Simulations of Progressive Potential Scenarios of Pu Multirecycling in SFR and Associated Phase-out in the French Nuclear Power Fleet

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SIMULATIONS OF PROGRESSIVE POTENTIAL SCENARIOS OF Pu MULTIRECYCLING IN SFR AND ASSOCIATED PHASE-OUT IN THE FRENCH NUCLEAR POWER FLEET

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Abstract – *After the studies carried out in the frame of the 2006 French Act for waste management, the CEA, EDF and AREVA decided to work together on progressive potential scenarios of the French transition between the current nuclear fleet and a SFR fleet which does not require natural uranium to operate. To do so, several steps were defined, each of them having a different purpose and allowing a gain of experience to move on to the next one.*

In one of these scenarios, between 2030 and 2062 the current PWR fleet is renewed by an EPR reactor fleet in which plutonium keeps on being monorecycled. This EPR reactor fleet is loaded with about 10% of MOX fuel which enables to stabilize the UOX spent fuel inventory. Beginning from the 2040 decade, a few FR reactors and their associated cycle are progressively introduced: MOX PWR spent fuels reprocessing begins in 2040 in order to feed three 1000 MWe breakeven SFR, commissioned between 2050 and 2059.This enables to test at an industrial scale the new Nuclear System and to stabilize used MOX fuel inventory. To prepare for a larger FR deployment, three 1450 MWe breakeven SFR are commissioned between 2075 and 2085. An SFR spent fuel reprocessing of 15 to 21 tHM/y starts in 2060 in order to feed the three 1450 MWe SFR. From 2090, thirteen additional 1450 MWe SFR are deployed in order to reach an equilibrium fleet composed of sixteen 1450 MWe breeder SFR and 22 EPR reactors (with an average MOX load of 39.5%). At this point of the scenario, the Pu global inventory is stabilized, and the energy production remains constant at 420TWhe. From 2150, this EPR/SFR reactor fleet is progressively renewed by a new one composed of 41 breakeven SFR, which does not require natural uranium to operate.

SFR deployment in 2150 leads to a slight increase in the global plutonium inventory which stabilizes definitively in 2180. At the end of the scenario, the Pu inventory is reduced by 47% compared with a 100% UOX PWR fleet ("open cycle scenario"). The global minor actinides inventory is increasing at a rate that can be managed at the back end. Over the whole scenario, $1.01.10^6$ tons of natural uranium have been used. This represents a 40% reduction compared with the open cycle scenario.

A faster SFR deployment scenario was also studied, identical to the previous one up to 2090. From 2090, a 41 SFR fleet is deployed according to Pu availability. The equilibrium is reached in 2135 when the global Pu inventory is stabilized.

Nuclear phase-outs have been studied at several dates in order to evaluate the impacts in terms of inventories at each step of the scenario. Studies of optimized phase-out, aiming at reducing the Pu global inventory, the spent fuel mass and the waste inventories, have also been carried out. They involve MOX EPR reactors with high moderation ratio and enriched uranium support and burner SFR.

I. INTRODUCTION

Following the studies carried out in the frame of the French Act for waste management [1,2], the CEA, EDF and AREVA decided to work together on progressive potential scenarios of the French transition between the current nuclear fleet and a SFR fleet which does not require natural uranium to operate.

Scenarios considering the multirecycling of plutonium and the progressive deployment of a SFR fleet have been studied with the simulation software COSI developed by the CEA Nuclear Energy Division. In this paper two scenarios are discussed:

- the "progressive scenario": a progressive SFR deployment in accordance with a progressive evolution of fuel cycle plants functionalities;
- the "accelerated SFR deployment": a faster SFR deployment, for example to deal with an uranium shortage by the end of the century.

Phase-out studies were carried out on those scenarios. Scenarios of instantaneous decommissioning of the fleet and optimized phase-out scenarios are compared in this paper.

The scenarios and the assumptions made on the fuel cycle and the reactors are first described. Then, the results on the progressive scenario and on the accelerated SFR deployment scenario are discussed respectively in part 3 and 4. Phase-out studies are finally proposed in part 5.

