SCENARIOS FOR THE DEPLOYMENT OF THE SODIUM COOLED FAST REACTORS IN FRANCE

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INTRODUCTION

In the frame of the french law for the waste management :

Transition scenarios studies starting from the present situation in France and simulating the deployment of Sodium cooled Fast Reactors (SFR)

2 scenarios selected :

Scenario 1 : Pu in the SFR core, Minor actinides to the waste

Scenario 2 : Pu in the SFR core, heterogeneous recycling of MA in the radial blankets

INTRODUCTION

The insertion of a new concept (fuel, reactor, process) must be evaluated in the global electronuclear system with an analysis of the impact on the fuel cycle (Enrichment, Fuel Fabrication, Reactor, Processing, Interim Storage, Waste storage).

- ⇒ **The scenario studies are used to evaluate different solutions to manage nuclear materials (uranium, plutonium) and wastes (minor actinides and fission products), from the present situation in France (closed cycle with storage of used MOX fuels) until the final equilibrium: SFR nuclear park**
- ⇒ **The simulation of transient scenarios from the present situation to the future situation is performed with the code COSI**

SCENARIO ASSUMPTIONS

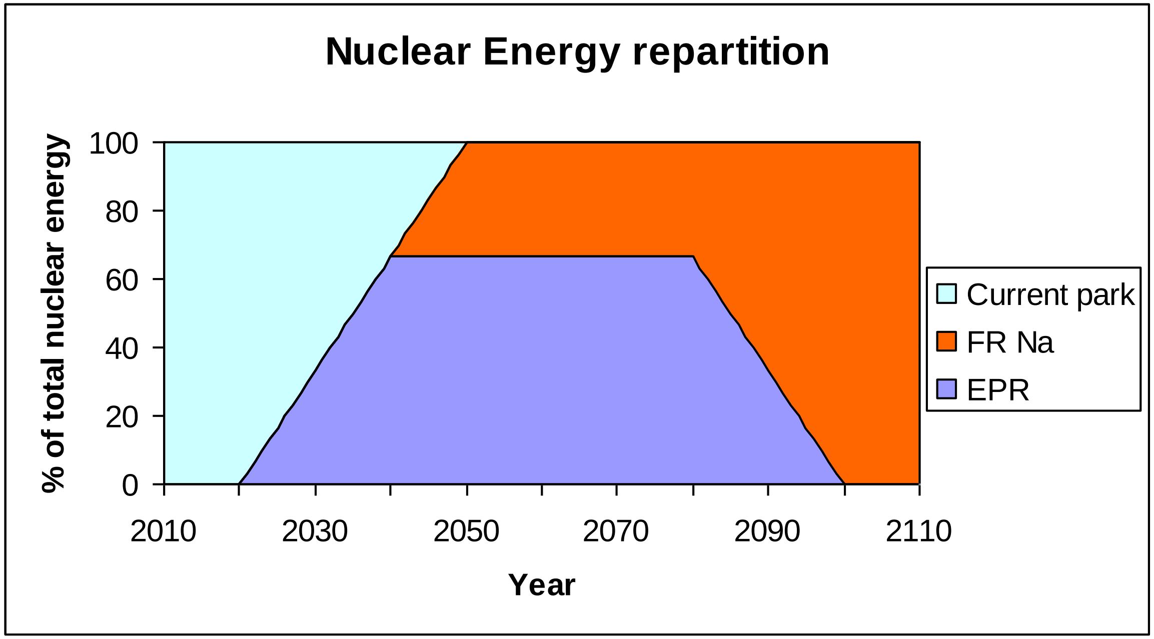
Main assumptions :

•Constant nuclear energy demand : 430 TWhe / year.

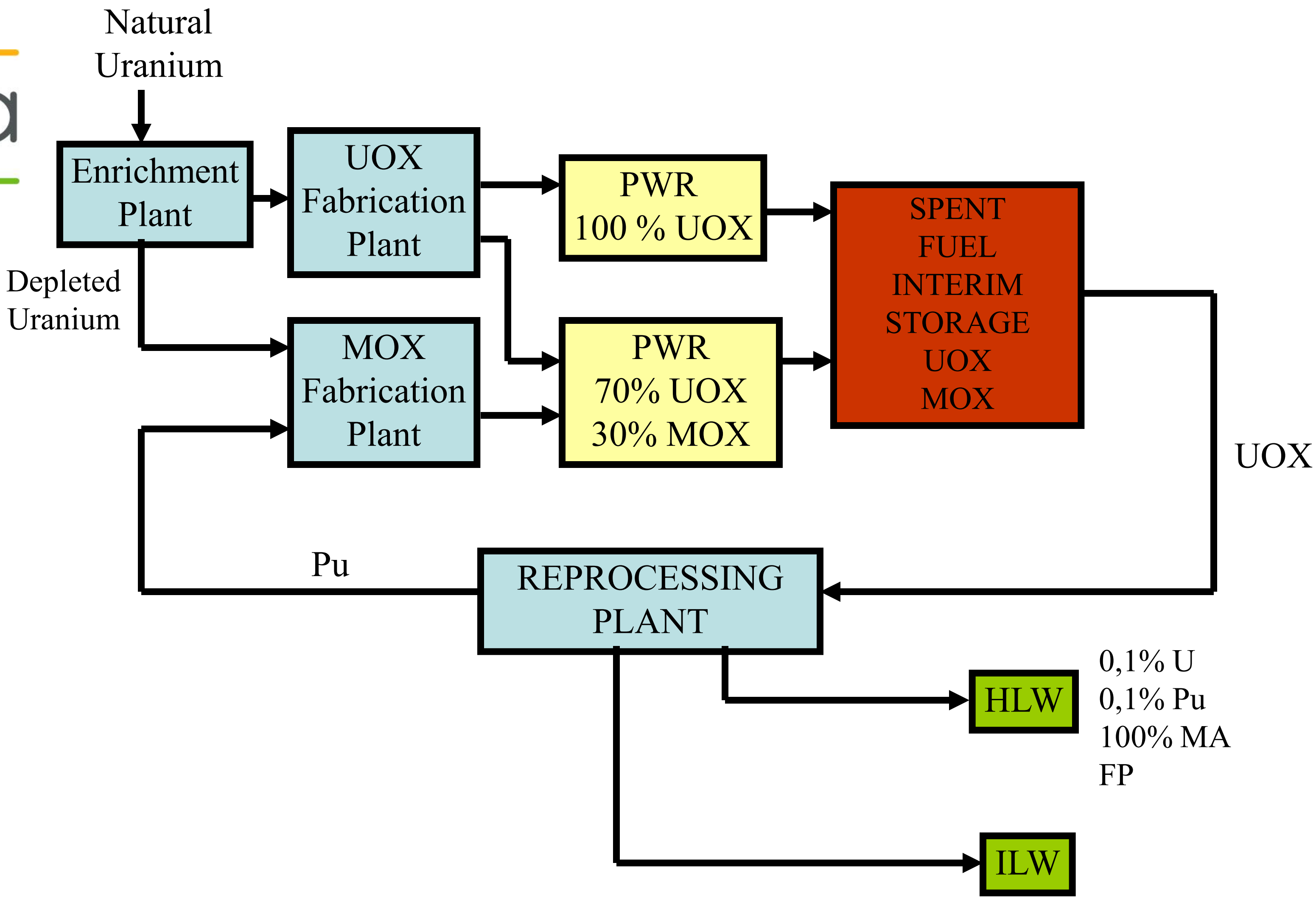
•The current nuclear park is replaced between 2020 and 2050 by a mixed nuclear park : 67 % of Generation III EPR reactors and 33% of Generation IV SFR.

