Waste management

The failure of the “rational” waste management policy

> *“Another essential outcome of processing-recycling is to facilitate the management of radioactive waste. Compared to the direct disposal of spent fuel […], processing-recycling allows for the separation of non reusable radioactive waste from the other components, which provides a 5-fold reduction of the volume of ultimate waste arising from spent fuel (HLW, MLW and LLW generated through these operations). The other benefit from processing-recycling, through the recovering and reuse of uranium and plutonium which are responsible for an important share of long-term radiotoxicity, is a 10-fold reduction of the radiotoxicity of the waste.”*
>
> **Christian Bataille, Claude Birraux, Report of the Parliamentary office for the assessment of scientific and technological options, April 2007**

The French policy for radioactive waste management developed in tandem with strategic options regarding spent fuel management. The piling up of radioactive waste and nuclear materials stocks, a large part of them waiting for a long-term management solution to be implemented or even designed, shows no clear benefit from the reprocessing choice as regards waste inventories. However, the systemic use of biased methods and over-optimistic assumptions builds a much more favourable image which, in turn, is used to place reprocessing at the core of France’s long-term policy.

The buildup of the ‘processing-recycling’ doctrina

Reprocessing started as part of the military programme. The extension of French reprocessing into a large civilian programme was first justified by the need to produce (separate) plutonium to feed the start-up of fast breeder reactors. The saving of uranium resources was the driving argument. The impact on radioactive waste management was, if ever mentioned, really taken as secondary. And from the beginning, the argument was used in a very dubious way.

The CEA, when it strongly pushed for the launching of an FBR programme, started to develop an additional radioactive waste rationale. The argument used was based on the calculation of the radiological content of long-lived waste – therefore the projected evolution of its intrinsic radiotoxicity. Since some plutonium isotopes are amongst the most radiotoxic of radionuclides – especially long-lived ones – plutonium is the largest contributor to the aggregate radiotoxicity of spent nuclear fuel, if calculated over a sufficient period of time. (Long enough for the share of short-lived radionuclides to decline, although not long enough to let very long-lived radionuclides dominate.) The CEA conveniently chose a 100,000 year period, over which the 1 percent plutonium content of typical LWR spent fuel would represent 90 percent or more of the intrinsic radiotoxicity. Thus reprocessing the spent fuel and indefinitely reusing the plutonium would significantly reduce the risk associated with the final disposal of nuclear waste.

This argument does not elaborate, however, on the link between the intrinsic radiotoxicity and the real risk. One important point is that all radionuclides do not behave the same, also it depends on the type of disposal. It is therefore very interesting to note that the same CEA, at the very same time, developed such analysis in reports supporting a strategy of geological disposal. The reports used the new findings from the "natural reactor" found in Oklo, Gabon, where a slow chain reaction had been naturally sustained for millions of years in a geological structure of uranium ore, producing the same radionuclides as those to be found in spent nuclear fuel, making it possible to measure how they had migrated in the geological deposit. The CEA concluded that uranium and plutonium had practically not migrated, therefore it would be safe to dispose of spent nuclear fuel in deep geological repositories. In other words, the intrinsic radiotoxicity of plutonium would not be a problem if safely contained by a sufficient structure of appropriate rock.

More precisely, the right conclusion should be that disposal of spent fuel as such would reduce the danger of being actually exposed to the intrinsic radiotoxicity of plutonium, compared with a strategy where the most dangerous materials would be separated and circulated. If protection from plutonium was really taken as the main objective of spent fuel management, direct disposal should be implemented instead. On the contrary, the so-called "reprocessing-recycling" strategy means more routine exposure to the materials (especially for workers) and more potential for high exposure of larger populations in terms of safety and security.

The exclusion of 'reusable' materials from waste accountancy

Moreover, the calculation that reprocessing and re-using plutonium would reduce ten-fold the radiotoxicity is based on the assumption that it would be indefinitely re-used, which is very unlikely in current conditions for quantitative and qualitative reasons. First, the French nuclear reactors produce more plutonium than they can actually use. This is true under current conditions, where 22 of the 900 MWe reactors are licensed to use up to 30 percent of MOX fuel. (Made of mixed oxides from up to 95 percent of depleted uranium and less than 10 percent of separated plutonium.) In total, around 1,100 tHM (tons of heavy metal) of spent fuel are unloaded from EDF reactors each year, of which around 1,000 tHM are of uranium fuel (UOX) and 100 tHM of MOX fuel. With spent UOX containing around 1 percent of plutonium and spent MOX still containing between half and two-thirds of its initial plutonium content, EDF reactors would typically load in the order of eight tons of plutonium (in fresh MOX) and unload in the order of 15 tons (of which ten tons are in spent UOX, and five tons in spent MOX). Since only 28 reactors are technically designed to be able to use MOX, the balance would remain negative (i.e. the reactors would altogether produce plutonium) if MOX use was extended to its technical maximum.

Moreover, still under current conditions, only UOX fuel is reprocessed to separate the plutonium re-used in MOX. Only a share of around 80 percent of UOX is reprocessed, so as to maintain what the industry claims to be an "equilibrium of flux" between quantities of separated plutonium and re-used plutonium. This means that about 20 percent of UOX fuel, although placed in spent fuel pools at La Hague officially waiting for "postponed reprocessing", is actually not reprocessed but placed in interim storage. Also, spent MOX fuel is not reprocessed apart from in very small testing quantities, and is, like unreprocessed spent UOX, piling up in the spent fuel storage ponds of La Hague.

Finally, the industry has never actually achieved the balance between separated and re-used quantities. Since the first use of plutonium as MOX in one of its reactors, in 1987, EDF has constantly claimed that its policy for plutonium management is based on the fundamental principle of maintaining the "equilibrium of flux". Since 1987, the French separated plutonium stockpile went up from almost zero to 52.4 tons as of the end of 2006,[86] of which around 47 tons belong to EDF and are stored in various forms and plants. This includes quantities involved in fabrication processes, but also 26 tons in the form of excess plutonium powder, separated and stored at La Hague.

