DE LA RECHERCHE À L'INDUSTRIE

Scenarios for Fast Reactors Deployment with Plutonium Recycling

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SUMMARY

French context

- Variety of scenarios for the introduction of SFR in the French context:
  - Transition to a full SFR fleet
    - SFR deployment in replacement of the French PWR fleet
  - More progressive SFR deployment to ensure a symbiotic recycling of Pu
    - SFR deployment in complement of the French PWR fleet

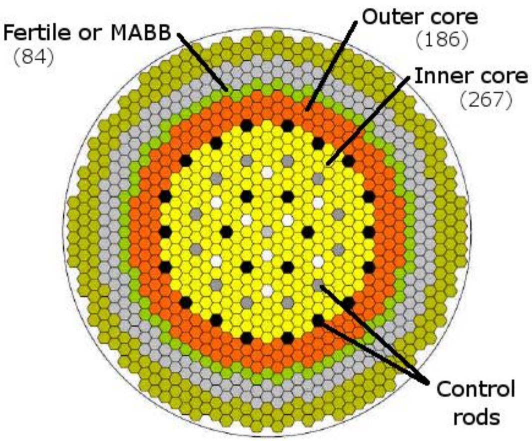
- Transition scenarios studies to evaluate:
  - The sustainability of SFR deployment
  - The associated impacts on facilities
  - The sensitivity to SFR core design

Calculation scheme (developped by CEA):

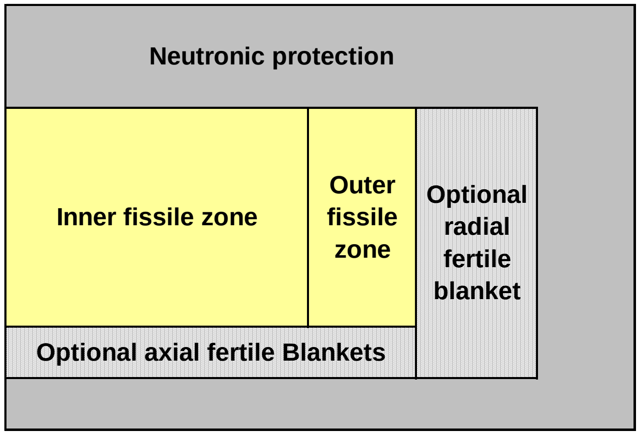
- COSI simulates the evolution of the material flows in a nuclear fleet and the associated facilities over a defined period
- Evolution calculation performed by a coupling with CESAR:
  - Reference code at AREVA La Hague reprocessing plant to evaluate the spent fuel isotopic composition
  - Based on neutronic data libraries supplied by APOLLO2 (thermal spectrum) or ERANOS2 (fast spectrum)

Reactors assumptions

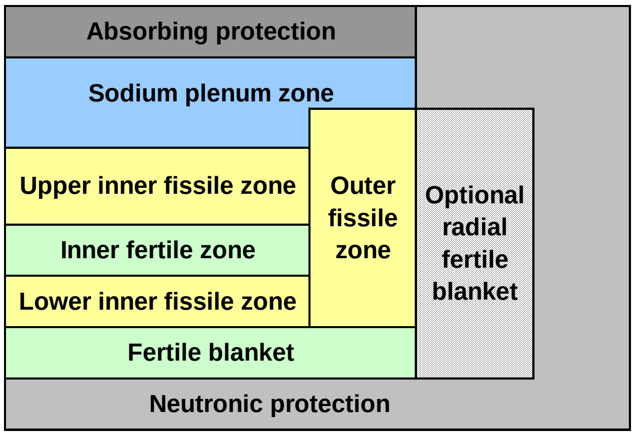
- Basically, **SFR V2B** core developed in 2008 is considered.
- New heterogeneous core named **CFV** with a significant gain on sodium void effect is considered in sensitivity studies.



SFR V2B



CFV



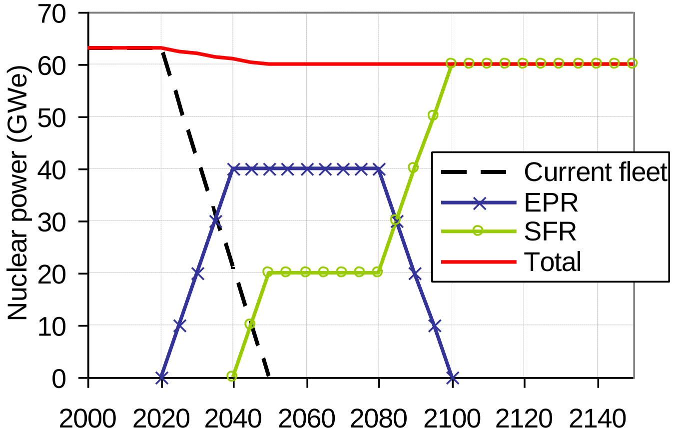
- Main characteristics of reactors:

	EPR^{TM} reactors	SFR V2B	CFV V0
Thermal / Net electrical power (MW)	4500 / 1550	3600 / 1450	3600 / 1450
Net yield (%) / Load factor (%)	34.4% / 81.8%	40.3% / 81.8%	40.3% / 81.8%
Heavy metal mass in core (tons)	120.0	Core: 74 Axial fert. blankets: 22 Radial fert. blank. (2 rows): 41	Core: 51 Axial fert. blankets: 37 Radial fert. blank. (2 rows): 44
Fuel type	17×17 UOX 17×17 MOX	MOX (U-Pu)	MOX (U-Pu)