•The lifetime of the EPR and the SFR is 60 years, which means that the first EPR are replaced from 2080.

•From 2080 to 2100, the EPR are replaced by SFR. In 2100, the park has 100% of SFR, corresponding to 60 GWe.

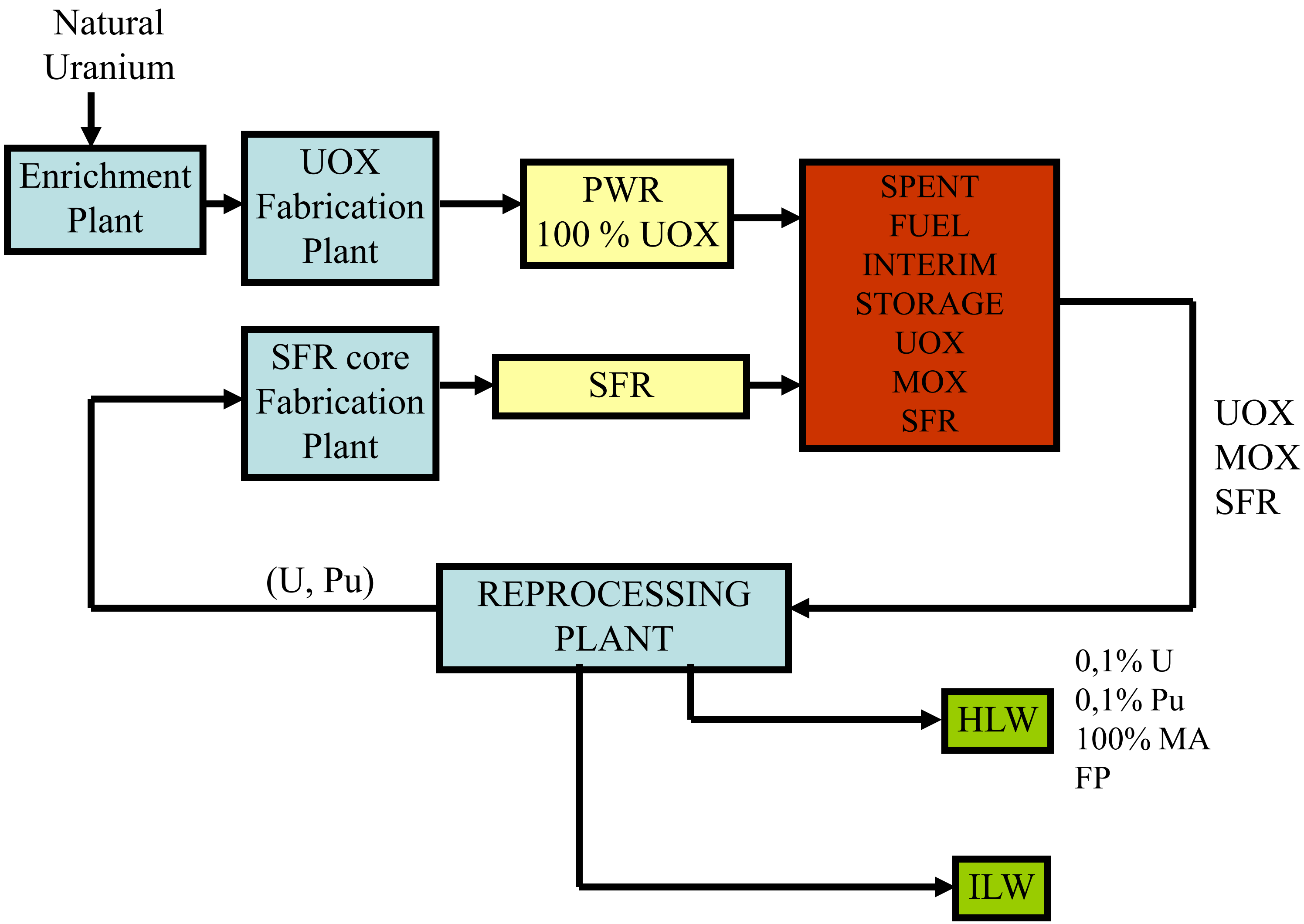


Presentation of the scenarios



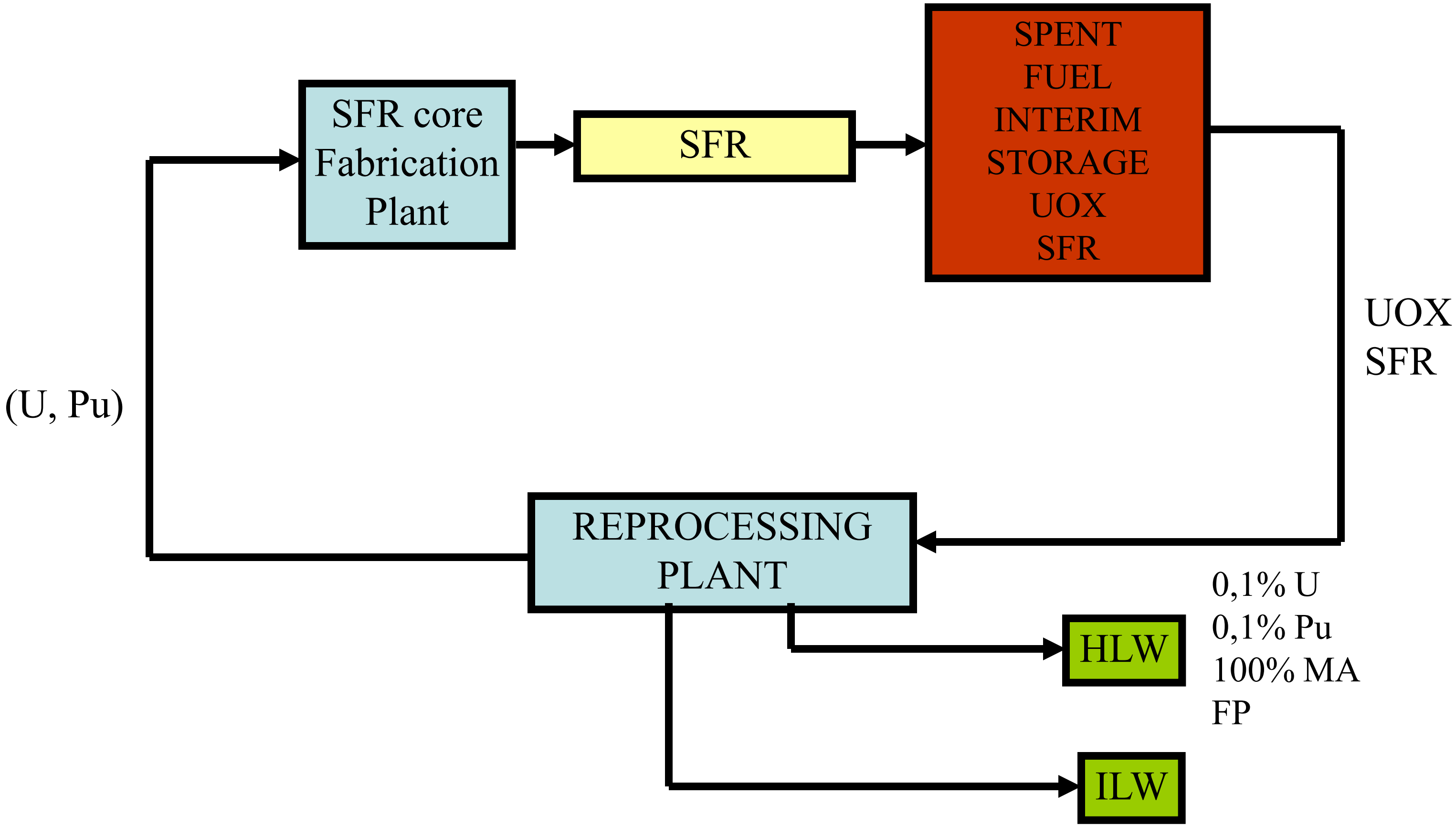
Scenario 1 and 2 : Flow sheet in 2010

Presentation of the scenarios



Scenario 1 : Flow sheet between 2040 and 2080

Presentation of the scenarios



Scenario 1 : Flow sheet after 2080

CORE PERFORMANCES

Assembly and core characteristics	V0 concept	V2B concept
Number of fissile fuel assemblies	424	454
Heavy nuclide volume fraction (%vol) (Fuel porosity = 0,96)	47.4	43.7
Na volume fraction (%vol)	27.1	27.7
Structure volume fraction (%vol)	18.5	20
Average Core power density (W/cm3) (Volume is calculated at T = 20°C)	231	206
Reloading frequency	5	5
Average BU (GWd/t)	106	98
maximum BU (GWd/t)	184	148
Average Pu enrichment (%vol fuel)	14.8	15.8
Equivalent Pu 239 enrichment mass (%)	10	10.96
Initial Pu mass (kg) Pu vector : Pu238=3,57 / Pu239=47,39 / Pu240=29,66 / Pu241=8,23 / Pu242=10,38 / Am241=0,78	10 472	12 043
Total Heavy nuclides mass (tons)	71	74

