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Note

THE UNBEARABLE RISK

Proliferation, terrorist threats and the plutonium industry

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The necessary immobilization of plutonium surplus from military stocks in USA and Russia should be developed in the most secure way. The interests of the European plutonium industry, hit by a severe crisis and in search of perspectives for the long term, converge with those of the two countries to propose a single strategy. It focuses on the utilization of the plutonium in MOX fuel in commercial reactors, rejecting more direct and cost-effective options of disposition of the plutonium as waste.

The European Union, and some of the Member States through the G8, are pressed to contribute the implementation and funding of this programme. This needs to be challenged in view of its real achievements for global security.

The 9/11 events and their consequences on international relations have made the problems of proliferation and terrorist threats even more serious than they were before. The management of plutonium stocks through the proposed MOX strategy, as compared to more direct alternatives for immobilization, results in longer delays; it increases the quantities of separate nuclear material in storage and the number of transports of highly dangerous material. Furthermore, the so-called MOX-option is a decisive support to the construction, development, and survival of a civilian plutonium industry respectively in the United States, Russia and the European Union.

The proposed MOX strategy for the management of plutonium, as compared to alternatives of direct immobilization, is an unbearable risk for the safety and security of Europe and the World.

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1. The power of plutonium

The use of uranium to produce electricity in nuclear reactors also produces, through fission and activation, various kinds of radioactive elements. Of all these radioactive materials contained in spent nuclear fuel, plutonium raises undoubtedly the highest concerns.

1.1. The specificities of plutonium

Plutonium, which only exist in traces in nature, would be the most valuable of the elements appearing in nuclear reactors, because of the high energy its fission liberates, if this potential was not so deadly. Plutonium can be used in nuclear bombs, cause severe accidents in the industry in case of uncontrolled crticallity, and is always dangerous because of its high radiotoxicity.

a) The proliferation risk

If plutonium was firstly separated from spent fuels to make bombs, it became of interest for industrial purposes when reprocessing facilities progressively lost their military customers in the 60s. Then was developed the idea that plutonium could serve uranium economies and the myth of a closed fuel “cycle” indefinitely re-using plutonium.

While the military use of plutonium required a very fissile quality of the plutonium used, the civilian use of plutonium allows for the use of plutonium containing less fissile isotopes than the military one. The isotopes with odd numbers (plutonium-239, plutonium-241…) are those provoking fission.

However, the military potential of plutonium remains[1]. The plutonium, of so-called "reactor grade" is perfectly usable for the making of bombs, as attested by the position of the International Atomic Energy Agency (IAEA), which considers that 8.5 kg of plutonium constitutes the "significant quantity" from which the possibility of making of a bomb cannot be technically excluded.

Current reprocessing and MOX fabrication activities deal with tens of tons of plutonium. The diversion of one thousandth, so to say 0.1%, of the annually manipulated quantities of plutonium by the reprocessing-MOX industry, still constitutes more than two times the “significant quantity”.

In a large MOX fabrication plant like MELOX, in France, a theoretical active insider, working at the weighing of the master blend, the first step of the MOX fabrication process, who would divert 1 g of each weighed kilogram of plutonium, he could near the “significant quantity” in one year.

It is not clear to which extent, material balances precision would permit to detect a voluntary diversion of plutonium. The Tokai Mura (Japan) reprocessing plant, of 100 tHM/yr of capacity which started operation in 1977, could be a good illustration of the material balance precision. In fact, Japanese officials acknowledged in January 2003, that it took a 15-year investigation to account for a more than 200-kilogram shortfall in plutonium at the reprocessing plant[2]. From the 6,890 kg separated by the plant during its 25 years of operation, roughly 3% escaped to the operator material balances.

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1 We can quote Hans Blix, then Director of the International Atomic Energy Agency (IAEA) who, in a letter of 1 November 1990 to Paul Leventhal, President of the Nuclear Control Institute, Washington D.C., USA, wrote: "*The Agency considers plutonium from irradiated fuel with high burn -up rate and in general any isotopic composition of plutonium, with the exception of those containing more than 80 per cent of plutonium-238, as being usable for an explosive nuclear device.*"
The IAEA defines the "*significant quantity (SQ)*" as "*the approximate quantity of nuclear material for which, taking account of the necessary conversion processes, the possibility of producing an explosive nuclear device cannot be excluded*".

2 See WISE-Paris news: “Missing plutonium probe latest flap for Japan's beleaguered nuclear power industry”, Associated Press, Tokyo, January 28, 2003
http://www.wise-paris.org/english/othersnews/year_2003/othersnews030128b.html

b) The risk of criticality

Although the criticality risk of fissile materials depends on multiple parameters (the fissile content, the geometry and many other parameters such as the presence of water and reflectors), some thresholds can be defined on the quantities above which criticality risk is sensitive.

Plutonium is, in terms of lower limit for the quantities needed, highly subject to criticality. For example, 60 kg of uranium enriched up to 3.5 % in uranium-235 (close to the quality of uranium used in standard fuel for most of the current reactors) is considered an order of magnitude beyond which the criticality risk is substantial.[3] In the case of plutonium-239, the equivalent threshold falls down to 500 grammes only.

More than 60 criticality accidents in nuclear installations worldwide, since 1945, led to 17 dead and tens of severe irradiations, often beyond the thresholds admitted for workers or public exposure. Until the 80s, there was around one criticality accident per year. The most famous one is the Tokai Mura accident in Japan, late September 1999, which involved highly enriched uranium in a conversion facility. Of the above total, 12 criticality accidents involved plutonium, causing in official accounting 4 deaths and 37 significant irradiations.

The different radiations produced by a criticality accident are comparable to those produced during the explosion of a nuclear device, some of these, the α (alpha) rays, can be easily stopped by any obstacle, but some other, like γ (gamma) rays, are able to irradiate through many concrete walls before being stopped. Moreover, criticality accidents produce fission products that can be released in the environment, and because of their high radiotoxicity, can have a high impact on populations.

There is very few communications from the nuclear industry on the criticality risk, and it appears to be generally treated with lightness. Main criticality prevention systems consist in reducing fissile materials quantities as well as adopting unfavorable geometries. However, the lack of active protection systems is of high concerns in reprocessing and MOX plants were tons of plutonium are manipulated every year, and on the transport routes were tens of tons of plutonium transit every year aside the population.

c) The high radiotoxicity of plutonium

Among all nuclear materials that can be found in spent fuels, plutonium isotopes are some of the highest toxic one.

Of these, plutonium-241, even if short lived, produces β (beta) rays, which necessitate radioprotection systems to handle it. Moreover, its decay produces long lived americium-241, also of high radiotoxicity, which in turn necessitates even heavier radioprotection systems, because of its γ ray radioactivity.

Plutonium-239 is not only one of the most radiotoxic plutonium isotopes, but because of its γ ray radioactivity, coupled with a tens of thousands years decay period, poses one of the major health concerns. For example, plutonium-239, produced with neutrons captures by uranium-238, is for equal quantities, 250,000 times more harmful than this last uranium isotope. In fact, around 135 µg of inhaled plutonium-239 is able to provoke the lethal dose of 5 Sv. In the meantime, less than 10 µg of plutonium-241 is sufficient (although its inhalation dose factor is much lower, its radioactivity is stronger due to a much shorter period).

Depending on the isotopic composition, the quantity of plutonium inhaled that could kill someone is between one and a few dozens of micro-grammes. The risk associated to the manipulation, storage and transport of separated plutonium (especially in the form of very small powder) is therefore very important. Moreover, the high radiotoxicity of plutonium makes it a very attractive product to be incorporated in a so-called "dirty bomb": a classical explosive device used to disperse radioactive material in a located area.

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[3] IPSN, *« Les accidents de criticité dans l'industrie nucléaire »*, update of November 2001

Table 1 Main characteristics of some plutonium and americium isotopes

Isotope	Symbol	Period	Radioactivity (1)	Radiotoxicity (2)	Inhalation dose factor (Sv/Bq)
Plutonium-238	^{238}Pu	86.4 y	α	very high (gr. I)	$1.6 . 10^{-5}$
Plutonium-239	^{239}Pu	24,390 y	α, γ	very high (gr. I)	$1.6 . 10^{-5}$
Plutonium-240	^{240}Pu	6,563 y	α	very high (gr. I)	$1.6 . 10^{-5}$
Plutonium-241	^{241}Pu	14.4 y	β	very high (gr. I)	$1.7 . 10^{-7}$
Americium-241	^{241}Am	432.2 y	α, γ	very high (gr. I)	$1.6 . 10^{-5}$

(1) Radioactivity: α = alpha, β = beta, γ = gamma
(2) The classification in groups of radiotoxicity (gr. I to IV) is that of the French regulation (Decree n° 86-1103), following the international recommmandations.

Source: IAEA-RasaNet Web site

Plutonium high radiotoxicity also served to justify its retrieval from the spent fuel, to avoid its presence in the reprocessing waste, and therefore was used as a further argument in favor of the plutonium economy. In this view, reprocessing of spent fuel, as opposed to its direct disposal, would reduce the long term radiotoxicity of waste from the nuclear fuel chain.

1.2. The plutonium "chain"

Compared to the simpler, "once-through" uranium fuel chain, the plutonium industry developed the concept of a fuel "cycle" where the plutonium, extracted from the spent uranium fuels, is "recycled" into fuel and reloaded in power reactors. However, record of the reprocessing-MOX policy of the plutonium industry shows the "recycling" rates of separated plutonium and uranium are far lower than 100%. One can see from the global picture that the so-called "closure" of the fuel "cycle" is a myth and therefore the term of fuel "chain" seems more appropriate.

The fuel chain consists in the different steps leading from the uranium ore extraction to the spent fuel storage. These steps can be summarized as follow:

• uranium ore *extraction*. The natural ore uranium is extracted from mines;

• uranium *concentration*, which consists in separating the uranium element from the ore;

• uranium *conversion*, which sees the concentrated uranium purified and converted into gaseous UF_6;

• uranium *enrichment*. The isotopic composition of the natural uranium is modified by upgrading the fissile content, i.e. uranium-235, up to the desired enrichment level;

- UF_6 *conversion*, turns the gaseous form of UF_6 to a solid oxide metallic form. The enriched oxide powder form of uranium obtained at this step, is the form under which uranium is used as fuel;

- fuel *fabrication*, consists in pelletizing and sintering the uranium powder, then fabricating the fuel pellets into pins and assemblies. Most of the reactors use the uranium oxide, or UOX, type of fuel.

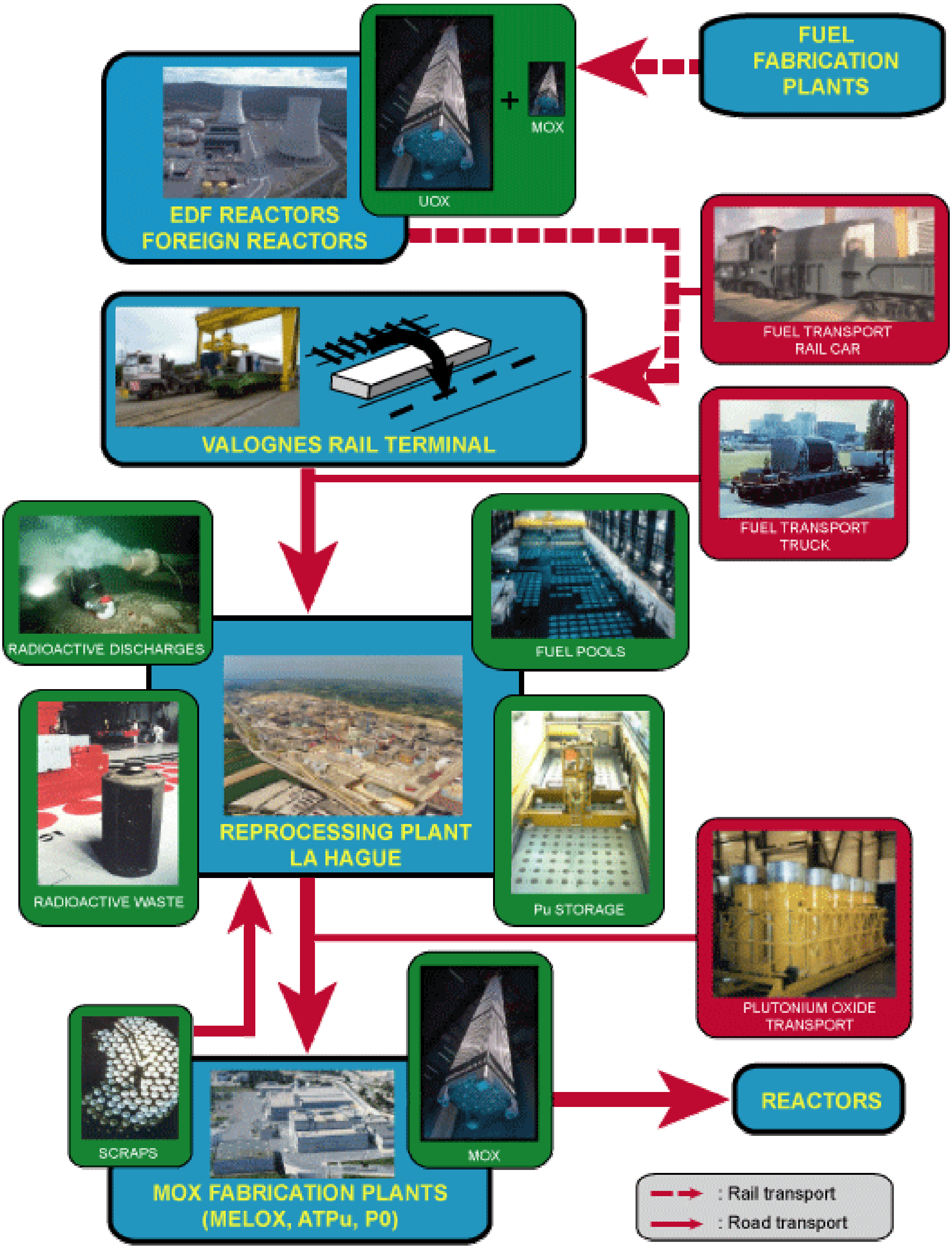
Then the fabricated fuel can be loaded in a nuclear reactor, where it will stay many months in the reactor core. Uranium fission and neutrons capture will change the fuel composition, the fissile content will be exhausted, and new elements will appear. When the fissile content of the fuel has been exhausted down to around the level of natural uranium, the irradiated fuel is unloaded.

