DE LA RECHERCHE À L'INDUSTRIE

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SCENARIOS FOR MINOR ACTINIDES TRANSMUTATION IN THE FRAME OF THE FRENCH ACT FOR WASTE MANAGEMENT

International Conference on Fast Reactors and related Fuel Cycles: Safe Technologies and Sustainable Scenarios

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CONTEXT & CALCULATION SCHEME

The French Context

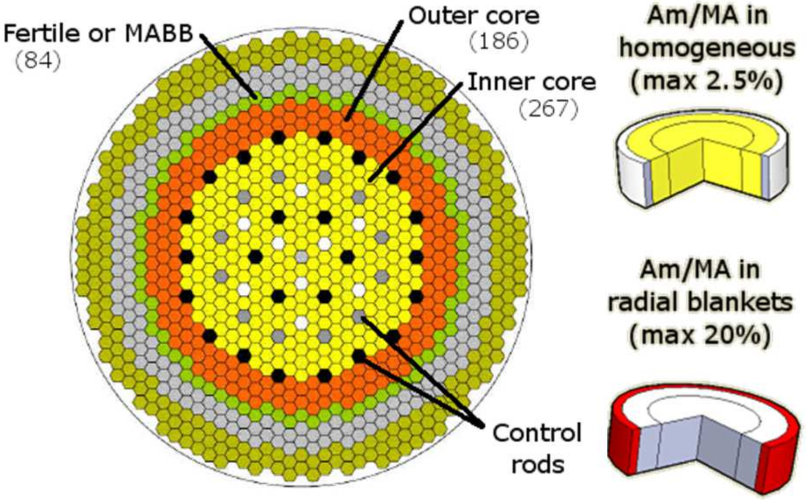
- French reactor fleet:
  - 58 PWR loaded mainly with UOX and MOX (about 1/3 of the fleet);
  - Pu from UOX is recycled once in MOX fuels.

Calculation Scheme

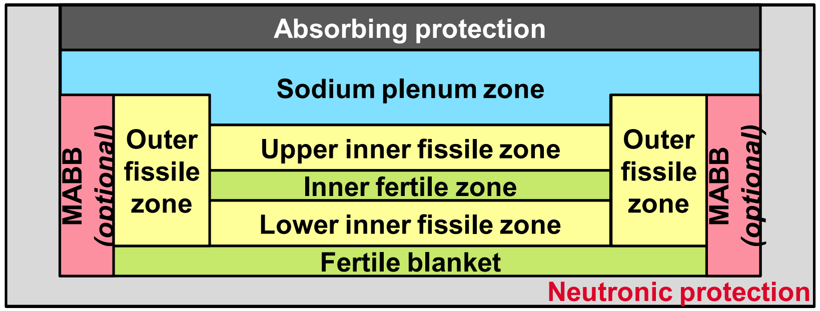
- **Scenario calculations are performed with COSI6**:
  - COSI6 simulates the evolution of a nuclear fleet and of its associated facilities over several decades (simulations are time-dependent);
  - it provides all the material fluxes at stake in the fuel cycle.
- **Evolution calculations are performed by coupling COSI with CESAR**:
  - CESAR is used as reference code at the AREVA La Hague reprocessing plant to evaluate the spent fuel isotopic composition;
  - irradiation calculations are based on neutronic data provided by APOLLO2 (for thermal spectrum) and ERANOS (fast spectrum).
- **COSI6 and CESAR are both developed by the CEA.**

REACTOR ASSUMPTIONS

SFR-V2B



CFV (Low Void Coefficient)



Remark: This is a CFV preliminary industrial version which is bigger (3600 MWth) than the one used in ASTRID (1500 MWth).