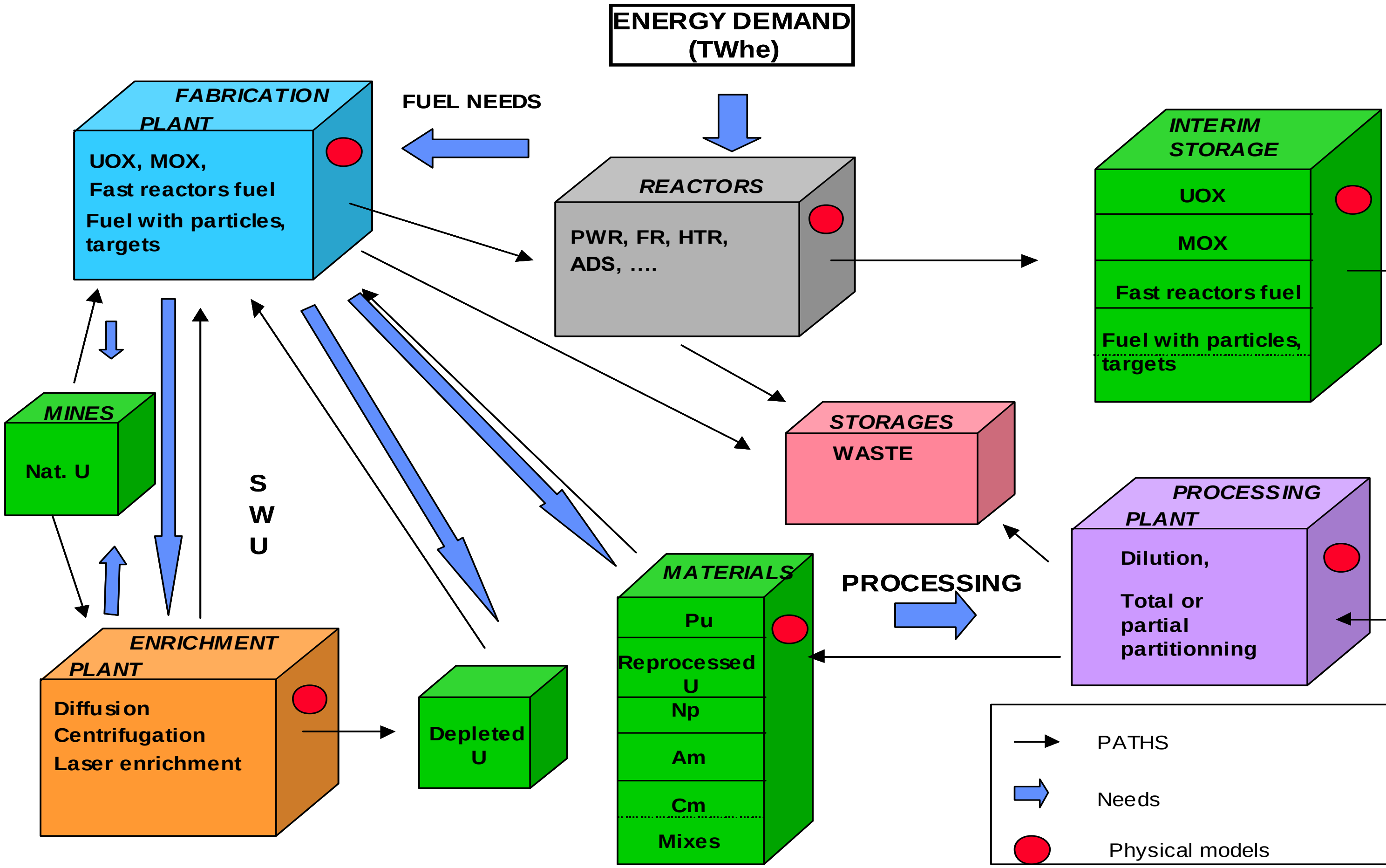
REACTOR ASSUMPTIONS

	EPR	SFR
Thermal power	4500 MWth	3600 MWth
Net Electrical power	1550 MWe	1450 MWe
Load factor	81.76%	81.76%
Core management	4* 366.6 EFPD	5 * 410 EFPD
Net yield	34.44%	40.3 %
Fuel assemblies Average burnup	55 GWd/tons	106 GWd/tons – SFR V0 98 GWd/tons – SFR V2B
Fuel type	UOX, 17 x 17 MOX pins	See core performances

FUEL CYCLE ASSUMPTIONS

Enrichment	
Depleted Uranium enrichment	0,25% until 2019 0,2% from 2020
Fabrication	
Standard MOX and SFR fuel fabrication time	2 years
Reprocessing	
Minimum cooling time before reprocessing	PWR fuel : 5 years SFR fuel : 2 or 5 years
Reprocessing losses	Scenario 1 : 0,1% for U, Pu Scenario 2 : Until 2037 : 0,1% for U, Pu, 100% for Am, Np, Cm From 2038 : 0,1% for U, Pu, Am, Np, Cm
Priorities for reprocessing	First In – First Out until 2037 First In – Last Out from 2038

Tool of calculation : COSI



- Fuel cycle plants (Mines, enrichment, fabrication, reactors, reprocessing, stockpiles, waste storage)
- Input data (Energy demand, fuel and nuclear materials requirements)
- Transfers of nuclear materials
- Physical models for nuclear materials (irradiation, cooling,..)

SCENARIO 1

Scenario 1

The SFR burn Plutonium and MA go to the High Level Waste (HLW)

	SFRV0	SFR V2B
SFR fuel cooling time = 2 years Pu 239 equivalent margin Installed capacity margin (GWe)	 +214 tons +27 GWe	 +90 tons +10 GWe
SFR fuel cooling time = 5 years Pu 239 equivalent margin Installed capacity margin (GWe)	 +61 tons +6 GWe	 -105 tonnes - 9 GWe

The Pu margin takes into account the total necessary Pu mass : Pu for reactors, fabrication plant and the Pu contained in the spent fuel cooling.

In case of lack of Pu, it appears after 2090.

SCENARIO 1

The Plutonium margin depends on the SFR design and fuel cycle assumptions. The margin can be :

- **positive, which means that we have the possibility to deploy more SFR ;**
- **or negative, which means that an external source of Plutonium is necessary to deploy 60 GWe of SFR in 2100.**

=> it is interesting to perform some sensitivity studies, so as to assess the impact of the SFR design and fuel cycle assumptions on the Pu margin.

Relevant parameters :

1. **Thermal Power : 3600 MWth (data)**
2. **Volumic Power: variable, depending on SFR design**
3. **Cycle length : 410 EFPD, depending on core design**
4. **Number of cycle: 5**
5. **Heavy nuclide mass: variable depending on SFR design**
6. **Maximum fuel assembly burnup : 150 000 MWd / t (design criteria)**
7. **Average fuel assembly burnup: 100 000 MWd / t (hypothesis: Form Factor = 1.5)**
8. **Minimum cooling time before reprocessing : variable**
9. **Fabrication time : 2 years**
10. **Equivalent Pu 239 mass : depends on 2, 3, 4, 5, 7**
11. **SFR net yield : 40.3%**