SFR deployment in replacement of the French PWR fleet

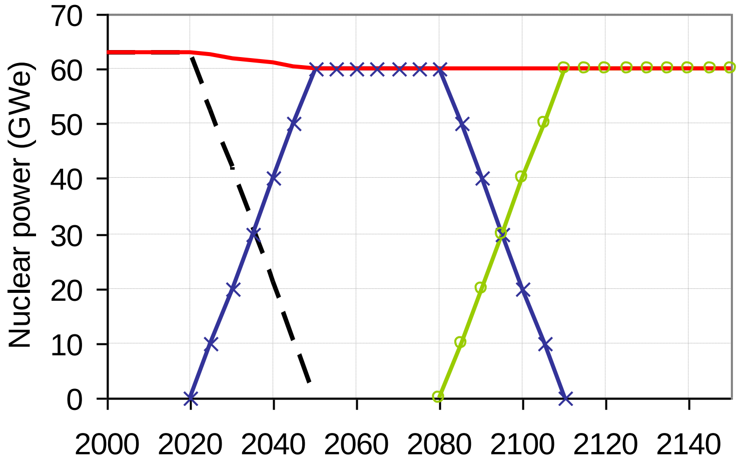
Scenarios assumptions

- Constant nuclear energy production: 430 TWhe/year
- Two chronologies of SFR deployment:



SFR deployment from 2040
over 60 years

- 2020 - 2050: Current French PWR fleet phases out, deployment of 40 GWe of generation III PWR reactors (EPR^{TM}) then 20 GWe of SFR
- 2080 - 2110: Deployment of 60 GWe of SFR



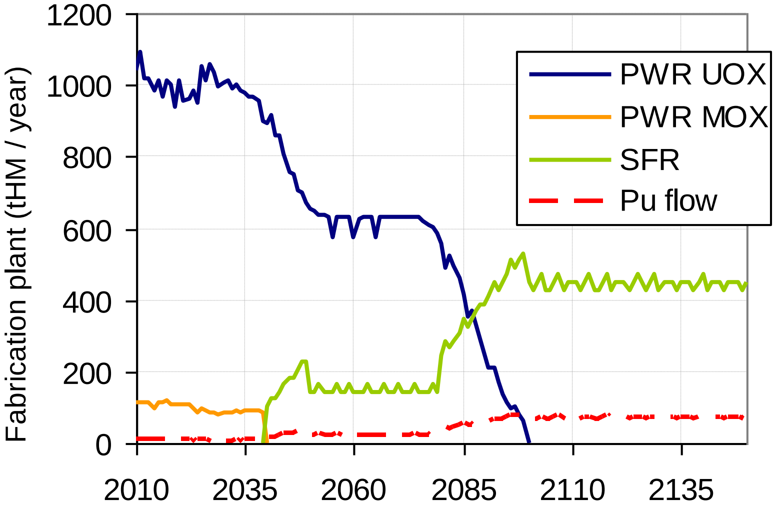
SFR deployment from 2080
over 30 years

- 2020 - 2050: Current French PWR fleet phases out, deployment of 60 GWe of generation III PWR reactors (EPR^{TM})
- 2080 - 2110: Deployment of 60 GWe of SFR

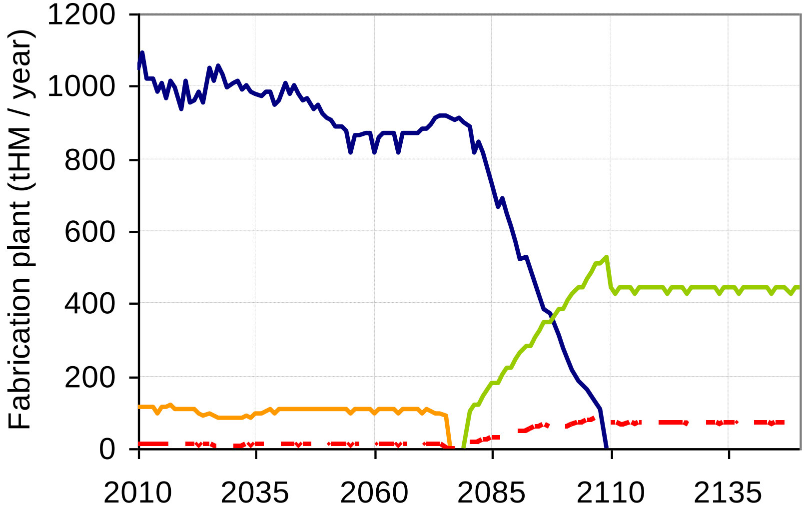
SFR deployment in replacement of the French PWR fleet
Impacts on facilities capacities

Fabrication fuels requirements

- Fuels fabrication needs for the PWR fleet : 1,000 tons/year of UOX fuels, 100 tons/year of MOX fuels
- Fuels fabrication needs for the SFR fleet at equilibrium: 450 tons/year