II. SCENARIOS ASSUMPTIONS

II.A. Calculation Scheme

The scenario studies presented in this article have been performed with the COSI6 code developed by the CEA Nuclear Energy Division [3,4,5,6,7]. COSI6 simulates the evolution of a pool of nuclear power plants and of its associated fuel cycle facilities over a define period (ranging from some years to several centuries). It gives access to fluxes and isotopic contents of materials at each point of the cycle and at any time of the scenario.

The evolution calculation is performed by coupling COSI with CESAR 5.3 [8], also developed by the CEA Nuclear Energy Division. CESAR 5.3 is the reference code used at the AREVA NC La Hague reprocessing plant to evaluate the isotopic content of spent fuels.

CESAR 5.3 computations are based on the JEFF 3.1.1 neutron data library and on energy-integrated cross sections libraries provided by the CEA reference depletion codes: APOLLO2 [9] for thermal spectra and ERANOS [10] for fast spectra.

II.B. Reactor and fuel cycle assumptions

The current French fleet is composed of 58 PWR, loaded with UOX fuels, ERU (Enriched Reprocessed Uranium) fuels and MOX fuels (a third of the fleet is loaded with 30% of MOX fuels). Those 58 PWR are commissioned between 1978 and 2002 and will be decommissioned until 2062. EPRs are commissioned at a rate of 2 EPR every 1.5 years from 2017 to 2051 and then 1 EPR every 1.5 years. The CFV V1 core concept [11], developed by the CEA, is considered for the FR fleet. For the FR cores, two power levels are considered: 1GWe and 1.45GWe. Both EPR and CFV cores characteristics are detailed in the TABLE I.

TABLE I

Main neutronics characteristics of EPR and CFV cores

		EPR	CFV V1	CFV V1
Power (MWth)		4500	3600	2400
Power (MWe)		1529	1450	1000
Net yield (%)		35.6	40.3	41.7
Load factor (%)		83	83	83
Mass in core (tHM)	Fissile	120	52	36
	Fertile axial		34	21
	Fertile radial		22	14
Irradiation time (EFPD)		3x460	5x388	5x388
Average burn-up (GWd/tons)		51.8	116 (*)	116 (*)
Equivalent ^{239}Pu (wt%)		-	15.5	15.5

(*) Fissile fuels burn-up.

The fabrication time is fixed at 2 years. The minimum cooling time before the reprocessing of spent fuels is 5 years, the effective cooling time being adapted to meet the need in fissile materials. All along the scenarios, the facilities capacities remain steady over several decades and are consistent with realistic values.

II.C. Description of the Scenarios

The scenarios presented in this article consider a progressive deployment of SFR in the French nuclear fleet in order to stabilize the Pu inventory and to stop relying on natural uranium extraction, while taking into account realistic constraints on the fuel cycle. To do so, several steps were defined:

- Step A: renewal of the current French fleet by an EPR one having the same characteristics.
- Step B: deployment of a few fast reactors (FR) and MOX spent fuels (SF) reprocessing to fuel the FR and stabilize the MOX SF storage.
- Step C: deployment of an EPR-FR symbiotic fleet and FR SF reprocessing to stabilize the Pu inventory. Pu from EPR MOX fuels is enhanced in FR and re-used in PWR.
- Step D: deployment of a 100% FR fleet to stop relying on natural uranium extraction.

From these steps, several scenarios were studied. The first one considers the step sequence A, B, C and D and will be referred to as the "Progressive scenario" in this paper. The second one considers a faster SFR deployment with the step sequence A, B and D and will be referred to as the "Accelerated SFR deployment" scenario. The chronologies of those scenarios are detailed in parts III and IV.

In those scenarios, the nuclear energy production remains steady at its current level (about 430TWhe/y).

III. RESULTS ON THE PROGRESSIVE SCENARIO

The "progressive scenario" considers the step sequence A, B, C and D, as described in part II.C. The key stages of this scenario are the following:

- 2030-2060: renewal of the current French fleet by an EPR one:
  - 35 EPR (10% of MOX fuels).
- 2040: beginning of MOX SF reprocessing.
- 2050-5059: deployment of 3 CFV 1000MWe.
- 2075-2085: deployment of 3 CFV 1450MWe and FR SF reprocessing on a small scale.
- 2090: FR SF reprocessing on a large scale.
- 2094-2122: deployment of a mixed EPR-FR fleet and increase of the FR breeding capacity:
  - 16 CFV 1450MWe (breeders)
  - 22 EPR (39.5% of MOX fuels).
- 2153-2185: deployment of a 100% breakeven FR fleet:
  - 41 CFV 1450MWe (breakeven).