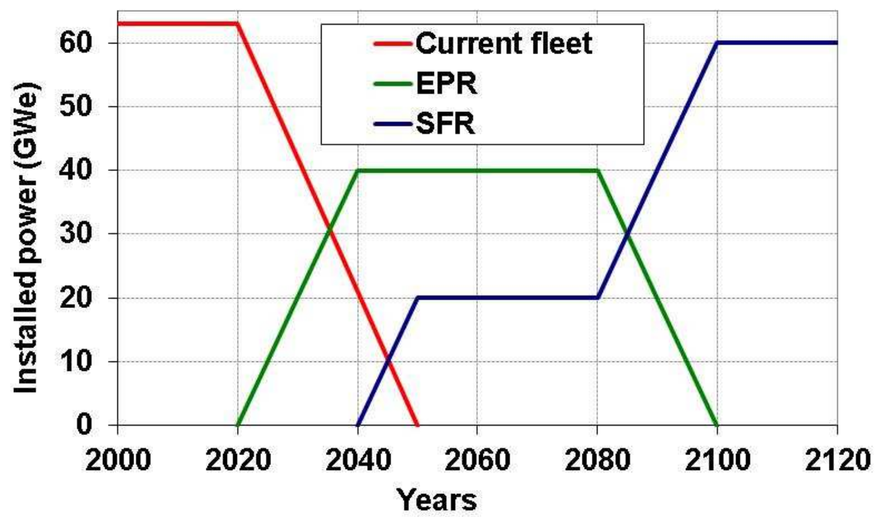
	SFR-V2B	CFV	
		Fissile	Fertile
Thermal power (MW)	**3600**	**3600**	
Electrical power (MW)	1450	1450	
Net yield	40,3 %	40,3 %	
Load factor	81,8 %	81,8 %	
Mass (tihm)	**74**	**51**	**37**
Fuel management (EFPD)	5 x 410	5 x 400	
Initial Pu content	~16 %	~25 %	
Discharge BU (GWd/t)	98	120	23

SCENARIO ASSUMPTIONS

Reference scenario

- 2020-2040: deployment of 40 GWe of generation III PWR (EPR).
- 2040-2050: deployment of 20 GWe of generation IV SFR.
  - **Equilibrium state: 1/3 SFR, 2/3 EPR**
- 2080-2110: deployment of 60 GWe of SFR.
  - **Equilibrium state: 100% SFR**

Constant energy production:
430 TWhe/year (produced by 60 GWe)