SFR deployment from 2040



SFR deployment from 2080

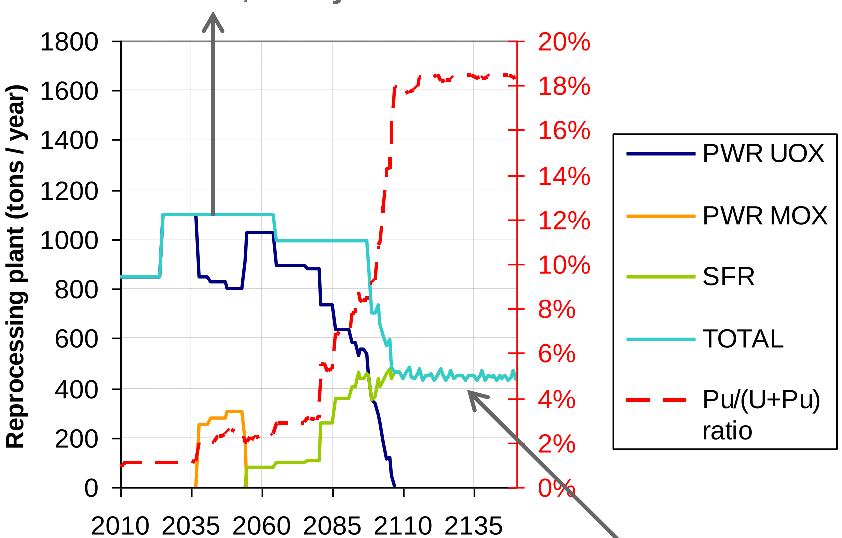
SFR deployment in replacement of the French PWR fleet

Impacts on facilities capacities

Spent fuels reprocessing requirement

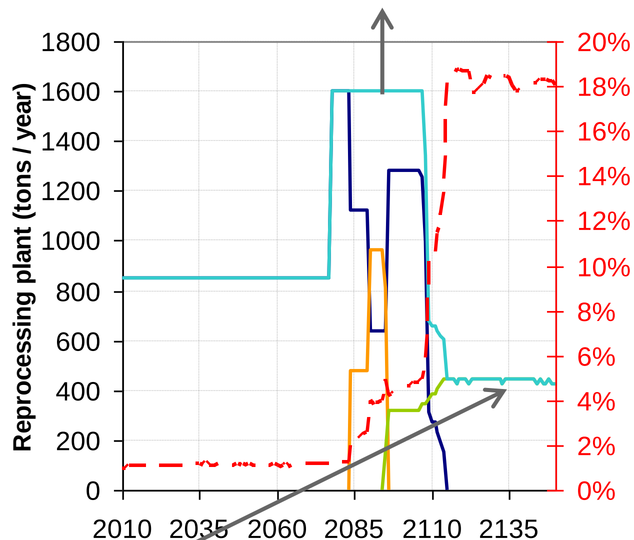
- Optimization to timely feed SFRs and to maintain a steady global capacity over several decades
- PWR fuels (UOX and MOX) are reprocessed in priority before SFR fuels
- Steeper introduction rate of SFR in case of SFR deployment from 2080 over 30 years: additional reprocessing capacity is temporarily required

Max: 1,100 t/y



SFR deployment from 2040 over 60 years

Max: 1,600 t/y



SFR deployment from 2080 over 30 years

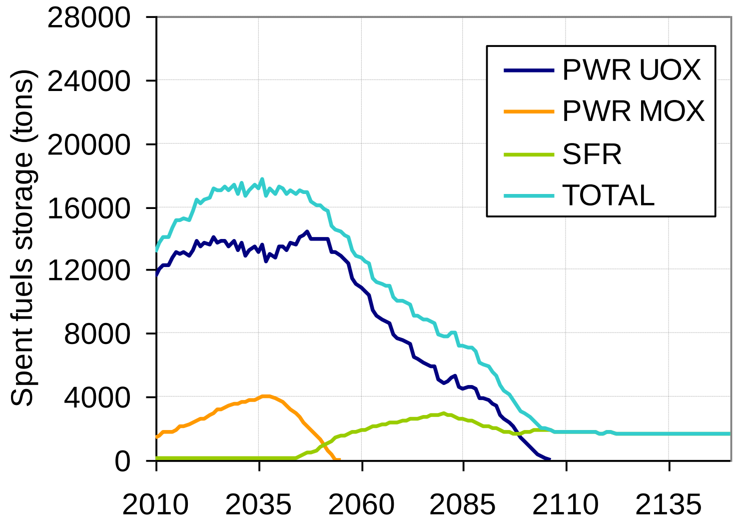
- Equivalent needs at the equilibrium

SFR deployment in replacement of the French PWR fleet

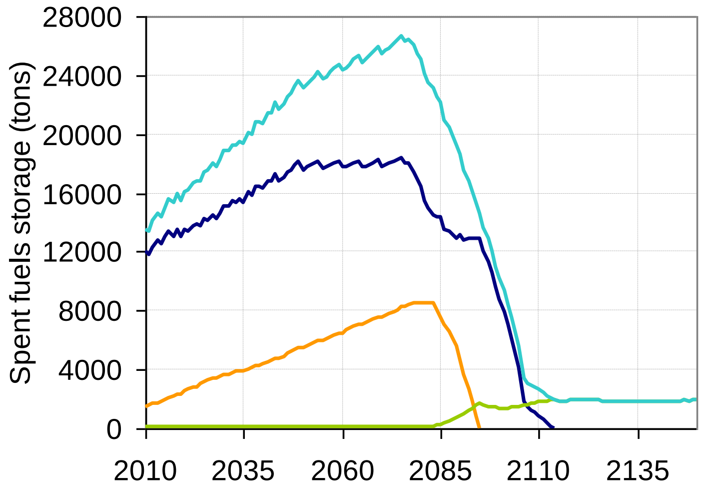
Impacts on facilities capacities

Spent fuels storage

- PWR UOX and MOX fuels are accumulated during the operation of PWR fleet, then PWR fuels storage decreases due to fuels reprocessing to produce the Pu for SFRs



