Nuclear power, the great illusion

Promises, setbacks and threats

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GLOBAL CHANCE

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A short information about Global Chance and the authors is provided in the end of this report.

Editorial

In the context of high oil, gas and coal prices, and of ever deepening and more specific anxieties about global warming, France seems to have decided to use its EU presidency from July to December 2008 to do everything to persuade its European partners that a massive resurgence in nuclear energy is absolutely necessary. This will, of course, be to the great benefit of France's industry. Nicolas Sarkozy has made it a key point of the 'energy/climate package' whose negotiation he hopes to have completed by the end of his European mandate. He has received significant support from the current President of the European Commission for this initiative, which has been widely debated across Europe.

More widely, the French President has undertaken nothing short of an international crusade on the subject, focusing in particular on Mediterranean countries such as Morocco and Algeria, to whom he has proposed active collaboration with French industry and the French Government, stressing the advantages of such cooperation in the "war on terror". In so doing, he is relying on the global reputation which France and its industry has acquired in this field by tirelessly extolling the virtues of energy independence and the economic boost that large-scale nuclear electricity production can bring to a country's energy system, while being environmentally harmless and perfectly safe, secure and long-lasting.

This line of argument, developed over decades by French governments both right and left, and the nuclear lobby which is closely linked to them, has managed to take hold in a France weak in independent expertise. This weakness has been deliberately maintained by the authorities and the elites, who prefer the comfort of an almost religious consensus to the debate which would inevitably be triggered by an independent and unrestricted evaluation. The French President is counting on the self-declared virtues of nuclear energy and the exemplary nature of the French experience to convince Europe, which is very divided on this issue.

In this light it seemed especially important to our association Global Chance (which includes among its members several of France's few independent nuclear experts, and produces analyses in the fields of energy and the environment whose relevance is appreciated both in France and beyond) to offer European decision-makers and citizens a fact-based critical analysis of the French experience, so as to shed a more realistic light on the illusion of a nuclear 'earthly paradise' that France is trying to impose on its European partners. Global Chance thereby hopes to alert international opinion to the largely illusory nature of any plan for a massive international and European revival of nuclear power as a means of meeting the challenges of development and the environment.

First we question the capacity of such a revival, even supposing that it met no technical, political or economic obstacles, to make a decisive contribution within the required timescale to the underlying goals of the 'energy/climate package': European energy security and a massive reduction in greenhouse gas emissions in the short and medium term (20% to 30% by 2020, 75% by 2050).

Second, using the example of France we investigate whether the proponents of such a revival have the industrial and economic capacity to carry it through, and the ability to contain its consequences and risks for the environment, peace and the health of the population.

This publication appears at a time when in France, more or less for the first time, the wall of silence that the authorities have erected around the more or less serious 'incidents' that have peppered the history of the country's nuclear industry is beginning to crack. In the climate created by the possibility of a revival of nuclear power, the French press has taken a greater interest than usual in the various incidents that have occurred in June and July 2008 (the halting of work on the Flamanville reactor site by the French nuclear safety authority, radioactive pollution in the water table at Tricastin, a fire in the Finnish EPR etc). Both the press and public opinion have rediscovered the obscurity which in France cloaks the whole management of nuclear power's inherent risks, and the disdain for the populace that this implies.

This is just one more reason to make this dossier, which we have entitled *Nuclear power, the great illusion*, widely available both to the public and to decision-makers.

Global Chance

In short

Nuclear Power: the Great Illusion

Promises, setbacks and threats

At a time when France is setting itself up as the political and industrial leader of a supposed European and worldwide 'renaissance' in nuclear power, *Global Chance* shows how this plan is a largely illusory response to the challenges of development and the environment. The present dossier, published to coincide with France's European Union presidency, approaches the issue from two complementary angles.

Nuclear "solution": short of power to meet energy and climate challenges

The first part of the dossier considers in overall terms the extent to which nuclear power is really capable of making a decisive contribution, within the necessary timescale, to the objectives of energy security and combating climate change. While these preoccupations are not new, they are looming ever larger as risks in the short term, to which an answer must be found within the next 20 years. It is against this timescale that the nuclear industry's capacity for revival – after a long period of stagnation of which French people are generally unaware – should be measured and compared with other solutions.

Left behind as an energy source at the global level

Nuclear power was responsible for 15% of the electricity produced worldwide in 2006, contributing 6% of primary energy production but only 2.4% of final energy consumption (ie the share of consumers' energy needs that it met). Its contribution was twice as large within the 27-member European Union (EU), at 29.5%, 13% and 5% respectively.

The nuclear industry's relative stagnation, set against a considerable increase in electricity production, has seen its contribution to global and European electricity output fall regularly since 1995, and more rapidly since the beginning of the present century. Between 2000 and 2006, 18 times as much gas-fired, 13 times as much coal-fired, 5 times as much hydroelectric and even 3 times as much wind-powered electricity generating capacity entered service worldwide than nuclear capacity.

The level of greenhouse gas (GHG) emission reductions brought about by nuclear power depends on what power sources it is assumed to replace: its associated reductions represented 3.6% of global emissions and 10% of EU emissions in 2006, and 20% of French emissions in 2005, on the assumption that it replaced a generation mix identical to that of the overall electricity generation fleet. However, if it is assumed to have replaced a fleet of combined cycle gas plants, these savings fall to 2%, 7% and 15% respectively – and even less if renewable energy is added to the equation. Nuclear power's effective contribution to GHG emissions reduction per unit of energy generated has been falling steadily since the 1990s.

From the energy security standpoint, while nuclear power can take the place of coal- or gas-fired electricity generation, it has only a very marginal effect upon oil consumption, which is dominated by transport. Conversely, by reason of its extremely centralised production and the particular risks that it presents, nuclear power increases energy vulnerability.

In its present state, the nuclear industry is not in a position to make a major contribution to improving energy security or to combating climate change over the coming decades. SUNBURN, the highly proactive scenario postulated by *Global Chance* in 2005 which involves multiplying by 50 the number of reactors to be constructed between 2005 and 2030, would result in a mere 2.9% drop in global GHG emissions and a 5% cumulative saving in fossil fuel resources by 2030, by comparison with the International Energy Agency's (IEA's) business-as-usual scenario. In any case, such a successful growth of nuclear energy, quite apart from the security, proliferation and waste management risks that it would engender, appears more and more unlikely in view of recent developments.

The marginal nature of nuclear power's contribution, even in the most proactive scenarios, emphasises in contrast the considerable potential of other solutions. The IEA suggests a proactive scenario for reducing worldwide GHG emissions by 2050 which includes, among other proposals, a development of nuclear output from 2,800 TWh a year today to 6,000 TWh in 2030 and 9,000 TWh in 2050. At this level, nuclear power would cut by 3.5% GHG emissions in 2050. This only represents 6% of total emission reductions in the scenario, far behind the total contribution in the same scenario of energy savings (54%) and even that of renewable energy (21%).

France, showcase for the limitations of nuclear power

Although marginal in global terms, nuclear power is nevertheless presented by its promoters as an effective tool for countries or regions that are ready to take full advantage of it. France, which has long relied on nuclear power to an extent unmatched elsewhere, offers the perfect example by which to measure the reality of this contribution.

France's energy balance and GHG emission figures and projections give a full picture of the limitations of nuclear power. Despite a contribution unparalleled worldwide, with 79% of France's electricity output in 2007, nuclear power represents just 14% to 16% of final energy consumption, far behind oil products (49%) and gas (21%). France's energy independence is much closer to 20% than to the 50% artificially calculated in official statistics.