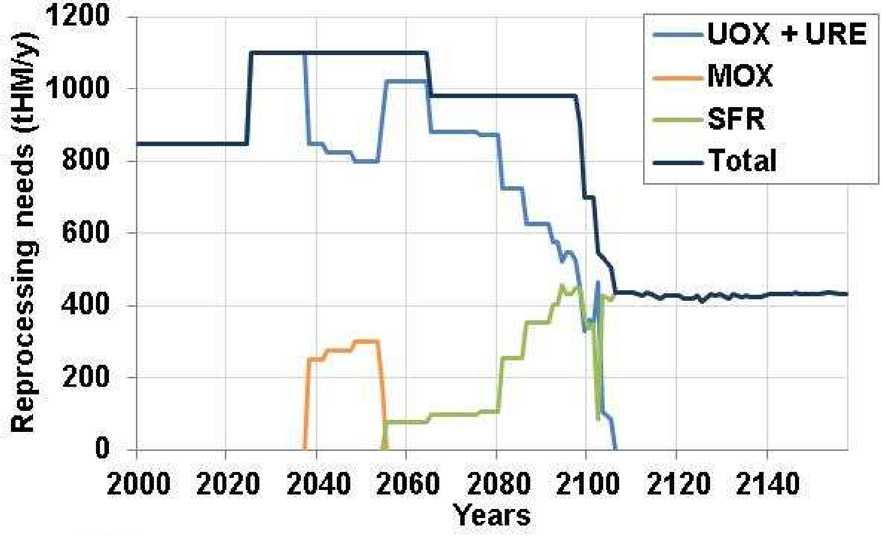


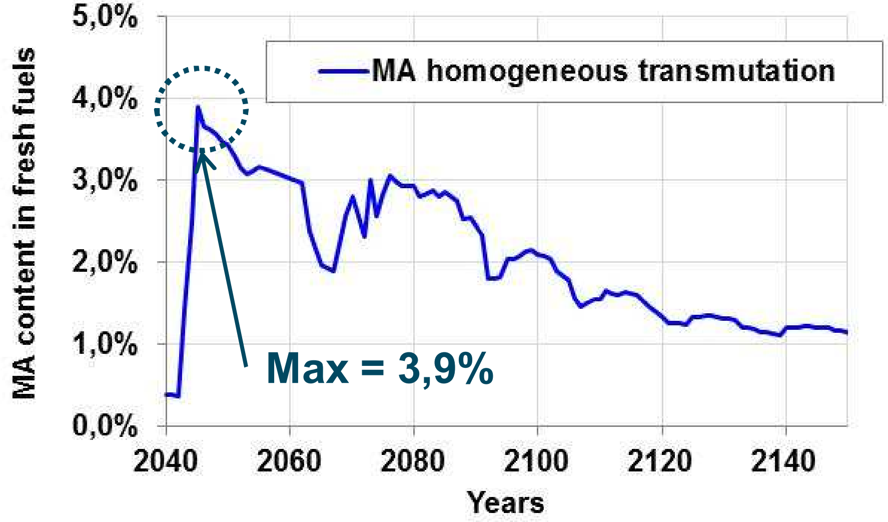
Scenarios assumptions

- Cooling time of spent fuel before being reprocessed: minimum 5 years.
- Fabrication time: 2 years.
- The reprocessing capacity adjusts itself on the fabrication needs. It remains constant over 30 to 40-year periods.