From this point, different spent fuel managements have been chosen by the countries that operate nuclear reactors, although they start by a similar interim storageperiod: either the direct disposal of spent fuel or the insertion of a supplementary loop in the fuel chain, the reprocessing-MOX option.

This loop consists in separating plutonium and uranium, both elements which contain fissile isotopes, by reprocessing the spent fuel. Separated plutonium and uranium can be once again converted, then enriched, and finally fabricated into fuel. Separated plutonium is added to depleted uranium to fabricate a mixed oxide fuel called MOX, and separated uranium is treated like natural uranium, but in dedicated facilities, to fabricate a re-enriched uranium fuel called URE (enriched reprocessed uranium). Both fuels can be loaded into nuclear reactors where their fissile content will be exhausted, and once unloaded, will be sent to storage. In the "cycle" theory, these fuels can be reprocessed and their content used again. In practice, only very small quantities of such fuels have been reprocessed, and there is currently no real industrial plan to reprocess more.

The reprocessing-MOX loop, which is specific of the French and British nuclear industries, is illustrated by the figure hereafter. It has been chosen to represent the French reprocessing-MOX industry, which is more complete than the British one, as there is currently no re-use of plutonium separated from British spent fuel in fresh MOX fuel in British reactors.

Figure 1 **The plutonium chain in the plutonium economy: the French illustration**



Source: WISE-Paris, 2003

2. The failure of the plutonium economy

More than three decades after the launching of a "civilian" plutonium industry on the grounds of its first military developments, the project of a sustainable plutonium economy has incontestably turned into a complete failure.

2.1. The material and economic balance of the plutonium option

After more than 25 years of industrial scale experience in reprocessing, and 15 years of experience in MOX fabrication and use, it is possible to evaluate the real material and economic balance of the plutonium economy, and to compare this woth the theoretical advantages it claims.

• The plutonium "chain", as a management option for the spent fuel arising from nuclear reactors, has failed to meet its supposed goals, although they evolved with time.

- The shut-down of the French reactor Superphénix, in 1998, marked the end of the energetic *perpetuum mobile* myth, leaving the nuclear industry with the option of using plutonium (mixed with uranium in MOX fuel) in the existing fleet of light water reactors. This solution, as proven by the extensive French experience, is extremely inefficient, saving not more than 10% in natural uranium needs.
- As a consequence of the technical obstacles and high costs of the reprocessing plus MOX option, the plutonium stocks of France and UK, in spite of the claim of their energetic potential, are given a nil value in the respective registers of assets of EDF and the Britannic nation.
- Moreover, the justification has shifted from valorization of an energy resource to the disposal of an unwanted waste. There again, a comprehensive evaluation of the French practice concludes in its low efficiency but high cost. France is actually spending about 150 million euros for each ton of plutonium less in the inventory of final waste to achieve a reduction by only 15%.

a) The limited re-use of nuclear materials

As of the end of 1998, "recycling" rates of French separated plutonium and uranium were respectively less than 50% and less than 10%[4]. Instead of reducing the plutonium stocks, the progressive development of MOX use in the French reactors has strongly increased the stocks of separated plutonium. Stocks of British plutonium have grown even more, as no re-use of the separated plutonium was implemented. And the stocks of foreign separated plutonium held by those two European reprocessing countries, UK and France, evolved the same.

The re-use of plutonium in MOX fuel in the same light water reactors (LWR) that use standard UOX uranium fuel is not a first-hand choice. It is a consequence of the failure of the plutonium industry to develop its large programme of fast-breeder reactors (FBR), definitely sealed by the shut-down of Superphénix, the French 1,250 MWe, decided in 1997-1998.

To replace the FBR as 'plutonium consumers', the plutonium industry developed the MOX program during the 80s. Although the Light Water Reactors (LWR) were not initially designed to load plutonium based fuel, client countries which chose the reprocessing-MOX loop to manage their spent fuels, licensed some of their reactors to load MOX.

But in technical terms, MOX fuel is not an efficient mean of re-using plutonium, as shown by the compared balances of a reactor using UOX alone and one using the classical mix of UOX and MOX fue. If a moxed reactor, in fact, produces less plutonium than a reactor loaded with UOX fuel, it also produces more of the byproducts of the fission reactions, minor actinides and fission products. Estimated nuclear materials balances for both MOX and UOX loaded reactors, show that for each TWh produced, classic reactor management produces from 6 to 7 times more plutonium, but around 2 times less minor actinides.

4 See X. Coeytaux & M. Schneider, *"Recyclage des matières nucléaires - Mythes et réalités"*, WISE-Paris, April 2000. http://www.wise-paris.org/francais/rapports/000505RecyclagePuU.pdf
These figures have not been contradicted by the plutonium industry since the publication of the report.

Table 2 Nuclear materials balances in standard UOX and MOX managements[5]

in kg/TWh	Standard uranium fuel	Uranium and plutonium fuel
Fuel	100% UOX	30% MOX / 70% UOX
Uranium	-180.0	-157.9
Plutonium	35.6	5.5
Minor actinides	3.4	6.6
Fission products	141.1	145.8

Source: WISE-Paris, 2003

b) The limited gain in the material balance of the fuel chain

Plutonium industry claims it brings important gains both in frent-end and back-end of the fuel chain: an economy of natural uranium by replacing some of it by re-using plutonium, and a reduction of the plutonium inventory left in the final nuclear waste.

The material balance over time of the whole nuclear fleet is more complicated to establish than that of a single reactor on a short period. The theoretical advantage of a reprocessing-MOX industry is opposing industrial realities. In fact, trying to reach a plutonium equilibrium hasn't been achieved by the plutonium industry over a 15 years timescale in France, i.e. the country with the most advanced MOX program.

Even with an intensive reprocessing program of around 75% of the annually discharged spent fuel, and the use of MOX fuel in 20 of its 58 reactors, France hasn't been able to eliminate its plutonium. In the United Kingdom, because the national electric utilities are clients of the reprocessing industry only, no MOX is fabricated and the separated plutonium remains unused.

The initial plan to avoid plutonium in nuclear wastes also clearly failed. In France, both non-reprocessed spent fuels (UOX and MOX) stocks and separated plutonium stocks have been growing since the beginning of the French MOX program. In the United Kingdom, the separated plutonium stock has been increasing faster than any other in the world, and the reprocessing industry faces serious nuclear wastes management problems.

A report to French Prime Minister, Lionel Jospin, in 2000, drew a comprehensive balance of the plutonium option in the French nuclear industry[6], from the first start-up to the last shut-down of the current reactors. It concluded that reprocessing plus MOX could, in the "best" case, only save around 10% in natural uranium needs and 15% of plutonium in final waste.

c) The bad economics of the plutonium industry

As compared to the theoretical goals of the plutonium option, those gains fall short of compensating the overcosts of reprocessing plus the fabrication of MOX fuel.

The strongest indication of this is the nil value given to the stocks of separated plutonium (and uranium). The plutonium is given a nil value in EDF accounts since at least 1997, and in the National Book of Assets in UK since at least 2001.

If plutonium is worth nothing, then it is a waste and all the money spent to separate and re-use it can be seen as an accepted cost to eliminate as much as possible of it in the final waste. In this perspective, the report to French PM cited above calculated that France is actually spending 150 million Euros on average to reduce by 1 ton the final plutonium inventory in nuclear waste.

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5 Hypothesis for the fuel management correspond to current practice in French reactors:
Standard: Kp=75%; UOX only, burn-up=45 GWd/t
Hybrid: Kp=75%; MOX, burn-up=36 Gwd/t; UOX, burn-up=43 Gwd/t

6 Charpin, J.-M., Dessus, B., Pellat, R., *Etude économique prospective de la filière électrique nucléaire*. Rapport au Premier ministre, La Documentation française, Paris, 2000.

2.2. The detrimental impact of the plutonium option

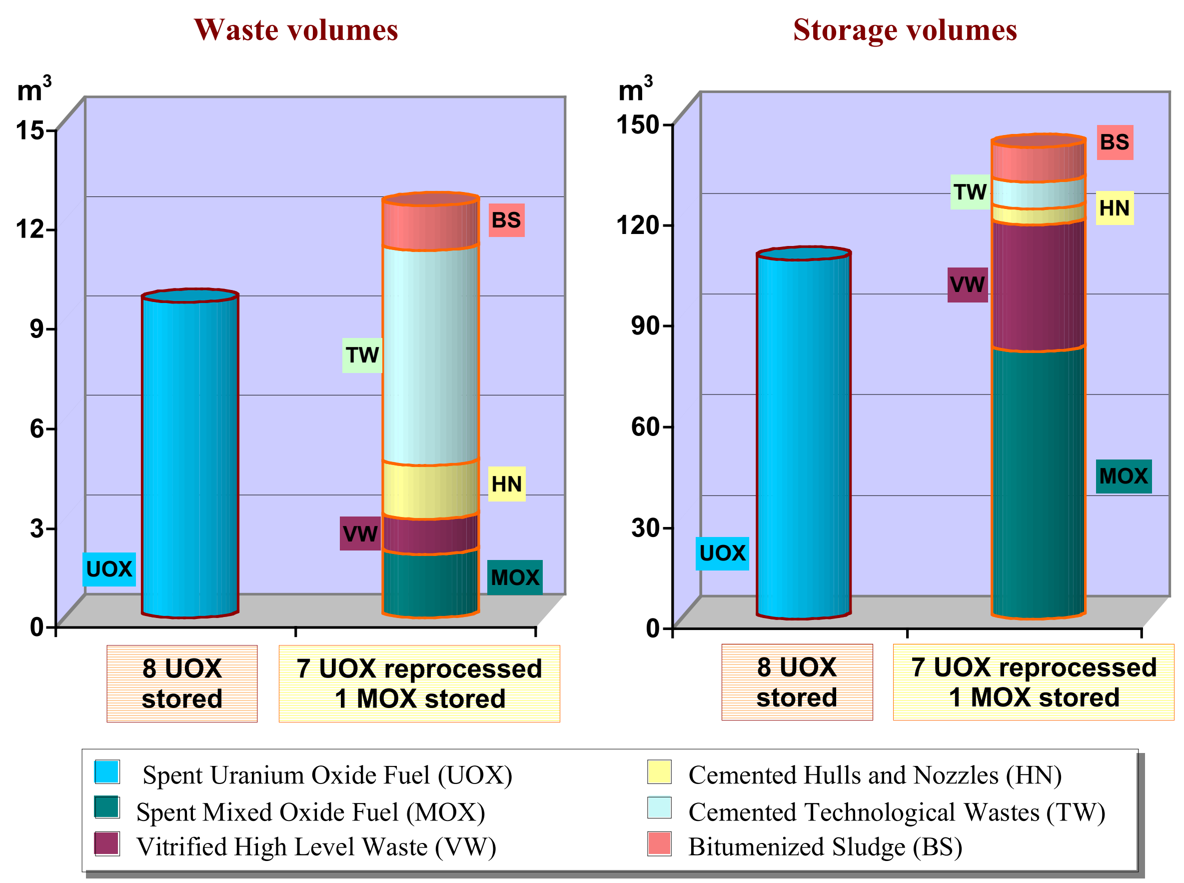
• The plutonium economy does not take into account the externalisation of a higher and contested burden on human health and the environment.

- The reprocessing industry produces quantities of various secondary long-lived waste, resulting in higher volumes and a more complicated, hazardous and expensive management than direct disposal of spent fuel.
- In spite of the commitments under the OSPAR Convention, radioactive discharges of the French and British reprocessing plants in La Hague and Sellafield are still thousands of times those of a nuclear power plant. This notably results in important pollutions of coastal areas of other countries, such as Ireland and Norway.

a) The complication of the waste management issue

The choice of a reprocessing-MOX loop weights heavily on the nuclear wastes management options, because of the multiplication of wastes types. If the reprocessing industry achieved some reduction of the wastes volumes, as compared to the initial design, the comparison between the plutonium option and the direct disposal one, can only be grounded when considering the storage volumes.

Figure 2 Waste and storage volumes for direct disposal and reprocessing options*



* Estimates of waste and storage volumes remain largely uncertain. In particular they depend on the concepts of waste packaging and repository design, which are subject to modifications as long as no final decision is taken.
Figures above are based on the French situation, according to package concepts as presented by COGEMA in 2001-2002, and to a repository concept as studied by ANDRA in 1999.
There is no possibility of comparison in the case of UK, for there are no relevant concepts of package or repository so far.