SFR deployment from 2040



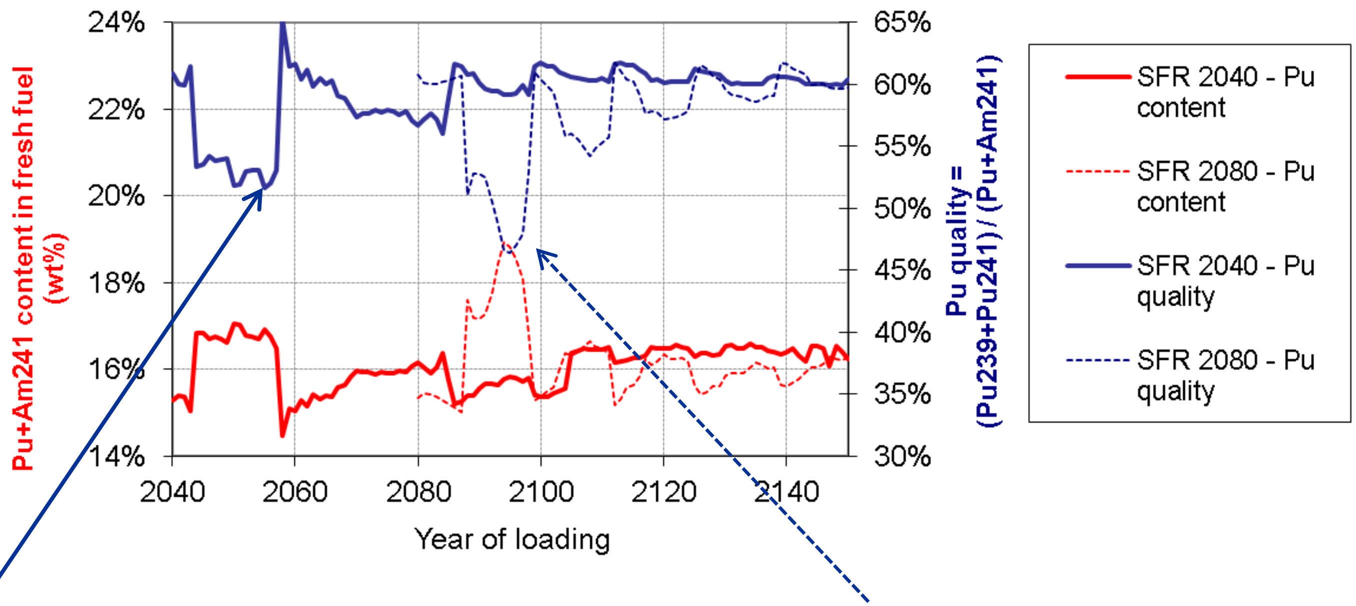
SFR deployment from 2080

- Storage peaks at:
  - 17,700 tons (including 4,000 tons of PWR MOX fuels)
  - 26,700 tons (doubled PWR MOX fuels storage)
- In the two cases, SFR spent fuels storage stabilizes at less than 2,000 tons at the equilibrium

SFR deployment in replacement of the French PWR fleet
Pu recycling in SFR

Evolution of the Pu quality (fraction of odd isotopes in Pu) and initial Pu content

- Pu content in fresh SFR fuels is adjusted during the scenario to compensate the variability of isotopic composition of Pu coming from the reprocessing plant



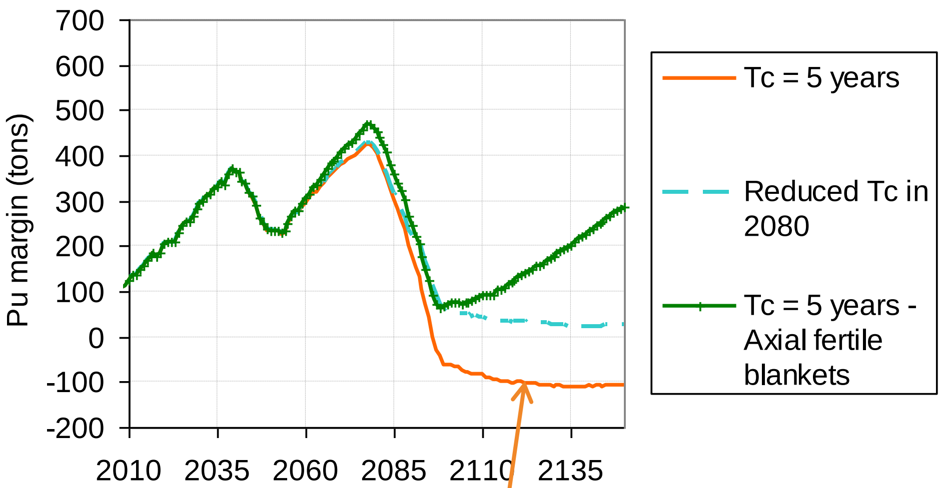
- Lowest Pu quality comes from PWR MOX fuels reprocessing:
  - 51.7% (corresponding to 17.0 wt% of Pu content) in case of SFR introduction from 2040
  - 46.4% (corresponding to 18.9 wt% of Pu content) if SFR introduction is delayed to 2080

- Impact on reactivity coefficient limited to less than 10%
- Similar values of Pu quality and Pu content at equilibrium of SFR fleet