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[86] As deduced from the French Government's declaration on the civilian plutonium inventory to the International Atomic Energy Agency in December 2007. France declared a total inventory of 82.1 tons of unirradiated plutonium stored on its territory, of which 29.7 tons were foreign property.

The same accumulation process applies to reprocessed uranium (RepU), for which the industry does not even claim to try to maintain a balance. According to the latest comprehensive figures published by Areva, 21,550 tons of reprocessed uranium were stored in France as of the end of 2005, of which 18,960 tons are under French propriety – including 6,720 tons belonging to Areva, partly of foreign origin. These quantities put in interim storage are considered a “strategic stock”. By comparison, only 6,950 tons of separated uranium had, still according to Areva, been re-used in France or sent back to foreign clients as of the end of 2005.

The 2,200 tons of reprocessed uranium said to have been re-used by EDF actually correspond to a few hundred tons of re-enriched uranium fuel (REU) used in French reactors.[87] EDF has always limited the use of such fuel to two units of one nuclear power plant (Cruas 3 and 4). The use of REU seems to have declined or even ceased as of 2005-6. The difference between the quantity of reprocessed uranium said to be “recycled” and the actual quantity re-used in fuel corresponds to the six-sevenths share of depleted reprocessed uranium. This material is currently given up at storage sites in Russia where French reprocessed uranium is re-enriched. (Re-enrichment of RepU raises some problems in a gaseous diffusion plant like the French one in Tricastin, compared to centrifugation plants like Russian ones.)

In total, these figures outline how much the exclusion of nuclear materials (uranium and plutonium) from the radioactive waste inventory through the “reprocessing-recycling” strategy has more to do with myth than reality. In 2000, a report by Jean-Michel Charpin, Benjamin Dessus and René Pellat to the prime minister proposed a notable assessment of the real impact of this strategy over the lifetime of currently operating LWRs. It concluded that even reprocessing all the French spent UOX fuel – more than current quantities – would only lead to a 23 percent reduction in the amount of plutonium remaining at the end of the lifetimes of the existing reactors, compared to no reprocessing at all.

A comparison of the existing and projected stocks of nuclear materials supposedly to be re-used with the potential to actually re-use them in the reactors currently able to do so show that it is practically impossible (Table 13.) On the contrary, it can be forecast that pursuing the current balance of separation and re-use will increase the stocks of separated materials left unused when all existing reactors are shut down. In other words, a new fleet of reactors would be needed to proceed with the promised re-use, but this is never discussed as such, although it raises new concerns.

Table 13 **Past evolution and projection up to 2020 of ‘re-usable’ materials in storage**

Quantities in storage (tons heavy metal)	**1987**	**1997**	**2000**	**2010**	**2020**
Spent LEU fuel (~1% plutonium)	3,050	9,020	10,350	11,250	10,850
Spent MOX fuel (4-6% plutonium)	0	195	520	1,300	2,350
Spent REU fuel[a] (1% plutonium)	0	0	150	350	700
Reprocessed uranium	~7,500	~12,000	16,000	20,000	25,000
Separated plutonium	2.5	38	48	~48	~48
Availability of reactors[b] (years)	25 to 35	15 to 25	10 to 20	2 to 12	0 to 2

a. Fuel using re-enriched uranium separated through reprocessing (reprocessed uranium).

b. The availability of reactors is the calculated expected number of remaining operating years, as an average for the 28 reactors of 900 MWe in which EDF theoretically could pursue the use of re-enriched reprocessed uranium fuel or MOX. These reactors were started-up between 1977 and 1987, with a planned lifetime of 30 years, recently extended by the operator to 40 years. However, the extension has yet to be approved by the Nuclear Safety Authority on a case-by-case basis. The low and high values respectively correspond to 30 and 40 years of operation.

Source: WISE-Paris estimates based on CDP (2000), Andra (2006).

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[87] In total, 420 tHM of REU fuel had been manufactured in France as of the end of 2005, corresponding to the re-enrichment of 3,100 tons of reprocessed uranium for EDF and some foreign clients.

This bias heavily affects any future accountancy of nuclear waste to be disposed of. For instance, Andra (the French agency for radioactive waste management) presented in 2005 an assessment of a geological disposal facility using scenarios to estimate the global inventory under consideration. Andra concluded that the area covered by the underground repository would double if reprocessing ended in 2010, compared to a complete reprocessing of all spent fuel arising from the reactors currently operating. This actually compares the final management of all the nuclear materials concerned in the former case with the final management of just a minor share, as in the latter case around 200-300 tons of plutonium and 30,000 tons of reprocessed uranium would be put in interim storage to be managed later, but no waste arising from their future use or disposal was taken into account.

So it remains myth rather than reality that shapes the French policy for nuclear waste management. The distinction between nuclear waste and re-usable materials is the cornerstone of the 2006 law on radioactive waste management that followed 15 years of research on solutions – under a 1991 law – and based on a national public debate on the issue in 2005-6. This law codifies a specific, more permissive approach to defining radioactive waste, as compared to any waste in general environmental law,[88] concluding that "ultimate radioactive waste shall include any radioactive waste for which no further processing is possible under current technical and economic conditions, notably by extracting their recoverable fraction or by reducing their polluting or hazardous character".

Of course, this approach puts reprocessing at the core of a sustainable policy for radioactive waste management. The 2006 law states as a guideline that "the reduction of the quantity and toxicity of radioactive waste shall be sought especially by processing spent fuel and by processing and conditioning radioactive waste". Again, the indicators needed to define and precisely assess that "reduction" are not discussed or even made explicit.

The complication of waste management

One issue rarely discussed when it comes to "reduction" is the range and size of the inventory to be managed. France defines six classes of radioactive waste on the basis of their concentration and the lifetime of their radioactivity. (Long, short and very-short lived; high, intermediate, low and very low level.) In view of the resulting categories, the so-called "closing of the fuel cycle", which Areva generally summarises in a circular figure of flux, is supposed to simplify the problem by minimising the quantities of high-level or long-lived waste in the non re-usable materials in spent fuel.