Source: WISE-Paris estimates, 2002, from ANDRA, 1999 and COGEMA, 2000-2001

Figure 2 shows, in the French case, what the total volume of waste and the total volume of storage (i.e. the volume of gallery needed in a deep ground repository, including the waste package plus the concrete around) in the two options. The introduction of MOX to replace one eighth of the standard UOX fuel produces numerous categories of waste that, when conditioned and disposed of, could represent more volume than the spent UOX fuel in direct disposal.

The French example of the most advanced reprocessing-MOX loop shows that it cannot solve the nuclear wastes problem, but even complicates it, is unable to solve the plutonium equation, and contributes to create stocks of wastes under multiple forms (including spent fuels) as well as stocks of separated fissile materials of first importance regarding proliferation concerns.

a) The massive radioactive discharges into the environment

If the plutonium industry displaces or even worsens the spent fuels management problem, its specific activity creates a supplementary risk by generating important radioactive releases. Quantities of radioactive elements released annually by the reprocessing plants of Sellafield (UK) or La Hague (France) are tens to thousands orders of magnitude higher than the discharges of a single LWR.

Table 3 **Comparison of Discharge Limits for the La Hague Site and the Nuclear Power Plant of Flamanville**

Type of Effluent	La Hague Authorisation for the whole site (in GBq)	Flamanville Authorisation for 2 PWR 1,300 MWe (in GBq)	Ratio La Hague vs. 1 PWR Flamanville (2)
Gaseous Releases			
Gases other than tritium	470,000,000	45,001	**10,444**
Tritium	150,000	5,000	**30**
Halogenes (iodine, chlorine…)	20	0.8	**25**
Carbon-14	28,000	1,400	**20**
Alpha emitters	0.01	**prohibited** (1)	–
Liquid Discharges			
Radio elements other than tritium	101,100	25	**4,044**
Tritium	18,500,000	60,000	**308**
Carbon-14	42,000	400	**105**
Alpha emitters	170	**prohibited** (1)	–

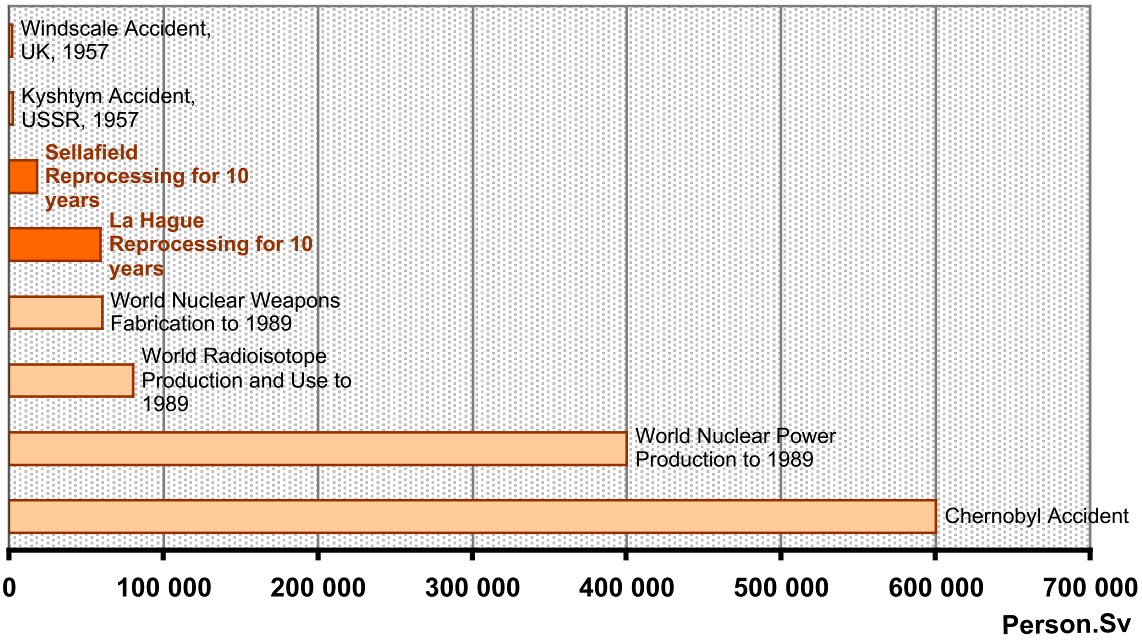
(1) The discharge of gaseous or liquid alpha emitters is prohibited at the reactor site of Flamanville (Arrêté du 6 juin 2000).
(2) The Flamanville site is 17 km of the La Hague site on the same coast.

Source: Journal Officiel de la République française.

The risk linked to those massive discharges has notably been studied in a WISE-Paris report[7] to the STOA (Scientific and Technological Options Assessment) office of the European Parliament in 2001. Among other conclusions, the report showed the global collective doses induced by the radioactive releases of the European reprocessing activities, are equivalent or even higher than the collective dose induced by a major nuclear accident, such as the Kyshtym accident in 1957, every year.

[7] Schneider, M. (Dir.), *Possible Toxic Effects from the Nuclear Reprocessing Plants at Sellafield (UK) and La Hague (France)*, Report commissionned by the STOA office of the European Parliament, WISE-Paris, 2001.

Figure 3 **Global Collective Doses Induced by Anthropogenic Radiation Sources, in Person.Sievert**



Source: WISE-Paris, 2001

Because releases of the reprocessing industries have not only a local impact, but because of a dilution-dispersion strategy, have also a diffuse, long range impact, countries that even do not have a nuclear activity, undergo the effects of the French and British plutonium industry. For example, Norway accused Britain of ruining its lucrative Arctic lobster business by failing to stop radioactive discharges from Sellafield[8], and Ireland made a submission to the Hamburg-based International Tribunal on the Law (ITLOS) of the Sea in November 2001, against the United Kingdom, to prevent any further radioactive pollution of the Irish sea by the British plutonium industry[9], followed by other complaints filed to the Permanent Court of Arbitration.

A May 2003 report by the Radiological Protection Institute of Ireland (RPII) confirmed that radioactive discharge from Cumbria's Sellafield reprocessing plant continued to be the dominant source of contamination of the Irish Sea, two years after the case was submitted to ITLOS[10].

2.3. The alternatives for plutonium immobilization

Comparison with direct disposal shows the reprocessing plus MOX option is costly, inefficient and bad for the environment. However, stocks of separated plutonium already piled up in very large quantities and require management – at least to prevent the proliferation risk. The use of plutonium in MOX is not the only option to manage the plutonium problem. Alternatives exist for the immobilization of plutonium.

The Öko-Institut studied, as soon as 1999, the low cost possibilities of immobilizing the plutonium either in a ceramic matrix, or in "bad MOX" assemblies, i.e. MOX fabricated with low control-quality

8 See WISE-Paris Others' News, *"UK accused over Sellafield pollution"*, *The Guardian*, April 29, 2003 http://www.wise-paris.org/english/othersnews/year_2003/othersnews030429.html

9 See Wise-Paris Our News, *"International Tribunal for the Law of the Sea holds hearing on the Irish case against the UK over MOX facility on 19-20 November 2001"*, WISE-Paris, 13 November 2001 http://www.wise-paris.org/english/ournews/year_2001/ournews011115.html

10 RPII, "*Radioactivity monitoring of the Irish marine environment 2000 and 2001*", May 2003 http://www.rpii.ie/reports/2003/MarineReport20002001final.pdf

requirements and destined to storage[11]. This storage MOX strategy is particularly proliferation resistant when mixing storage MOX assemblies together with uranium based spent fuels. This plutonium immobilization option has been considered as a possibility of turning the controversial Sellafield MOX Plant before it was commissioned, and is still possible in all MOX plants. Turning the existing MOX plants, and even the projected US one, into immobilization plants, makes this immobilization option of high interest because it doesn't need a financial effort to achieve its goal.

The other option, immobilization into ceramic inert matrix, consists in a vitrification-like process in which plutonium is embedded into ceramic disks, then stacked and canned and finally placed in steel frames canisters[12]. This "can in canister" approach was formerly adopted by the US to dispose of some of their military plutonium, before they finally abandoned this option in April 2002 for political reasons. In fact, the long experience of the reprocessing plants in vitrification processes, very similar to the immobilization process, was a strong argument in favor of the technical feasibility of ceramic immobilization.

However, if immobilization in ceramic matrix seems now abandoned, the immobilization of plutonium in glass or glass-ceramics in existing facilities gained some interest. Because vitrification currently operated in existing reprocessing plants is basically an immobilization of fission products and minor actinides, disposition of unused plutonium stocks could be performed in existing vitrification workshops. This plutonium disposition option requires important stocks of high level liquid waste, to be mixed with plutonium in the glass to prevent the retrieval of the plutonium from the waste. Such stocks are available in Sellafield, where the vitrification process has been very slow, but not in La Hague, where the liquid waste is vitrified "on-line".

All the three methods of disposing plutonium, shortly described above, present the advantages of disposing the plutonium more quickly and at costs at most equal – but often lower – to the actual MOX option. Moreover, storage of plutonium disposed through one of these methods would be facilitated when compared with the high levels of radioactivity and heat released by spent MOX fuels.

3. The survival strategy of the plutonium industry

There should be no plutonium market. The "civilian" plutonium economy has not greatly developed outside the European Union, where it benefitted support or passivity from a majority of Member States. But the plutonium industry players, BNFL and COGEMA, used this situation to create a "fait accompli" that allows for the prolongation of their activities.

3.1. Operating facilities of the civilian plutonium industry

The civilian plutonium industry is mainly based in Europe. Most of the reprocessing and MOX fabrication capacity of the world is concentrated in three European countries, as shown in Tables 4 and 5. France and UK are by far the main players of this industry, dominated by their respective companies COGEMA (now part of the AREVA holding) and BNFL.

[11] C. Küppers, W. Liebert, M. Sailer, *"Realisierbarkeit der Verglasung von Plutonium zusammen mit hochradioaktiven Abfällen sowie der Fertigung von MOX-Lagerstäben zur Direkten Endlagerung als Alternativen zum Einsatz von MOX-Brennelementen"*, Öko-Institut, 1999

[12] For more details see A. Macfarlane, F. von Hippel & al. *"Plutonium Disposal, the Third Way"*, Bulletin of the Atomic Scientists, May/June 2001 http://www.thebulletin.org/issues/2001/mj01/mj01vonhippel.html

Table 4 **Operating reprocessing plants**

In Europe

Country	Operator	Site	Capacity (tHM)	Type of fuel	Commis-sioned	Production (end 2001, tHM) Output [cumulated total]	Clients[d]
France	COGEMA	UP2-400 La Hague	400	UNGG	1966	0.0 [4,896.5]	FR SP
				PWR BWR FBR	1976	0.0 [4,449.4]	FR DE SP JP N CH
		UP2-800 La Hague	1,000[a]	PWR BWR	1994	733[b] [5,882.6]	
		UP3 La Hague	1,000[a]	PWR BWR	1989	217[b] [6,905.1]	
United Kingdom	BNFL	B205 Sellafield	1,500	UNGG	1964	786[c] [26,108[c]]	UK
		THORP Sellafield	1,200	AGR PWR BWR	1994	736[c] [3,900[c]]	UK DE SP JP N SW

a. Annual capacities of UP2-800 and UP3 are limited by decree, dated 10 January 2003, to 1,000 tHM per year for each plant, but the total annual output of both plants together shall not exceed 1,700 tHM.

b. It should be noted that COGEMA has ceased on 20 March 2002 to indicate reprocessed quantities at La Hague per plant. Reprocessed quantities in 2002 for UP2-800 and UP3 together reach 1060 t of spent fuels.

c. Output figures for B205 and THORP are given by BNFL from April to April, presented data reflect the situation as of the end of April 2002.

d. FR: France, SP: Spain, DE: Germany, JP: Japan, N: Netherlands, CH: Switzerland, UK: United-Kingdom, SW: Sweden.

Outside Europe

Country	Operator	Site	Capacity (tHM)	Type of fuel	Commissioned	Clients
India	DAE	PREFRE Tarapur	400	CANDU	1982	India
		KARP Kalpakkam	100	CANDU	1996	
Japan	PNC	Tokai Tokai-Mura	100	PWR BWR	1977	Japan
Russia	Minatom	RT1 Chelyabinsk	600	VVER	1976	Russia Finland CEEC[a]

a. CEEC: Central and Eastern European Countries. Some of those countries, operating VVERs, have fuel contracts with Russia that include the provision of fresh fuel and the return of spent fuel to Russia, where it is supposed to be reprocessed.

Source: WISE-Paris

Table 5 Operating MOX fabrication plants

In Europe

Country	Operator	Site	Capacity (tHM)	Type of fuel	Commis-sioned	Production (end 2001, tHM) Output [cumulated total]	Clients[c]
France	CEA - COGEMA	CFCa Cadarache	15	FBR	1961	0.0 [~105.0]	FR DE
			or ~40	PWR BWR	1989	39.0 [286.4]	
	COGEMA	MELOX[a] Marcoule	101.3	PWR	1996	97.3 [531.9]	FR JP
			and 44.2	BWR	1999		
United Kingdom	BNFL	MDF Sellafield	8	PWR BWR	1993	0.0 [~18[b]]	DE CH JP
		SMP Sellafield	120		2001	0.0 [0.0]	DE CH
Belgium	Belgo-nucléaire	P0 Dessel	10	FBR	1973	0.0 [?]	FR B DE CH JP
			or 40	PWR BWR	1986	36.0 [491.0]	

a. The technical capacity of MELOX is actually 145.5 tHM at least, but its output is limited by decree (n°99-664 of 30/07/1999), to 101.3 tHM. A public inquiry aiming at increasing the annual capacity up to 145 tHM was held in January-February 2003.

b. BNFL, written answer to Sellafield Local Liaison Committee, dated 2 December 1999, from CORE (Cumbrians Opposed to a Radioactive Environment).

c. FR: France, DE: Germany, JP: Japan, CH: Switzerland, B: Belgium.