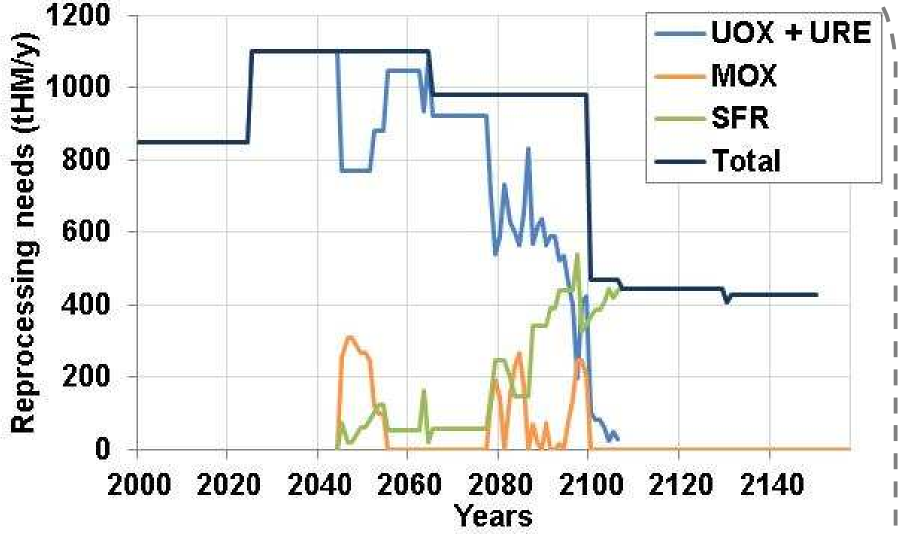
MA TRANSMUTATION IN HOMOGENEOUS MODE

Reference scenario





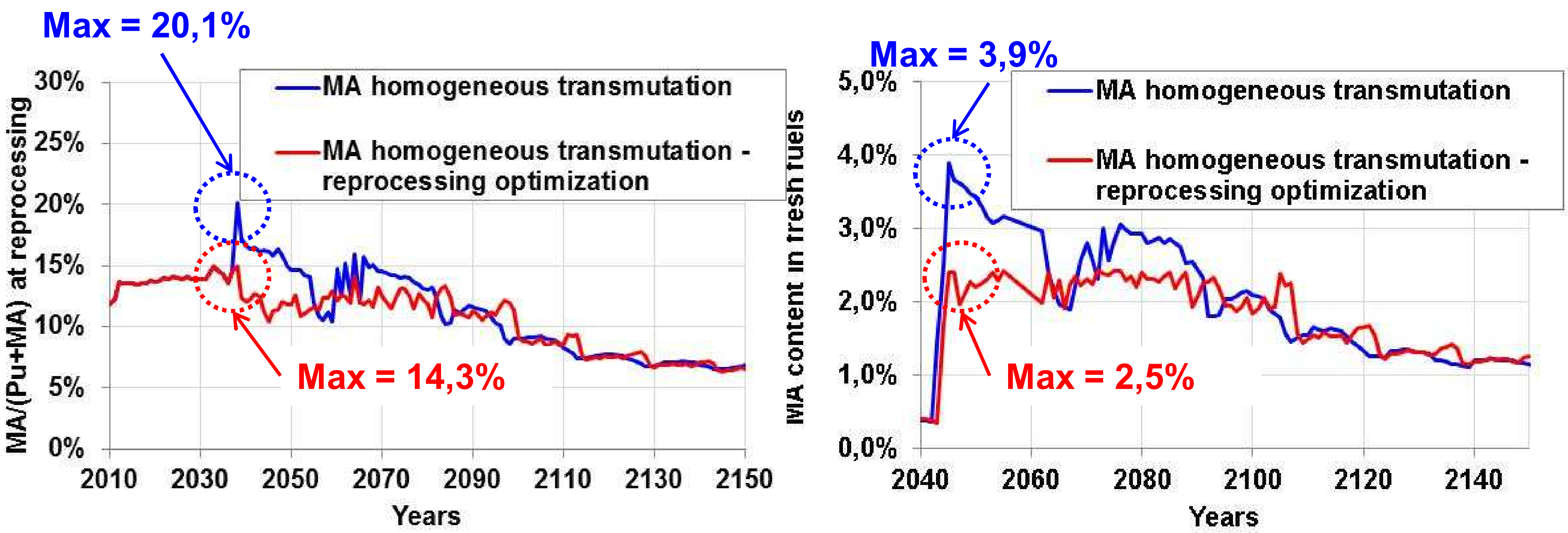
Optimized scenario



Optimization of the reprocessing strategy:

- PWR MOX are reprocessed over a longer period;
- spent fuel are reprocessed in "last-in-first-out" mode.

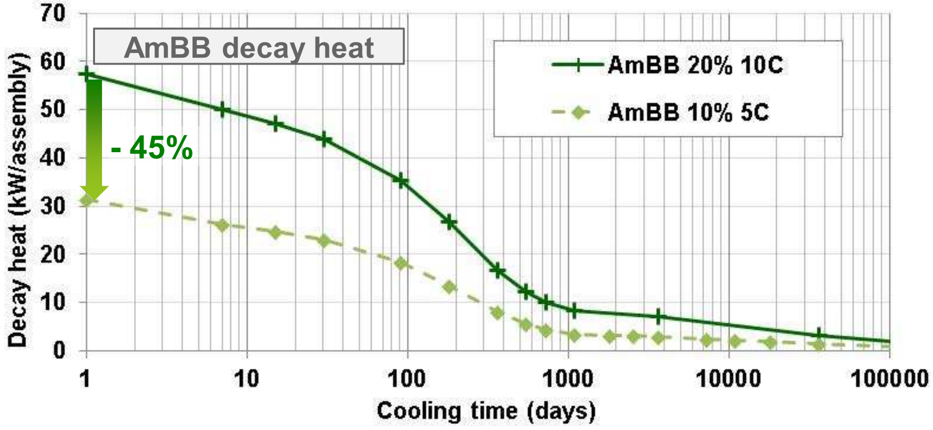
MA TRANSMUTATION IN HOMOGENEOUS MODE



- Thanks to the optimization, the MA content in Pu+MA in spent fuels is reduced from 20,1% to 14,3%.
- This leads to a reduction of the MA content peak in fresh fuels from 3,9% to 2,5%.