A more comprehensive view of the impact of the reprocessing option in radioactive waste management shows that it definitely raises the level of complexity, as shown in figure 15. In the direct disposal option, there is basically one type of high-level waste to deal with – spent fuel assemblies – and one type of intermediate-level waste – irradiated pressure vessels and their internal core-support structures. There are also large volumes of long-lived low-level or very low-level waste in the form of uranium mill tailings and depleted uranium. In the reprocessing option, many more waste streams need to be dealt with.

First, there are the wastes from reprocessing itself: high-level vitrified waste, containing the minor transuranic elements and fission products; intermediate-level structural wastes – such as hulls and nozzles from LWR fuel assemblies; and intermediate-level process waste – sludge from liquid effluent treatment in particular. In its 2006 national inventory for the end of 2004, Andra distinguished no less than 38 categories of waste associated with reprocessing. These wastes are at various sites, including the reprocessing plants of Marcoule (shut down) and La Hague – a large part of them unconditioned or poorly conditioned, and France's disposal sites for short-lived intermediate-level and low-level wastes at the Centre de Stockage de la Manche (CSM), now closed, and the Centre de Stockage de l'Aube (CSA), which is still in operation.

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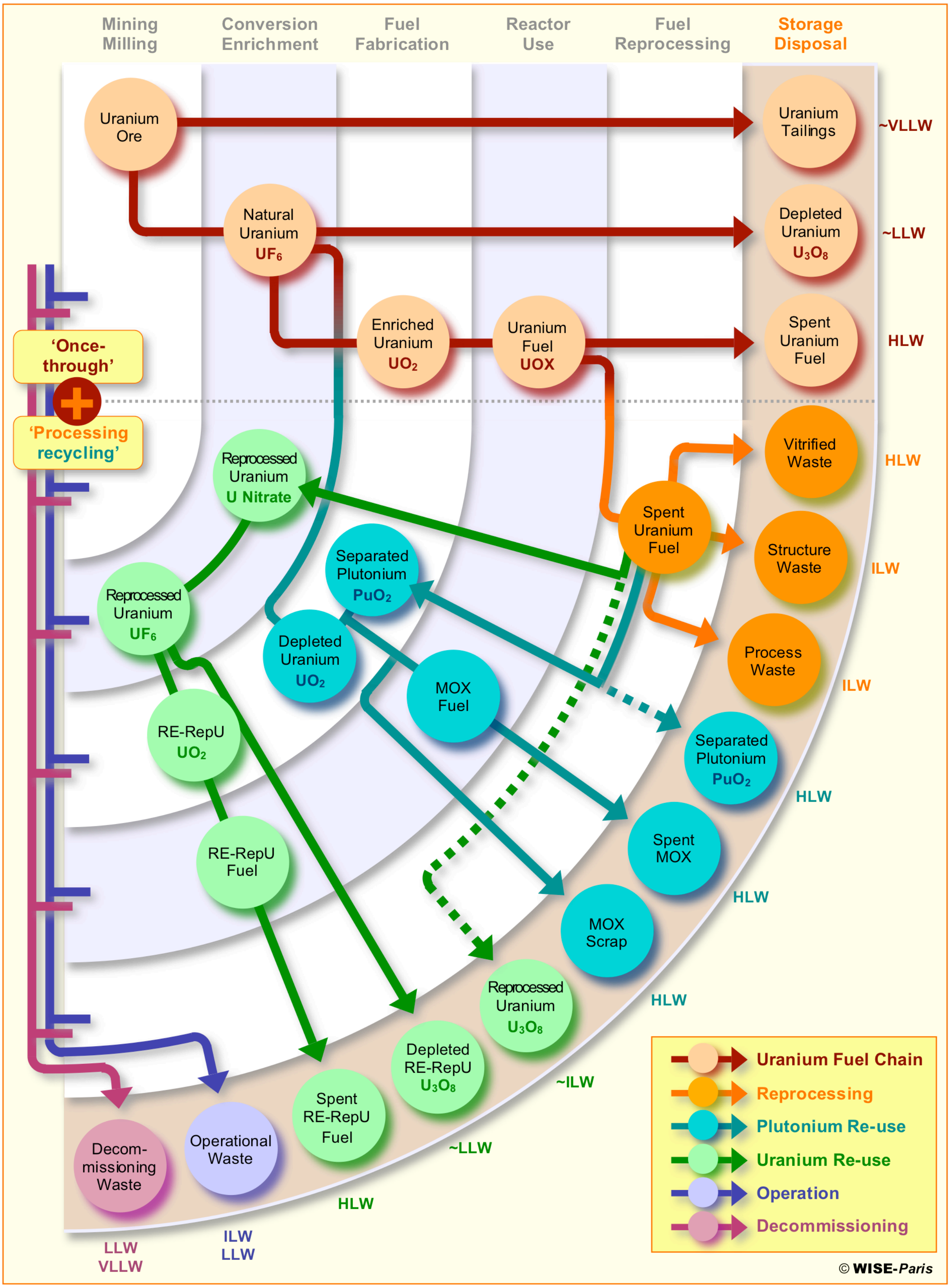
[88] Under the principles of general law, materials arising from industrial processes should be regarded as waste unless and until they are actually undergoing an industrial recycling process. Under nuclear law, it is enough that a material could be potentially reused at an undefined time in the future to be exempted from being classified as waste.

Figure 15 **Waste and materials generated in the nuclear fuel chain**



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Source: based on International Panel on Fissile Materials (IPFM), 2008

Unlike the case of direct disposal, however, the residual uranium in the fuel (95 percent of the original LEU) and plutonium (1 percent) are separated for reuse. Their reuse produces new irradiated material and waste streams: spent MOX fuel and scrap MOX from the fuel fabrication process, spent re-enriched reprocessed uranium fuel and the depleted reprocessed uranium from the re-enrichment process. Finally, each of the industrial processes eventually produces operational and decommissioning waste – especially intermediate-level waste from the reprocessing plants.