SCENARIO 1

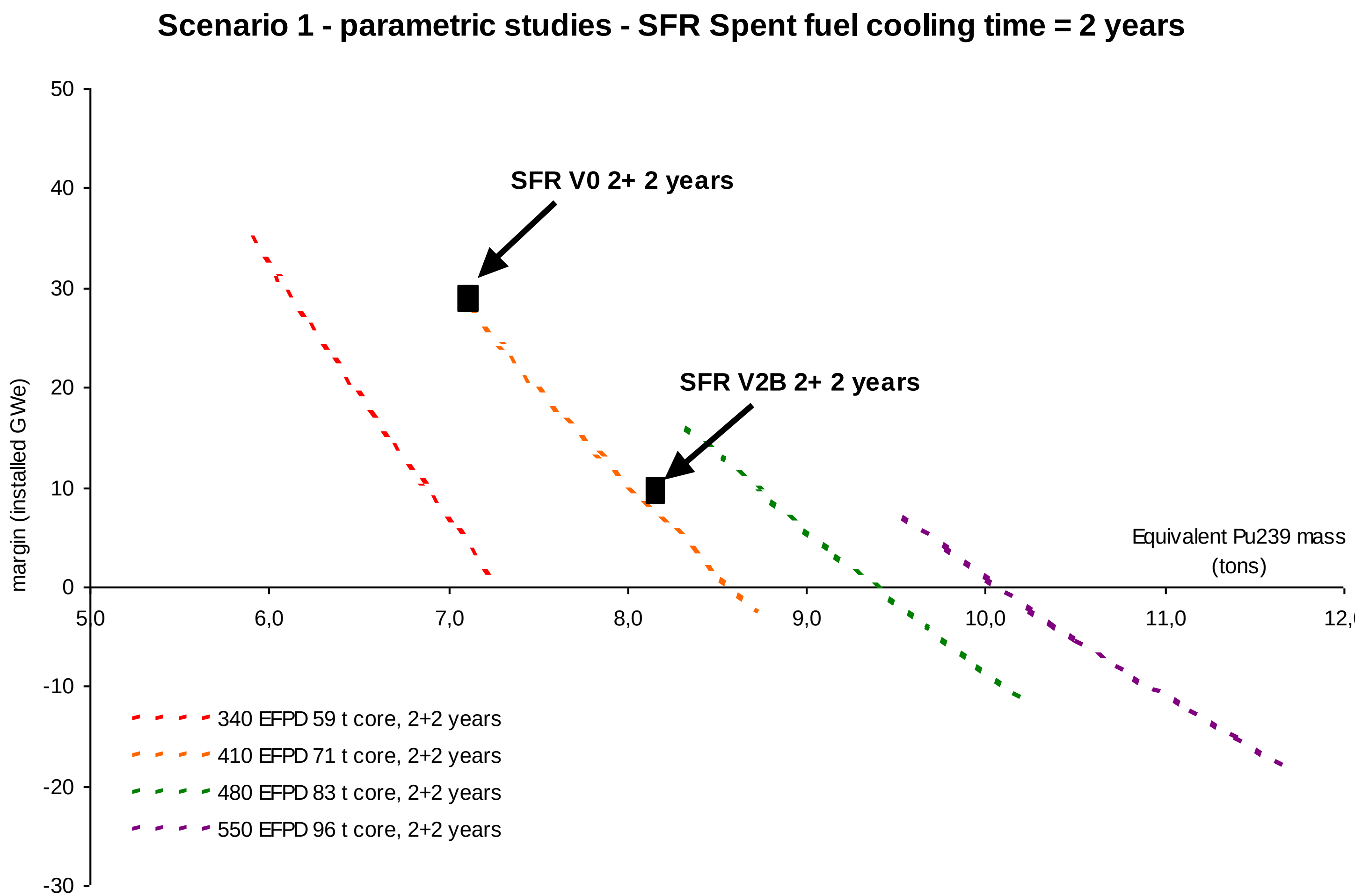
Given the large number of parameters involved in the Plutonium balance, it was decided to retain 3 parameters for the parametric studies :

•2 core parameters: Equivalent Pu239 mass and mass of heavy nuclides in the core. The cycle length can be deduced from these 2 parameters with the help of average discharge burnup

•1 cycle parameter : the minimum cooling time of SFR spent fuel before reprocessing.

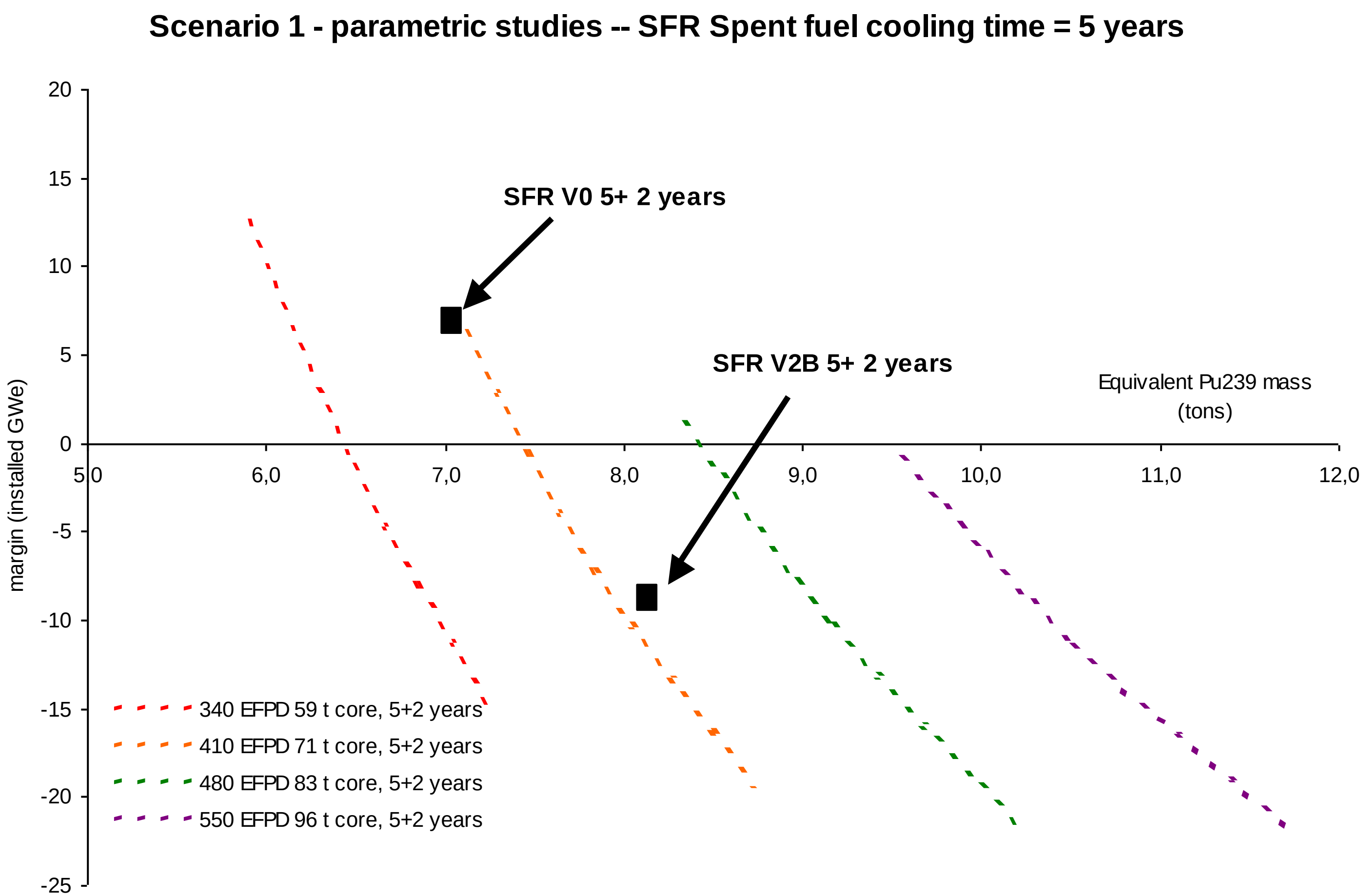
For each configuration (Pu mass, Heavy Nuclides mass, minimum cooling time), a COSI calculation is made. Other calculation assumptions are the same for all the calculations. The results are presented in the following figures, giving the margin, in term of SFR installed capacity.