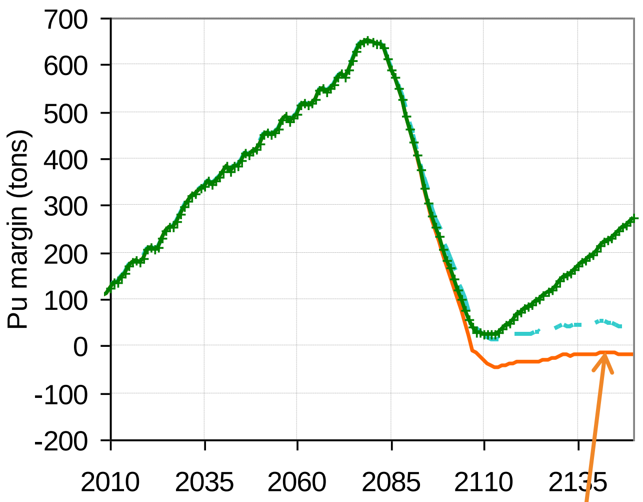
SFR deployment in replacement of the French PWR fleet

Sustainability of SFR deployment

- Definition of Pu margin (Pu available to start SFRs):
  sum of separated Pu and Pu in fuels enough cooled to be reprocessed



SFR deployment from 2040



SFR deployment from 2080

- With a minimum cooling time (Tc) of 5 years for spent fuels, a Pu deficit appears at the end of SFR deployment
- The delay to 2080 of SFR deployment reduces this deficit without removing it

- It is possible to maintain a positive Pu margin through SFR deployment:
  - By reducing the minimum cooling time (Tc) of SFR spent fuels to less than 5 years from 2080 (3.4 years with SFR deployment from 2040 and 4.1 years with SFR deployment from 2080)
  - By adding axial fertile blankets to increase SFR breeding gain

SFR deployment in replacement of the French PWR fleet
Sensitivity to SFR core design

Comparison of Pu need for SFR V2B and CFV deployment

- Two examples of Pu isotopic composition:
  - Transition : representative of the transition period of SFR deployment (Pu coming from PWR fuels)
  - Equilibrium : composition of Pu recycled in SFR fleet
- Higher Pu quality at equilibrium with CFV
- Pu contents are not comparable between SFR and CFV due to the difference of mass of heavy metal in cores (74 tons in SFR and 51 tons in CFV), but similar Pu need expressed in tons/GWe

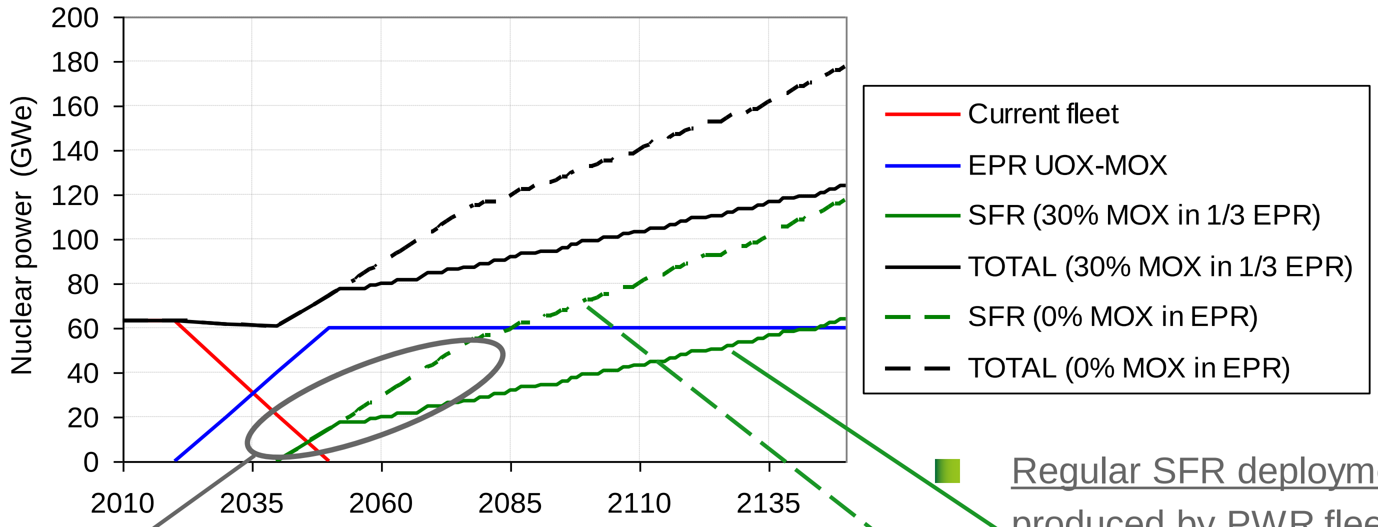
		SFR V2B		CFV V0		Difference (CFV – SFR)	
		Transition	Equilibrium	Transition	Equilibrium	Transition	Equilibrium
Pu isotopic composition	Pu238	3.6%	0.5%	3.6%	0.4%	0%	
	Pu239	47.8%	58.9%	47.8%	61.6%	0%	+4%
	Pu240	29.9%	33.9%	29.9%	32.6%	0%	
	Pu241	8.3%	3.3%	8.3%	2.8%	0%	
	Pu242	10.4%	3.4%	10.4%	2.6%	0%	
	Pu quality	56.1%	62.2%	56.1%	64.4%	0%	+4%
Initial Pu content		16.3%	15.5%	24.9%	23.3%	-	-
Initial Pu mass		8.3 t/GWe	7.9 t/GWe	8.8 t/GWe	8.2 t/GWe	+5%	+4%

- Slightly increased constraints on Pu availability with CFV deployment, but the feasibility is not questioned
- Limited impacts on facilities