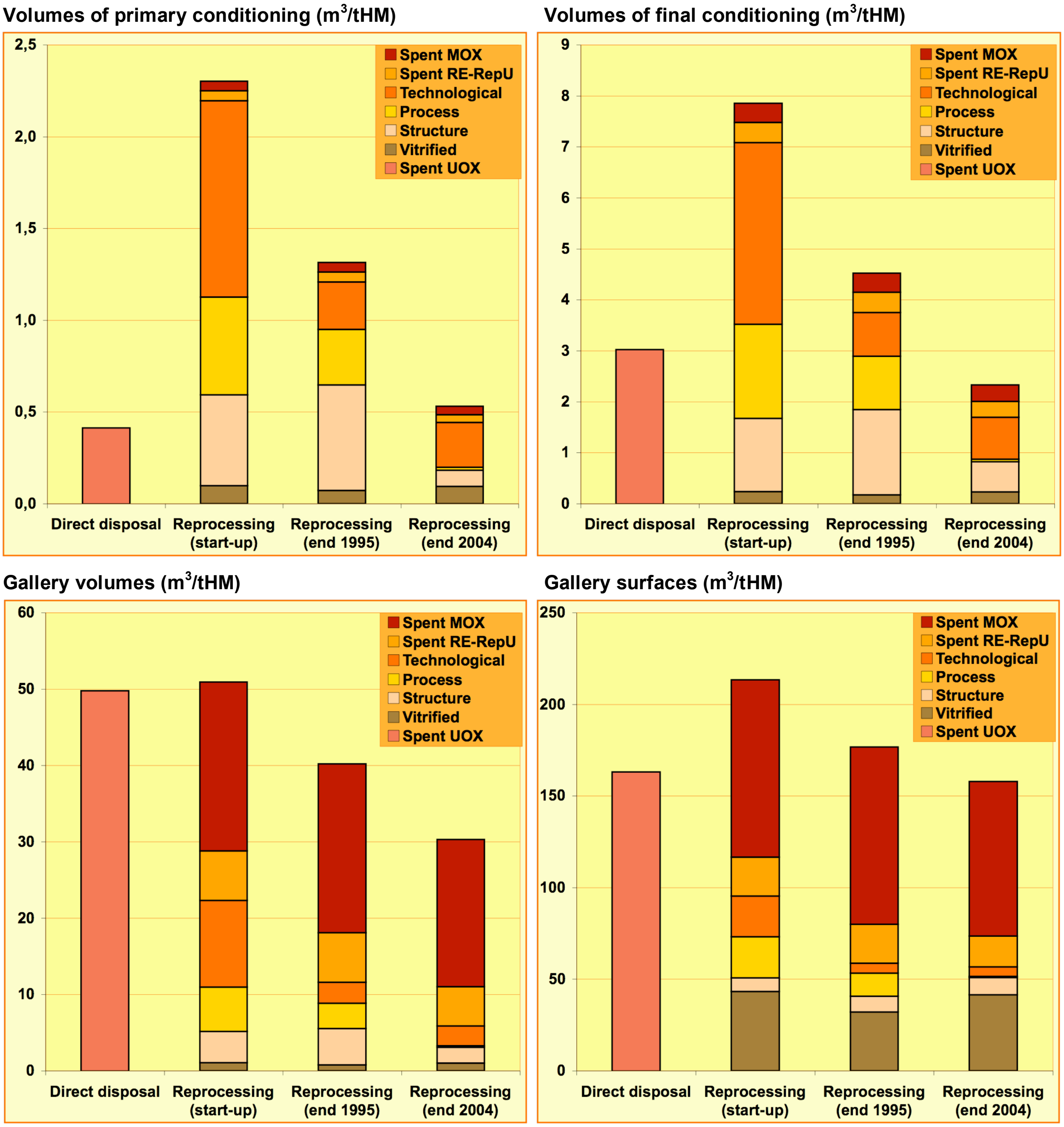
The failure of waste volume reduction plans

This complexity is dismissed in the industry's rhetoric, based on Areva's claim that "the volume of ultimate waste to be disposed of in any geological repository is drastically reduced by treatment-conditioning." According to Areva, reprocessing would produce 0.5 m^3 of intermediate (ILW) and high level waste (HLW) residues per ton of heavy metal (tHM, ie uranium) in uranium oxide fuel (UOX), compared to more than 2 m^3/tHM to be disposed of in case of direct geological disposal of the irradiated fuel. During the 2005-6 French national debate on long-lived radioactive waste management, EDF explained that reprocessing, compared to the direct storage of spent LWR fuel, is "a process that reduces by a factor of ten the volume of highly active long-lived waste".

This 'reduction factor' has become key for justifying reprocessing. But it is misleading in many ways:

- it ignores the complexity factor, and does not consider the waste arising from any future management of plutonium and uranium separated from vitrified waste, as compared to the direct disposal of all materials as spent fuel;
- it does not account for the increase of waste volumes of less active categories, in particular the large additional volumes of operational and decommissioning waste arising from the reprocessing and MOX fuel fabrication facilities;
- it is also based on current reprocessing technologies, including the latest achievements of waste compaction techniques, or even projected practices, and ignores the impact of earlier reprocessing. Reprocessing up to the end of 2004 produced an average of about 1 m^3 of high level and long-lived intermediate level waste for every ton of spent fuel reprocessed – two to three times the numbers quoted by Areva and EDF;
- in addition, it ignores the effect of packaging, or more precisely compares the volume of spent fuel with its packaging (seven and a half times larger than the volume unpacked) to that of reprocessing waste in primary condition before its final packaging. (From two and two-fifths to four times smaller than the volume of the final package);
- and it fails to consider the heat factor, which plays a major role in the volume of repository needed. (The warmer the waste is, the more space it needs around the package for cooling.) Vitrified waste packages have a thermal output in the same range as spent UOX fuel assemblies and might need as much space for cooling although their package volume is smaller. The main concern comes with spent MOX fuel, which reaches much higher thermal outputs, thus requiring much more space in disposal or a much longer interim storage. (E.g. 150 years against 50 years.)

