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Briefing

Nuclear Reprocessing - Direct Disposal for Billions of French Francs

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Nuclear Reprocessing – Direct Disposal for Billions of French Francs

1. The History of Nuclear Reprocessing – Weapons, Breeders and Plutonium Stocks

The nuclear reprocessing technology was developed during the Second World War to extract plutonium from spent nuclear fuel for the fabrication of nuclear weapons. The bomb that devastated Nagasaki was fuelled by plutonium while the Hiroshima bomb contained highly enriched uranium. The bomb makers increasingly used plutonium rather than uranium because its critical mass is much smaller than that of uranium and allows the design of much smaller weapons. That characteristic was fundamental for the miniaturisation of nuclear weapons in order to develop multiple warheads.

The first and second generation of nuclear reprocessing plants are still operating for military purposes. In France, not only UP1[3] in Marcoule operated for military needs but also UP2-400 at La Hague, which was financed for 50% out of the military budget of the Atomic Energy Commission CEA. That fact did not prevent the operators, first the CEA (Commissariat à l'énergie atomique) and then its subsidiary COGEMA, processing foreign civil materials in both plants.

Today, the problem is to get rid of the vast amounts of separated plutonium that have been generated for nuclear weapon States. Four of the five nuclear weapon states that have signed the Non-Proliferation Treaty[4] have declared that they no longer produce weapons grade plutonium.

From the very beginning, the dream of plutonium fuelled fast breeder reactors significantly influenced the decision making process in the nuclear field. The first reactor in the world to produce electricity, enough to light four light bulbs of 200 Watts, was a fast neutron research reactor called EBR-1 (Experimental Breeder Reactor) in the US. The fascination of the idea to develop a machine that would eventually produce more nuclear material than it consumes – a sort of energy perpertuum mobile – is easy to understand. In 1976, the head of the French Atomic Energy Commission forecasted the operation of 540 Superphénix type fast breeder reactors in the world for the year 2000 – that is today. The construction of the Superphénix reactor was forced on the population at Creys-Malville despite fierce opposition.[5] Superphénix went critical in 1985 and was shut down permanently in 1996. The 10 years of operation constitute a negative world record with a lifetime load factor of 6.3% for a total production of 8.3 TWh at a total cost estimated by the National Accounting Office (Cour des Comptes) at 60 billion French francs.[6]

In fact, four years before the start-up of Superphénix – as noted in a 1989 internal EDF memo[7] – *«in 1982, when it appeared that the development of these reactors would be postponed for a long, time, EDF had to reexamine the situation to see if recycling plutonium in pressurized water reactors was of sufficient interest to legitimate the pursuing of the reprocessing program»*.

In that same year 1982, Jean-Louis Fensch, a nuclear engineer with the CEA submitted a report to the Superior Council for Nuclear Safety[8], a consultative body for the French Government, that concluded: *«Interim storage (40 to 100 years, or more) of light water reactor spent fuel followed by geological disposal (non-reprocessing option) is infinitely less costly than the reprocessing option»*. The author

3 UP stands for "usine de plutonium" or plutonium factory, may be a more appropriate term than reprocessing plant.

4 The US, Russia, France and the UK. Only China has not made any public statement.

5 At a large demonstration in the summer of 1977, a teacher was killed and several other demonstrators were severely wounded by riot police.

6 One can roughly calculate the costs per kWh generated by Superphénix to be 7.30 FRF, more than 10 times the price per kWh recently established in France for the purchase of wind power.

7 *Combustible MOX - Aspects techniques, économiques, stratégiques*, Direction Production Transports, EDF, 24 November 1989. Translation of the extract by WISE-Paris.

8 Conseil supérieur de la sûreté nucléaire

added that *«recycling plutonium in light water reactors is an economic aberration, and only provides theoretical savings of 18% in natural uranium needs»*[9].

However, this declaration did not change the industry's orientation and in 1985 it was decided to invest in new reprocessing plants in La Hague (UP2-800 and UP3) and in a commercial MOX fabrication plant in Marcoule (Mélox). This would enable both a program of plutonium recycling in LWRs, and a reprocessing contract for 8,000 tons over the 1990-2000 period between EDF and COGEMA[10].