France consumes more oil per head of population than the European average, and more than Germany, the UK and Italy. On the other hand, its per capita GHG emissions are lower. But it appears incapable of reining in their upward trend, even though its long-term objective is to reduce them by three-quarters. This situation is connected to the weakness of policies on energy efficiency and support for new energy sources, under the influence of the priority accorded to nuclear power.

Thus the example of France shows the fatal gap between, on the one hand, the substitution of nuclear power for other energy sources and, on the other, a fundamental reform of the energy system – and raises the question of how compatible these approaches are. Analysis of official and alternative scenarios shows that pursuing its present policy would not enable France to comply either with European commitments at the 2020 timeline or with its own commitments for 2050.

Controlling energy demand, and to a lesser extent developing renewable energy, are more crucial than pursuing the nuclear programme as means to achieve France's objectives of energy security and long-term emission reductions. In fact, the development of nuclear power actually encourages the system to evolve in various ways that are opposed to these goals – like the large scale use of electric heating.

Empty promises: behind France's nuclear dream

In the minds of many national leaders and on the international stage, the French nuclear industry nevertheless embodies an effective, safe and proven response to present-day energy problems. The second part of this dossier questions this myth, which underpins plans for a revival of the nuclear industry. After a brief résumé of the programme which France has implemented, it reconsiders that programme's performance and, point by point, confronts the official narrative with the facts.

Industrial policy

The French nuclear programme's image is first and foremost that of **a highly successful industry**, but this is **a sham**. The development of nuclear power in France has been marked by a succession of technological blind alleys, planning errors and all kinds of difficulties, which are generally noted and corrected without any public discussion. The need to preserve the image of control can in itself be a sufficient reason for refusing to acknowledge mistakes: it is on this ground that a 1989 EDF report concluded that it was necessary to go ahead with the reprocessing and reuse of MOX even though the whole initial justification for this, connected to the introduction of breeder reactors, had disappeared.

The French nuclear industry has frequently gambled on the wrong technologies. Prior to the failure of the breeder reactors, the French Atomic Energy Commission (Commissariat à l'Énergie Atomique – CEA) had supported the development of a fleet of natural uranium-graphite-gas (UNGG) reactors; but EDF ultimately established its programme with American pressurised water reactor (PWR) technology, building the first 50 of its current 58 reactors under American licence. Again, France rejected centrifuging as a method of enriching uranium, instead choosing gas diffusion in the present

Eurodif plant and then conducting research and development on laser technology, before Areva finally bought the centrifuging technology of its main competitor Urenco to replace Eurodif.

France has also persistently failed to bring new equipment up to the performance standards envisaged, including those for factors which are crucial to its economic justification. The official projected investment costs, for example, have consistently been lower than the actual costs subsequently acknowledged, which have never fallen as promised. Construction times and load factors have lagged badly behind the projected figures.

Even the size of the reactor fleet, far in excess of the required capacity, is based on hugely erroneous estimates: France's electricity consumption in 2000 was oversestimated by a factor of 1.75 when the programme was launched, while the development of the global nuclear fleet was overestimated by a factor of 10! Export projections have also proved erroneous, with only nine reactors exported (before the EPR), whereas exports were supposed to match the number of plants built in France.

The EPR reactor project, by aiming to replace the fleet with this vaguely 'evolutionary' line of reactors, continues in the footsteps of past decisions. Above all it reflects the need to maintain capability, the loss of which, in terms both of human resources and of industrial capacity, is a major challenge for the French nuclear industry. The problems encountered with the first stages of the two EPR reactor construction sites in France and Finland exemplify this difficulty.

Safety

The development of the French nuclear industry is not without danger. The lack of major accidents conceals, from the viewpoint of safety, **an evolution laden with risks**. The French nuclear programme's proponents initially claimed that a major accident was impossible, before gradually conceding that it was merely unlikely. The lessons of Three Mile Island (based on the same technology as the French PWRs) in 1979 and Chernobyl in 1986 could be incorporated only very belatedly and incompletely into a fleet three-quarters of whose units (42 out of 58) had been ordered before 1980 and completed before 1987. Even the most recent reactors have been essentially designed before 1984 – to the point that the authorities have acknowledged since 1995 that as new reactors they would no longer meet evolving safety demands.

The statistics testify to a large number of significant incidents at French reactors – around 700 to 800 a year. While the number has tended to rise in recent years, the number and seriousness of incidents classified on the International Nuclear and Radiological Event Scale (INES) has tended to fall, ranging between 50 and 100 classified incidents annually. The main criteria of the INES classification are related to the immediate seriousness of the event more than to its in-depth lessons for safety.

However, analysis of the numerous incidents over the last 20 years throws up many serious alerts covering the whole range of initial accident causes, from design faults or equipment failure to inadequate procedures and human error. In particular it illustrates the limitations of the current probabilistic approach and the worrying proliferation of generic incidents affecting one or more series of EDF's standardised fleet. In addition to these problems, there is the factor of ageing reactors and, increasingly, the burden imposed by the demands of profitability.

The limitations of the approach to safety apply to the EPR, which closely follows the probabilistic approach and introduces new technologies such as the 'core catcher' whose practicability remains theoretical, implying new vulnerabilities. What is more, its concept offers no improvement in terms of the rest of the sector – the upstream and downstream stages of the fuel chain – whose safety levels, although less closely examined, remain open to question.

Security

Analysis of recent developments in terms of security, moreover, reveals **an industry incapable of adapting to the post 9/11 environment**. In the area of protection against malicious acts, the nuclear industry runs up against a fundamental difficulty: the credible threats have evolved so far as to exceed the load levels (mechanical, thermal etc) incorporated, essentially from a safety standpoint, into the design of the installations.

While no public evaluation exists of the consequences of an aeroplane crashing onto a reactor, public discussion has highlighted the important questions to be answered on this subject, and has revealed the vulnerability of other installations such as the irradiated fuel storage pools at La Hague. Other attack scenarios must also be taken into account. Transports are a weak security link in the nuclear chain, their vulnerability and potential for danger exacerbated by France's opting for reprocessing.

The authorities nevertheless favour the developing of security measures rather than the industry itself adapting – or even a reinforcement of secrecy rather than concrete measures. The fundamental role of secrecy in this doctrine – to the point of absurdity when it is applied to clearly visible elements – prevents the emergence of any democratic debate on this issue.

Furthermore, in terms of proliferation, France conducts itself as though it were a **pyromaniac fireman**. In the past, French technology has helped to develop official or unofficial military nuclear programmes (for example in Israel, Iraq and South Africa). Today, without any debate on the risks of misuse, France is negotiating nuclear cooperation agreements with numerous North African and Middle Eastern countries (from Algeria to the United Arab Emirates by way of Libya), to whom it is offering its EPR reactor. This plan exceeds both these countries' inspection capacity and the capacity of their energy systems.

France is moreover sending a very negative signal to the world by stockpiling the separated plutonium produced by reprocessing – which, as the industry admitted only in 2006, could be used to manufacture a bomb. At the end of 2006 a total of 82.1 tonnes was being stored in France, of which 29.7 tonnes was foreign-owned. EDF's stock of unused plutonium powder at La Hague alone represents 26 tonnes, or over 3,000 times the 'significant quantity' required for a bomb. The operator of the French nuclear fleet is currently the main producer of separated plutonium in the world.

Waste management

Despite the efforts recently made in this area, the figures reveal **the false reasoning** that remains **the backbone of the waste management policy**. The central principle of systematically reusing the 'usable' material (uranium and plutonium) produced by reprocessing, although in reality far from being applied, serves as the basis for a flattering but incomplete balance sheet.