SCENARIO 1



Scenario 1 - parametric studies - SFR Spent fuel cooling time = 2 years
SFR V0 2+ 2 years
SFR V2B 2+ 2 years
margin (installed GWe)
50
40
30
20
10
0
-10
-20
-30
5,0
6,0
7,0
8,0
9,0
10,0
11,0
12,0
Equivalent Pu239 mass (tons)
340 EFPD 59 t core, 2+2 years
410 EFPD 71 t core, 2+2 years
480 EFPD 83 t core, 2+2 years
550 EFPD 96 t core, 2+2 years

SCENARIO 1


Scenario 1 - parametric studies -- SFR Spent fuel cooling time = 5 years
SFR V0 5+ 2 years
SFR V2B 5+ 2 years
Equivalent Pu239 mass (tons)
margin (installed GWe)
20
15
10
5
0
-5
-10
-15
-20
-25
5,0
6,0
7,0
8,0
9,0
10,0
11,0
12,0
340 EFPD 59 t core, 5+2 years
410 EFPD 71 t core, 5+2 years
480 EFPD 83 t core, 5+2 years
550 EFPD 96 t core, 5+2 years

SCENARIO 1

The results indicate that:

1. **The margin in term of Plutonium and installed capacity <u>is very sensitive to the equivalent Pu 239 mass in the core</u>. For example, an increase of 10% of the equivalent Pu239 mass in the core induces a decrease from 9 GWe to 15 GWe for the possible installed capacity (no external source of Plutonium is taken into account).**

2. **There is no lack of Pu in the first stage of deployment of SFR (2040 - 2050)**

3. **In case of lack of Pu, it appears at the end of the second stage of the deployment of the SFR, after 2090.**

SCENARIO 2

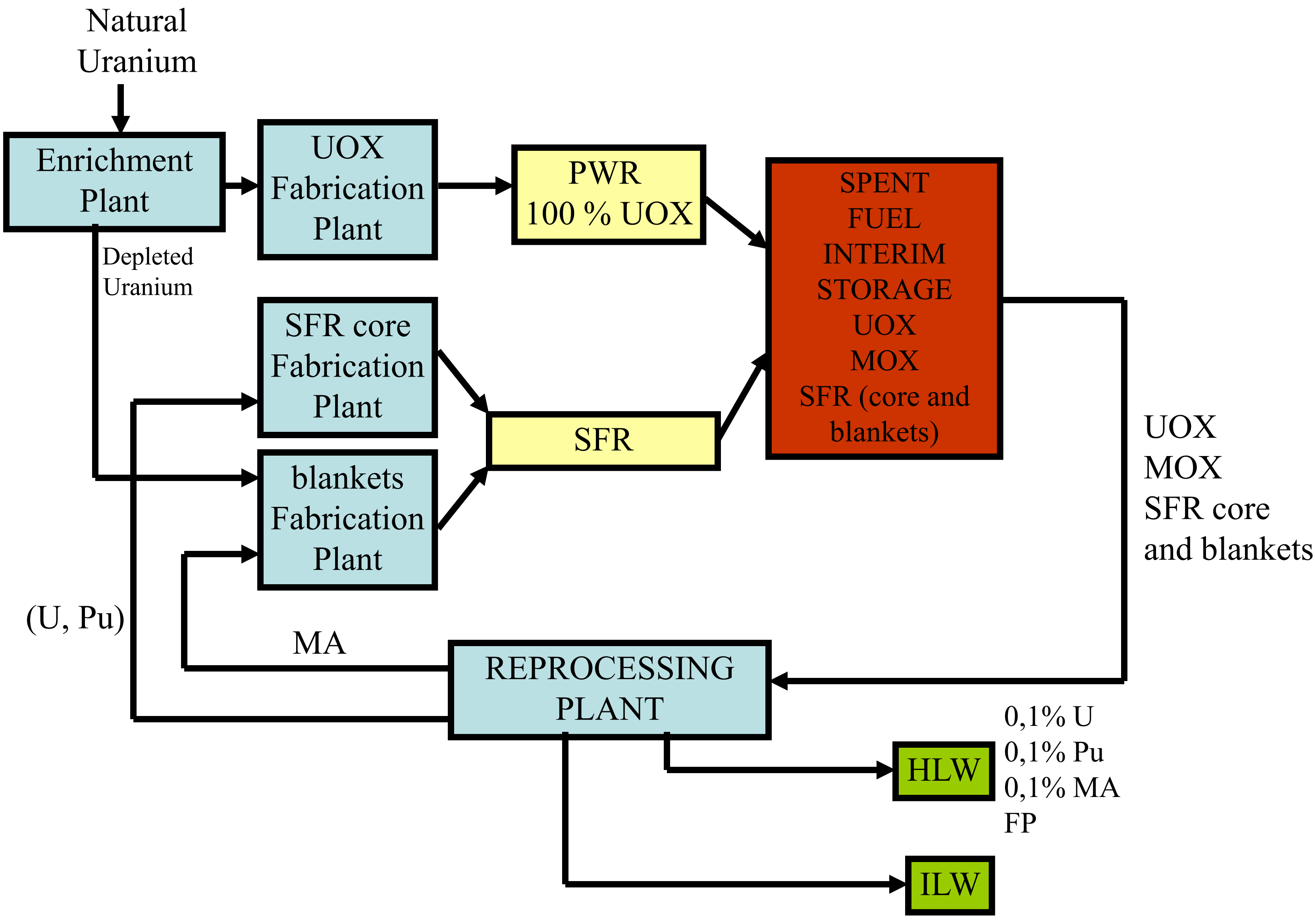
Scenario 2 : Pu and MA in the SFR core

heterogeneous recycling of MA in the radial blankets, UO2 matrix

Heavy nuclide mass per reactor	12,2 tonnes
U Enrichment (U235 / U)	0,9 %
Initial MA fraction	10 %
Burnup (MWd/t)	42 000
Reloading frequency	1
Cycle length (EFPD)	4100
Transmutation rate	41,1 %
Pu production (discharge)	1,05 tons