The economic studies that supposedly back these decisions are not public. According to a global economic evaluation of the French nuclear option, ordered by the Prime Minister and published in 2000 (see below), *«in the years 1975-1985 decisions have been taken on the basis of the projected mid-term evolution of natural uranium prices (2000-2010), [including] the launching in 1985 of the reprocessing and recycling in PWRs path, which competitivity, compared with a long term storage solution, needed a hypothesis of high cost for uranium»*[11]. But *«the forecasts made from 1975 to 1985 are very far from the actual current price for natural uranium»*: with a value around 300 FF/kg, natural uranium is today well under the projected cost, with estimates ranging at the time from 900 to 1,700 FF/kg[12].

The choice of the reprocessing option in France has been decided by politicians and industry on the grounds of its supposedly favorable economics, although any real evaluation was never made public. Retrospective analysis shows that these evaluations were based on unrealistic hypothesis and inappropriate methodology.[13].

2. The Plutonium *System* Failed

Some 25 years after the enthusiastic forecasting by the French promoters of plutonium fuelled reactors, not a single commercial size plutonium fuelled fast breeder reactor is operating in the world. Russia operates the only large fast reactor, the BN-600 at Beloyarsk, on the basis of high enriched uranium fuels. Plutonium bearing fuels have so far only been tested there. All the other government sponsored fast breeder programs, in the US, UK, Germany, Italy, Belgium, etc. have been cancelled. While Japan officially remains committed to its long term fast breeder program, the small 250 MW Monju reactor has been shut down for over five years since a sodium fire devastated the plant on 8 December 1995 and any follow up project has been delayed indefinitely.

The key point though is that, besides the technical problems with the development of reliable fast breeder reactors, the plutonium ***system*** failed. Plutonium was meant to rapidly replace natural uranium because the nuclear industry envisaged a very rapid expansion of nuclear programs. In 1974 the IAEA forecasted the operation of the equivalent of up to 4,450 reactors (1,000MWe) for the year 2000. It turns out that the IAEA was wrong by a factor of more than 10. Therefore the price of natural uranium, instead of skyrocketing, fell from one historical low to the next to reach by the middle of the 1990s about a quarter of the level of the beginning of the 1980s. Therefore the large plutonium stocks - whether civil or military – of France, Germany Japan, Russia, the UK and the US have no economic value.

On the contrary, while the French utility EDF has assigned a zero value to its stocks, other utilities have attempted in vain to give their stocks away for free. Dutch utilities, for example, have approached EDF in order to inquire whether it would take over the Dutch plutonium. EDF turned the offer down. In other words, plutonium turns out to be a liability rather than an asset.

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9 Fensch, M., *Finalités du retraitement*, Report presented to the Conseil supérieur de la sûreté nucléaire, Paris, 1982. Translation of the extract by WISE-Paris.

10 EDF is a State-owned public utility that operates the French 58 PWRs (pressurized water reactors, total installed capacity 63 GWe); COGEMA is the public utility that operates, among others, La Hague and Mélox plants.

11 Girard, Ph., Marignac, Y., *Le parc nucléaire actuel*, preparatory report to the Mission d'évaluation économique de la filière nucléaire, Commissariat général du Plan, Paris, 2000. Citation translated by WISE-Paris.

12 As forecasted for the year 2000 in French government reports on electricity production costs published between 1975 and 1985.

13 See for instance Coeytaux, X., Schneider, M., "L'industrie du plutonium: de l'effritement d'un mythe à l'urgence d'une reconversion", *Contrôle, n° 138,* (edited by the French Safety Authority DSIN), January 2001, pp 94-98.

WISE-Paris has shown in a study[14] that reprocessing plants can be considered "waste production" facilities, because the volume of waste as compared to the non-reprocessing option is greatly increased. Even if COGEMA has achieved significant progress in waste reduction over the years this does neither reduce volumes to a level comparable to the non-reprocessing option nor change the volumes of waste already generated. Also, one should consider the dismantling wastes at the end of the lifetime of the plants. The WISE-Paris study has estimated the additional amount of waste per ton reprocessed generated by the dismantling operations of the La Hague facilities to some 30 m^3.