On the one hand, this principle relies on perpetual move: the materials accumulated by the present fleet could never be entirely reused by that fleet; renewal of the fleet with the same technology would only defer the problem. On the other hand, the principle enables part of the problem to be skirted: when the Government compares the inventory of waste to be stored underground at the end of the present fleet's lifespan depending upon whether or not the nuclear fuel is reprocessed, it omits all waste associated with the reuse or storage of the 300 tonnes of plutonium and 30,000 tonnes of uranium to be transferred to a future fleet.

Far from reducing the volume of waste by a factor of four or even ten as the industry claims, reprocessing complicates waste management from both a qualitative and a quantitative standpoint, by increasing the number of categories. Comparisons between storage volumes and disposal footprints, once corrected for a set of systematic bias identified in the official evaluations, show no clear advantage in favour of reprocessing. Conversely, the complexity that it entails goes hand in hand with increased risk.

France today has no industrial solution for all its long-term radioactive wastes, which are the subject of research according to their degree of radioactivity. Large quantities of waste and 'usable' material of different categories are accumulating in conditioning and storage conditions which are in many cases inadequate. In the area of dismantlement, too, reality contrasts with the industry's pretended expertise: dismantlement sites have all witnessed serious technical difficulties – sometimes unanticipated – and soaring associated costs.

Economics

The French nuclear industry's good reputation also relies on **the manipulation of economic reality**. A comparison between France's economic development over the last 40 years and that of comparable countries that have made different energy choices reveals no competitive advantage that can be attributed to nuclear power. On the contrary, it seems incapable of protecting the balance of payments. Indeed, in 2006-07 France's energy bill saw levels of deficit comparable to those of the first and second oil crises, before the present nuclear fleet came into service.

Nuclear power's contribution is not zero: in 2007 it is estimated to have 'saved' gas imports worth up to €10.7 billion. But demand for hydrocarbons has not fallen, and the energy bill reached €44.8 billion in 2007, leading to a balance of payments deficit of €39.2 billion. Conversely, the supposed financial benefits attributed to massive exports of electricity (actually a way of disposing of the French nuclear fleet's excess capacity) have never exceeded €3.5 billion a year and are falling markedly: base-load exports are dropping while peak-rate imports, at much higher tariffs, are increasing.

Electricity price comparisons do not support the French authorities' claim that French prices are the lowest in Europe thanks to nuclear power, even if overall they do appear to be low. Moreover, the comparison is skewed by some important factors. For example, France's high ranking is in part due to the fact that it maintains a dominant regulated market, whose rules as regards the passing on of real costs are set by the state, which is both the regulator and the principal shareholder of EDF. Furthermore, while French households enjoy attractive tariffs, they also, as a result of the policy of promoting electricity, consume on average twice as much electricity per dwelling as the European norm (used for price comparisons).

What is more, it is known that the official reports, with very few exceptions, have systematically underestimated the real costs of nuclear power compared with the alternatives, and continue to do so – sometimes hiding behind commercial confidentiality. When EDF presented its EPR reactor project to the public debate in 2005, it had to justify the fact that its own cost estimate appeared to be 44% higher than the estimate presented by the Government in 2003 in order to include the programme in energy planning legislation. EPR's costs – both those of EDF's French project and those of the plant being built in Finland by Areva – have risen continually since the outset. The most recent estimates in mid-2008 were respectively €3.4 billion (for a reactor announced at €3 billion) and €5 billion (for a reactor sold at €3.3 billion).

Current discussions on the cost of reactors should not draw attention from the **hidden associated costs**. These of course include all the costs associated with the fuel cycle and with decommissioning, which are subject to the same distortion in the official estimates. For example, the assumed costs of reprocessing are set not at the actual level but at half that level, explicitly in order to ensure parity with the cost of the non-reprocessing option. Structural costs, although their extent is hard to establish, must also be taken into account. For example, they include the additional electricity network infrastructure costs associated with the highly centralised nature of nuclear generation, and the costs of inspection and security.

Democracy

Finally, the pursuit of the nuclear programme in France is a **permanently undemocratic choice**. Contrary to the image presented abroad, the French population is no more in favour of nuclear power than the European average – indeed a majority is opposed to the building of new plants. Surveys repeatedly show that the public lacks confidence in the institutional promoters of nuclear power.

This disconnect between public opinion and the thrust of policy, which is dogmatically pro-nuclear, results from an institutional system which sequesters policy from any genuine democratic control. Evaluations are carried out and key decisions taken by the country's technocratic elite, away from any external scrutiny – in particular, a central role is played by the Corps des Mines, a state body of 700 engineers who hold almost all the key posts connected with energy.

While the overall progress in terms of information and public participation in decision-making is exerting a growing pressure, the nuclear industry in France remains a separate fiefdom, where the procedures of evaluation and public debate develop but remain disconnected from the real decision-making processes.

Nuclear: not up to energy and climate challenges

Nuclear power supporters see the emergence of an ambitious nuclear programme for the short and medium term as a cornerstone of the solution to the energy and climate crisis that humanity is facing. Fully endorsing this thesis, the President of the French Republic would try, during his Presidency of the European Union, to convince its European colleagues that a voluntarist nuclear revival plan is an inescapable rescue for Europe; thus he would propose this to be a major part of the 'energy and climate package'.

We question In this chapter the real capacity of such a plan to bring a decisive contribution, in the required timeline, to the goals of European energy security and short and medium-term mitigation of greenhouse gas emissions. In particular, we show what lessons could be drawn from the French experience, often displayed as an exemplary success on those two issues.

Global Chance

Energy & climate

Nuclear, short of power to solve energy and climate issues

1. The converging of risks in the short-term

In today's world facing a surge in prices of fossil energy products and fears of a climate upheaval in the short term, nuclear power seems to be moving up the political agenda once again. This comes after a 20-year period of global stagnation of which the French are generally unaware. Both in the EU institutions and at international level, the French Government is pressing for a strong revival of nuclear energy in countries which already implement the technology and for widespread access to nuclear energy for civil uses in countries which do not have it yet, particularly in the Mediterranean countries.

The main arguments put forward in support of this revival are climate change and energy security. **What are these two risks?**

The climate risk

The latest report by the Intergovernmental Panel on Climate Change (IPCC) shows the urgent need to take action to avoid the worst in terms of global warming. It first shows that if the global average temperatures in the atmosphere rise 2.5°C-3°C above pre-industrial levels, there is a strong risk that irreversible impacts, such as the melting of permafrost, a highly reduced role of forest cover and oceans as carbon sinks, will occur. These phenomena, in turn, can lead to unavoidable destabilisation of the climate. This is the reason why regions such as Europe have set a target which, if it became a multilateral commitment, would enable the global average temperature rise not to exceed 2°C.

Comparing the scenarios defined by climate experts shows that the only reasonable chance of statistically reaching the '2°C constraint' is if humanity manages to stabilise concentrations of all greenhouse gases (GHGs) between 400 and 450 parts per million by volume of CO_2 equivalent (ppmv CO_2eq) in the long term. However, the analysis also highlights that if GHG concentrations go significantly beyond this target threshold at any time in the intermediate period between 2020 and 2100 (above 475 to 500 ppmv), it is likely that it would become impossible to reach the target at all and that irreversible climate impacts would occur.

In 2005, atmospheric concentrations of CO_2 had already reached 379 ppmv and since the year 2000, global emissions of GHGs, as a whole, have been increasing at a rate of 3% per year and this upward trend shows no sign of reversing. Clearly, under these conditions, it is likely that the maximum acceptable concentration will be exceeded well before 2050.