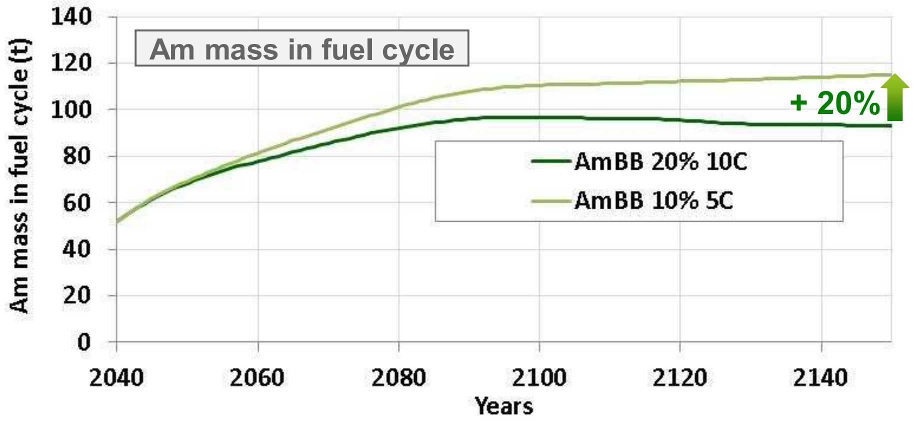
Am TRANSMUTATION IN HETEROGENEOUS MODE[1]

- For the **Am transmutation in heterogeneous mode**, using the previous reprocessing optimization makes possible to:
  - reduce the Am bearing blankets (AmBB) Am content from 20% to 10%;
  - shorten the irradiation time from 10 cycles to 5 cycles.



Reduction of Cm production in AmBB
→reduction of AmBB decay heat.

AmBB loading frequency being multiplied by 2, Am mass in cycle is higher.

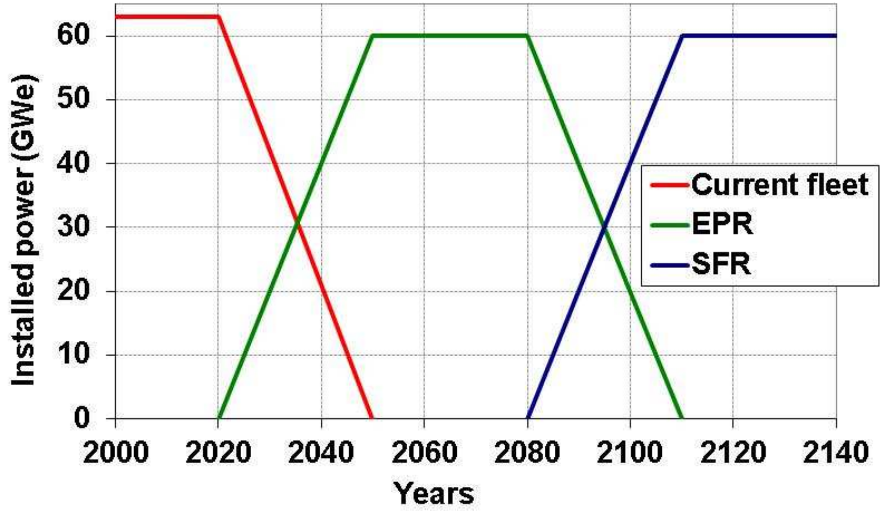


[1]C. COQUELET, et al., "Comparison of Different Scenarios for the Deployment of Fast Reactors in France – Results Obtained with COSI," Proc. of GLOBAL 2011, Makuhari, Japan, Dec. 11-16, 2011.