The choice to discharge vast amounts of radioactive waste in liquid and gaseous form to the environment is equally a waste management option that significantly reduces overall costs. If calculated into equivalent retained and solidified low level waste (full radioactivity load per waste package according to technical specifications), one would have to aid more than 35 m^3 or waste per ton reprocessed.

The La Hague discharges for year 1999, if compared to a typical French 1300 MW reactor (example Flamanville, 17 km from La Hague), are huge:

- 35,000 times higher for gaseous releases;
- 1,000 times higher for liquid discharges[15].

3. Reprocessing Versus Direct Disposal – Economies and Economics

The industrial reality is very different from a theoretical economic comparison between the reprocessing and the direct storage option. Savings due to reprocessing - reduced consumption of natural uranium and enrichment services - as compared to direct disposal are very questionable when examined at global level (i.e. for a given number of nuclear reactors over their lifetime[16]) and under real industrial conditions.

We give here some elements on the basis of the study of the best available real size case of the economics of reprocessing. The successive stages involved in the fabrication of fresh nuclear fuel, its use in nuclear reactors and the management of the spent fuel are described as the "fuel cycle".[17] For many reasons, France offers the best possible case to study the economics of the reprocessing option. In particular, it has chosen this option at quite an early stage of its nuclear development, and has put this choice in full application. In this utterly favorable context, the economics of reprocessing can be expected to be optimized:

- France is now the world leader in the plutonium industry, both for reprocessing and MOX fuel fabrication;

- France has developed a fully integrated fuel cycle industry, including all stages of the cycle and dimensioned according to its anticipated needs;

- The French reprocessing industry has developed from the beginning with obvious political and industrial support, beyond any economic consideration.

Recent evolutions in France and Europe have opened the political and economical game in the nuclear field: in particular, opening of the European electricity market has created a new pressure for competitiveness and a requirement for transparency on costs, which are somewhat new to the French nuclear sector. Moreover, the progressive phasing out of reprocessing, now clearly emerging in Europe, is bringing into question the priority given to this option in France, especially from the point of view of economics.

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14 Homberg, F., Pavageau, M., Schneider, M., "*COGEMA-La Hague: The Waste Production Techniques*", WISE-Paris (ed.), Paris, Mai 1997, 136 S.

15 Calculated by WISE-Paris from COGEMA (communication to CRII-Rad, 21 March 2000) and EDF data (fax from EDF-CNPE Flamanville, 27 March 2001).

16 As opposed to the rather theoretical calculation that can be done, for instance, on the input and output of one typical reactor in one year.

17 Although the term of "fuel chain" would be more appropriate because, in any case, it generates vast amounts of radioactive wastes all along the way.

The French Prime Minister decided, on 9 December 1998, to set up a Mission of economic evaluation of the nuclear option in France, including the analysis of the real costs *«of the later stages of the fuel cycle»* **–** a blunt way of recognizing that they have been concealed so far.

Contrary to previous evaluations, the Mission report[18] adopts a global methodology: instead of evaluating the only annual input and output of one reactor and extrapolate the theoretical result to the industrial scale. It directly estimates the material and economic balance of the current French nuclear facilities over their lifetime, on the basis of a year-to-year analysis.

This description includes both a reconstitution of the past (from 1977, when the first EDF commercial PWR started, to 1999) and a prospective evaluation of the future management of the facilities (from 2000 to the end of service life of reactors – 2049, with an operating life of on average 45-years). Scenarios for the future differ in particular for the later stages of the fuel cycle, with three main hypothesis:

- pursuing of the present strategy, a dual one since only around 70% of the uranium fuel is reprocessed, with use of MOX in around 20 PWRs reactors as currently ("partial reprocessing");

- extension of reprocessing to all uranium fuel, leading to use of MOX in the 28 PWRs (900 MWe) technically designed to use it ("total reprocessing");

- abandoning of reprocessing and switching to a direct disposal strategy, with a final abandoning of reprocessing in 2010 ("end of reprocessing")[19].