Consequently, the climate question will arise in a far shorter term than policy-makers generally imagine. To avoid uncontrollable destabilisation of the earth's climate, a turning point needs to be reached in the extremely short term followed by a steep decline of around 40% of global emissions by 2030 (in t CO_2eq[1]) compared to 1990 levels.

[1] One t CO_2eq: tonne of CO_2 equivalent, a conventional common unit to measure the emissions of all greenhouse gases.

This implies that policies must be adopted and implemented to reduce emissions of GHGs, each of which has a different impact on the climate over time. These emission reductions have to target very different sectors.

Energy security

National and regional energy security is generally – and wrongly – limited to **security of energy supply**. Obviously, it also depends on several other parameters. In addition to vulnerability in relation to raw material imports, depending on the nature of the energy products (and the associated geopolitical conditions), economic sectors and energy efficiency in the different sectors, there are a series of parameters concerning the vulnerability of economies on a domestic level: vulnerability to natural phenomena (rainfall, wind patterns, floods and droughts, hurricanes, earthquakes, etc.) or technological accidents, disturbances caused by man (malevolent action, strikes, peak consumption phenomena, etc.). Again, analysis of energy security infers not only analysis by technology, product, energy carrier, economic sector and region, but also an analysis of the wide range of alternative solutions in the event of a crisis.

Energy security problems in Europe are thus not limited to questions of dependence on oil or gas even if the recent and extremely sharp rise in the cost of these raw materials and the fear of resource shortages has rightly been the focus of attention of the Governments, citizens and consumers.

Rapid and vigorous action

These energy security and climate change concerns are not new.

However, what is new is that the associated risks are today no longer recognised as long term risks, likely to occur towards the end of the century, but as short term risks arising before or around 2030. The scale of values of the solutions put forward to deal with these two crises primarily depends on their potential dynamics to penetrate in the next 20 to 30 years.[2]

Not only do economic and financial considerations lie at the heart of these questions of dynamics but also a whole series of issues concerning technical training, social and industrial organisation, spatial planning, as well as regional and world trade.

Nuclear energy in the face of these issues

It is thus against the backdrop of these issues that the potential revival of nuclear energy must be assessed. If not, there is a high risk, as has happened several times in the past, that we will harbour illusions and let ourselves in for numerous difficulties.

2. In 2006 where are we at?

Figure 1 shows the breakdown of world primary energy consumption in 2006 by energy source. It can be seen that the source 'primary electricity'[3] accounts for 9% of total world consumption. Taking into account the internationally recognised coefficients of equivalence between TWh (electricity production) and Mtoe,[4] the share of nuclear energy in the primary energy balance is 6%. World electricity production reached 2,800 TWh in 2006. Nuclear energy accounted for 15% of this total, renewable energy for 23%, and fossil fuels the remaining 62% (Figure 2).

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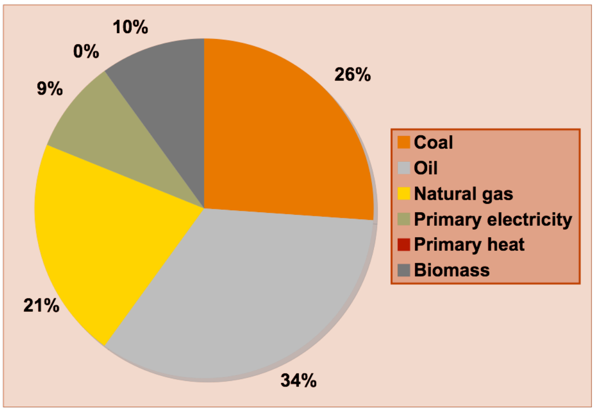
2 That is the reason why a series of technological step changes, such as controlled thermonuclear fusion, and even 4th generation reactors (which will not be commercially available until at best 2080 and 2040 respectively, according to their promoters) do not appear to be plausible solutions to the problem.

3 Mainly made up of nuclear- and hydro-generated electricity, but also wind and photovoltaics. World production of the latter two energy sources is still marginal.

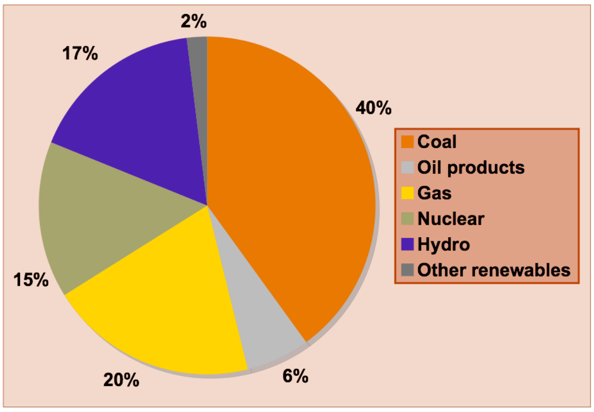
4 1 TWh of nuclear power = 0.21 Mtoe and 1 TWh of electricity produced from renewable sources = 0.086 Mtoe (TWh: TeraWatthour or billion kWh).

Figure 1 World primary energy consumption by source (2006)



Source: Enerdata

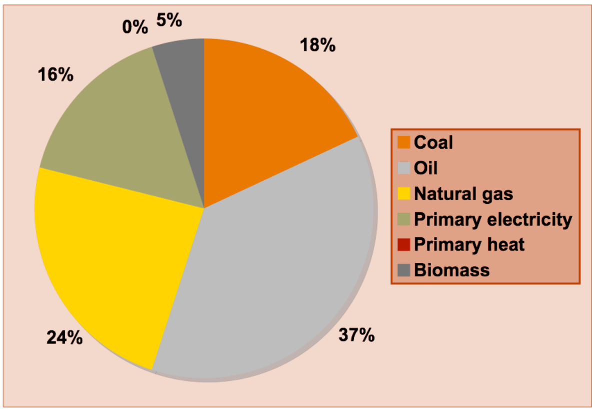
Figure 2 World electricity production by source (2006)



Source: Enerdata

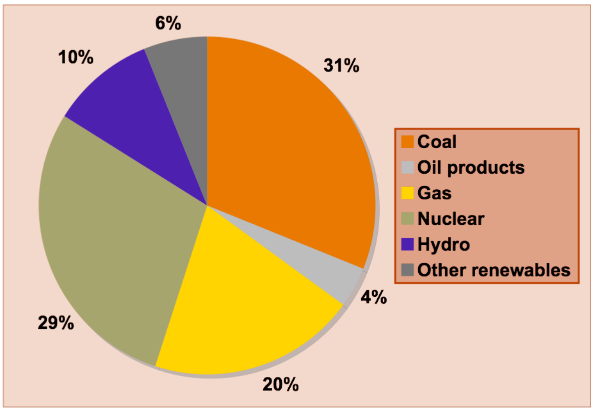
Primary electricity consumption in the 27 Member States of the European Union (EU-27) (Figure 3) accounted for 18% of its total primary energy consumption in 2006, ie double the share at global level. Nuclear power accounted for 13% of this primary balance. Nuclear generated electricity production in the EU-27 (Figure 4) accounted for 29% of total electricity production after coal (31%) and ahead of gas (20%) and renewable sources as a whole (16%).