The progressive deployment of SFR (3x1000MWe, and 3x1450MWe before commissioning larger fleet) allows to take into account the industrial feedback on those reactors. The deployment of 3 CFV 1450MWe in 2075 and 2085 allows also to avoid a "gap" between the commissioning of the 1000MWe reactors in 2050-2059 and the deployment of the mixed EPR-FR fleet from 2094.

The associated energy production is described in Fig. 1.

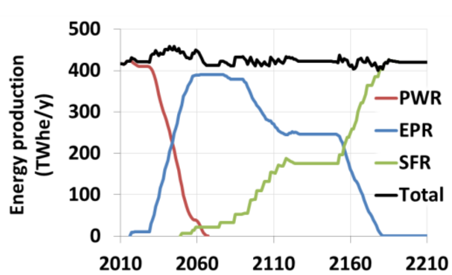

Fig. 1. "Progressive scenario" - Annual energy production

III.A. Fabrication needs and Fresh Fuels Characteristics

The annual PWR and FR fuels fabrication flows are described on Fig. 2.

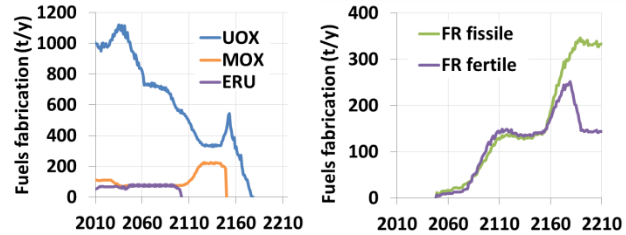

Fig. 2. "Progressive scenario" - Fuel fabrication flows

As the proportion of PWR in the fleet decreases and the proportion of MOX fuel in the EPR fleet increases, the PWR UOX fuel fabrication decreases all along the scenario. In 2150, the increase of the UOX fabrication is due to the stoppage of the MOX fuel fabrication to support the FR fuels fabrication. The PWR MOX fuels fabrication increases and reaches a maximum of 215 tHM/y at the equilibrium of the mixed EPR-FR fleet. The fabrication of PWR ERU fuels stops in 2100 when reprocessed uranium starts to be used for the FR fissile fuels fabrication.

The FR fabrication follows the progressive deployment of the FR fleet. The proportion of fissile and fertile fuels depends on the FR breeding gain: breeder between 2090 and 2150 and breakeven from 2150.

The fresh fuel Pu content is represented on Fig. 3 (PWR MOX on the left, FR fissile on the right).

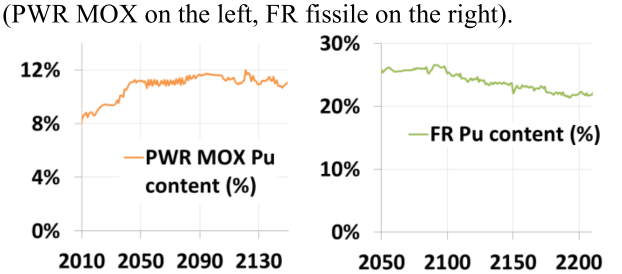

Fig. 3. "Progressive scenario" - Fresh fuel Pu content

During the renewal of the current French fleet by EPRs, the increase in the MOX fuel burn-up leads to an increase in their Pu initial content. At step C, from 2100, the Pu providing the PWR MOX fuels fabrication comes from both UOX and FR spent fuel reprocessing (see part III.B). This leads to some perturbation in the Pu content which remains near 11.4% up to 2120 and reaches its maximum (12%) between 2120 and 2130. Optimization studies are ongoing to reduce this Pu content.