Outside Europe

Country	Operator	Site	Capacity (tHM)	Type of fuel	Commis-sioned	Production (end 2000, tHM) Output [cumulated total]	Clients[c]
Japan	JNC	PFPF Tokai-Mura	40	ATR	1988	0.0 [~0.0]	Japan
			or 5	FBR		0.0 [~18]	
		PFFF Tokai-Mura	10	ATR	1971	~6.0 [~150]	
			or 1	FBR		0.0 [~0.0]	
India	BARC	AFFF Tarapur	20	PHWR BWR?	1990?	?	India

Source: WISE-Paris

3.2. Current status: towards the end of contracts

• The European plutonium industry represents some 3.3 billions Euros of annual turnover. But there is no long term perspective for the French, British and Belgian plutonium plants (reprocessing and MOX fabrication facilities), as there is no prevision for new contracts beyond the existing ones.

- The major part of the reprocessing contracts with European and overseas clients are either completed or in way of completion. The existing MOX contracts will be completed after a few years interval.
- There is currently no prospect in any of the past or present client countries, apart from the “domestic” contracts with the utilities EDF and British Energy, for new contracts to be signed.

The number of countries that have had or still have contracts with the plutonium industry operators in France, UK and Belgium is very limited. As shown in Tables 6 and 7, execution of the current reprocessing contracts is almost completed in the COGEMA plants of La Hague, and is well advanced in the BNFL plants of Sellafield.

Table 6 Status of the Contracted and Reprocessed Spent Fuel at La Hague as of 31 January 2002 (in tons of heavy metal)

Client	Total Contracted	Total Reprocessed	Status of the Contract in %
France	13,406	8,360	62,4%
Germany	5,981	4,470	74,7%
Japan	2,944	2,944	100,0%
Belgium	671	671	100,0%
Switzerland	761	619	81,3%
Netherlands	383	269	70,2%

Source: Commission Spéciale et Permanente d'Information de La Hague, bulletin n°10, April 2002

Table 7 Status of the Contracted and Reprocessed Spent Fuel at Sellafield as of July 2000 (in tons of heavy metal)

Client	Total Contracted	Total Reprocessed	Status of the Contract in %
UK(1)	2,158	1,160	53.8%
Japan	2,673	1,150	43.0%
Germany	969	248	25.6%
Switzerland	422	70	16.6%
Sweden	140	140	100%
Spain	145	n.a.(2)	n.a.
Italy	143	n.a.	n.a.
Netherlands	56	n.a.	n.a.

(1) Does not include unknown quantities of post baseload contracts
(2) n.a.: not available

Source: Cumbrians Opposed to a Radioactive Environment, “Status of THORP Baseload Contracts”, 23 March 2001

There is no renewal perspective for the contracts. On the contrary, most of the client countries of the European civilian plutonium industry are engaged in a process to abandon the plutonium option.

Belgium suspended reprocessing in 1998 and did not sign new contracts. Germany decided in June 2000 to stop sending nuclear fuel for reprocessing at the latest in 2005. In Switzerland, after the negative vote, on 18 May 2003, on the nuclear moratorium and phase out proposals, the Federal Assembly has passed a law which will declare a 10 years moratorium on the export of plutonium for reprocessing, as of 2006.

Moreover, renewal of the French MOX contract with the national electricity utility Electricité de France (EDF) in October 2001 did not lead to reassess MOX supply to a higher level. Concerning the

Japanese market, the freeze of the Japanese Pluthermal program after quality-control scandals led to cancellations of MOX contracts with COGEMA with no clear view on a future renewed Japanese market. It is therefore justified to say that the French reprocessing-MOX industry is a slow declining industry.

The situation of the British plutonium industry is even worse since it has been severely hit by Japanese MOX scandals and reprocessing operation problems. Moreover, the recent MOX plant, Sellafield MOX Plant (SMP), which started in October 2001, thanks to German contracts as justification of a minimal load factor, was threatened in January 2003 with the withdrawal of these contracts, leaving only few quantities of Swiss MOX to fabricate, on the plant schedule. The recurrent problems encountered in reprocessing operation, of which the great safety and security problems caused by the storage of huge quantities of liquid high level wastes, together with unbearable cost weight for the electricity utility British Energy, have weakened the British reprocessing industry.

Concerning the Belgian MOX industry, the step out from reprocessing by Germany and Belgium will have a high impact on the P0 plant, and since the MOX control-quality scandal, which hit also Belgonucleaire in 1999-2000, the Japanese parenthesis is closed for the Belgian utility. However, the precise date of the end of the German and the Belgian contracts is difficult to estimate, both clients constitute currently around two third of the plant's load factor. Moreover, the retiring of France, which represented two third of the plant production in the beginning of the 90s, led Belgonucleaire to fill a complaint against COGEMA in June 2002, in the arbitration court of the International Chamber of Commerce, after the company refused to honor a "capacity reservation contract" that represented essentially all P0 workload from 2004 to 2006[13]. One may deduct that with the stagnation or even the decline of the MOX market in the coming year, the P0 plant could be threatened of closure by lack of clients as soon as 2004-2005.

The very short description above, of the current situation of the European reprocessing-MOX industry, reflects also the general tendency for the coming years. It appears that both British and French industries, will be at least stagnant thanks to the contracts signed with their national electricity utilities, but the possibility of an acceleration of the current observed decline cannot be ruled out, because of the general depreciation of the plutonium industry, including by the national electricity utilities in the frame of a deregulated electricity market.

3.3. The "fait accompli" strategy

• However, the operators of the plutonium industry have developed stocks, capacity and time frame set for their survival. This was also allowed by important delays, or even giving up, in implementation of plutonium use in client countries.

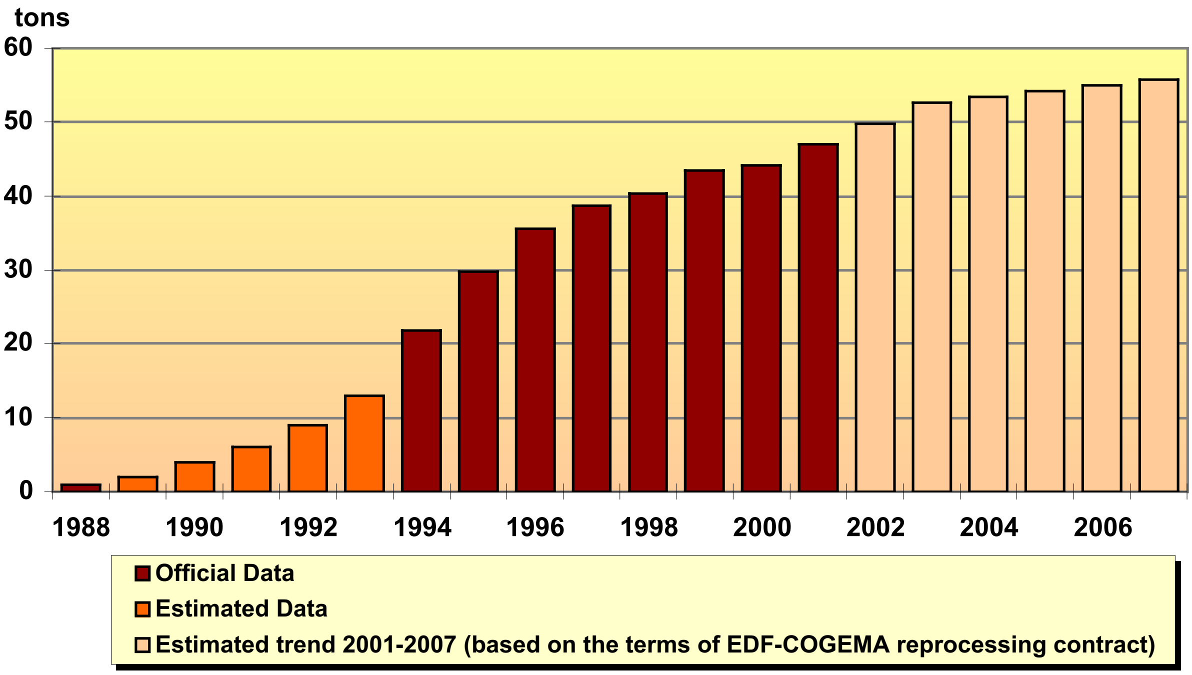
- In France, the development of MOX loading in reactors coincided with the rise of the plutonium stock, from almost zero to 47 tonnes (end of 2001). In the UK, where there is not even MOX use, the plutonium stock reaches 65.3 tonnes (end of 2001).
- In addition, the two countries hold 50.6 tonnes of foreign separated plutonium (33.5 tonnes in France and 17.1 tonnes in the UK, as of the end of 2001) mostly coming from European countries (6 Member States – Belgium, Germany, Italy, Netherlands, Spain, Sweden – plus Switzerland and, outside Europe, only Japan – and a very small quantity from Australia). Most of the client countries have obligingly delayed implementation of the return of their plutonium, even though some have decided the phase-out of nuclear energy.
- These stocks, in turn, have been used by COGEMA and BNFL as a justification for the recent increase of capacity of MOX fabrication. Recent or current extensions bring the total capacity from less than 200 up to 300-400 tHM (tonnes of heavy metal) by year – some 100-150 tHM more than currently needed.

[13] *NuclearFuel* n°25, *"Arbitration of BN-COGEMA Dispute over MOX to take 'another few months'"*, 9 December 2002

a) The acccumulation of separated plutonium

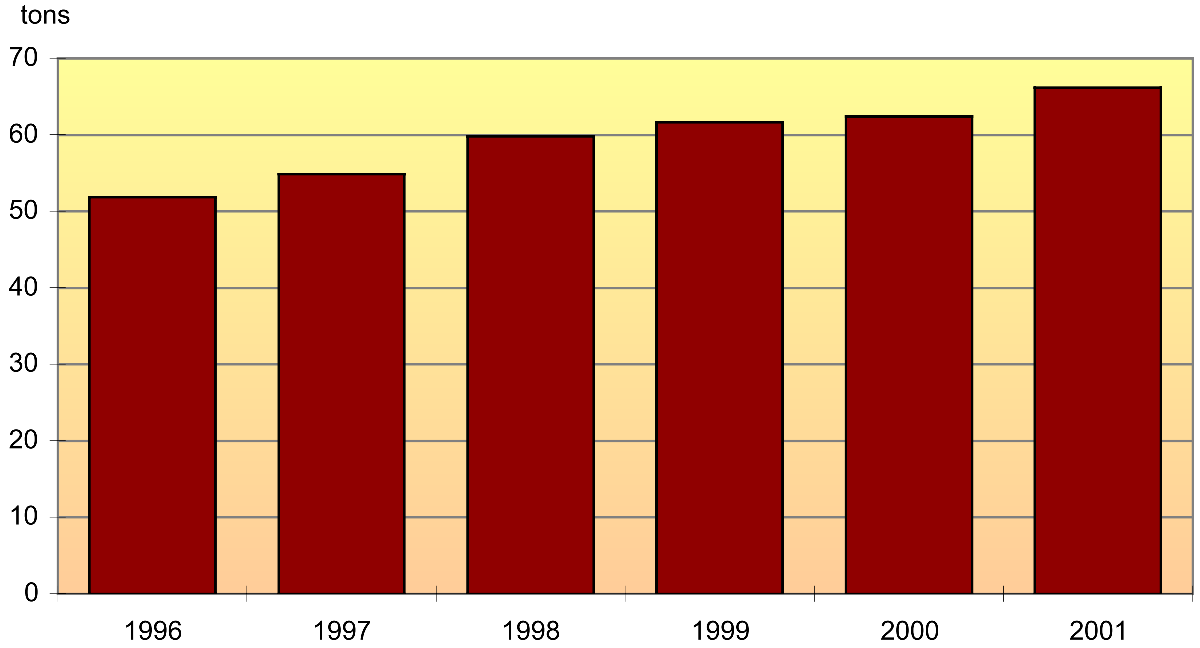
To survive, the European plutonium industry sat up a "fait accompli" strategy, consisting in creating a problem, and offering its solution in parallel. This resulted in a continuous growth of the stocks of plutonium separated by the reprocessing plants of France and UK. In both cases, the levels to which separated plutonium has been stockpiled in France and United Kingdom, is a promise of activity for COGEMA and BNFL for many years, even if reprocessing would come to an end in a near future. By proposing a temporary spent fuels management solution, with reprocessing, both reprocessing industries trapped the reprocessing clients in the separated plutonium dead-end. If France succeeded with setting up an industrial scale 'solution' for the plutonium problem, United Kingdom is currently trying to follow the same path.