Figure 16 Comparison[a] of waste volumes, gallery volumes and surface areas above the repository for the direct disposal and reprocessing options[b]



Volumes of primary conditioning (m^3/tHM)

Volumes of final conditioning (m^3/tHM)

Gallery volumes (m^3/tHM)

Gallery surfaces (m^3/tHM)

a. Calculations based on official assumptions (nominal values published by EDF, Areva, Andra, etc.).
b. Comparison for an equivalent energy output (one ton of fuel used in total in each option).

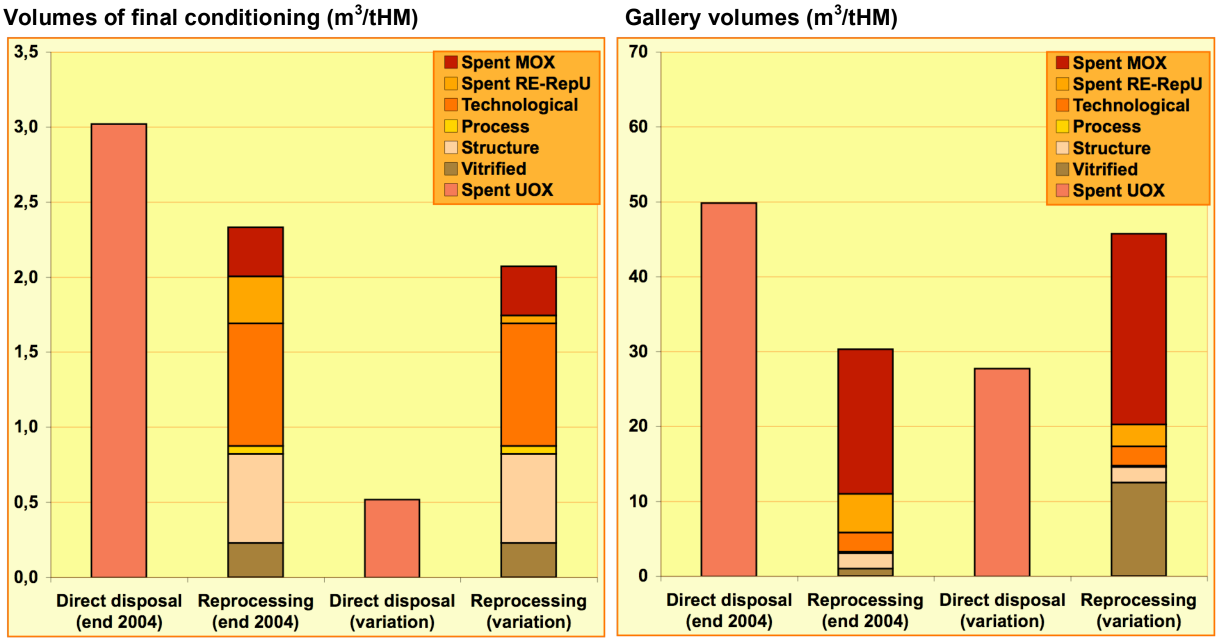
Source: WISE-Paris for the International Panel on Fissile Materials (IPFM), 2008, based on Andra, 2005 and IRSN, 2006

Figure 16 illustrates the impact of these factors on calculations. WISE-Paris compared the requirement for geological disposal of one ton of spent UOX fuel with those of the high-level and long-lived intermediate wastes from one ton of spent fuel in the reprocessing option (a ton shared between spent LEU fuel, assumed to be reprocessed, and the spent MOX and the re-enriched uranium fuels derived from it).[89] Results are shown according to the evolution of reprocessing techniques (start-up of the plants, operation in 1995, operation in 2004), and expressed in terms of volume of primary waste, final package, and volume and surface of galleries. Figure 17 shows how the ratios could evolve using less systemetic and favourable assumptions for reprocessing.[90]

Primary volumes are larger for the reprocessing option in all cases. Volumes of final packaging were in the range of two and a half times larger when reprocessing started, as compared to direct disposal, and only recent compaction techniques in La Hague provide a reduction to around 20 percent less than for direct disposal. The estimates for the volume or surface of the disposal, although more uncertain, are favourable to reprocessing but show no clear advantage. Moreover, alternative assumptions put the result in favour of direct disposal.

Altogether, both French claims about reprocessing in the past, and their future policy for radioactive waste management appear prone to controversy. Not only are the benefits not clear regarding the chosen indicators of intrinsic radiotoxicity and waste volumes, but the indicators themselves might not be best suited to characterise a sustainable waste management policy.

Figure 17 **Sensitivity analysis[a] for calculations of waste and gallery volumes for geological disposal in the direct disposal and reprocessing options[b]**



Volumes of final conditioning (m^3/tHM)

Gallery volumes (m^3/tHM)

a. Calculations based on official and alternative assumptions.
b. Comparison for an equivalent energy output (one ton of fuel used in total in each case).

Source: WISE-Paris for the International Panel on Fissile Materials (IPFM), 2008, based on Andra, 2005, GRS, 2005 and IRSN, 2006

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[89] The share of UOX, MOX and REU considered in one tonne (the unit for comparison on an "equivalent energy output" basis with the direct disposal of one tonne of UOX) depend on the grade of plutonium and reprocessed uranium obtained from spent UOX in fresh MOX and REU fuels. The comparison assumes that UOX fuel is reprocessed, with the corresponding waste voumes being produced; then it assumes that spent MOX and REU fuel are not reprocessed but disposed of (in line with the current absence of concrete plans to reprocess and reuse them).

[90] Alternative assumptions include: densified packaging of spent fuel, as developed in German designs for instance; the need for engineered barriers for vitrified waste galleries, while in Andra's current designs engineered barriers are only considered for spent fuel galleries; the application to MOX fuel of the same interim storage period as for UOX.