Up to 2100, while the Pu for FR fissile fuels fabrication comes from PWR MOX SF reprocessing, the Pu content in FR fissile fuels is around 26%. It decreases as the proportion of FR fuel at reprocessing increases (see part III.B) and reaches 22% in 2200.

III.B. Reprocessing Needs

Due to differences in the required Pu quality, reprocessing needs to feed the PWR fuels fabrication (Fig. 4, left) are separated from the reprocessing needs to feed the FR fuels fabrication (Fig. 4, right). Indeed, the PWR MOX Pu content is limited to 12% which correspond to a Pu fissile content above 60%.

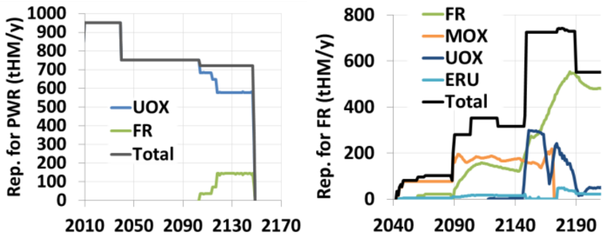

Fig. 4. "Progressive scenario" - Reprocessing flows

At the beginning of the scenario, until 2100, PWR MOX fuels fabrication is supplied with Pu from UOX SF. In 2090, when the PWR-FR symbiotic fleet is being deployed, the multirecycling of Pu begins: the fissile quality of Pu issued from MOX SF is enhanced in fast reactors before re-using it in PWR. Between 2120 and 2150, FR SF represent 20% of the reprocessing flow to supply the PWR MOX fabrication. Furthermore, it is noteworthy that the decrease in the reprocessing capacity in 2040 is linked to a more efficient use of Pu in EPR than in the current French fleet reactors and to a decrease of the UOX flow to spent fuels storage due to the increase of their burn-up.

The first FR fissile fuels are fabricated with Pu from PWR MOX SF only. FR SF are reprocessed according to their availability. FR SF reprocessing is introduced on a small scale (15 then 21 tHM/y) between 2060 and 2090 and on a larger scale from 2090. At the end of the scenario, when the equilibrium of the 100% FR fleet is reached, 550tHM/y are reprocessed, 90% of which being FR SF (the remainder being UOX and ERU spent fuels).

III.C. Spent Fuels Storage

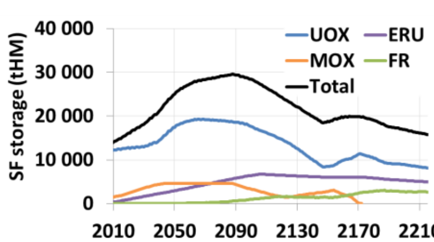

Fig. 5. "Progressive scenario" - Spent fuels storage

All along the scenario, UOX SF represent the major part of SF storage. Due to a decrease in the UOX SF reprocessing needs during the current French fleet renewal, UOX SF storage increases and reaches a maximum of 19100 tons between 2055 and 2095. Then, the UOX SF reprocessing and the decrease in the UOX fuels fabrication lead to a decrease of this storage which reaches 8200 tHM at the end of the scenario.

It is noteworthy that the different steps objectives of SF stabilization are fulfilled. The UOX SF storage is stabilized at steps A and B. At step B, between 2045 and 2090, the MOX SF storage is also stabilized (at 4650tHM). Finally, at step D, due to breakeven cores, the FR SF storage is stabilized at 2700tHM.

III.D. Pu and MA Inventories

All along the scenario, the Pu inventory (Fig. 6) is mainly composed of the Pu in the stored spent fuels. The Pu inventory increases steadily until 2120, date on which it stabilizes for the first time at 1055 tons (step C objective). It increases again during the 100% FR fleet deployment and finally stabilizes at 1260 tons in 2180. At the end of the scenario, in 2210, 17% of the Pu inventory is composed of separated Pu (between reprocessing and fabrication) and of Pu in spent fuels which are cooled enough to be reprocessed.