Figure 3 EU-27 primary energy consumption by source (2006)



Source: Enerdata

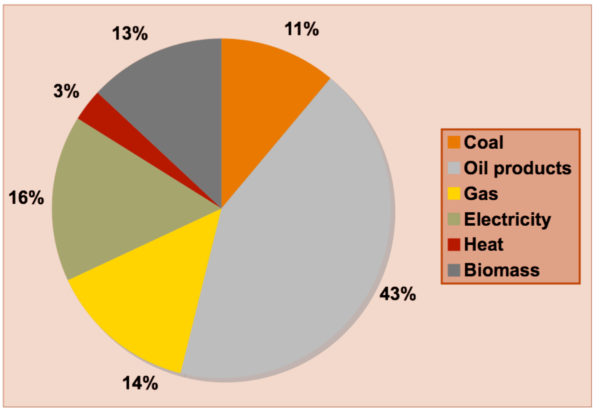
Figure 4 EU-27 electricity production by source (2006)



Source: Enerdata

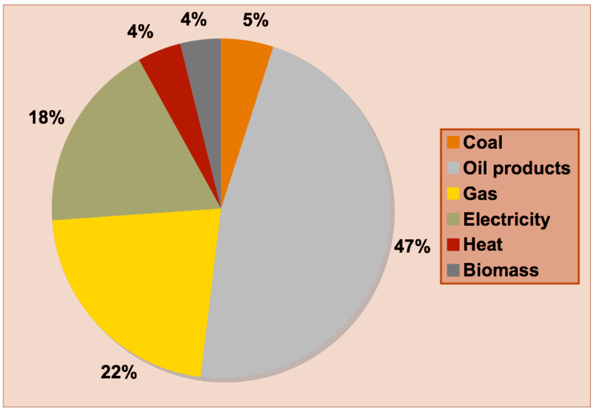
It is important to complete this general overview by an analysis of final energy consumption by energy source in the world and in the EU-27. This is the energy actually supplied to users after the conversion process: gas, electricity and heat to households, fuel for the tanks of heavy goods vehicles and cars, and for factories etc. (Figures 5 and 6).

Figure 5 **World final energy consumption by product (2006)**



Source: Enerdata

Figure 6 **EU-27 final energy consumption by product (2006)**



Source: Enerdata

Since electricity's share in the world final energy balance is 16% (Figure 5) and nuclear energy accounts for 15% of electricity production (Figure 2), it follows that the share of nuclear energy in world final energy consumption is 2.4%.

Similarly, as electricity's share in the EU-27's final energy balance is 18.3% (Figure 6) and nuclear energy accounts for 29.5% of electricity production (Figure 4), it follows that the share of nuclear energy in the EU-27's final energy consumption is 5%. Table 1 summarises these data:

Table 1 **Share of nuclear energy in energy consumption (2006)**

Share of nuclear energy in 2006 (in %)	In primary energy consumption	In electricity production	In final energy consumption
World	6%	15%	2.4%
EU-27	13%	29.5%	5%

Source: Enerdata

The share of nuclear energy in total electricity production varies enormously depending on the different countries. Three countries alone, the United States, France and Japan account for 56% of world nuclear-generated electricity production. France alone produces 45.5% of nuclear-generated electricity in the EU.

In France, and for year 2007, oil products represented 49% of total final energy consumption, far ahead of gas (21%), electricity (21%) and thermal renewable sources (6%). Final electricity consumption was 424 TWh, of which 24 TWh imported, 50 TWh from fossil fuelled power plants, 60 TWh from hydro power plants (and a small wind contribution) and 286 TWh from nuclear power plants. Which leads to a 67% contribution of nuclear in the final electricity consumption. Since the share of electricity in final energy consumption is 21%, the contribution of nuclear to the total final energy consumption of France is then 14%.

The claim that nuclear ensures the French energy independence is obviously farfetched. Table 2 shows the share of nuclear energy in national electricity production in the main countries which implement this energy technology. It highlights France's very specific situation in this field.

Table 2 **Share of nuclear energy in national electricity production (2005)**

Country	France	Ukraine	Sweden	South Korea	Japan	Germany	UK	USA	Russia	Canada	Rest of world
Share %	79	48	46	38	28	26	20	19	16	15	8

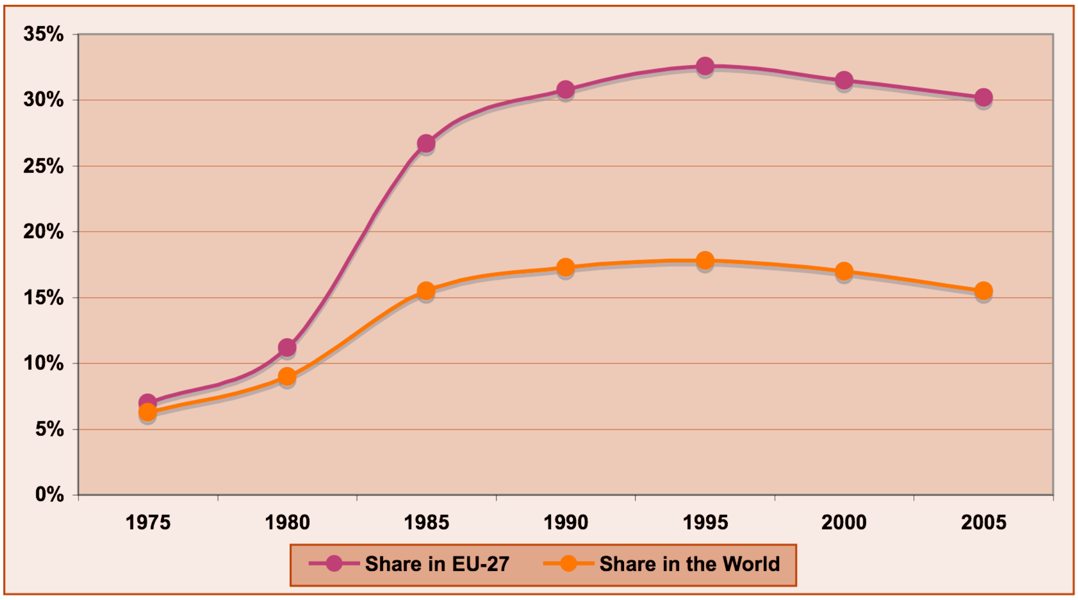
Source: IEA, *Key World Energy Statistics*, 2007

What has happened over the last two decades?

In the last 20 years, there has been a 40% increase in nuclear generated electricity production: 2,800 TWh in 2008 compared to 2,010 TWh in 1989. However, installed capacity, 371 GW in early 2008 (439 reactors) compared to 328 GW in 1989 (423 reactors), has only grown by 13%. This is a result both of orders for new build stagnating and an improvement in the use rate of existing plants.

During the same period (1989-early 2008), nuclear generated electricity production in the EU-27 rose from 775 to 999 TWh, ie +29%.This is less than the global increase (+40%). However, during the same period, world electricity production rose by 63% and that of the EU-27 by 33%. Changes over time in the share of nuclear generated electricity in world and EU electricity balances (Figure 7) logically show a peak around 1995 followed by a decline since then.

Figure 7 **Share of nuclear generated electricity in total electricity production in EU-27 and in the world (1975-2005)**



Source: Enerdata

Changes in capacity of the different sources of electricity production in recent years (Table 3) illustrate the reasons for this decline in the nuclear share which has been accentuated since the beginning of the 21st century. Worldwide, between 2000 and 2006, 18 times more gas generated electricity capacity was brought on stream than nuclear capacity, 13 times more coal generated electricity capacity, five times more hydro and even three times more wind.[5]

Table 3 **Increase in world installed capacity between 2000 and 2006, by source**

Source	Coal	Oil	Gas	Biomass	Nuclear	Hydro	Wind	Total
x1,000 MW	280	28	398	11	22	105	53	897
Share	31%	3%	44%	1.3%	2.4%	11.7%	6%	100%

Source: Enerdata

5 The table indicates installed capacity. In terms of electricity generated, a fossil fuel-fired power plant or a nuclear power plant, with the same capacity, and operating on base load, will supply between 2 and 3 times more electricity than a wind turbine subjected to the intermittent character of the wind.