In terms of risks for the population and the environment, efforts supposedly driven by the need to reduce intrinsic radiotoxicity in final disposal actually increase the danger by creating more real or potential exposure situations, including to the most radiotoxic materials involved. These situations include the whole range of events affecting safety and security: specific waste produced or materials separated as result of the reprocessing choice; specific facilities for associated manufacturing and storage; and specific transports between them. They also include “normal” exposure arising from routine operations, such as the radioactive discharges of La Hague reprocessing plants. With authorized discharge levels up to 1,000 times the order of magnitude of those applying to the nearby nuclear power plant of Flamanville, La Hague plant discharges reach amounts equivalent to a nuclear accident like Kyshtym every year - amounts that would not be accepted in the case of a final repository.[91]

In terms of industrial complexity and costs, the focus on primary volumes is illusory. Not only is this objective hardly ever met, but it comes with a broad range of additional stocks of radioactive waste of various kinds, creating more volumes to deal with, and multiplying the range of technical issues to manage. R&D is still needed to find an appropriate solution for some specific wastes produced with no satisfactory concern for long-term management. This includes for instance 175 m^3 of packaged waste to arise from the future vitrification of a liquid highly active solution from the reprocessing of uranium-moybdenium spent fuel in the 1960s, or 40,000 containers to arise from the conditioning of bitumised sludge waste from La Hague.

Finally, in terms of democratic choices, the active implementation of reprocessing goes against the basic principle of leaving as many options as possible open until comprehensive assessment and decision processes have been conducted. The vitrification of minor actinides and fission products, once separated from uranium and plutonium, runs contrary to the claim that their separation and transmutation might be a solution to reducing their inventory in the future. Conversely, leaving plutonium and uranium in spent fuel placed in interim storage would preserve all potential to recover them for re-use should it be later decided to build new reactors able to use them, instead of forcing the construction of such reactors as a way to eliminate materials separated in advance. The illusion that “reprocessing-recycling” would strongly minimise the waste management problem has also been instrumental in advancing decisions towards the implementation of a geological repository for high-level and intermediate-level long-lived waste.

Although the 2006 law tends to close the options, the national public debate in 2005-6 outlined the need for a more complete analysis of the impact of reprocessing on waste management compared to other solutions. Meanwhile, the radioactive waste inventory is growing in size and complexity, and much of the final decisions regarding the serious implementation of long-term solutions for the management of French radioactive waste remain to be made.

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[91] It is interesting to note that when France decided to give up the dumping of radioactive waste in the Atlantic ocean, at the end of 1969, cumulated liquid discharges from La Hague since its start-up in 1966 already represented, without tritium, 340 TBq, close to the level of radioactivity France had dumped, evaluated to 353 TBq. More recently, La Hague still discharged 338 TBq into the sea over a ten-year period. (From 1996 to 2005, excluding tritium.)

Focus 14

Long-lived waste: still an unsolved problem

Under criteria of radiological period and level of activity introduced into French legislation in 2006, six classes of radioactive waste must be distinguished. Table 14 shows these categories and indicates their current management status. Short-lived intermediate and low-level wastes (SL-ILW/LLW) are disposed of in dedicated surface sites. A decision has yet to be taken, however, on the long-term management of the high-level and long-lived intermediate-level wastes (HLW and LL-ILW), most of which arises from spent fuel management. According to Article 3 of the law of 28 June 2006, research on the management of these wastes must be pursued in three “complementary” programs, each with its own deadlines:

- Partitioning and transmutation of long-lived radionuclides. A strategy is to be selected in 2012 and a prototype reactor is to be in operation by 2020; France, as part of the Generation IV Forum, focuses on liquid-sodium-cooled fast breeder reactors (Superphénix was in that category), and gas-cooled fast reactors as an alternative.
- Interim storage. By 2015, existing sites must be expanded or new ones created to satisfy estimated needs; and
- Geological disposal. The licensing process for a site is to be started by 2015 and it is to be put into operation in 2025. A laboratory is carrying out research work in Bures, and the eventual site is to be found in a geographical area of interest around there. The 1991 law on research in radioactive waste management had planned that a second laboratory be implemented, but it could never be sited due to the opposition of the local population in every potential area.

In addition, a plan for the long-term management of uranium mining legacy (mining sites and disposal of residues) should be presented before the end of 2008. Also, a repository site for long-lived, low-level waste (LL-LLW), including the graphite residues from the first generation of French reactors, should be put into operation in 2013. However, when opening the process to find the potential sites (through closed consultation of city councils in areas of interest) in June 2008, Andra acknowledged that a site could not actually start operation before 2018. This was not taking into account doubts casts by the independent consultative commission CNE in a July 2008 report on the feasibility of the safety demonstration for the graphite waste.

Table 14 **Categories of radioactive waste in France and their current management status**

		LL – Long-lived	*SL - Short-lived*	*VSL – Very short-lived*
	Period Activity	> 30 years	≤ 30 years > 100 days	≤ 100 days
HL High Level	> 10^8 Bq/g	Under study Art. 3 of the law of 28 June 2006 1 laboratory for geological disposal: **Bures**		Management by radioactive decay
IL Intermediate Level	≤ 10^8 Bq/g > 10^5 Bq/g	Under study Art. 3 of the law of 28 June 2006	Surface disposal[(a)] 1 closed facility: **Centre de Stockage de la Manche (CSM)** 1 facility in operation: **Centre de Stockage de l’Aube (CSA)**	
LL Low Level	≤ 10^5 Bq/g > 10^2 Bq/g	Study of dedicated subsurface disposal		
VLL Very Low Level	≤ 10^2 Bq/g	Dedicated surface disposal 1 site in operation: **Morvilliers** Limited recycling for some categories		

a. With the exception of specific waste, eg contaminated with tritium, for which dedicated management is still being studied.