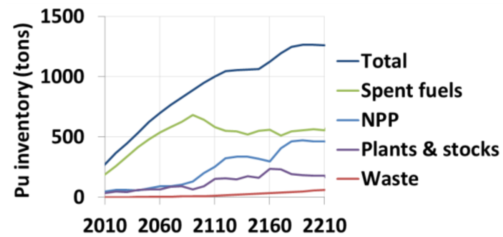

Fig. 6. "Progressive scenario" - Pu inventory

As the scenario does not include any transmutation strategy, the MA inventory (Fig. 7) increases all along the scenario and reaches 645 tons in 2210. In 2210, 91% of the MA are contained in the vitrified wastes.

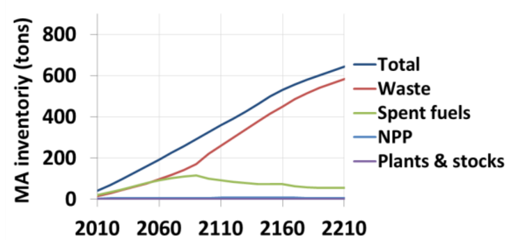

Fig. 7. "Progressive scenario" - MA inventory

III.E. Natural Uranium Consumption

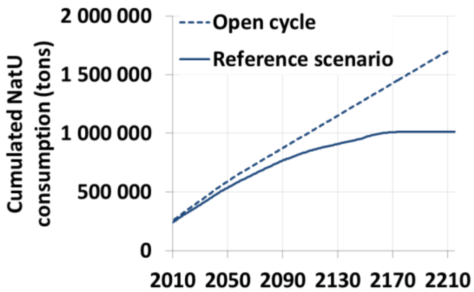

Fig. 8. "Progressive scenario" - Cumulated NatU consumption

Due to the deployment of FR and to the increase in the PWR MOX fuels fabrication, the annual natural uranium (NatU) consumption decreases all along the scenario. It becomes nil in 2180, when the 100% FR fleet is deployed. During the scenario, 1 011 300 tons of NatU are consumed (Fig. 8).

We can compare this consumption to the one of an equivalent fleet which would have been operated in open cycle only (without any reprocessing, nor ERU, MOX or FR fuels). In this case, 1 695 900 tons of NatU would have been consumed. Thus, compared to the open cycle case, the NatU consumption of the "progressive" scenario is reduced by 40%.

IV. ACCELERATED SFR DEPLOYMENT

The "Accelerated SFR deployment" scenario (also referred to as "Accelerated SFR" later in this article) considers the step sequence A, B and D (see in part II.C) without going through step C. This scenario aims at assessing the possibility of deploying a 100% SFR fleet directly from step B, for example in the case of a natural uranium shortage occurring around the end of the current century.

This scenario is exactly the same as the "progressive" one up to 2090. From 2090, EPR are decommissioned at the end of their operating life (60y) and FR are deployed according to Pu availability. PWR MOX fuels are abandoned and FR are made breeders during their deployment.

IV.A. Energy Production

The energy production of the "Accelerated SFR deployment" scenario is described on the Fig. 9.

The gap in the total energy demand only indicates that, all things being equal, it is not possible to deploy a 100% FR fleet at the same pace as the one at which the EPR fleet is decommissioned. The Pu availability and the reprocessing capacity set the FR fleet deployment pace at 1 to 2 FR per year between 2090 and 2100 and 2 FR per year between 2110 and 2135.

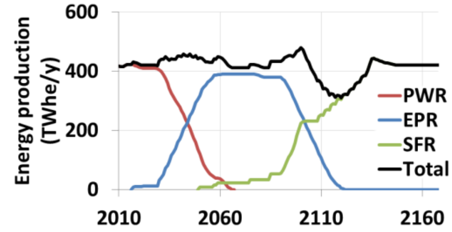

Fig. 9. "Accelerated SFR" – Annual energy production

The gap in the total energy demand only indicates that, all things being equal, it is not possible to deploy a 100% FR fleet at the same pace as the one at which the EPR fleet is decommissioned. The Pu availability and the reprocessing capacity set the FR fleet deployment pace at 1 to 2 FR per year between 2090 and 2100 and 2 FR per year between 2110 and 2135.

Studies are ongoing to resorb this gap. They include a prolongation of the reprocessing plant operating between 2040 and 2090 to separate the Pu contained in the spent UOX fuels.