Figure 4 Historical and Projected French Separated Plutonium Stockpile from 1988 to 2007 (as of 31 December of the year, in tons)



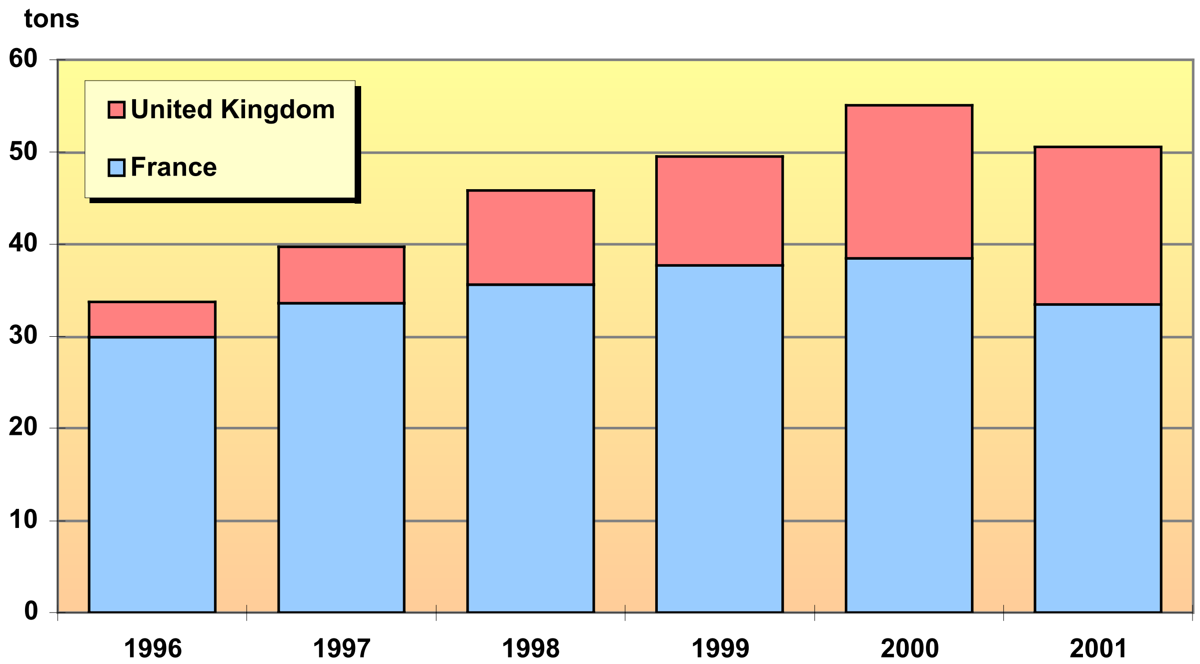
Source: IAEA, Information Circulars n°549/5, declarations by the Permanent Mission of France; estimations by WISE-Paris

Figure 5 **U.K. Separated Plutonium Stockpile from 1996 to 2001 (as of 31 December of the year, in tons)**



Source: IAEA, Information Circulars n°549/8, declarations by the Permanent Mission of United Kingdom

Figure 6 **Holdings of Foreign Separated Plutonium in France and United Kingdom from 1996 to 2001 (as of 31 December of the year, in tons)**



Source: IAEA, Information Circulars n°549/5&8, declarations by the Permanent Missions of United Kingdom and France

b) THe stretching of delays

In conjunction to the accumulation of plutonium, the industry uses elusive and delayed dead-lines to stretch its activities.

One very effective way to achieve this is to offer storage in the reprocessing plants for fuel that will be said "waiting to be reprocessed" and in long term intermediate storage. The British and French reprocessing companies offer to their national electric utilities, British Energy (BE) and Electricité de France (EDF) storage in excess of contracted quantities.

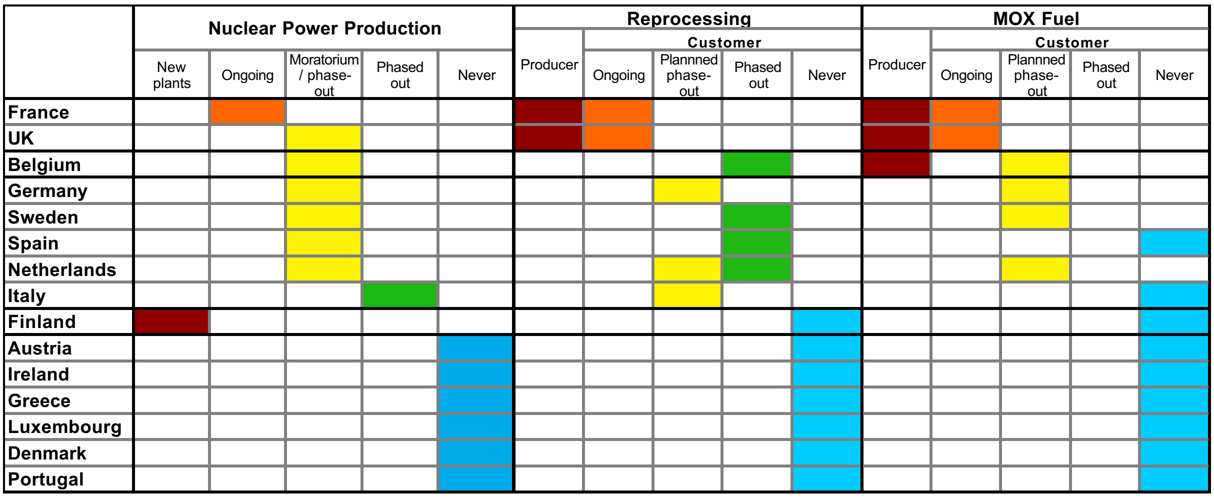
For example, in July 2000, British electric utilities had delivered 3,500 tHM of spent fuels to the Sellafield site, however the contracts covered only 2,158 tHM.

In France, the arising of EDF spent fuel in the cooling ponds of La Hague is principally due to the difference between the annually discharged spent fuel from EDF reactors, i.e. 1,150 tHM (of which 100 tHM of spent MOX), and the annually reprocessed spent fuel at La Hague, or 850 tHM at the maximum. It is also noteworthy that the reprocessing agreement signed between EDF and COGEMA in October 2001, covered 5,250 tHM of spent UOX fuel to be reprocessed until mid-2007 at a mean rate of 850 tHM/yr, while around 6,850 tHM of spent UOX were already stored in La Hague ponds.

COGEMA also used this strategy to attract non standard fuel from French and foreign clients and storing them in La Hague before their reprocessing was actually fully authorized. This concerns all MOX fuel, specific "bad MOX" imported from Hanau, or the MTR fuel (like the Australian one) stored in La Hague before its new authorization decrees of January 2003, which authorize reprocessing of such fuels.

On the other hand, clients of the plutonium industry have generally accepted – or even looked for – delays in the implementation of the services they requested. This results in a situation where, in a general trend to the decline of nuclear energy in the European Union, some countries that have decided a nuclear phase-out still send some fuel for reprocessing and commission MOX fabrication.

Table 8 **Status of Member States of the European Union regarding nuclear power, reprocessing and MOX fuel (as of April 2003)**



Source: WISE-Paris, 2003

c) The development of the MOX fabrication capacity

With the two 'fait accompli' strategies described above, both captives methods to assure the survival of the plutonium industry, BNFL and COGEMA also justified their will to extend the MOX industry on a larger scale.

In the Sellafield case, the German contracts were the only economic justification for starting in December 2001, the 120 tHM/year Sellafield MOX Plant, however the British plutonium industry was still undergoing the storm of the Japanese MOX scandal.

In the French case, the demand of capacity extension of the MELOX plant, in January 2003, was only grounded on the German MOX contracts fulfilled at the ATPu plant, planned to cease commercial operation in July 2003 on safety grounds.

In both cases, one should remind that Germany decided to end reprocessing in 2005, which is significant on the duration of the German MOX contracts. Estimates show that these contracts could be fulfilled as soon as 2008-2010, which raises the question of justification for the commissioning of a 120 tHM MOX plant in the UK and the increase of 50% of capacity of the MELOX plant in France.

The resulting capacity exceeds the current needs, but this capacity can in turn be used to argue for more MOX fabrication. Once a plan started-up, it is economically more sound to operate it as much as possible.

4. The unbearable risk of using MOX for disarmament

Now the interest of the European plutonium industry to create a new perspective converges with the strategies of the two other great producers of separated plutonium – for military purpose –, the USA and Russia, to achieve their political commitment to dispose of part of their stocks.

In face of the post 9/11 world, the combined strategy of the European plutonium industry, the US and Russia to dispose of 68 tonnes of surplus plutonium under the form of MOX fuel for commercial nuclear reactors unacceptably increases the risks related to proliferation and terrorist attacks.

4.1. The convergence of the plutonium producers' interest in disarmament

• After they have agreed in 2000 on the immobilization of 34 tonnes each of "surplus" plutonium, the USA and Russia have both resolutely turned to the sole re-use of plutonium in reactors, ruling out alternative options of direct disposal.

- Russia has made it clear that it would not regard plutonium as a waste, but as the resource for a new programme of fast breeder reactors. In the meantime, they could fund this through being paid to produce MOX fuel to be used either in their light water reactors, or sold to Western utilities.
- The USA, that had first developed a "dual-track" strategy, including the direct immobilization of 9 tonnes of plutonium, have given it up to prefer the sole MOX option. Although they officially justified it in other ways, they explicitly made that choice to satisfy Russia.
- This choice is contrary to most of the evaluations, which show the direct immobilization options (vitrification, ceramic, bad MOX) are safer, more practicable and less expensive than the use of the plutonium as MOX in reactors.
- The US Administration appears only driven by concern about the immobilization of Russian plutonium. It must be noted that, in the meantime, the US have restarted production of plutonium pits (i.e. the fabrication of nuclear bombs) and are studying the possibility to develop a new kind of small nuclear bombs.

With a total stock over 130 tons currently held by France and the UK, the European plutonium industry is by far the largest producer of civilian plutonium. However, the stocks of military plutonium in the world are even larger. Although no precise figure is available, the main producers of military plutonium are, by large, the two superpowers of the cold war, the USA and Russia, which probably hold stocks of more than 100 tons each.

The two countries have agreed to disarm part of their nuclear arsenal, hence to immobilize large quantities of plutonium used in the corresponding warheads. Through this plan, interest of the two military plutonium producers converge with those of the European civilian plutonium industry. The latter brings the experience and know-how of its MOX technology to implement the planned immobilization of plutonium; the USA and Russia provide plutonium industry players in Europe with large stocks to manage that create a new long-term perspective.

a) The US interest in the plutonium disposition plan

Since the plutonium disposition agreement signed on 1 September 2000 between the U.S. and Russia, the firstly chosen "dual track" approach, i.e. fabrication of the plutonium under MOX form for one part and immobilization for the other part, has been progressively abandoned, under pressure from the plutonium industry, in favor of "one way only" approach, which consists in the conversion of the military plutonium into mixed uranium-plutonium oxide fuel (MOX) and burning in commercial reactors.

Final decision to abandon immobilization of 8.4 MT (metric tons) of plutonium (of a total of 34 MT destined to be disposed, taken from 50 MT declared as excess for defense needs) has been amended by the U.S. Department of Energy's National Nuclear Security Administration (DOE/NNSA) on 19 April 2002.

Although the immobilization option *"achieves full disposition [...] of U.S. plutonium with the lowest cost"*, according to an official assessment[14], the MOX option has been preferred due to international considerations:

- the immobilization option *"would lead almost certainly to termination of bilateral plutonium disposition with Russia. Russia would have no incentive to complete disposition of its surplus plutonium"*
- *"this option would have limited support internationally"*.

However, US have a limited experience in plutonium recycling and especially in MOX fabrication. The US Department of Energy seek the necessary knowledge, which had been developed since the end of the 80s in Europe by both COGEMA and BNFL, and French COGEMA was included in the Duke, COGEMA, Stone &Webster consortium which awarded a Base Contract in March 1999, to develop the US MOX program.

COGEMA would therefore bring its feedback experience in MOX fabrication and MOX plant building and operation. In fact, the US MOX program includes the building of a MOX plant at the Savannah River Site (SRS), based on the design of the French MELOX plant operated by COGEMA on the Marcoule site..

b) The Russian interest in the plutonium disposition plan

By encouraging the disposition of military plutonium through MOX fabrication, US brought another justification to Russia not to dispose of its 34 t of military plutonium – covered by the US-Russia agreement – through immobilization. In fact, Russia always pushed for a massive development of nuclear power as the only solution to the energetic problems, but with fast breeder reactors development to search for an efficient solution.

This explains why Russia didn't seek any other solution than military plutonium fabrication into nuclear fuel. Immobilization wasn't even evoked as an option for the Russian part, during the US-Russia military plutonium disposition agreement negotiations. However, because of US pressure not to use FBR, mainly because of proliferation concerns, Russia agreed the US plan to dispose military plutonium disposition into MOX, but expressed reserves. Such a plan could be conceivable by Russia but only with *"financial and technological input from the world community"*, according to Evgeny O. Adamov , Minister for Atomic Energy (Minatom) in March 1998 to March 2001.[15]

Because MOX fabrication is not in accordance with Russian plans to develop FBR, Russian plutonium disposition into MOX fuel is only considered as a possible nuclear business. Evgeny O Adamov confirmed his initial statement in 2000 by pointing out that *"one possible solution to the problem of partial compensation for nuclear disarmament costs would be "commercial" use of the Russian MOX fuel for electricity generation at NPPs in those countries which already have licenses to use such type of fuel, with subsequent return of irradiated MOX fuel back to Russia for safe storage"*.[16] This statement confirms that there is no will to use MOX fuel in Russia, but rather to turn MOX fuel into an exportation goods.

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14 National Nuclear Security Administration Office of Fissile Material Disposition, *"Report to Congress: Disposition of Surplus Defense Plutonium at Savannah River Site"*, 15 February 2002.

15 Evgeny O Adamov, *"Supply of Fuel for Nuclear Power – Present Situation and Perspectives"*, Uranium Institute 24th Annual Symposium 8-10 September 1999, London

16 Statement by the Head of the Russian Federation Delegation E.O. Adamov to the 44th Session of the IAEA General Conference, 19 -20 September 2000

By abandoning the immobilization option, US favored Russia to develop a plutonium business. However, if US disposition program, even if it suffers delays, is on track, Russian program stands still. In fact, beyond the Russian will to create a MOX business with its military plutonium stocks, there is no real market for the Russian MOX. European and Japanese electric utilities did not show any interest in Russian MOX[17], and the MOX market suffers already an over capacity problem that the Russian MOX program could only worsen.

c) The implcation of Europe in the plutonium disposition plan

• The US and Russia need European support for the technical implementation and funding of their disposal strategy.