SFR deployment in complement of the French PWR fleet

Maximal achievable SFR deployment

- Progressive introduction of SFRs from 2040 can provide a complementary service to PWR fleet (for example to take advantage of Pu in PWR MOX fuels)
  - ➢ To determine the number and the paces of SFRs deployed in function of Pu resource produced by PWR fleet
- Maximal achievable SFR deployment, with (full lines) or without (dotted lines) MOX fuels in EPR™ reactors:

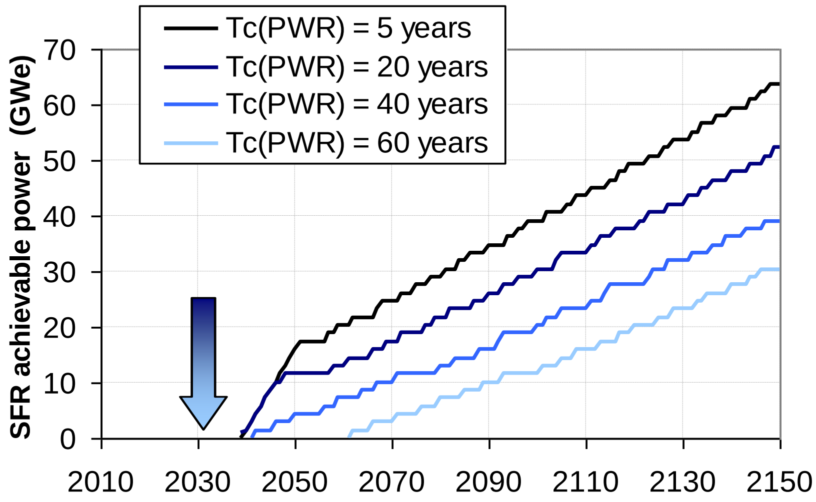


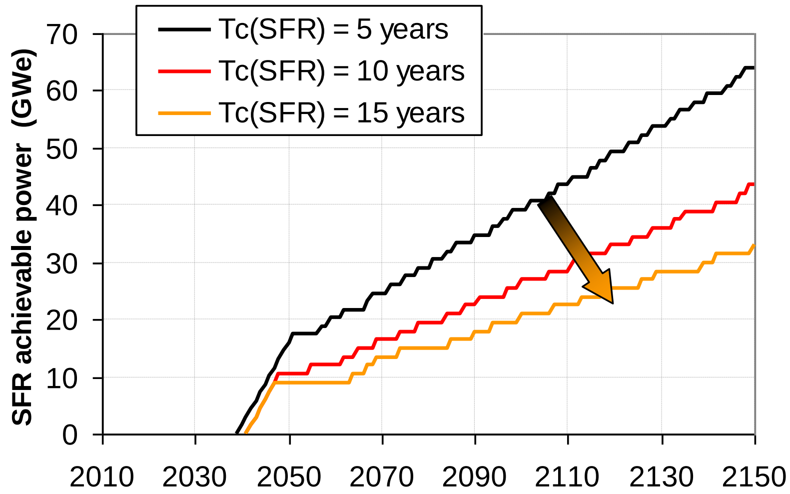
- First stage of SFR deployment using Pu of accumulated PWR fuels (pace limited to 1 reactor/year):
  - 17 GWe using Pu in MOX fuels
  - 55 GWe using Pu in both UOX and MOX fuels
- Regular SFR deployment using Pu yearly produced by PWR fleet:
  - 0.5 GWe/y with 30% MOX in 1/3 of EPR™ reactors
  - 0.9 GWe/y assuming no MOX in EPR™ reactors

SFR deployment in complement of the French PWR fleet

Key drivers to modulate SFR deployment

- Results given for the case of continuity of MOX use in EPR™ reactors
- Sensitivity of SFR deployment to the cooling time before reprocessing (Tc) of PWR fuels and SFR fuels



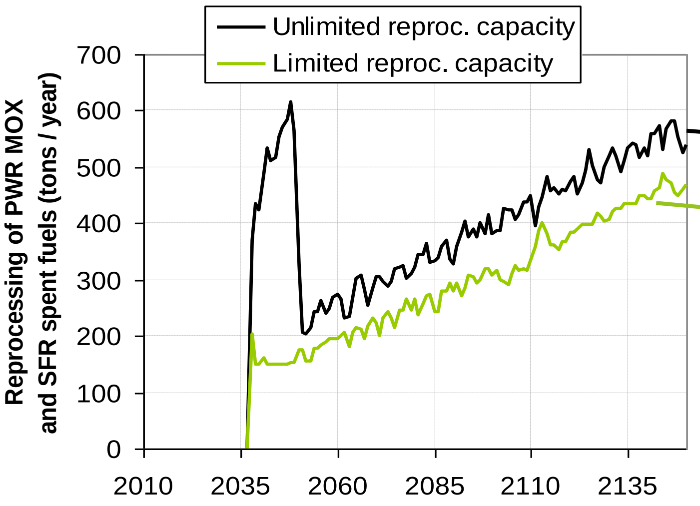


- Impact on the available amount of Pu to start SFRs during the first stage:
  - First stage is reduced if Tc(PWR) increased
  - If Tc(PWR) > 40 years, SFR deployment is delayed
- Impact on the period for a SFR to be able to use its own Pu and the Pu inventory required to start a new SFR:
  - The pace of SFR deployment during the regular stage is reduced by a factor 2 if Tc(SFR) increased from 5 to 15 years