CO_2 emissions avoided in 2006

In order to assess the CO_2 emissions avoided by the different nuclear energy programmes at world, European and national levels, it can be assumed that if there were no such nuclear programmes, the electricity substituted would be produced by a range of sources similar to that which we see today minus nuclear power.[6] On this basis, global CO_2 emissions avoided in 2006 as a result of world nuclear programmes would be 1.8 Gtonnes of CO_2. This figure would be 0.43 Gtonnes for the EU-27.

These emissions avoided in 2006 would account for 3.6% of global GHG emissions (50 Gt CO_2eq) and 10% of GHG emissions in the EU-27. If this analysis is confined to CO_2 emitted by energy systems, it is estimated that the nuclear programme would account for a 6% reduction in emissions worldwide and for a 15% reduction in the EU-27.

However, if, as part of the fight against climate change, all currently operating nuclear power plants were replaced by modern gas turbine power plants,[7] this would require an additional consumption of 420 Mtoe of natural gas (+17%), which would lead to 1 Gtonne of CO_2 emissions. Europe would use an additional 135 Mtoe of natural gas (+30%) which would cause an additional 320 Mtonnes of CO_2 emissions. Table 4 summarises the various aforementioned data for 2006.

Table 4 Nuclear energy's contribution to avoid GHG emissions in 2006

Nuclear energy's contributions to:	World	EU-27
Reduction of CO_2 emissions from the energy system	6%* to 4%**	15% to 11%
Reduction of emissions of all GHGs (in CO_2eq)	3.6% to 2%	10% to 7%

* current configuration of electricity production
** natural gas combined cycle gas turbine power plants

Source: Global Chance

In realistic terms, this is what nuclear power represented in 2006 in terms of the fight against climate change. It is obviously not insignificant. However, it is important to bear in mind that the impact of current nuclear programmes on GHG emissions, even in Europe, remains minimal and has been decreasing each year since the 1990s.

Nuclear and greenhouse emission reduction in France. In 2005, the total emission of GHG in France is 553 Mt CO_2eq, of which 378 tonnes of CO_2.

To evaluate the contribution of nuclear to the CO_2 emission reduction, we compare the level of emission of the nuclear system with the emission of the natural gas combined cycle power plants which would deliver the same quantity of electricity to the final consumer (see above). Depending on the level of emission attributed to the nuclear system , the difference in emission level is 60 to 100 Mteq CO_2eq, that is 15 to 20% of the total greenhouse gas emission of France: it is far from negligible but 80% or 85% are remaining.

If nuclear electricity is replaced by renewable electricity, the gain on emission reduction is the same, or even superior (for wind energy for instance).

Energy security

The global consequences of nuclear programmes on the world's and the EU-27's supply have been indicated in terms of primary energy (respectively 6% and 13% using the coefficients of equivalence for electricity production) and of final energy (respectively 2.4% and 5%). This global analysis must be completed by an analysis by sector and by energy source. Thus:

- **Electricity:** It is well-suited to certain uses in the residential, tertiary and industrial sectors but almost impossible to use in some sectors, such as road, air and maritime transport. In practice, the

[6] The corresponding 'electric mix' is as follows: for the world, 21% renewable sources, 48% coal, 24% gas, 7% oil; and for Europe: 22.5% renewable sources, 44% coal, 28% gas, 5.5% oil.
[7] Combined cycle gas turbine power plants which reach a 58% energy efficiency.

specific features of nuclear generated electricity limit its uses to 'base load' operations (relatively stable use over a long period of the year).

- **Oil**: 68% of the consumption[8] of oil for energy purposes is due to transport at world and EU levels. The contribution of current nuclear programmes to the required substitution of oil is very small. Conversely, nuclear energy can be used as a substitute for oil in the industry sector, and more marginally, in the residential sector where electricity for heating may be supplied by oil-fired power stations (for back-up purposes) during peak consumption periods.
- **Coal:** This is where the contribution of world nuclear programmes is the greatest by replacing coal-fired electricity generation capacity which provides a similar service (base load or semi-base load power) and, via electric heating or specific electric processes, meeting industrial and residential sector needs. In the latter sector, electric heating is produced from coal during peak consumption periods.
- **Natural gas**: Current nuclear generated electricity in part replaces gas-fired electricity production capacity and, via electric heating, it replaces industrial and residential sector applications. In the latter sector, electric heating is produced from gas during peak consumption periods.

Table 5 illustrates these different points for selected European countries whose use of nuclear energy to produce electricity is highly heterogeneous.

Table 5 **Per capita consumption of fossil energy products and nuclear share in electricity production in selected European countries in 2007**

Consumption per capita (toe)	EU-27	Germany	France	Italy	UK
Oil	**1.32**	**1.36**	**1.46**	**1.31**	**1.33**
of which electricity production	*0.05*	*0.03*	*0.04*	*0.12*	*0.02*
Natural gas	0.88	0.95	0.62	1.17	1.35
of which electricity production	*0.28*	*0.22*	*0.09*	*0.47*	*0.45*
Coal	0.66	1.02	0.22	0.29	0.63
of which electricity production	*0.5*	*0.86*	*0.11*	*0.2*	*0.53*
Nuclear share	**28%**	**22%**	**77%**	**0%**	**16%**

Source: based on Enerdata

It can be seen from the table that a country like France which produces almost 80% of its electricity from nuclear energy consumes more oil per capita than the European average as well as Germany (22% share of nuclear generated electricity), the UK (20% share of nuclear generated electricity) and Italy (0% nuclear generated electricity).

It is thus obvious that nuclear power, contrary to widespread opinion, was not an effective answer to oil pressure in 2006. It is not the same for gas or coal, per capita consumption of which in France is lower than the European average (-25% for gas and -69% for coal). Finally, it should be noted that if all nuclear power plants were replaced in France by combined cycle gas turbine power plants in order to provide the same amount of electricity to the final consumer, this would require a consumption of 47 Mtoe of natural gas, or 34 Mtoe of natural gas plus 7.5 Mtoe of primary electricity produced from non thermal renewable sources (hydro, wind, solar PV). The per capita consumption of natural gas would increase by 0.6 to 0.8 toe,[9] but the primary energy consumption per capita would fall by 1.4 toe.[10] In these conditions, the quantity of natural gas 'replacing' nuclear would represent 16 to 20% of total primary energy consumption.

[8] Excluding non-energy uses.

[9] Fact Sheet n° 4 in "Petit mémento énergétique – Eléments pour un débat sur l'énergie en France", *Les Cahiers de Global Chance*, special issue n° 1, January 2003.

[10] The reason for this difference is the poor thermodynamic efficiency of nuclear power plants (33% as opposed to 58% for combined cycle gas turbine power plants) and the energy consumption of the nuclear fuel cycle (in particular Eurodif, the uranium enrichment facility).

Other aspects of energy security

Centralising the means of production, exacerbated in the case of nuclear power,[11] makes a country highly vulnerable to the consequences of an electricity production or transport failure, particularly owing to the large size of the plants and sites. In the case of a high share of nuclear generated electricity in total electricity production (greater than 25 to 30%), and of course even higher in France (79%), possible generic breakdowns, which can affect a whole generation of power plants, are a further major source of vulnerability.

In addition to these different sources of domestic insecurity, there are intrinsic vulnerabilities associated with the nuclear industry: the supply of uranium, the risks of a major accident, environmental risks as a whole and risks of proliferation resulting from the nuclear fuel cycle. These problems will be dealt with specifically in the second part of the report.