SFR-V2B DEPLOYMENT DELAYED TO 2080 1/2

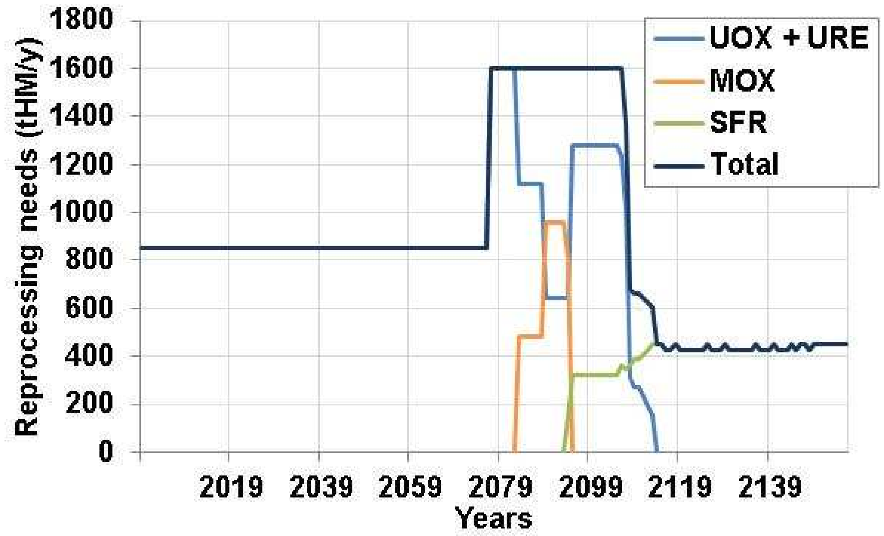
Main hypothesis

- SFR introduction between 2080 and 2110.
- Pu is recycled in PWR MOX fuels until 2075.
- From 2080, MA are recycled in homogeneous mode is SFR.



Reprocessing strategy

- To recover the largest Pu amount all fuels are reprocessed between 2078 and 2108.

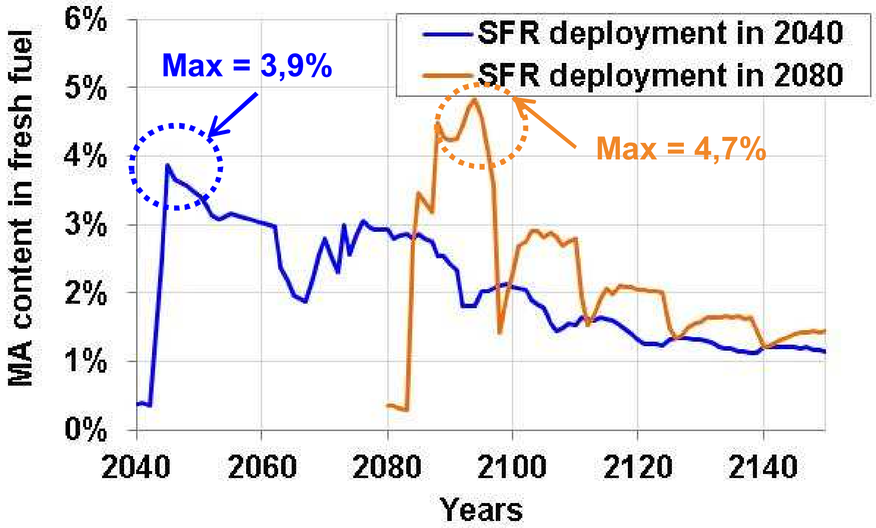


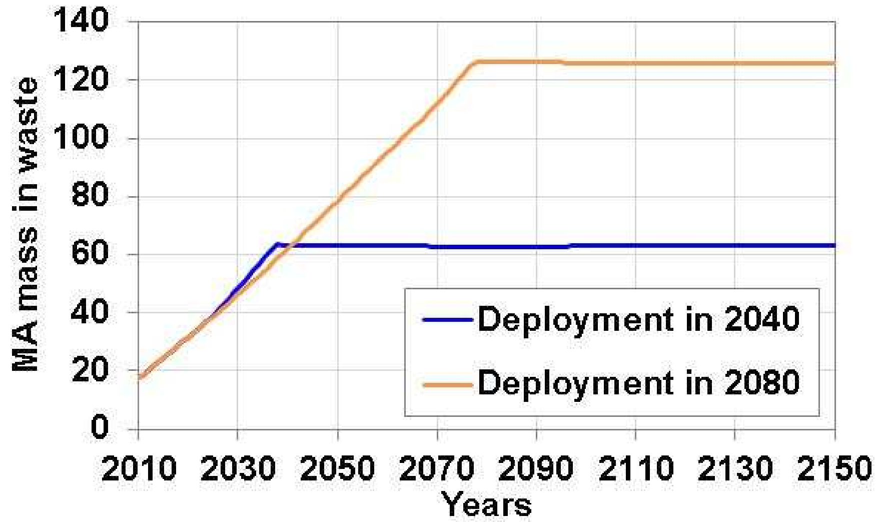
SFR-V2B DEPLOYMENT DELAYED TO 2080 2/2

Main results

- From 2013 to the PWR fleet phase-out in 2100 **600 000 t of Unat** are required (140 000 t more than in the reference scenario).
- Due to the higher fraction of MOX fuel at reprocessing and the longer cooling time before reprocessing of spent fuels, the **^{241}Am content in spent fuels and fresh fuel is higher.**