SFR deployment in complement of the French PWR fleet

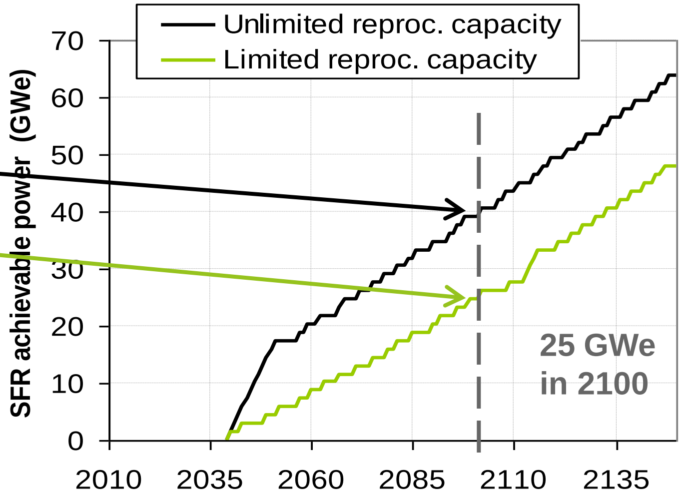
Key drivers to modulate SFR deployment

- Results given for the case of continuity of MOX use in EPR^{TM} reactors



No limitation on reprocessing capacity ⇨ maximal achievable SFR deployment

If reprocessing capacity is limited to 150 t/y of PWR (MOX) spent fuels, suppression of the first stage of SFR deployment



- If reprocessing capacity is limited to a realistic value, PWR MOX spent fuels storage is stabilized to its level of 2040 (4,000 tons) before SFR deployment

> 25 GWe of SFR from 2040 to 2100, in complement of a 60 GWe PWR fleet:
> Minimum SFR deployment to benefit from the Pu produced by the PWR French fleet while stabilizing spent fuels storage

Conclusions

- Illustrative scenarios with contrasting assumptions to sketch the capability of SFR deployment to renew the French PWR fleet with different chronologies and to take advantage of Pu in PWR spent fuels

- Scenarios of SFR deployment in replacement of PWR French fleet:
  - Made feasible in terms of Pu availability by reducing the minimum cooling time of SFR spent fuels to less than 5 years or by adding fertile blankets
  - Limited impacts on fuel cycle facilities (capacities are higher if SFR deployment is delayed to 2080, even if fuels composition remain compatible with the range of operation of SFRs)
  - Similar results obtained for different SFR cores design (SFR V2B and CFV)

- Scenarios of SFR deployment in complement of PWR fleet:
  - Highlight a first stage of SFR deployment using Pu of accumulated PWR fuels, followed by a stage of regular SFR deployment using Pu yearly produced by PWR fleet
    - Pace of SFR deployment: from 0.5 GWe/y to 0.9 GWe/y
  - Key drivers to modulate SFR deployment:
    - PWR spent fuels cooling time impacts the first stage of SFR deployment
    - SFR spent fuels cooling time impacts the pace of SFR deployment
  - 25 GWe of SFR from 2040 to 2100: minimum SFR deployment to benefit from the Pu produced by the PWR French fleet with capacities (reprocessing, storage) in continuation of current available capacities

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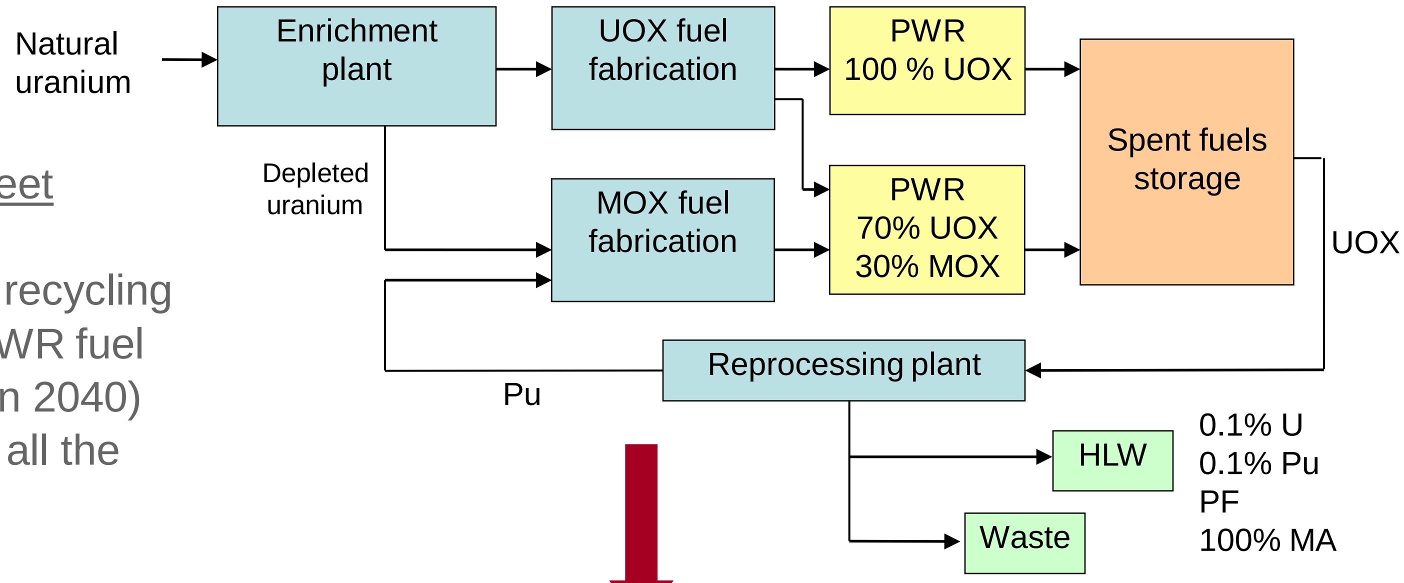
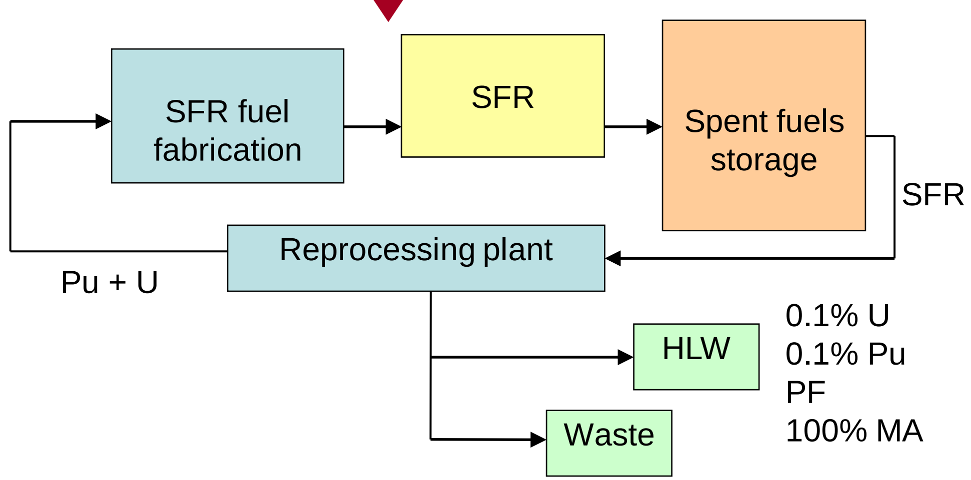
Backup slides