- The European plutonium industry has a unique experience in fabrication and use of MOX fuel. COGEMA is part of the consortium, DCS, to build the US MOX plant in Savannah River Site. It is based on the design of the French MELOX plant, as should be the MOX plant the Russians plan to build in Seversk.
- The US, before their MOX plant is ready, developed a plan to accelerate the process of MOX fuel qualification in their reactors by having the Lead Test Assemblies (LTAs) fabricated in Europe. Two options are discussed: the fabrication in Belgium (P0 in Dessel), where the Government blocked the process in August 2002, or in France, where it could take place in the old ATPu plant in Cadarache, even though it has to stop commercial operation by July 2003 for safety reasons.
- Moreover, the plan needs financial support. According to the US, the required budget to start the plan is over 4 billion dollars for the US part, and nearly 2 billion dollars in Russia, which are to be funded by the international community.
- This could be achieved by direct support, through the G8, which the US recently announced it will have gathered 1 billion dollars, or half the needed support, by the end of 2003. The European Union and some Members States are pushed to contribute.
- Another form of financial support could come from direct contracts between Russia and European countries. The Russians already offer spent fuel management services to foreign countries, under attracting conditions that appear very vague on the eventual return of waste to client countries. They also consider to develop services providing MOX fuel using their plutonium surplus.

The implication of the European MOX industry has been reinforced because of delays dead-ends encountered by the DOE and the Nuclear Regulatory Commission (NRC) in the development of the program. In fact, development steps have been fixed in the Base Contract:

- design and licensing of a plutonium/MOX fuel fabrication facility at Savannah River Site;
- design and licensing of nuclear reactor modifications at Duke Power Company's Catawba and McGuire Nuclear Power Plants near Charlotte, NC and Rock Hill, SC; (although Virginia Power Company's North Anna 1 and 2 nuclear power reactors are still listed as mission reactors in the contract);
- qualification of plutonium/MOX fuel for use in U.S. light water reactors (LWR);
- design and certification of a first-of-its-kind plutonium/MOX fuel shipping package;
- fabrication and irradiation of plutonium/MOX fuel Lead Test Assemblies

The last step, which includes fabrication of Lead Test Assemblies (LTAs), is a very important step before commissioning of the future SRS MOX plant planned for 2008. In fact, this key step is fundamental to qualify both the MOX fabrication process, the advanced MIMAS process, chosen for the SRS MOX facility, and the MOX fuel in reactors. However, the initial manufacturer, the Los Alamos National Laboratory, failed to produce the LTAs because of delays and costs. From this point, US turned toward European facilities to fabricate the LTAs to speed the qualification step. In June

[17] See WISE-Paris News, *"Electricity companies refuse to use Russian plutonium"*, Bulletin n°19 France, November 2000
http://www.wise-paris.org/english/ournewsletter/19/news.html#news

2000, the Eurofab plan was set up and became a key point of the European implication in the whole plutonium disposition plan.

The main European companies potentially interested in fabricating the LTAs, COGEMA and Belgonucleaire, support the Eurofab arguing that it would be a perfect opportunity for them to contribute to the international disarmament and nonproliferation.

The LTA fabrication is a very special process because of the initial material used: the weapon-grade plutonium used to fabricate MOX is probably enriched at more than 93% in Pu-239. The specific composition of this weapon-grade plutonium implies a number of manipulation issues at every step of the fabrication process and raises the issues of radioprotection and proliferation resistance of the Eurofab. Weapon-grade plutonium is a highly fissile material of great interest regard to nuclear weapon fabrication and necessitates anyway further safety and security precautions in the fabrication process to avoid criticality accident. As of May 2003, no public information has been released on how physical protection of the plutonium would be assured during its transfer between US and Europe, and no feasibility study regard to the commercial MOX fabrication process has been issued.

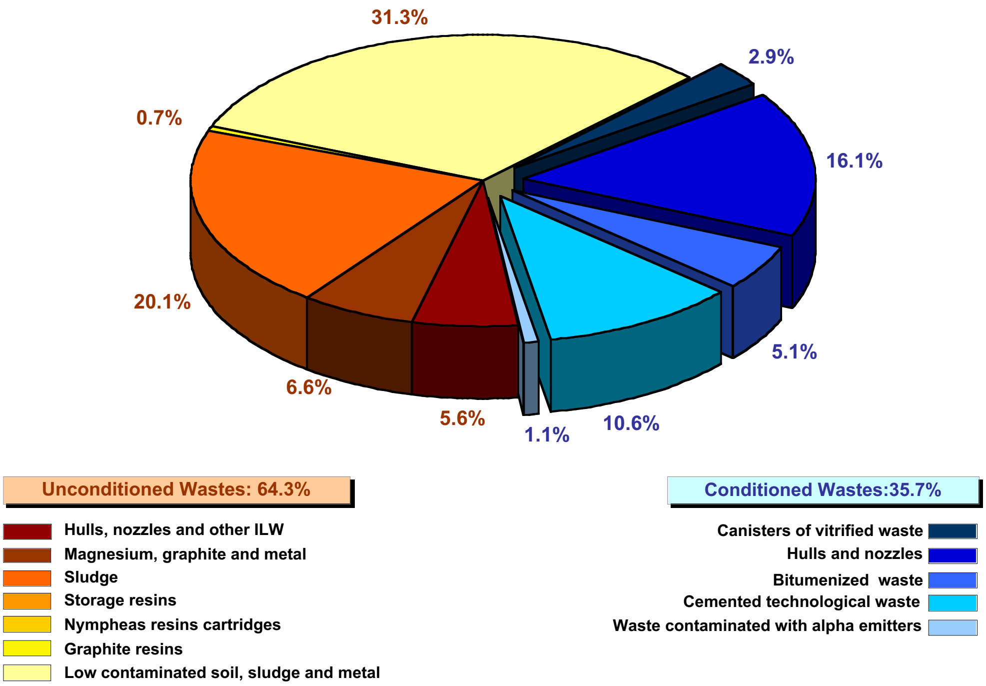
4.2. The multiplication of storage and transports

Compared with direct disposal of spent fuel, reprocessing multiplies the sources and the forms of radioactive waste, with characteristics different enough to imply different management needs, and stretches the delays before the implementation of final solutions. Its global logic of separation and concentration of the nuclear materials increases the needs for storage and transport of dangerous products.

a) Separation, concentration... and storage

In France, until the national agency for management of radioactive waste (ANDRA) was created in 1991, management of HLW and ILW by the reprocessing operators, i.e. CEA and COGEMA, was a long term intermediate storage strategy. To apply this strategy, conditioning of reprocessing waste has been chosen so that the wastes wouldn't be extractable from their inert matrix. Approximated figures are of around 15% of wastes for 85% of inert matrix per waste canister in general. This specific strategy conditioned until now the field of choices for management of reprocessing waste. With no adapted research program for the management of ILW and HLW, the only available management option has been restricted to an on-site long term storage.

Figure 7 Conditioned and unconditioned wastes at La Hague as of 31 December 1999 (in % of total volume)



Source: ANDRA, National Inventories of Radioactive Wastes, 2000

One should note that as of the end of 1999, 61,397 drums of bituminized sludge were in intermediate storage facilities on the Marcoule reprocessing site where the reprocessing facility UP1 closed in 1997.

Figures for HLW long term intermediate storage in France as of the end of 2001, reached approximately 11,000 tHM of spent UOX (of which 6,850 tHM at the La Hague site, and 4,150 tHM at EDF reactors sites), 450 tHM of spent MOX (of which 195 tHM at La Hague site and 255 tHM at EDF reactors sites) and around 11,300 canisters of vitrified waste (of which 8,300 canisters at La Hague site and 3,000 canisters at Marcoule site) for a total weight of around 4,500 t of vitrified HLW[18].

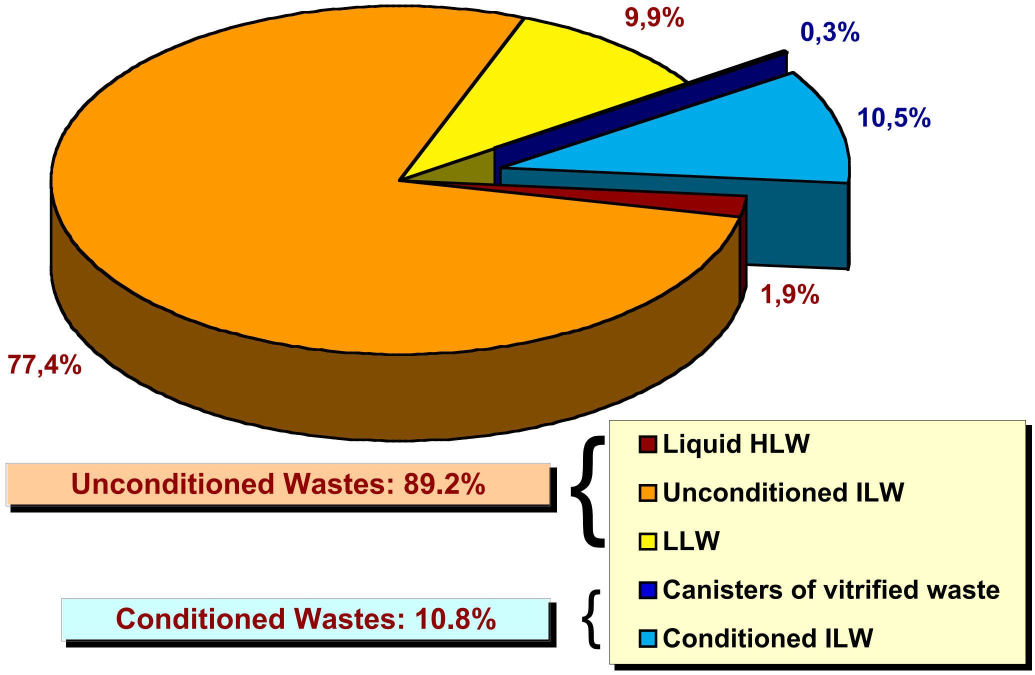
All these HLW are in intermediate long term storage facilities, cooling ponds for spent fuels, and ventilated shafts for vitrified canisters, with no clear view of the time schedule towards final disposal. Some vitrified HLW has already been in intermediate storage for 30 years (vitrification started in 1982).

Concerning the case of foreign radioactive waste produced by the reprocessing of foreign spent fuels, only a portion of vitrified HLW has been returned so far. As of the end of 2002, 1,596 canisters of vitrified HLW had been returned since the first shipment took place in 1995 toward Japan, 13 years after the first vitrification of foreign HLW. Reprocessing of foreign spent fuels should produce around 8,260 canisters of vitrified waste, of which less than 20% had been returned as of the end of 2002. The French management of foreign HLW is therefore comparable to the intermediate long term storage operated by COGEMA for EDF vitrified HLW. For radioactive waste other than HLW, it is noticeable that COGEMA presented projections for the return of compacted hulls and nozzles only for its German clients.

[18] P. Girard, Y. Marignac, *"Le parc nucléaire actuel"*, Commissariat Général au Plan, March 2000
ANDRA, *National Inventories of Radioactive Wastes*, 2000
COGEMA Web, compilation of weekly bulletins, intermediate storage situation, as of 30 December 2001
CEA, *"Les recherches pour la gestion des déchets nucléaires"*, in *Clefs CEA n°46,* spring 2002

Among all nuclear wastes produced by the British nuclear industries, management of the plutonium industry wastes is the most problematic. If France encounters difficulties in managing its reprocessing wastes, the British plutonium industry is even threatened by its lack of management of its own wastes. In fact, in September 2001, the Sellafield reprocessing plants were temporarily shut down after the Nuclear Installations Inspectorate (NII) judged that volumes of liquid high level nuclear waste were reaching unacceptable levels[19]. However liquid high level waste vitrification is the most advanced conditioning program of the British plutonium industry.

Figure 8 Conditioned and unconditioned wastes in the United Kingdom as of 1 April 1998 (in % of total volume)



Source: NIREX , Radioactive Wastes in the UK - 1998 Inventory, July 1999

The United Kingdom's delay in nuclear waste conditioning and management is symptomatic of its incomplete reprocessing-MOX loop, already underlined by the uncontrollable growth of its separated plutonium stock. As a consequence, the part of conditioned waste in the national radioactive waste inventory is lower than the one in the French inventory, illustrated by the La Hague situation.

Like HLW and ILW produced by the reprocessing industry, non-reprocessed spent nuclear fuels "beneficiated" of the intermediate storage strategy set up by the reprocessing plant operators. In fact, the lion share of the annually discharged spent fuels were sent to the La Hague cooling ponds, covered or not by reprocessing contracts. This has always been justified by projections made by COGEMA that all spent fuels stored at La Hague would some day or another be reprocessed, but turned La Hague ponds dedicated to spent fuel cooling before processing, into long term storage facilities.