Detailed results of the material and economic comparison of the scenarios are presented in the annexes, together with the main hypothesis on costs used for the evaluation – which are globally optimistic[20]. The main finding of the report is however very clear: although the major part of the investment for the development of the reprocessing option has already been paid for, it appears that ***from the economic point of view, the French industry should change its strategy for direct disposal, and the earlier the better***.

The fuel cycle[21] in the "total reprocessing" scenario, in comparison with the "end of reprocessing" scenario, produces additional costs assessed at FrF39 billion[22], representing FrF800 million per year for the remaining years of the power plant service life, or as much as 11-12 % of costs that remain to be covered.

Moreover, the additional cost of the reprocessing option is estimated by way of comparison with a fictional (for the retrospective part) scenario of "total direct disposal" of uranium spent fuel from 1977 to the end of lifetime of current reactors. The total savings of the direct disposal option in comparison to the "total reprocessing" scenario is FrF 164 billion: this difference in fuel cycle costs represents more than 5.5% of the total cost (investment, operation and fuel). The ***saving through direct disposal would be on average FrF2 billion per year*** over the total service life of the power plants, ***or around FrF2.7 billion per GWe installed***. The cost advantage of the non-reprocessing option is also reflected in the average cost per kWh with 13.65 centimes against 14.46 centimes for the reprocessing option.

4. The Failure of the Resources and Waste Management Strategy

Beyond these plain economic results, this report also demonstrates, for the first time in a French public document, some of the failures of the plutonium industry. In particular, the authors point out some of the real scale consequences of the reprocessing option for waste management.

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18 Charpin, J.M., Dessus, B., Pellat, R., *Economic Forecast Study of the Nuclear Power Option*, Report to the Prime Minister, Commissariat général du Plan, Paris, July 2000. See also the annex report, Girard, Ph, Marignac, Y., op.cit.

19 The Mission also considered and calculated a scenario of abandoning of reprocessing in 2001, but decided not to publish it, mainly for political reasons.

20 For instance, the costs of reprocessing, or MOX fabrication, are considered for the operation at full capacity of the plants although in some scenarios this condition is not fulfilled.

21 Investment and operational costs of the nuclear installations are supposed to be the same in all scenarios that are also adjusted to represent the same cumulated production of electricity.

22 The savings are even higher, around FrF49 billion, in a scenario where reprocessing stops in 2001.

First of all, the report analysis the impact of the plutonium recycling on the quantities of plutonium left in the final waste: assuming, according to industrial reality, that spent MOX fuel will not be reprocessed, the report estimates that the ***"total reprocessing" option only reduces by 23% the quantities of plutonium quantities in the final waste in comparison to direct disposal*** of uranium fuel. The gain is even smaller from the front-end point of view: the difference between those two scenarios is only of 8% in the needs of natural uranium and enrichment work.

The report also shows that, although the reprocessing option strongly reduces the quantities of UOX fuel in final waste, this advantage is compensated by a greater complexity in waste management: these are diversified (with specific HLW and MLW, spent MOX and UOX fuel instead of only the latest) and some of them are more difficult to manage. Especially, spent MOX fuel has a few times higher heat output that leads to a much longer interim storage period – 150 years when 50 years are needed for UOX – before final disposal, where it occupies more space and thus is more expensive.

On these grounds, in a public notice on this report, the French Commission for Sustainable Development[23] points out that it *«contradicts the official justification for continuing with reprocessing»* and declares that *«the MOX option is not an equitable one for future generations»*.

However, the Mission Report still fails to incorporate some elements of the industrial situation, that would make the economics of reprocessing even worse: these are for instance the real costs for stockpiling of separated plutonium and large quantities of MOX fabrication residues or the purification of plutonium (separation of americium) after extended storage periods. Also, nobody ever integrated the costs for the physical protection of the shipments of reprocessing wastes returning to the producing countries. The latest shipment of high level vitrified waste from the La Hague reprocessing plant to the German interim storage facility at Gorleben is estimated to have cost more than DM 110 million. A non-negligible add-on.