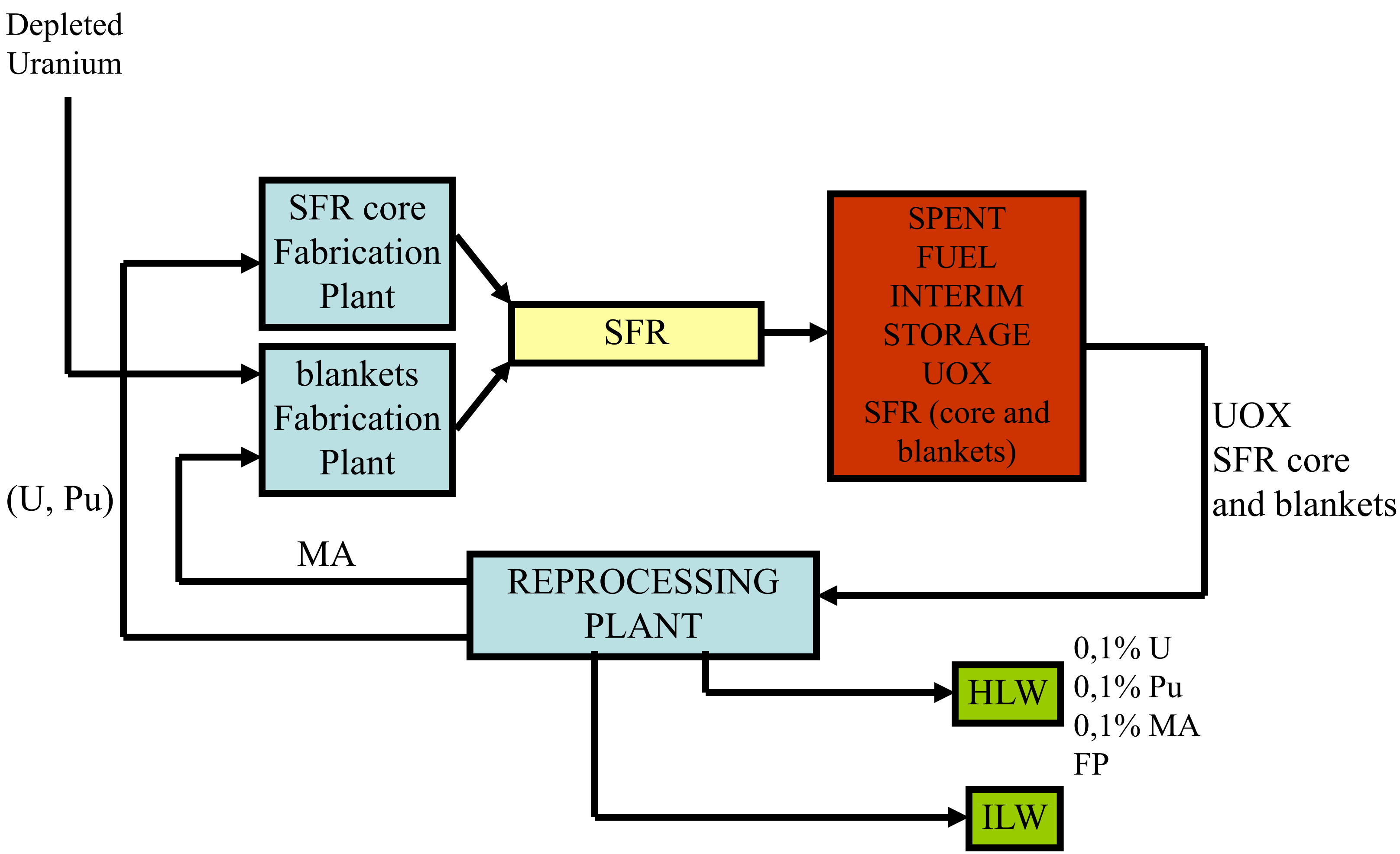
Radial blankets characteristics

SCENARIO 2



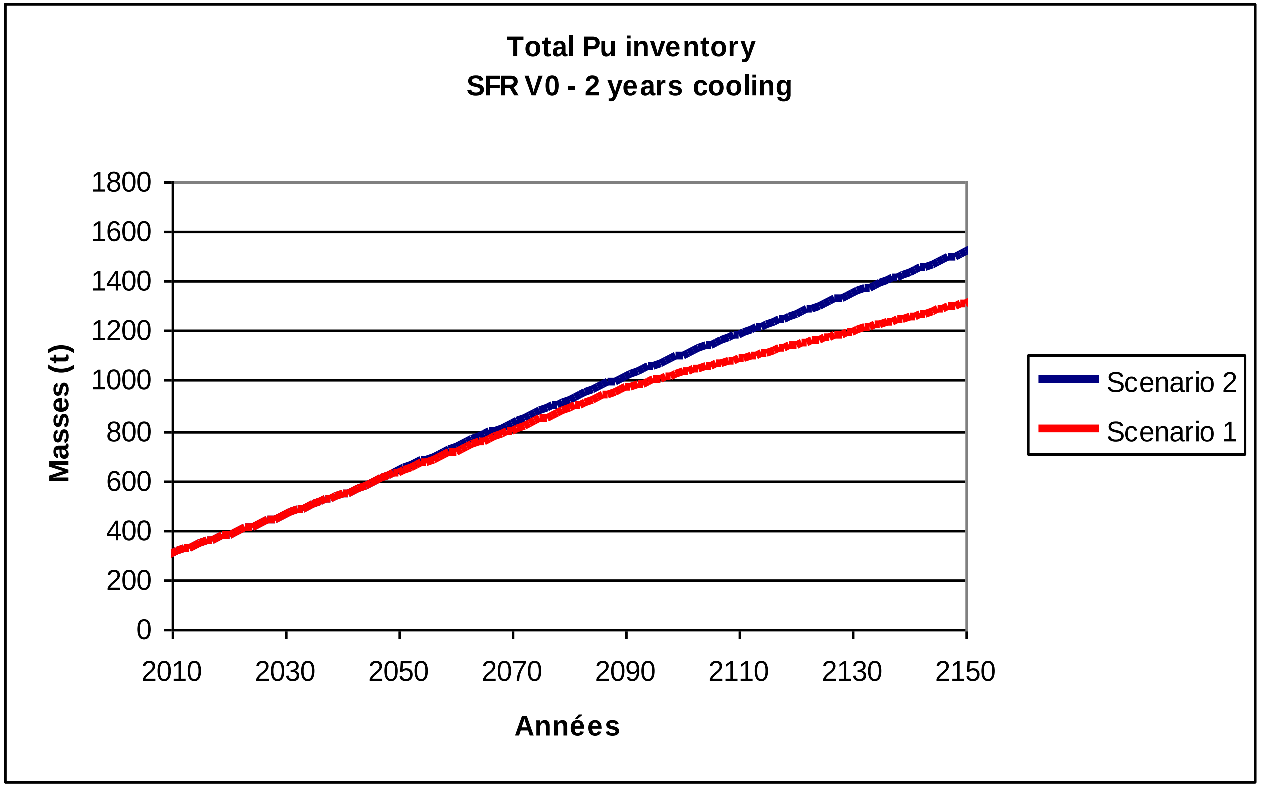
Scenario 2 : Flow sheet between 2040 and 2080