[19] See WISE-Paris Others' News, *"Sellafield shuts plants as N-waste builds up"*, *The Guardian*, 22 September 2001 (http://www.wise-paris.org/english/othersnews/year_2001/othersnews010924.html)

Table 9 Intermediate storage of spent and fresh fuels in La Hague cooling ponds (as of 30 September 2002)

	France	Germany	Belgium	Switzerland	Netherlands	Australia
Spent LWR	6,961.0	346.0	—	77.0	10.0	—
Spent URE	44.0	1.0	—	—	—	—
Spent MOX	263.0	49.0	—	—	—	—
Spent MTR	0.5	—	0.3	—	—	0.2
Fresh MOX[a]	87.0	11.0	—	—	—	—

URE: Enriched Reprocessed Uranium; MTR: Material Testing Reactor

[a] For fresh MOX, figures as of 31 December 2001. Fresh MOX has disappeared in figures published by COGEMA since.

Source: COGEMA website, 2002

Current storage of thousands of cubic meters of nuclear wastes as well as thousands of tons of nuclear fuels, irradiated or not, on reprocessing sites in France and United Kingdom, raises the concerns of the risk brought by the concentration of a radioactive inventory which cannot be compared with any other case in the world. Moreover, the concentration of tens of tons of separated plutonium on these sites brings BNFL and COGEMA to the first ranks of the most proliferating industries in the world.

b) The multiplication of plutonium transports

The building of a French MOX industry during the 80s implicated the setting up of a 'plutonium network'. Three main installations dispersed on the French territory, of which UP2-800 and UP3 at La Hague for reprocessing, and ATPu at Cadarache and MELOX at Marcoule for MOX fabrication, constitute the national anchors of this network. One more MOX fabrication plant, the P0 plant at Dessel in Belgium should be added to the French reprocessing-MOX loop. However, a 'plutonium network' of this width implicates transports of plutonium between these installations, in connection with nuclear reactors in France and abroad, clients of the MOX loop. The French reprocessing-MOX industry is a good illustration of transports implicated by an industrial scale 'plutonium network'. Hereunder are presented the figures of nuclear materials flows implicated by the French reprocessing-MOX industry.

Table 10 Estimates of the total quantities of nuclear materials shipped in one year of the plutonium transports in France (tML U and/or Pu)

	EDF	Foreign	Total
Irradiated fuel	***950***	***289.6***	**1,239.6**
Irradiated UOX fuel	850	289.6	***1,139.6***
Irradiated MOX fuel	100	–	***100.0***
Plutonium oxide powder	***6.68***	***5.16***	**11.8**
Products of MOX fabrication plants	***100.4***	***39.9***	**140.3**
Fresh MOX fuel	97.4	39	***136.4***
MOX scraps	3.0	0.9	***3.9***
Total	**1,057.1**	**334.6**	**1,391.7**

Source: WISE-Paris, "Les transports de l'industrie du plutonium en France: une activité à haut risqué", February 2003

Table 11 Estimates of the number of packages shipped in one year of the plutonium transports in France (number of packages)

	EDF	Foreign	Total
Irradiated fuel	***297***	***61***	**297**
Irradiated UOX fuel	182	61	***243***
Irradiated MOX fuel	54	–	***54***
Plutonium oxide powder	***50***	***39***	**89**
Products of MOX fabrication plants	***50***	***18***	**68**
Fresh MOX fuel	27	11	***38***
MOX scraps	23	7	***30***
Total	**336**	**118**	**454**

Source: WISE-Paris, "Les transports de l'industrie du plutonium en France: une activité à haut risqué", February 2003

Table 12 Estimates of the quantities of plutonium shipped in one year of the plutonium transports in France (tPu)

	EDF	Foreign	Total
Irradiated fuel	***14.55***	***3.22***	**17.77**
Irradiated UOX fuel	9.51	3.22	***12.73***
Irradiated MOX fuel	5.04	–	***5.04***
Plutonium oxide powder	***6.68***	***5.16***	**11.84**
Products of MOX fabrication plants	***6.68***	***2.65***	**9.33**
Fresh MOX fuel	6.48	2.59	***9.07***
MOX scraps	0.20	0.06	***0.26***
Total	**27.91**	**11.03**	**38.94**

Source: WISE-Paris, "Les transports de l'industrie du plutonium en France: une activité à haut risqué", February 2003

4.3. The increased risks of the plutonium-MOX plan

The services offered by the plutonium industry to dispose of the military plutonium stocks in excess represent an increase of threats to the local and global security that are contrary to the supposed goal of disarmament. As compared to more direct, cost-effective alternatives for the immobilization of plutonium, the MOX option is extending delays and increasing storage and transports of highly dangerous materials, in first place separated plutonium.

In the post 9/11 world, where proliferation and terrorists threats have become even more serious, and the unthinkable is now possible, these effects turn into a growing vulnerability.

a) The end of the probabilistic approach

Risk assessment is largely based on a probabilistic approach. The risk assessment process is a two phase process: the first step consists in a general risk identification; it takes into account the specificity of a definite installation to assess the associated risks, and lists all possible specific risks bound to the installation with regard of the plant surrounding. A first impact quantification is calculated through dedicated guidelines. The second step is supposed to quantify and give a hierarchy of the risks due to their associated impacts.

To perform this hierarchy, probability of occurrence is applied to each risk identified during the first step. Finally, probability thresholds are given in the safety guidelines to restrain the risk assessment area to the only 'most probable' events. For each risk type, probabilities lower than the given threshold allow to eliminate the risk from the risk assessment process, whatever impact it may have.

Somehow, one may consider that the affected probability weights the risk potential impact. That means that a definite event with a large and wide impact, but with a very low probability, even if not equal to zero, can be ignored.

However, since the 9/11 events, the probabilistic approach has been severely challenged with the demonstration that unimaginable events ignored by the probabilistic method, because under the probabilistic threshold, had now to be taken into account because of voluntary nature.

b) The proliferation risk

• While the proliferation risk has always been a concern, the recent undermining of the international safeguards system under the responsability of the International Atomic Energy Agency, and the new threat that terrorists groups could also try to develop some nuclear device, enforces the need to limit the potential sources of proliferation. On the contrary, the plutonium disposal strategy is raising tremendous risks.

- The MOX strategy, in comparison with options of direct immobilization, implies more delays, storage, transports and manipulation of so-called "weapon-grade" plutonium that undoubtedly increase the risks of proliferation through diversion of some material. About 1/10,000th of the 68 tonnes that will circulate under the US-Russian plan is enough for the fabrication of a nuclear device.
- Moreover, this strategy is a support to the pursuit of the activities of the reprocessing industry, including the management of its separated plutonium stocks through the MOX option, which also increases the proliferation risk by circulating so-called "reactor-grade" plutonium.
- Contrary to declarations from the plutonium industry, there is no discussion that this plutonium, although less suitable, is still perfectly usable for the making of bombs. The daily output of a reprocessing plant like La Hague or Sellafield is enough plutonium to make a bomb.

c) The increased vulnerability to terrorist threats

• The attack of the World Trade Centre created a new terrorist threat to the world, which raises unthinkable risks for the nuclear industry. Because they tend to extend storage and transports of highly dangerous materials, the reprocessing and MOX industry are particularly exposed to this new threat.

- Since the 9/11 events, the probabilistic approach has been severely challenged with the demonstration that unthinkable events, ignored by the probabilistic method because they fell under the probabilistic threshold, had now to be taken into account as voluntarily provoked.
- In that perspective, the reprocessing industry is of particular importance. On one hand, the structure and organization of the plutonium industry makes it highly vulnerable, while on the other hand the nature of the materials involved makes the risk more sensible, i.e. there can be severe consequences in the event of an attack.

Figures of stocks and transports of nuclear materials, and especially plutonium, as presented above, underline the importance of one of the most important sources of risk, among all of the categories of dangerous substances in general.

On one hand, the source of risk constituted by the plutonium stocks, together with thousands of tons of stored spent nuclear fuels and thousands of cubic meters of diverse radioactive wastes, designate the reprocessing plants as very sensible targets. Reprocessing plants at La Hague concentrate a stock of radioactive substances that largely exceeds those of all the French nuclear reactors put together. WISE-Paris estimated that a serious accident scenario in only one of the irradiated fuel cooling pools at La Hague could lead to the release of radioactive cesium up to over 60 times the amount release during the Chernobyl accident.

A voluntary crash of an airliner on La Hague, a hypothesis still judged « improbable » by COGEMA, but which today has become « plausible », could result in such a scenario. Neither the reactors, nor the La Hague facilities are designed to resist such an impact. The crash of a big plane on La Hague could severely damage or destroy, besides the spent fuel pools, other parts of the plant such as the storage of high active wastes and the store of tens of tons of plutonium, the consequences of which would be impossible to price.

On the other hand, the hundreds of nuclear materials transports implicated annually by the reprocessing-MOX industry, constitute the second weakness point of this industry. Dangers in the handling and transport of plutonium arise from the risk of criticality (start of a fission reaction), the substance's high radio-toxicity, and from the problem of proliferation (theft of nuclear material to make atomic weapons). As illustrated by the events of 11 September 2001, the threat of terrorist activity targeting transport, or hi-jacking of plutonium for its use in a nuclear device or "dirty bomb" has now to be considered an increased risk.

Under normal transport conditions, the levels of neutron radiation and contamination of shipments, coupled with the number of packages transported each year, result in significant doses for the personnel involved in the transport. They also give rise to a risk for the population—arising from the possibility of inhalation, ingestion or deposition of highly radioactive particles—which is generally ignored.

Safety of plutonium transport is, within the logic developed by the French authorities along international guidelines, guaranteed by regulatory requirements on the capacity of the transport packages to withstand impacts (drop through 9 metres onto a hard rigid surface or through 1 metre onto a metal bar) and to withstand fire (30 minute hydrocarbon fire at 800 °C) and immersion (depth of 15 metres of water for 8 hours).

It seems that the mechanical and thermal design of the transport packages is minimal, or even inadequate, given the conditions of transport encountered on the roads and the hypotheses taken into account for design of the road infrastructures. According to the statistics on transport of dangerous substances and accidents, the regulatory requirements are not sufficient to guarantee total integrity of packages, and therefore confinement or sub-criticality of the materials transported, in 1 in 20 road accidents involving impact and half of the accidents involving fire.

In an accident situation, significant release of radioactivity can be envisaged. Release will depend on the type of transport (rail or road), the quantities and categories of materials involved (irradiated fuel, plutonium oxide powder, un-irradiated MOX fuel) and on the circumstances of the accident.

d) The new potential of danger

The new potential of danger of the reprocessing-MOX industry, as it would be perpetuated through its support to the disposal of military plutonium, is illustrated by the evaluation of possible scenarios of accidents or terrorist attacks and their consequences.

- The first concern is the voluntary crash of a large plane on the storage facilities of the reprocessing plants – both Sellafield or La Hague store probably more radioactivity than is stored in total in other nuclear facilities in their countries. Independant studies conducted after 9/11 have concluded that a plane crash on facilities such as one spent fuel in La Hague or the high level liquid waste storage in Sellafield could result in consequences tens of times that of the Chernobyl accident.
- The second concern is the potential use of plutonium transports as a radiological bomb in urban areas, through a rocket attack against such a transport. Trucks carrying plutonium powder circulate accross France every week, under such bad secrecy conditions that Greenpeace protesters were able, in February 2003, to stop one of them. Scenarios of attack conclude to a potential impact on zones covering about 250 km^2, or more than 100,000 people in urban areas, with possible hundreds of fatalities.

• *The consequences of a plane crash on a reprocessing plant*

To design the facilities against the only risk taken into consideration, that of the crash of a small aircraft (i.e. below 5.7 tons), two types of planes are judged as representative: 1.5-ton single-engine

CESSNA 210 (propeller engine) and a 5.7-ton twin-engine LEAR JET 23 (twinjet), both of which are supposed to hit the facilities at a speed of 100m/s.

However, 9/11 events implicate that large planes should be considered as potentially usable as missiles against buildings.

Table 14 **Evaluation of the energy released by the crash of different types of aircraft**

Aircraft type	*Mass (tons)*	*Speed (m/s)*	*Kinetic energy (MJ)*	*Energy/ CESSNA*	*Energy/ LEAR JET*	*Fuel (liters)*
General aviation						
CESSNA 210	1.5	100	7.5	x 1.0	x 0.3	~ 350
LEAR JET 23	5.7	100	28.5	x 3.8	x 1.0	~ 1,500
Commercial aviation						
BOEING 747	397	252.8	12,680	**x 1,690.7**	**x 444.9**	216,840
BOEING 767	179	236.1	4,994	**x 665.9**	**x 175.2**	90,770
AIRBUS 320	77	243.9	2,289	**x 305.3**	**x 80.3**	29,660
AIRBUS 380	560	261.7	19,177	**x 2,556.9**	**x 672.9**	310,000

Source: WISE-Paris, "La Hague Particularly Exposed to Plane Crash Risk", 26 September 2001

The Cessna is 120 times less heavy, and contains 260 less jet fuel in its tanks than a Boeing 767. The study published by the NRC in October 2000, in the chapter dealing with potential plane crashes, presents the possible resistance of a site to the penetration of an aircraft.

Table 15 **Penetration probability in terms of location and thickness of reinforced concrete**

		Penetration probability (%) relative to the thickness of concrete (cm)			
Location of the site	**Aircraft category**	***30.48 cm***	***45.72 cm***	***60.96 cm***	***182.88 cm***
≤ 8 km away from airport	Small ≤ 5,4 t	0.3 %	0 %	0 %	0 %
	Big > 5,4 t	96 %	52 %	28 %	0 %
> 8 km away from airport	Small ≤ 5,4 t	28 %	6 %	10 %	0 %
	Big > 5,4 t	100 %	100 %	83 %	32 %

Source: NRC, October 2000

Among the nuclear facilities located on the French territory, the scenario of a targeted plane crash on COGEMA's La Hague facilities would be the most extreme in terms of impact on the environment and public health: the spent fuel reprocessing facilities in the Nord-Contentin represent in fact an inventory of radioactive substances several orders of magnitude larger than that of a nuclear power station. The site is in particular used to store thousands of tons of irradiated fuel, tens of tons of separated plutonium and thousands of cubic meters of radioactive wastes.