In summary

The nuclear industry has been in relative decline over the last 10 years compared to other means of producing power and, more generally, energy. In 2006, its contribution to the world's final energy demand was less than 2.5%. Its contribution to the EU-27's final energy demand was 5%. This is obviously very low.

Nuclear energy enables between 2 to 3.6%[12] of GHG emissions to be avoided at global level, and between 7 to 11% at EU level. Worldwide, it prevents the use of an additional 420 Mtoe of natural gas and 550 Mtoe of coal (respectively 17% and 18% of current consumption).

Conversely, its effect on oil consumption remains altogether marginal.

Beside the specific risks that nuclear energy incurs (major accident, proliferation, waste), it creates particular vulnerabilities given its extremely centralised means of production.

3. The issues up to 2030

Is the currently planned, or rather proclaimed revival of nuclear power, both at global and EU levels, such that it will significantly change the order of things in the next 20 years with regard to energy security and climate change?

To assess the real issues, it is useful to take a closer look, in light of recent developments, at the SUNBURN world nuclear revival scenario[13] produced in 2005, the main assumptions of which are as follows:

- A universal solution, in the sense of refusing to exclude certain countries for ideological, political or economic reasons, etc.;
- Maintaining the national character of programmes that we know today until 2030;
- Base load operations (around 7,000 hours per year) to ensure sufficient profitability of the installations;
- A minimum threshold for annual electricity demand below which it cannot be envisaged, for supply security reasons, to bring new nuclear plant on stream. The minimum threshold proposed in the scenario is 4 GW. Combined with the assumption of base load production, this leads to an access threshold of around 60 TWh/year;[14]

[11] Owing to the size of reactor units and the difficulties in finding sites (in France, 58 reactors located on some 20 sites which generated a net total of 419 TWh of electricity in 2007). The size of coal-fired power plant sites can however reach similar proportions to those of nuclear plants.

[12] Depending on the type of substitution envisaged.

[13] B. Dessus, Ph. Girard, "Le scénario SUNBURN de relance du nucléaire mondial", *Cahiers de Global Chance*, n° 21, March 2006.

[14] Basic needs account for about 50% of total annual needs.

- Contributions to base load production from other energy sources: hydro: 30%, wind: 20%, biomass: 60%, waste and geothermal: 100%;
- Lifetimes of the power production facilities ranging from 20 to 50 years depending on the technology used, construction times ranging from 1 year (wind) to 6 years (nuclear) and lead time to launch nuclear programmes ranging from 3 to 5 years for countries previously with no nuclear power.

Based on these assumptions and drawing on the 2004 'Business as usual' scenario published by the International Energy Agency (IEA),[15] the SUNBURN scenario estimates, by country or geographical region, year on year, basic power needs, existing capacity on stream and its contribution to base load power production, renewable energy capacity installed and its contribution to base load power production, and lastly, the remaining needs likely to be met by nuclear energy. A more or less large share of this remaining need is thus met by nuclear energy, given the initial lead times for starting nuclear programmes and industrial dynamics.

Based on these assumptions, there would of course be an extremely rapid development of world nuclear power from 2015 onwards. Under these conditions, new capacity coming on stream, around 3 GW per year on average between 2000 and 2005, would reach some 20 GW by 2015, 40 GW by 2020, 75 GW by 2025 and over 100 GW by 2030 (ie the equivalent of the current capacity of the US nuclear reactors on stream), this means a world market multiplied by 50 in 25 years. Nuclear capacity would amount to 1,200 GW in 2030, generating almost 9,000 TW of power per year. Some 30 new countries (8 in Europe,[16] 4 in South Amercia , 5 in Africa, 5 in the Middle East and 7 in Asia) would have nuclear power. The EU-27 would generate 1,400 TWh in 2030. Despite the abundance of cheap local coal resources, China, India and South Korea alone would generate almost 1,400 TWh in 2030.

However, even in circumstances so obviously propitious to nuclear energy, the consequences on CO_2 emissions and fossil fuel reserves would remain relatively insignificant. Comparing this with IEA's scenario, in which nuclear capacity is maintained at current levels, sheds an interesting light on the matter:

If it were fully implemented, the SUNBURN scenario would enable 9% of total CO_2 emissions from energy to be avoided in 2030 compared to IEA's forecast scenario (5 to 6% of GHGs as a whole in 2030), but only 2.9% of cumulative emissions from 2006 to 2030 in this same scenario, ie seven times fewer emissions in 2030. Furthermore, it would enable a 15% saving of fossil fuel-generated energy in 2030 but only a 5% saving of the cumulative fossil fuel-generated energy used between now and 2030, mainly coal and natural gas. It would prove to be widely ineffective for oil.

In Europe, this revival would enable a 200 Mtoe saving of natural gas (30%) in 2030 and 480 Mtonnes of avoided CO_2 emissions compared to a total phase-out of nuclear power in 2030.

When all is said and done, this situation is quite similar to the one we experienced in 2006.

The authors of the SUNBURN scenario strongly emphasised the many vital issues to be resolved:

- The financial question, with an annual investment of € 50 billion per year on average from 2015 to 2030, on the basis of an estimated cost, at the time, of € 1500/kW (with an exchange rate of €1 = $1.20);
- The question of a need for a skilled workforce requiring 500 000 technicians to be trained before 2030 for production facilities and control authorities yet to be created;
- The question of industrial capacity, both to build the power plants and to set up the fuel cycle, or to open new uranium mines;
- The question of governance, with the need for major investments in human resources and organisation on the part of countries wishing to adopt a nuclear energy programme in the next 10 to 15 years, but also the need to define and adopt international rules applicable to all

15 *World Energy Outlook 2004*.
16 Including Portugal, Italy, Poland, Greece, Austria and Denmark.

countries concerned (transport of raw materials and waste, measures to protect against the risk of proliferation, safety and security of nuclear installations, etc.). In connection with this, a recent memorandum issued by the French Nuclear Safety Authority (ASN) insists on this issue in unequivocal terms, with a subheading as follows: "Let's be clear. Learning nuclear safety is a long process."[17]

Not to mention of course the specific risks that this nuclear revival would incur (risks of major accidents, proliferation, waste) due to the increased number of installations, their rapid geographical spread and the irreversible nature of the technological solutions that such a scenario would entail by imposing the success of the challenge of widespread use of nuclear power in most countries of the world, relying on large-scale use of plutonium, which will have become essential for the sake of making the resource last.

Three years on, where are we at, beyond the declarations, in relation to this vision? First of all, it should be noted that in 2007 nuclear power production continued its decline (-2% compared to 2006) and that no large-scale programme has been launched since 2005. Construction of the only two planned reactors in Europe, the Finnish and the French EPRs (admittedly, with the exception of the two Bulgarian reactors Belene 1 and 2 officially under construction since 1987) has been beset with difficulties and significant delays (at least two years for the Finnish EPR).

It can also be seen that there has been a surge in nuclear power investment costs in dollars since 2000,[18] +170%, a far greater increase than for wind power investment costs (+110%) and particularly for coal-fired power plants (80%) and gas-fired power plants (90%). In these conditions, it is highly unlikely that the major Asian countries and the United States which have significant and cheap coal resources will give up using this energy source for base load power production and take up nuclear energy on a large scale.

Similarly, the lack of investment in research and production of uranium over the last 10 years has led to tension in uranium prices which have increased tenfold on the spot market since 2002. Although spot market prices went back down to half that peak by mid-2008, the odds are that some tension will continue and even increase since lead times for the opening of new mines keep getting longer. Lastly, since 2005, political tensions both in North Korea and Iran surrounding the nuclear issue have heightened the international community's mistrust of a certain number of countries gaining access to nuclear energy, even if it is for non-military uses.