IV.B. Main Results

In this paragraph, only the main results of the "Accelerated SFR deployment" scenario are described. The fuels fabrication flows, the FR Pu contents and the SF storage are close to the ones of the "Progressive" scenario except that they stabilize around 2150 instead of 2180. Due to the stoppage of PWR MOX fuel fabrication in 2090, their Pu content always remains below 12%.

The reprocessing flows to feed PWR MOX fuels fabrication (Fig. 10, left) and FR fuels fabrication (Fig. 10, right) are represented on Fig. 10.

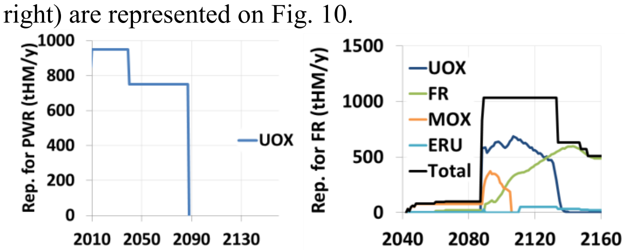

Fig. 10. "Accelerated SFR" - Reprocessing flows

The Pu used to fabricate PWR MOX fuel always comes from the reprocessing of UOX fuels.

From 2090, to sustain the FR deployment, PWR MOX SF are reprocessed in first priority. The MOX SF flow at reprocessing reaches 375tHM/y at the beginning of FR deployment and drops to zero in 2105 when all the stored MOX SF are consumed.

As in the "Progressive" scenario, FR SF are reprocessed according to their availability. Their flow at reprocessing reaches 600tHM in 2145.

The Pu inventory (Fig. 11) stabilizes approximately at the same level as in the "Progressive" scenario but 45 years sooner. In 2145, it stabilizes at 1270 tons, 18% of which being contained in a separated Pu stock (between reprocessing and fabrication) or in SF cooled enough to be reprocessed.

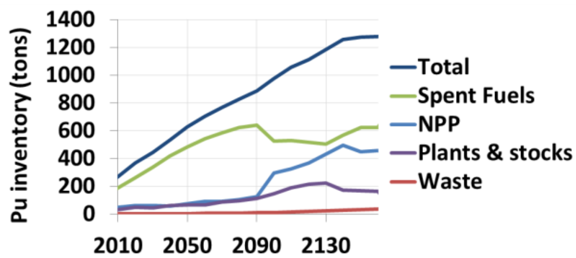

Fig. 11. "Accelerated SFR" - Pu inventory

As in the "Progressive" case, the MA inventory (Fig. 12) increases all along the scenario and is mainly composed of MA in wastes. In 2160, it reaches 460 tons, which represents a 13% reduction compared to the "Progressive" scenario at the same date (due to the reduction in the MOX fuels fabrication).

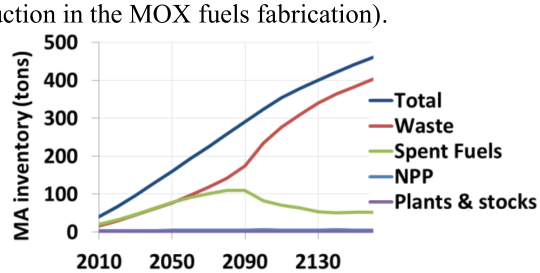

Fig. 12. "Accelerated SFR" - MA inventory

The cumulated natural uranium consumption is represented on Fig. 13.

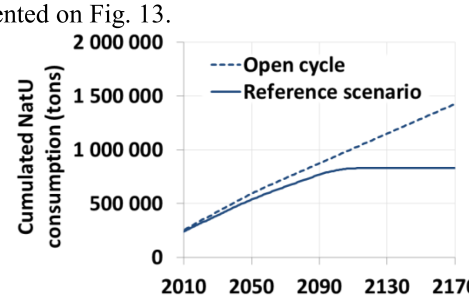

Fig. 13. "Accelerated SFR" - Cumulated NatU consumption

From 2115, the nuclear fleet does not require NatU anymore to operate. Over the whole scenario, the cumulated NatU consumption is of 828 800 tons. The "Accelerated SFR deployment" scenario requires 182 500 tons of NatU less than the "Progressive" scenario, which represents an 18% reduction.