Transition scenarios



- Current French fleet (2000-2040)
  - Single Pu recycling in MOX PWR fuel (stopped in 2040)
- Common part for all the scenarios



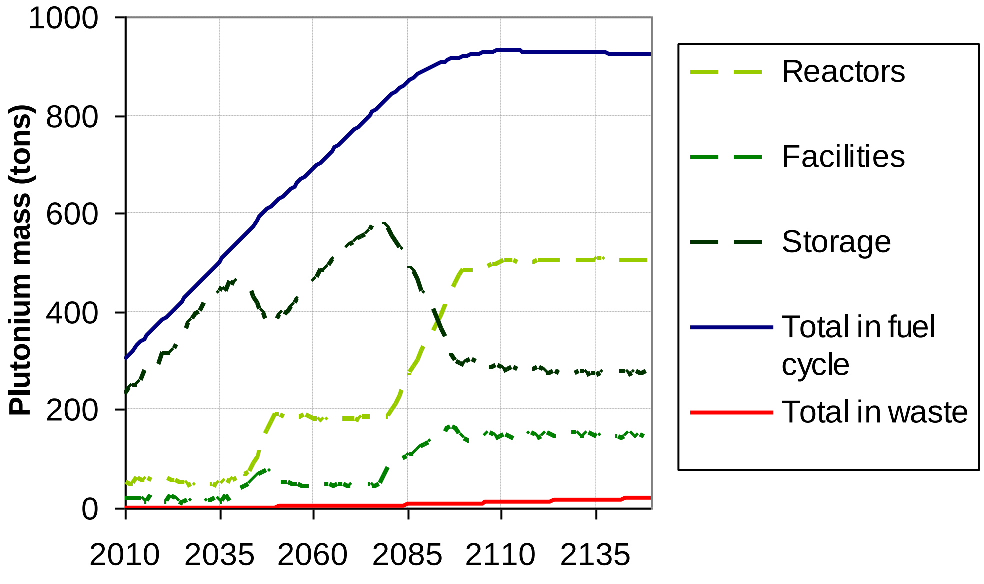
- Equilibrium situation (> 2100)
  - Closed fuel cycle

SFR deployment in replacement of the French PWR fleet

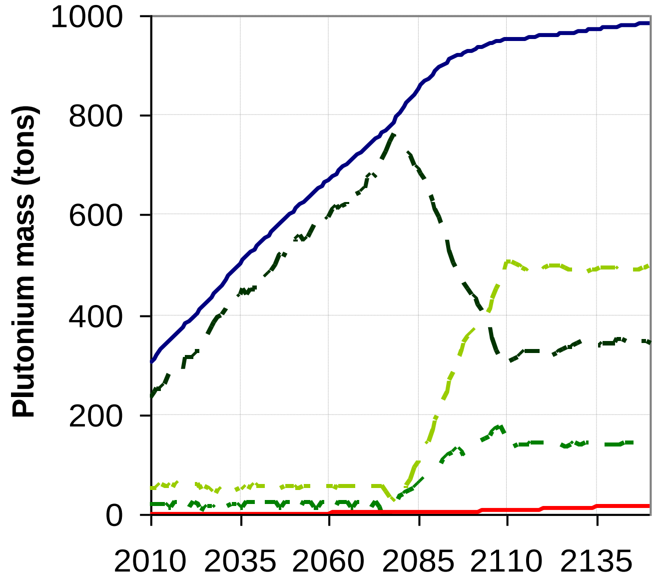
Plutonium inventory

Pu distribution in fuel cycle: Pu mass in facilities, in storage (spent fuels and separated materials), fuels irradiated in reactors and in ultimate waste

- Final distribution of Pu inventory similar in both scenarios and consistent with the transit time at each step:
  - 50% in reactors (almost 7 years of irradiation)
  - 15% in facilities (mainly 2 years of fabrication)
  - 35% in storage (5 years of cooling before reprocessing)



SFR deployment from 2040



SFR deployment from 2080