Given the unfavorable economic conditions for the future of reprocessing in France, the country with the most favorable conditions in the field, the prospects for a competitive import market for spent fuel management services in Russia seem highly unrealistic.

[23] Commission française du développement durable, *Notice N° 2001-05 on the "Charpin-Dessus-Pellat Report"*, February 2001 (translation by WISE-Paris).

ANNEX A: Main Results on the French Nuclear Power Plants from the "CDP" Report

Table 1: Material balances and economic comparison of various options for the fuel cycle of the French nuclear power plants

Scenarios[1] *(ref. in Report)* **Reprocessing**	***S4*** **Stops in 2010**	***S5*** **Partial**	***S6*** **Total**	***S7*** [2] **None**
Generated electricity (TWh)	20,238	20,238	20,238	20,238
Material balances				
Natural uranium (kt)	460	447	437	475
Reprocessed UOX (kt)	15.0	26.2	36.1	0.0
Separated Pu re-used (t)	146	275	387	0
Irradiated UOX (kt)	41.0	28.6	17.6	58.3
Irradiated MOX (kt)	2.0	3.5	4.8	0.0
Pu content [3] (t)	602	555	514	667
Medium Level Waste (m^3)	31,786	34,825	38,091	20,000
from operation	*20,000*	*20,000*	*20,000*	*20,000*
from reprocessing	*11,786*	*14,825*	*18,091*	*0*
High Level Waste (m^3)	1,601	3,325	4,808	0
Global cost (GF)	**2,888**	**2,910**	**2,927**	**2,763**
• Investment	682	682	682	652 [4]
• Operation	1,297	1,297	1,297	1,297
• Total of fuel cycle	909	931	948	814
Cycle front end	*602*	*589*	*578*	*611*
Cycle back end	*195*	*232*	*263*	*86*
End of cycle	*112*	*110*	*107*	*116*
Cost per kWh [5] **(cts)**	**14.27**	**14.38**	**14.46**	**13.65**

(1) All scenarios are based on the hypothesis of an average 45 years lifetime for the nuclear reactors of the power plants.
(2) Retrospective scenario corresponding to the same operation of the current nuclear power plants without any reprocessing, even in the past period (1977-2000).
(3) Plutonium content (plus Americium that it forms) in UOX and MOX irradiated fuel that are not reprocessed at the end of the period (when the last reactor shuts down).
(4) The difference in investment costs between the scenarios with reprocessing (S4, S5, S6) and the one without is due to the cut of 30 GF of R&D costs for the fuel back-end.
(5) Constant FrF 1999, non discounted levelized costs estimated from global cost over the producing life of the power plants.