In comparison with an open cycle scenario, the "Accelerated SFR deployment" scenario allows a 42% reduction of the NatU consumption in 2170 and a 51% reduction in 2210.

V. PHASE-OUT STUDIES

To evaluate the impact in terms of inventories at each step of the scenarios, phase-out studies have to be carried out. They can consist in a simple decommissioning of the fleet when reactors reach the end of their operating life, or in optimized strategies involving burner core concepts. They are compared with studies of instantaneous decommissioning of the fleet. In this article, studies involving burning core concepts are referred to as "Optimized phase-outs".

Impacts of the instantaneous decommissioning studies on Pu and MA inventories are detailed in part V.A. As optimized phase-out studies are still ongoing, only their hypotheses are detailed in part V.B.

V.A. Inventories in case of instantaneous decommissioning

Here we consider the instantaneous decommissioning of the whole operating nuclear fleet. Those studies aim at evaluating the impact of a brutal phase-out during the scenario. They have been carried out on both "progressive" scenario and "Accelerated SFR deployment" scenario, at steps A, B, C and D and at different key dates corresponding to the renewal of nuclear fleets (2030, 2090, 2150 and 2210).

The Pu inventory in case of an instantaneous phase-out is detailed for each step and at several dates in TABLE II.

TABLE II

Pu inventories

	2030	2090	2150	2210
Open cycle	525 t	1150 t	1700 t	2250 t
A	450 t	900 t	1290 t	1685 t
A-B	450 t	890 t	1250 t	(*)
A-B-C	450 t	890 t	1060 t	1080 t
A-B-C-D	450 t	890 t	1060 t	1260 t
A-B-D	450 t	890 t	1280 t	1270 t

(*) Step B has not been studied up to 2210.

In comparison with an open cycle scenario, recycling plutonium in PWR MOX or in FR leads to a 14% to 52% reduction in the Pu inventory (depending on the considered scenario and date).

In comparison with step A, MOX SF reprocessing at step B leads to a 1% to 3.5% reduction in the Pu inventory (the contribution of step B lies more in the stabilization of the MOX SF storage than in a Pu inventory reduction). In 2150, another reduction of 15% can be obtained with the deployment of some FR and the reprocessing of their spent fuels (step C).

The MA inventory in case of an instantaneous phase-out is detailed for each step and at several dates in TABLE III.

TABLE III

MA inventories

	2030	2090	2150	2210
Open cycle	90 t	250 t	400 t	545 t
A	95 t	295 t	495 t	700 t
A-B	95 t	290 t	485 t	(*)
A-B-C	95 t	290 t	500 t	715 t
A-B-C-D	95 t	290 t	500 t	645 t
A-B-D	95 t	290 t	440 t	560 t

(*) Step B has not been studied up to 2210.

In comparison with an open cycle, recycling plutonium tends to increase the MA inventory. However, amongst the scenario of Pu recycling, increasing the part of FR and decreasing the one of MOX fuels reduces this MA production. Thus, in comparison with step A, step B allows a 2% reduction in the MA inventory and, in comparison with step C, step D leads to a 10% reduction in the MA inventory. The accelerated SFR deployment (A-B-D) leads to another 13% reduction of the MA inventory in comparison with A-B-C-D in 2210.

To conclude, whatever the chosen strategy, multirecycling plutonium leads to a reduction in the Pu inventory. It also leads to an increase in the MA inventory which can be moderated by increasing the FR proportion in the fleet and decreasing the PWR MOX one.

V.B. Hypothesis for optimized phase-out studies

Optimized phase-out studies aim at reducing further of the Pu inventory or of the spent fuels storage by influencing the reprocessing strategy and by using burning core concepts.

Those studies will be carried out on the "Progressive" scenario and, as step B is a more transitional step, on steps A, B and D only. To compare the steps between them, phase-outs are studied at a same date, around 2210 (step D equilibrium).

In those studies, there is no new reactor deployment; the burner core concepts result from an adaptation of the power plants in operation at the beginning of the phase-out. Two burner core concepts are considered:

- EPR are adapted to be loaded with MOX EU IMR fuel [12]: MOX on an Enriched Uranium support, with an Increased Moderation Ratio (36 fuel rods are replaced by water holes).
- SFR are adapted into CAPRA [11], the French acronym for "increased consumption of Pu in fast reactor".