Source: based on PNGMDR, 2007-8

Focus 15 The piling-up of nuclear materials and radioactive waste

Large amounts of nuclear materials and radioactive waste arise from the French nuclear programme. Final solutions only exist for some categories presenting the less radioactive inventories and/or the shorter periods. Even for those, some problems exist. The Centre de Stockage de la Manche (CSM), the first disposal site for low-level and intermediate-level short-lived waste, which started in 1969 and closed in 1994, when it was replaced by the Centre de Stockage de l'Aube (CSA), has been placed under surveillance for 300 years, much more than initially planned, because of uncertainties on the safety of its design and the specification and status of some of the waste it contains. Also, some low-level waste that should be disposed of in the CSA remains stored elsewhere because of poor or unsufficient conditioning.

Andra's national inventory of radioactive waste and nuclear materials, published in 2006, summarises the status of radioactive waste in France as of the end of 2004. The inventory presents waste volumes based on their final conditioning, either actual or projected, in the case of waste to be produced or waste already produced but still unsufficiently conditioned.[92] In total, close to 890,000 m^3 ok radioactive waste (in final primary conditioning) had been produced. Almost 40 percent, or 344,600 m^3 is linked to reprocessing. This does not account for some Marcoule waste that was dumped into the sea in 1967 and 1969, the equivalent final volume of which is estimated at 12,000 m^3 or more.

About 64 percent of the waste volume has been disposed of, 5 percent is stored with primary conditioning, and 31 percent with insufficient or no conditioning (see Figure 18). Although solutions exist for the disposal of short-lived low and intermediate level waste, representing 85 percent of the total, almost 25 percent of it is still stored at reprocessing plants with unsufficient conditioning. About 12.6 percent of the total inventory is still stored at La Hague and 21.9 percent at Marcoule. Almost 25 percent of the waste volume produced by La Hague is still stored there, 66 percent of it with inadequate conditioning. Almost 50 percent of the waste volume produced by Marcoule is still on site, with only 4 percent of it having received appropriate conditioning.

This inventory of materials already labelled as waste does not include any of the "re-usable materials" currently in stock, the volume of which is also set for continuous growth. These are spent fuels stored at La Hague (low enriched uranium or LEU, re-enriched reprocessed uranium, and MOX), separated plutonium and reprocessed uranium, and scrap MOX. One irradiated and one unirradiated core of the Superphénix fast-breeder, both still stored on the reactor site, are also not included.

Finally, the inventory includes large volumes of low or very low-level long-lived waste inherited from uranium mining in France, that started in 1949 and went up to 2001. With a total of 76,000 tons of uranium produced, this industry accumulated around 50 million tons of residues of treatment disposed of in 17 sites, and about 166 million tons of waste rocks.

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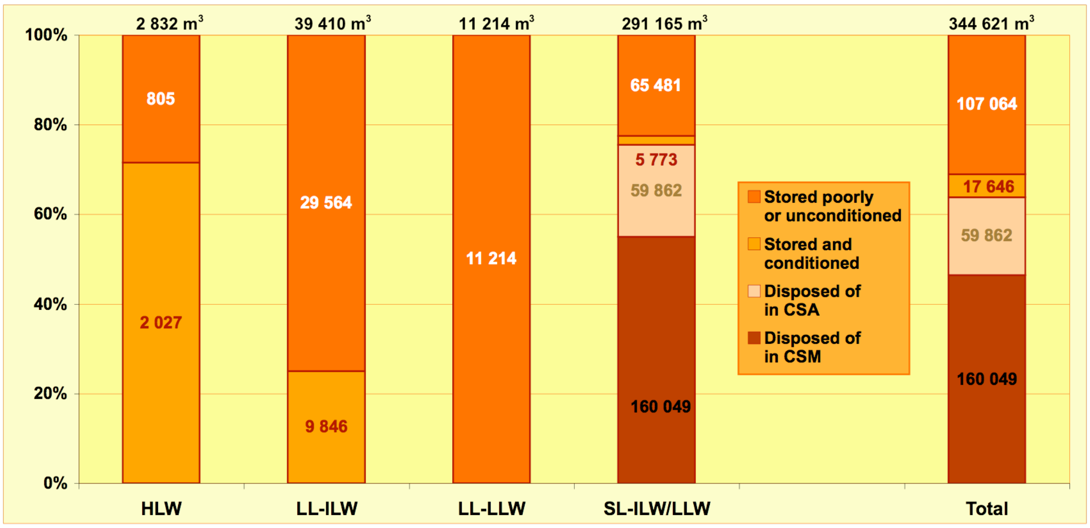
[92] This is subject to some uncertainty, as some of the conditioning techniques involved still remain to be fully developed. Also, the allocation to categories is based on the industry's arguable hypothesis that a large part of the yet-to-be-conditioned waste will qualify as short-lived intermediate-level and low-level waste instead of long-lived intermediate-level waste.

Figure 18 **Relative shares of different categories of French reprocessing waste conditioned, unconditioned, stored and disposed of**[a]



a. Status and quantities as of 31 December 2004. The volumes correspond to the realised, planned or estimated voumes of waste in their final condition.

Source: WISE-Paris based on Andra, 2006

Focus 16

Alongside waste, the problem of dismantlement

The legacy of nuclear activity does not consist solely of waste: it also entails the management of installations and their sites at the end of their useful life. For the time being, such activity involves only a relatively small number of installations, all old and very different from one another. The nuclear industry sees the carrying out of these various dismantling operations as preparation for the major phase of decommissioning which will be needed when the huge plants currently being operated have to be dismantled – plants such as UP2 and UP3 at La Hague (reprocessing) and Eurodif at Tricastin (enrichment), and above all EDF's whole complement of 58 reactors currently operating.

The difficulties encountered during the dismantling operations so far carried out or ongoing give little grounds for optimism. There is no existing example of a dismantling operation that has been carried through to the "green field" stage which is the theoretical goal of all operations of this type – in other words the disappearance of every trace of the installation, and the return of the land concerned to unrestricted use. The most successful decommissioning operations involve installations that have been cleared out, cleaned up and transformed into visitor attractions or monuments to the history of the nuclear industry – such as the building that housed France's first atomic pile, Zoé, at Fontenay-aux Roses, or that of the Chinon A1 "ball" reactor, a 70MWe reactor which entered service in 1963 and was turned into a museum in 1986. But these are exceptions.

