manufacturing and transportation

Time dependence of the decay heat after irradiation



Constraints on blanket S/A handling and wash (40% AM content)

Equilibrium results



Conclusions

- Transmutation of Minor Actinides in radial blanket of GEN-IV SFR core shows promising performances
- This type of radial blanket allows to give margin on the breeding gain without proliferation risk
- We define two designs of MA blanket which respect all the criteria (fuel behavior, mechanic constraints,…) and which reach the goal in term of transmutation capabilities.
- Constraints are on cycle aspect, and a possibility to reduce the impact on fabrication is to transmute only Am. But the decay heat will be quite similar with our without Cm loading.
- The 40% AM blanket seems too ambitious, we focus now on a 20% MA content with all MA or with Am only.
- Needs R&D in term of:
  - fuel behavior,
  - fabrication, handling, transportation of such assemblies.