The MOX EU IMR [12] concept multirecycles plutonium. It is loaded with MOX with a maximum Pu content of 12% and uranium enriched support to compensate the decrease in the Pu fissile quality. Its moderation ratio is increased to compensate for the hardening of the spectrum and increase the absorbents efficiency. The MOX EU IMR concept can be loaded with MOX with a Pu fissile quality up to 44% (with an uranium enrichment below 4%). It has a high average Pu consumption of about 70kg/TWhe.

To adapt a SFR into a CAPRA core, a part of the fertile and fissile fuels in the core and the spins is replaced by inert materials. It is noteworthy that the CAPRA void coefficient is of the same order of magnitude as the CFV one [11]. The CAPRA core involves Pu content ranging from 30%. Some of its burner performances are available on TABLE IV.

Note that, depending on the Pu fissile quality, a CAPRA core can burn up to 56kg of Pu per TWhe.

TABLE IV

CAPRA burner performances for two Pu vectors

	Pu 1	Pu 2
Pu isotopic content (wt%)		
Pu238	3.57	0.61
Pu239	47.39	62.89
Pu240	29.66	30.46
Pu241	8.23	2.54
Pu242	10.37	3.05
Am241	0.78	0.45
TRU balance after irradiation (kg/TWhe)		
Pu	-56.5	-48.2
Np	+0.3	+0.3
Am	+5.0	+1.7
Cm	+1.3	+0.5

VI. CONCLUSION

For the past two years, the CEA, EDF and AREVA have been working together on scenario of progressive SFR introduction in the French fleet with U and Pu recycling. Several scenarios has been proposed and studied.

This paper focuses on two scenarios. The first one consists in a progressive potential scenario of the French transition between the current nuclear fleet and a 100% SFR fleet. This scenario consists in the chaining of different steps each of them having a different purpose and allowing a gain of experience to move on to the next one. In 2180, a 100% SFR fleet reaches equilibrium, allowing the stabilization of the Pu inventory at 1260t and the cessation of natural uranium consumption. During this scenario, about 1.10^6 tons of natural uranium are used, which represents a 40% reduction in comparison with an open cycle scenario.

A scenario of accelerated SFR deployment was also studied. Such a scenario could answer to a natural uranium shortage occurring towards the end of the current century. All things equal, due to reprocessing capacity limitation, the Pu availability does not allow to deploy the FR fleet as fast as the EPR fleet is shut down which results in a drop in the energy production. Optimization studies are ongoing to resorb this gap. Furthermore, in this scenario the FR fleet reaches equilibrium in 2145 and the Pu inventory stabilizes at 1270t. The cumulated natural uranium consumption along the scenario is reduced by 18% in comparison with the “Progressive” scenario.

The end of life of the nuclear fleet is taken into account in phase-out studies. Inventories in case of instantaneous decommissioning of the fleet at different dates and for the different steps show that multirecycling plutonium leads to a reduction of the plutonium inventory when the whole fleet is decommissioned. It also leads to an increase in the MA inventory. This increase in the MA inventory can be reduced by increasing the part of FR in the fleet and reducing the one of MOX fuels.

Optimized phase-outs are being studied. They aim at reducing the Pu inventory and the spent fuel storage through an optimization of the reprocessing flows and the use of burner cores concepts. To do so, SFR are adapted into CAPRA design (increased Pu consumption in fast reactors) with an average Pu consumption of 50kg/TWhe and EPR are adapted to be loaded with MOX EU IMR fuel (Enriched Uranium, Increased Moderation Ratio) with an average Pu consumption of 70kg/TWhe.

NOMENCLATURE

CAPRA	Increased Consumption of Pu in Fast Reactor
EFPD	Equivalent Full Power Day
ERU	Enriched Reprocessed Uranium
FR	Fast Reactor
MOX EU IMR	Enriched Uranium Increased Moderation Ratio
SF	Spent Fuel
tHM	tons of Heavy Metal

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