SCENARIO 2



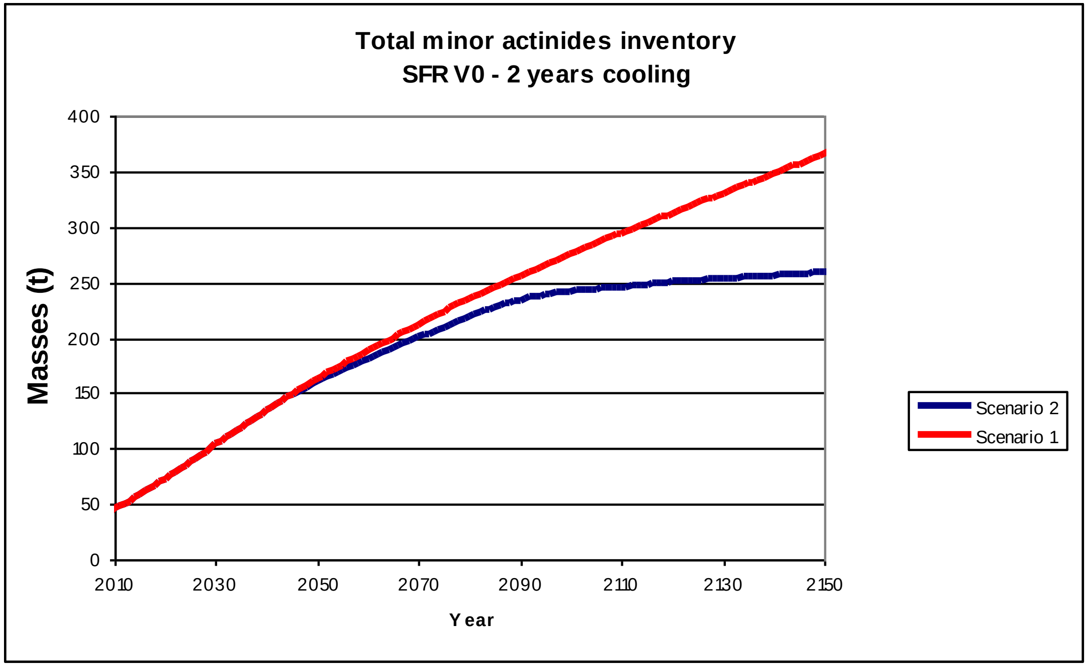
Scenario 2 : Flow sheet after 2080

RESULTS



Compared to the scenario 1, the Pu produced in the radial blankets allows to deploy 3 GWe more at the end of the century

RESULTS



The **initial MA fraction** in the radial blankets necessary to stabilize completely the minor actinides inventory in the fleet is linked to many assumptions or results as for example :

- The stabilization of the Plutonium inventory : An increase of the Pu inventory induces an increase of the Americium inventory due to the decay of Pu241 in the spent fuel storage
- The cooling time of the spent fuel before reprocessing, for the same reasons
- The recycling of the reprocessed Uranium in the fast reactors, which induces an additional production of Neptunium in the fast reactors

=> an initial minor actinides fraction from 10 to 20% in the radial blankets is sufficient to stabilize the minor actinides inventory, with the condition to involve 100 % of the SFR in the transmutation process.

CONCLUSIONS (1)

The studies conducted in 2008 has confirmed the previous studies (french context) :

1. In the case of a scenario with a constant installed capacity, the Plutonium margin obtained for the deployment of SFR is low, or negative if the minimum cooling time of SFR spent fuel is 5 years and if the SFR are deployed have a breeding gain close to 0. This margin decreases significantly when the Pu 239 equivalent rate in the SFR increases. **For example, an increase of 10% of the equivalent Pu239 mass in the core induces a decrease from 9 to 15GWe for the possible installed capacity** (no external source of Plutonium is taken into account).

2. In case of lack of Pu, this lack appears in the second part of the SFR deployment after 2090, at the end of the transition period.

3. The lack of Pu would be more important in the case of a scenario with an increase of the installed capacity.

CONCLUSIONS (2)

It is possible to recover significant margins with the condition :

- To reduce the cooling time of the SFR spent fuel before reprocessing to 3,4 years in the period when the lack of Pu occures, at the end of the century,
- To deploy SFR breeder (GRG = 0.2) with a small doubling time (approximately 50 years) early in the deployment of SFR (2040)
- To start the last SFRs with enriched U core instead of MOX core
- To reduce the burnup of LWR fuel to increase the quantity and quality of the Pu produced
- To deploy LWR instead of SFR in the last years of the deployment,
- To provide an external source of Pu,
- To stop the single recycling of Pu in the LWR

The transmutation scenario of MA in the radial blankets allows to deploy 3 GWe more. The MA inventory stabilization can be reached with a MA fraction from 10 to 20%, depending from fuel cycle assumptions, with the condition to involve 100 % of the SFR in the transmutation process. The optimization of the transmutation scenarios is still on going.