On 30 June 2001, COGEMA presented the situation of its storage pools: 7,484.2 t of varied nuclear fuels (of which 7,077.7 from France) for a total storage capacity of 13,990 tons, spread in five pools. In addition, there are more than 55 tons of separated plutonium[20], which is conditioned in the form of

[20] There was in France 81.2 t of "unirradiated" plutonium as of 31 December 1999, of which 37.7 t belonging to foreign companies, according to a statement made by the French Permanent Mission to the International Atomic Energy Agency (IAEA), INFCIRC/549/Add.5/3 of 19 March 2001. The same declaration indicated that 55 t of "separated" plutonium (i.e. in the form of oxide powder) are stored in the reprocessing plants, in La Hague.

oxide powder, more than 1,400 m3 of highly radioactive glass, more than 10,000 m3 of hulls and nozzles (of which 75% contained in temporary containers) and more than 11,650 m3 of radioactive sludge (of which only 20% are stabilized)[21], as well as thousands of cubic meters of other less radioactive wastes and unknown quantities of chemical products, of which some are highly flammable, such as solvents.

The accidental scenario calculation for La Hague plants, consist in a cesium release hypothesis, based on a study[22] published in October 2000 by the US Nuclear Regulatory Commission (NRC). In the study, the NRC calculated the risk of a «zirconium fire» following a loss of water in the storage pool of irradiated fuels. The NRC study shows that, should the temperature at the level of irradiated fuel for light water reactors reach 900°C approximately, the «zirconium fire», self sustained by various chemical reactions, would lead to the release of 50 to 100% of the volatile stored substances on site. The release periods vary according to the type of fuel and the configuration of the pool but the authors estimated that 4 to 8 hours are necessary in the case of light water fuels before a «substantial release» of fission products takes place. Besides, they underlined that criticality calculations should be specifically undertaken in the case of particular fuels such as MOX.

The impact analysis is a rather simple evaluation of the order of magnitude, because we assumed identical dispersion conditions as in the case of the Chernobyl accident. However, considering the exposure scenarios of the Chernobyl accident, the result then obtained, based solely on the stock of cesium in the spent fuel storage pool D (the smallest one), assuming that it is filled up to half of its nominal capacity of 3490 t, (corresponding to the present average saturation level of La Hague's spent fuel storage facilities), and supposing a release of up to 100% of the contained cesium, shows that a major accident in this pool could have an impact up to 67 times that of the Chernobyl accident.

In other words, a release limited to only 1.5% of the stock of cesium in a half full pool D would be consequently comparable to the release of cesium during the Chernobyl accident.

Sellafield vulnerability regarding aircraft crash stems in particular from its 1,550 m^3 of liquid high level waste in storage, which represent a non conditioned and therefore very volatile inventory of liquid fission products. In addition, over 79.9 t of separated plutonium in powder form were in storage on the site as of 31 December 2001.

With its French equivalent in La Hague, the Sellafield site concentrates the largest inventory of radioactivity in Europe. With nominal reprocessing capacities of 1,500 t per year of Magnox fuel for the B205 plant and around 1,200 t of oxide fuels for the B570 THORP[23] plant, Sellafield differs however from the La Hague site[24] by the way reprocessing have been operated during the last decade.

Frequent operational problems have led to low load factors of the reprocessing lines during the last 12 years, as well as the waste conditioning facilities. During these years, waste has been accumulating year after year of which hundreds of cubic meters of liquid high level waste.

The unavailability of the vitrification facility, which achieved a production of only 34% of its nominal capacity over the last decade, made the temporary stock of liquid fission products grow to more than 1,550 m^3 as of September 2001. That situation has been considered unacceptable by the Nuclear Installations Inspectorate in late September 2001. The following closure of the two reprocessing plants on 22 September 2001 can be interpreted as BNFL's response to the NII warning. Opening of two of the three vitrification lines in October 2001 (according to BNFL) will not rule out the particular risks that will continue to remain for years.

In order to simplify the approach, we limit our consideration in the present paper to the question of caesium-137. The choice is justified by the experience of the Chernobyl accident. Many radionuclides in various quantities were released in the course of this accident, but the release and dispersion of

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[21] Calculations made by WISE-Paris and based on ANDRA's national inventory of wastes, edition 2000.

[22] US NRC, *"Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants"*, October 2000.

[23] Thermal Oxide Reprocessing Plant.

[24] See WISE-Paris briefing, *"La Hague Particularly exposed to Plane Crash Risk"*, 26 September 2001.

caesium-137 accounts for about three quarters of the long term and collective offsite exposure following the reactor accident.

The B215 building, which is housing all of the 21 tanks of liquid high level waste is partitioned in cells separating the different storage tanks. However, the 1-8 tanks of 70 m^3 capacity are grouped by two for one cell and each of the 9-21 tanks of 160 m^3 capacity are placed in single separate cells.

The average composition of the high level liquid waste stored at Sellafield gives the figure of around 1.63 kg of caesium-137 per cubic meter of fission products solution (5.26 TBq or 1.63 g per liter). It can therefore be assumed that the total inventory of caesium-137 in the 21 tanks is currently around 2.53 t of which 17 kg in the 1-8 tanks and 2,353 kg in the 9-21 storage tank[25]. Calculations have shown that in a "loss of cooling" scenario, the boiling temperature could be reached within 10-14 hours and that significant evaporation could start after 12.5 hours. However these calculations do not take into account the high thermal input of the jet fuel fire following a plane crash which could probably significantly shorten these figures.

However, the scenarios of caesium-137 releases should not be limited to the rupture of a single storage tank alone, but should also take into account the possible "domino" effect that could lead to the release of the radioactivity contained in several storage tanks. The UK Nuclear Installations Inspectorate (NII) has described the safety level in B215 "*where active systems, requiring operator control, are needed to keep the HAL [liquid high level waste] in a safe state.*" In fact, the cooling circuits of the different storage tanks are not absolutely independent, and a single storage tank accident would likely lead to the disability of other cooling circuits (because of fire and/or explosion) which itself would finally engender boiling and release from some other storage tanks. We can therefore assume that because of the possible "domino" effect in loss of cooling systems, a scenario of the release of all the caesium-137 contained in the 21 storage tanks cannot be ruled out.

Moreover, considering the dimensions of a commercial airplane such as a Boeing-767, it seems highly optimistic to look at the consequences of a single storage tank release. A direct hit on the B215 would certainly concern more than one storage tank. The projection of the potential zone of damage in the event of a large plane crash shows that large parts or even the entire building could be affected.

On the hypothesis of a release of 50% of the B215 caesium-137 inventory, such an accident would lead to up to 48 times the quantities of caesium-137 released during the Chernobyl accident (or 26,4 kg).

With the radioactive caesium-137 inventory of the high level waste tanks reaching about 100 times the quantity released at Chernobyl, even a limited release of 1% of the total ceasium-137 inventory, the dimension of the impact under such a scenario would be still comparable to the Chernobyl accident.

• *The consequences of an attack against a transport of plutonium powder*

It is rather easy to imagine a scenario of attack on a plutonium oxide transport, able to generate consequences for the surrounding populations. For memory, one will recall that the attacks of 11 September 2001 implied 19 people ready and able to suicide with the only aim of achieving their malevolent action.

A scenario of attack of a plutonium transport could bring into play a gunner, ambushed on a bridge, equipped with a rocket launcher, as well as a driver controlling a suicide truck loaded with hydrocarbons. In this scenario, we chose to place the attack during plutonium trucks transit, in the suburb of Lyon, a high density area, on their way between La Hague and either MELOX or ATPu MOX fabrication plants. As of 27 August 2001, a rocket launcher was seized at Saint-Fons, in Lyons suburbs, and it should be recalled that several companies make it possible to rent tankers, including to private individuals. In addition one can remember that on 19 January 1982, the Superphenix reactor was impacted by four shootings of rockets, causing significant material damages.

A scenario can therefore be developed as follows: the hydrocarbon truck follows the transport of plutonium to less than 5 km, distance covered in less than three minutes and half at the speed of

[25] Idem.

90 km/h. With a minimum of coordination, of walkie-talkie type, the gunner immobilizes the transport by one or even two shootings of rockets, the transport being unable to escape the highway, then the driver of the suicide truck comes in less than four minutes crashing into the plutonium transport container. A simple load, correctly laid out is then able to explode the fuel cistern.

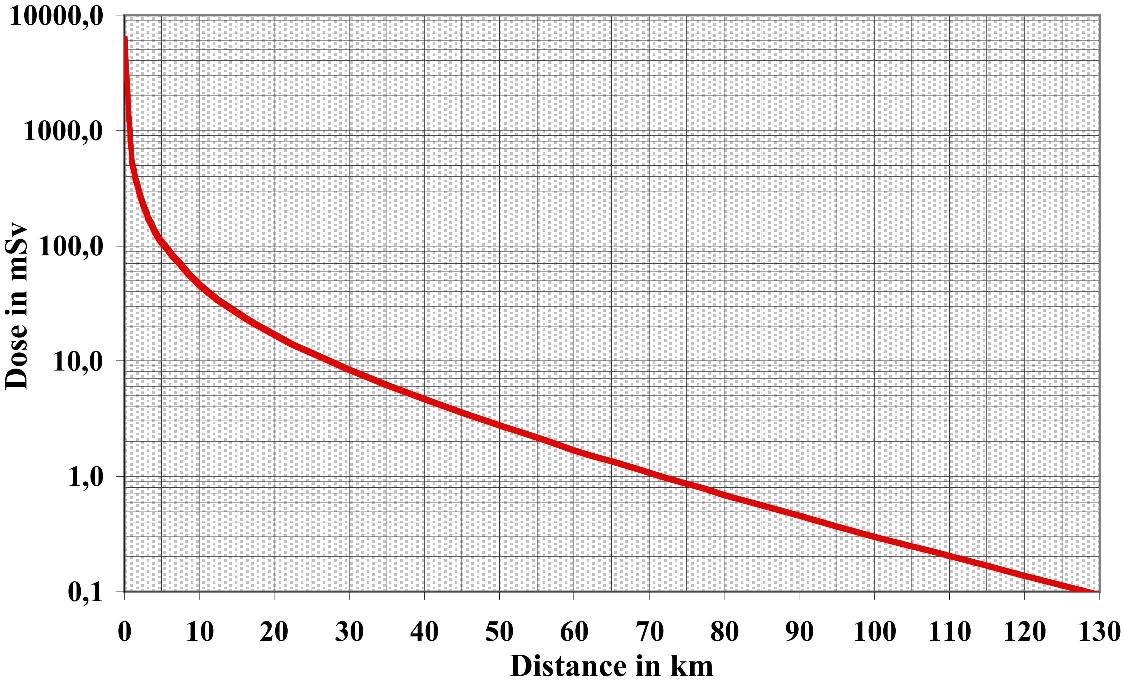
In such a scenario, which is not the most extreme conceivable, the coordination of two voluntary men is enough to reach a considerable impact on the integrity of the plutonium transport. Without precise knowledge on the various types of weapons, it is however difficult to evaluate the potential impact of the shootings, therefore of the continuation of the attack, on the transport container. However, it appears reasonable to think that such a scenario would have a devastating impact on at least a container FS47. We will thus take as assumption, the relaxation of 10% of the total contents of a FS47, one of the ten racked containers usually transported by a plutonium truck. Considering the average content of 13.5 kg of plutonium oxide under powder form, per container, a total quantity of 1,35 kg plutonium would be released by the impact of the rocket then dispersed by the fire caused by the suicide truck.

Considering that the plutonium powder will spread, under the wind effect, on an elliptic shaped surface, it is possible, while being based on calculations of dispersion and powder inhalation of plutonium, carried out by Steve Fetter and Frank von Hippel in 1990[26], validated thereafter by the American Department of Energy, to calculate the doses induced by the accident. In order to consider the population concerned with the impact of the accident, one will consider the density of population of 500 habitants/km2, corresponding to the furthest crowns of suburbs of Lyon.

The impact, estimated with the calculation code described above, shows that one can expect an ellipse of dispersion of about 100 km length on 10 km broad, that is to say a 250 km2 area, concerning a population of 125.000 inhabitants. The doses distribution inside this ellipse shows that the annual amount of 1 mSv, which is the prescribed limit for the public exposure, would be reached up to 70 km from the accident point. This distribution is represented on the following figure.

[26] S. Fetter, F. von Hippel, « The Hazard from Plutonium Dispersal by Nuclear-Warhead Accidents », *Science & Global Security*, 1990.

Figure 9 **Distribution of the dose to population, function of the distance from the accident point, with dispersion of 1,350 g of plutonium**



Source: WISE-Paris, "Les transports de l'industrie du plutonium en France: une activité à haut risqué", February 2003

The intrinsic mortality of such an accident, by inhalation of plutonium particles by the inhabitants of the concerned zone, would be likely to cause more than 500 fatal cancers. In addition, considering the general wind directions of this part of the Rhone valley, if the scenario described above took place in the northern suburbs, even remote of Lyon, considering the extent of the contaminated zone and the generated levels of contamination, it is possible that in the absence of a decontamination of an incalculable cost, the town of Lyon and its suburbs could become an exclusion zone for hundreds or even thousands of years.