As far as reactors are concerned, current experience relates essentially to models of the natural uranium-graphite gas line, for which the trial site is Bugey-1. This has been partially dismantled, as have the UNGG reactors at Marcoule and Chinon; dismantling is being completed at Saint-Laurent. In the course of this process, these plants have been turned into storage sites for their own waste. In the case of the CEA's reactors at Marcoule, treatment of steel and, above all, graphite waste was carried out in a fusion oven specially installed for the purpose. It has not been possible to apply this solution more widely. The process of dismantling EDF's UNGG reactors, involving the opening of the reactor vessels, is currently impeded by the lack of a management procedure for graphite waste, for which a definitive storage solution has still to be established in compliance with the 2006 legislation.

The dismantling of the Brennilis reactor, an industrial prototype heavy water reactor which entered service in 1963 and was shut down in 1985, should have been a model of its kind. The industry had presented it as a showcase for the progress from a "research and development" phase on the first deconstruction sites to an "industrial" phase of dismantling, which would demonstrate a process whose technical, economic and regulatory aspects had been mastered. In practice, difficulties proliferated at the site. The first phase, which consisted of removing all accessible radioactive material from the installation, began after authorisation in December 1994. The first demolition operations had to be halted, and the process revised, when it was discovered that the concrete was harder than anticipated. The Autorité de Sûreté Nucléaire (the French Nuclear Safety Authority) then interrupted work on the site for a complete revision of the zoning plan which categorised waste from different parts of the building (very low-level waste, low-level waste etc). Inspections regularly highlighted problems with specifications, non-conformities, the presence of highly corroded waste, and even, in 2004–05, a "complete incoherence" in the waste accounting data as presented by the operator, EDF. Recent developments in this story also illustrate the regulatory risks to which a badly managed dismantlement operation is exposed. At the end of 2007, the Council of State cancelled the decree authorising the final shutdown of the reactor (decree of 9 February 2006), including all the provisions relating to its dismantlement, on the grounds of an inadequate impact assessment.

The process of dismantlement is made all the more complex by the fact that the obligation to include a demonstration of the safety of the dismantlement operation at the design stage, which is now a requirement for the authorisation of an *installation nucléaire de base* (INB – regulated nuclear installation), did not apply when most of the existing installations were built. The example of Superphénix illustrates this difficulty. When the decision to shut down the reactor definitively was finally taken in 1997, after many years of technical and legal problems, it became clear that the technical conditions for its dismantlement had not been foreseen, or insufficiently so, when it was designed. This dismantling process is now throwing up numerous technical difficulties. First it was necessary to produce inert rods to replace one by one the fuel rods extracted from the core, in order to maintain its geometry so as to avoid the danger of a collapse. But the most delicate stage is being carried out at present, with the emptying of the approximately 4,000 tonnes of liquid sodium contained in the cooling circuit and 1,500 tonnes in the back-up reservoirs. Highly inflammable and explosive on contact with air and water respectively, this product is “neutralised” by means of a procedure developed by the CEA which is supposed to be capable of emptying five tonnes a day over two treatment lines. This level does not seem to be reached at present. The emptying of 100kg from the Rapsodie breeder reactor prototype, when this was being dismantled, caused an explosion which lifted in the air a concrete slab weighing several tens of tonnes and resulted in the death of an operator. The rest of the dismantling operation, which will essentially consist of deconstructing the reactor building, is still to come. The work is currently planned to be finished in 2027.

Leaving aside the troublesome dismantlement of mostly elderly CEA installations with a combined R&D and industrial status, France has little experience of dismantling fuel cycle plants. The only large-scale example is the first fuel reprocessing plant, UP1 at Marcoule, which was used by the military programme but also by EDF. An economic interest group comprising the CEA, EDF and Cogema (now Areva) was formed in 1996 to oversee the programme to clean up and dismantle the plant. Little information exists on the progress of work in an installation which retains its secret status, but the technical difficulties of waste retrieval and decontamination appear significant. The dismantling process is not foreseen to finish before 2040.

Taken as a whole, these operations of course raise the question of cost. They invariably entail an increase in projected costs as the beginning of the work approaches, and in actual costs as compared to projected costs once the work has begun. In 2006 the Court of Auditors (Cour des Comptes) assessed the cost of dismantling Brennilis at €482 million, or 20 times more than the sum envisaged by the reactor’s developers in the 1960s. In 2003 the Cour des Comptes assessed the cost of dismantling Superphénix and managing its waste at €2.081 billion. The dismantlement of UP1 had already cost €1 billion by the end of 2004, out of a total estimated in 2003 at €6 billion.

At the end of 2004, the Cour des Comptes estimated the overall long-term costs related to dismantlement for the three main operators, EDF, the CEA and Areva, at €65 billion (undiscounted costs). Nevertheless, numerous uncertainties remain regarding the cost of ongoing and (even more so) future dismantlement operations, and it was only in 2006 that France, in the context of the law on nuclear waste management, committed itself to setting up a dedicated mechanism intended to build up and safeguard the necessary provisions for this finance. Part of the uncertainty around costs also lies, more fundamentally, in uncertainty as to the industry’s strategy for dismantlement: a number of factors play a major role, such as the timescale of dismantlement (immediate or deferred), the existence (or not) of exemption thresholds for very low-level waste which the dismantlement process produces in large quantities (rubble, scrap metal), and the level of ‘return to normality’ aimed at. In the first half of this year the ASN conducted a consultation on a framework document setting out a broad outline for the safety of dismantlement –among all the regulatory texts, such a document does not at present exist. While dismantlement is becoming increasingly important, with the difficulties being encountered by the ongoing operations and the planned shutdown of further installations, France’s policy on the issue is still not fixed, and the real problems may just be beginning.