In case of homogeneous transmutation, MA content in fresh fuel reaches 5% and MA mass in waste stabilizes at 126 t (twice the one in SFR deployment in 2040 scenario)





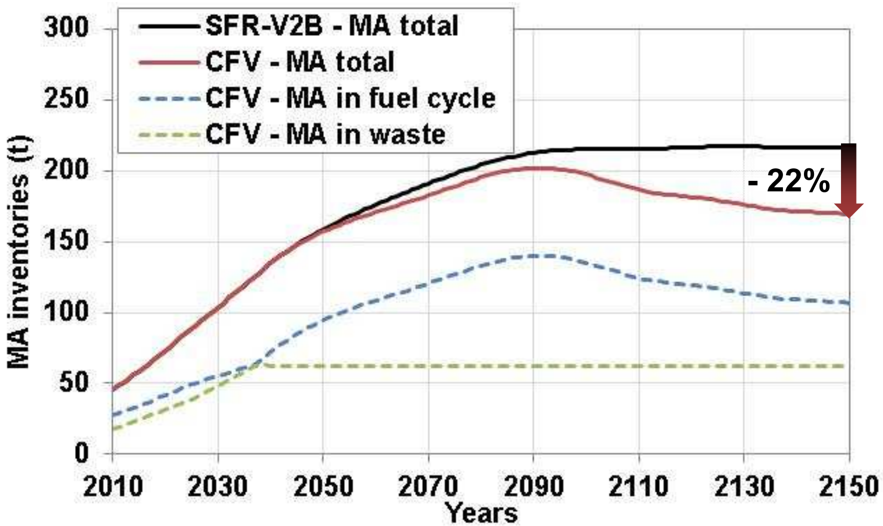
TRANSMUTATION IN CFV – HETEROGENEOUS MODE

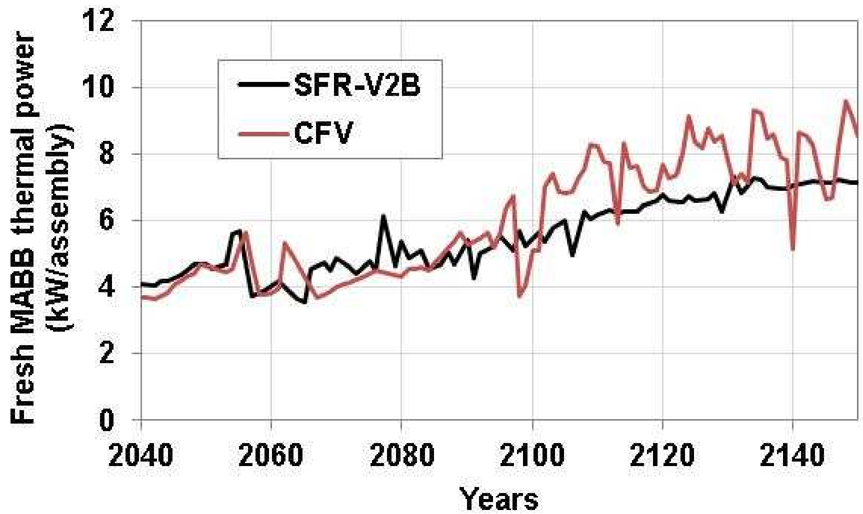
- Two rows of MABB containing 20% of MA and being irradiated during 10 cycles.

	SFR-V2B	CFV
Net MA production (kg/Twhe)	-1	-2,4

➔ The CFV transmutation rate is better than the SFR-V2B one, which leads to a 22% deviation on the MA global inventory in 2150.

➔ Increase of the Cm content in fresh MABB → increase in the MABB thermal power which almost reaches 10 kW/assembly in 2150.