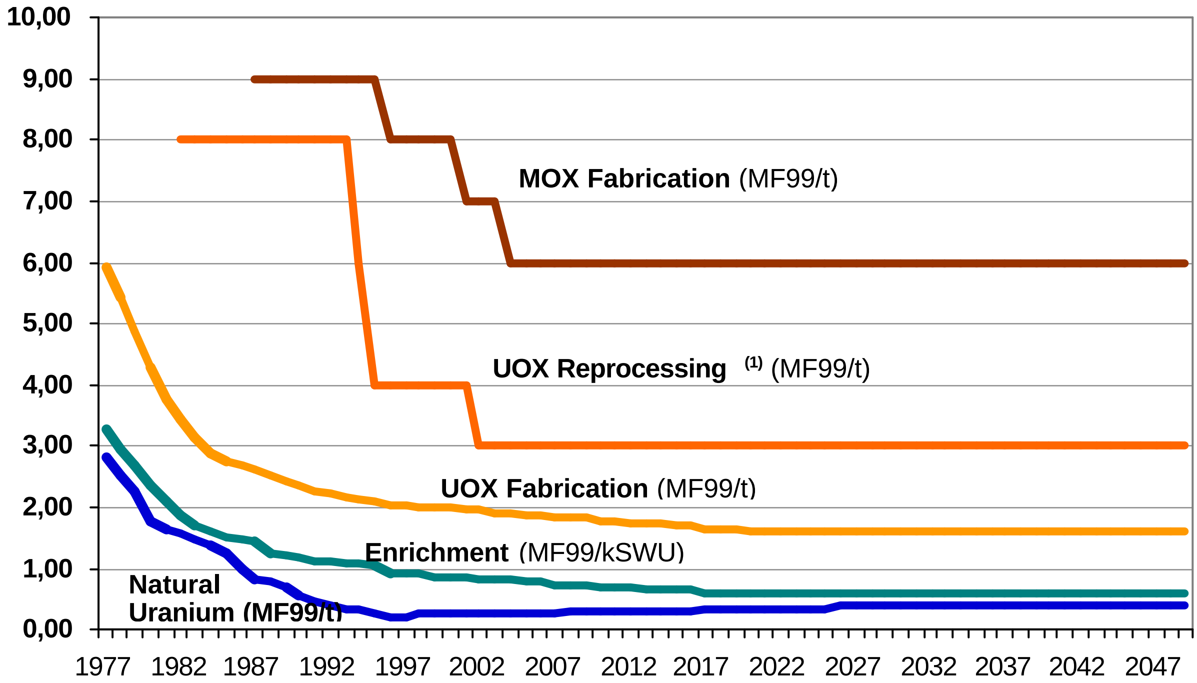
Table 2: Detail of the fuel cycle costs (GF 1999)

Scenarios *(ref. in Report)* **Reprocessing**	***S4*** **Stops in 2010**	***S5*** **Partial**	***S6*** **Total**	***S7*** **None**
Front-end 1977-1998	271	271	271	271
Front-end 1999-2049	331	318	307	340
Total Front-end	***602***	***589***	***578***	***611***
Back-end 1977-1998	93	93	93	0
Back-end 1999-2049	102	139	170	86
Final disposal MLW+HLW	12	21	29	0
Final disposal spent fuel	94	82	72	111
Total Back-end[1]	***301***	***336***	***364***	***197***
Total Fuel Cycle	**903**	**925**	**942**	**808**

(1) The "back-end" lines include the interim storage of final waste, and the "final disposal" includes that of MLW and HLW from reprocessing (but not MLW from reactors operation) and of non reprocessed spent UOX and MOX.

ANNEX B: Economic Hypothesis for the Unit Costs of the Fuel Cycle in the "CDP" Report

Graph 1: Unit costs for the fuel fabrication and reprocessing



(1) From the start-up of UP2-800 in La Hague in 1994, the cost of reprocessing is separated in investment cost and operation cost: only the second one appears on this figure. The investment cost of UP2-800 is assumed to amount to FrF30 billion (1999 value), plus FrF15 billion (1999 value) for the decommissioning of the plant, and FrF10 billion for upgrading at the half-life of the plant. Also assuming that the total cost for one year of operation of the plant is FrF4 billion (of which 80% are fixed cost and only 20% proportional to the quantities reprocessed), one can calculate the total average reprocessing cost for UOX fuel under various hypothesis, for instance:

- 7.3 MF/ton for a 30 years lifetime and 800 t/year;
- 6.7 MF/ton for a 40 years lifetime and 800 t/year;
- 8.2 MF/ton for a 30 years lifetime and 700 t/year;
- 6.6 MF/ton for a 30 years lifetime and 900 t/year.

Table 3: Unit costs for interim storage and final disposal of fuel cycle waste

Operation	Cost	per unit
Direct disposal of reprocessing waste		
Final disposal of MLW	0.46	MF/m^3
Final disposal of HLW (vitrified waste)	0.89	MF/container
	(or 4.2	MF/m^3)
Direct disposal of spent fuel		
Interim storage of spent UOX fuel (50 years)	1.00	MF/ton
Interim storage of spent MOX fuel (150 years)	2.50	MF/ton
Final disposal of spent UOX fuel	1.90	MF/ton
Final disposal of spent MOX fuel	8.00	MF/ton