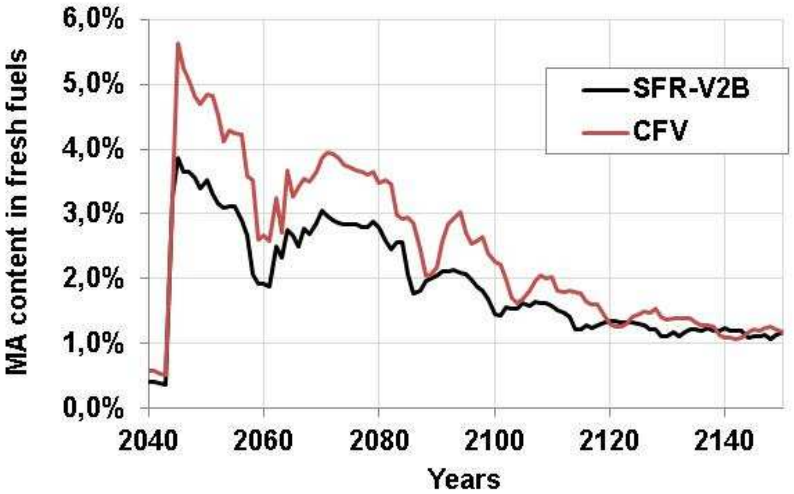
TRANSMUTATION IN CFV – HOMOGENEOUS MODE

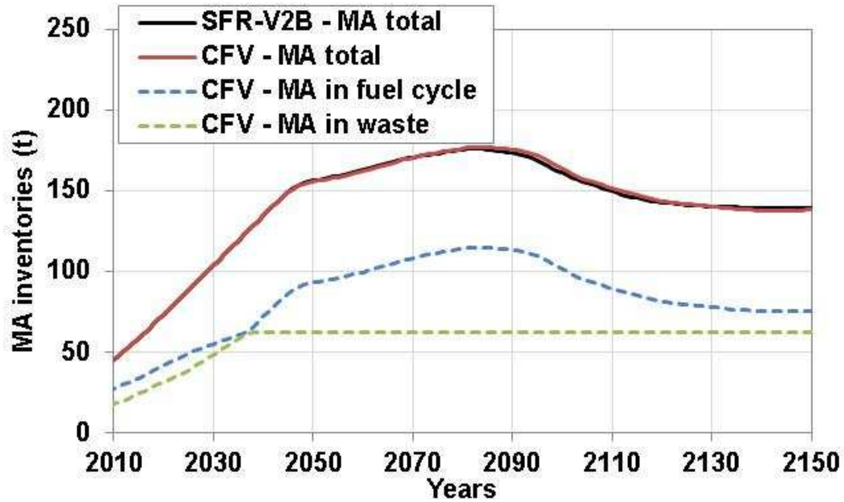
- MA are put homogeneously in the CFV fissile core from the beginning of CFV deployment (2040).

	SFR-V2B	CFV
Fissile zone mass (t)	74	51

➡ Due to the reduction of the fissile mass in CFV, the MA content in CFV is higher at the beginning of CFV deployment: MA content reaches 5,6%.
The optimization presented previously should reduce this value.

➡ In this scenario, the SFR design has no impact on the MA inventory.





CONCLUSION

- Different transmutation scenarios have been evaluated: homogeneous transmutation, AmBB, MABB.
- **Homogeneous transmutation**
  - The MA content peak at the beginning of the transmutation can be reduced from 3,9% to 2,5% thanks to a reprocessing optimization.
  - Delaying the SFR deployment to 2080 increases this peak from 3,9% to 4,7%. *Due to the constraints on reprocessing, the optimization may be less efficient in this case.*
- **Heterogeneous transmutation**
  - Shorting the AmBB irradiation time from 10 cycles to 5 cycles and reducing their Am content from 20% to 10%:
    - reduces AmBB decay heat (-45% at the cooling beginning);
    - leads to an increase in the Am mass in cycle (+20% in 2150).
- **Impact of the CFV core**
  - In heterogeneous mode, the CFV transmutation rate being better than the SFR-V2B one, the MA inventory is reduced by 22% in 2150.
  - In homogeneous mode, the reduction of the fissile mass in core leads to an increase of the MA peak at the beginning of the transmutation (3,9% → 5,6%). There's no impact on the MA inventory.

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Pu INVENTORY EVOLUTION

- SFR breeding gain increases when MA are transmuted: both SFR-V2B and CFV concepts goes from breakeven to breeders while transmuting MA.

➡ **Pu inventory is increasing.**