In light of these developments and despite the optimistic attitude of nuclear energy proponents, it appears clear that achieving such a scenario, which in 2005 was already considered particularly optimistic, is more and more unlikely (even with an additional 4 to 5 years' lead time, which would have serious consequences in 2030).[19]

More recently, for no clear reason, the IEA cast aside its usually reserved stance on world nuclear growth capacities in 2030.[20] On behalf of the G8, it produced a much more pro-nuclear energy scenario.[21] It is based on the relatively simplistic assumption of a growth rate of nuclear energy in relation to world GDP similar to that which it showed during its most prosperous period. On this basis, the "bluemap" scenario, the most pro-nuclear one, drawing on plans for strong potential development as stated by China, Russia, South Africa, the United States, Ukraine and India, and estimating future nuclear energy investment costs at around $ 2,500/kW, projects that world nuclear power production will amount to about 6,000 TWh in 2030 and 9,000 TWh in 2050. But, unlike the SUNBURN scenario, this industrial-type analysis avoids any description of regional needs and constraints, does not address

[17] The position of the French Nuclear Safety Authority (ASN): "Safety of the new plans to build nuclear reactors in the world must be ensured", 16 June 2008.
[18] Cambridge Energy Research Associates, *Construction Costs for New Power Plants Continue to Escalate*: IHS CERA Power Capital Costs Index.
[19] A five-year delay would cause a 30% fall in projected nuclear power production in 2030.
[20] In the Outlook 2004 and 2006 scenarios, nuclear energy growth stagnated or was slow (2 GW per year in *Outlook 2006*).
[21] *Energy Technology Perspectives 2008, Scenarios and Strategies to 2050*, AIE.

the issue of uranium resources and seems highly optimistic regarding investment costs in relation to the reality of today.[22]

Let us nevertheless imagine that it can be implemented in the timeframe envisaged. According to the IEA itself, it would enable 5% of CO_2 emissions from the energy system in 2050 to be avoided (around 3.5% of GHGs as a whole).[23] Not only is this a very small amount in absolute terms but also in comparison with other options put forward by the same study and in particular the saving of electricity generation, estimated alone to be more than double (10%) and incurring far lower costs.

Beyond the issues of political and economic credibility that they give rise to, all the studies focusing on a large-scale revival of nuclear power thus show the marginal nature of the results that can be expected in the medium term (2030) from the point of view both of energy security and climate change.

To say the least, it is far from having being proved that large-scale use of nuclear energy to address the main challenges facing humanity in 2030, climate change and energy security, is vital. In any event, nuclear power's contribution to solving these questions will be marginal.

On balance, on the basis of this marginality, deliberately omitted from the views aired by nuclear proponents, an analysis must be conducted of all the major political, economic, environmental and social problems that a large-scale revival of nuclear energy at EU and world level, as proposed today by the French Presidency of the EU, would give rise to.

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22 These costs are under-estimated by 30 to 40% compared to the estimated costs of the Finnish EPR reactor.

23 To the point where it is questionable whether the IEA did not deliberately produce this optimistic scenario to emphasise the ineffectiveness and lack of interest compared with other GHG emission reduction options.

Focus 01 Electricity savings versus nuclear revival?

In its report *Energy technology perspectives 2008: Scenarios and strategies to 2050*, the IEA proposes a scenario for a global relaunch of nuclear power which would allegedly enable an annual electricity output of 6,00 TWh to be achieved by 2030 compared with 2,800 TWh today, thanks to the installation of an extra 500 GW of capacity (as compared to its 'business-as-usual' scenario of nuclear stagnation), at an overall investment cost of at least €1 trillion. If extended until 2050, this programme, with an output of 9,000 TWh, would represent 6% of the minimum effort required to limit global CO_2 emissions to 14 gigatonnes per year at this point. In the same study, the IEA examines all the other possible means of reducing emissions by 2050, as shown in Table 6.

Table 6 Contribution of the different options for reducing CO_2 emissions from the energy system by 2050

CO_2 emission reduction activity areas	Gigatonnes of CO_2	Reduction (%)
Sequestration of CO_2 in industry	4.3	9%
Sequestration of CO_2 in electricity production	4.8	10%
Nuclear power	2.8	6%
Renewables	10.1	21%
Total for generating activities	***22.0***	***46%***
Efficiency and substitutions in electricity production	3.4	7%
Substitutions in final energy use	5.3	11%
Electricity savings	5.8	12%
Fuel savings	11.5	24%
Total for energy savings	***26.0***	***54%***
Total	**48.0**	**100%**

Source: IEA, 2008

Energy savings play the leading role with 54% of the total, followed by renewable energy at 21% and CO_2 sequestration at 19%. Nuclear power comes last of all with 6% of the total reductions, half the figure for electricity savings.

To illustrate this last point, it is worth recalling that in 2006 the IEA also published a report, *Light's labour's lost: Policies for energy-efficient lighting*, entirely devoted to a programme for electricity savings in the global lighting sector and the various consequences of this. This report states that total electricity consumption for lighting reached 2,650 TWh in 2005, or 19% of total global electricity consumption. The IEA then compares the projected consumption in a business-as-usual scenario and in a scenario in which low-energy bulbs are systematically installed wherever the annual level of use warrants it. Energy savings achieved by this means would reach 1,635 TWh a year by 2030, equivalent to half the additional nuclear electricity production proposed by the IEA.

But what would be the investment cost of this? The IEA gives cost estimates of $1 per 100W incandescent bulb with a lifespan of 1,500 hours, and $5 per low-energy bulb with a lifespan of 10,000 hours (around seven times as long). On this basis, since incandescent bulbs would have to be replaced 20 times between now and 2030, as against three times for low-energy bulbs, the cumulative investment required for this programme of supplying low-energy bulbs would reach $ 75 billion in 2030, compared with a cost of nearly $ 100 billion for the incandescent bulbs which would have had to be replaced seven times as often[24] – to say nothing of the electricity savings that would be achieved each year, of the order of $ 165 billion by 2030.[25]

24 A total purchase of 100 billion incandescent bulbs between 2010 and 2030 compared to 15 billion low-energy bulbs over the same period.

25 Assuming a cost of 10 cents per kilowatt hour.

France, showcase for the limitations of nuclear power

"The production of energy with low CO_2 emissions requires to mobilize renewable energy sources (…) and nuclear generation. Any decrease of the share of nuclear energy in electricity production (75% today) would make it impossible to reach greenhouse gas emissions reduction targets."

Report from the Energy Commission, chaired by J. Syrota, on 2020-2050 energy perspectives for France, Conseil d'Analyse Stratégique (CAS), February 2008

"Nuclear energy accounts for 6% of final energy in Europe, 2% worldwide and 17% in France. Given these percentages, focusing the debate on nuclear energy in order to build up a climate strategy does not seem justified. In France, the areas that need urgent attention are existing buildings, transport and the development of combined heat and power technology (CHP) in industry."

Report from the Working Group on "Achieving a fourfold reduction in greenhouse gas emissions in France by 2050", chaired by Ch. de Boissieu, August 2006

While the contribution of nuclear power to the energy consumption is undoubtedly marginal at a worldwide scale – hence its potential role in solving energy and climate crisis at that level –, its distribution is also very uneven. Only 31 countries run nuclear power plants, and the 6 biggest producers (United States, France, Japan, Germany, Russia and South Korea) generate almost 75% of the world's nuclear electricity production.

Confronted to the issue of scale limitation for nuclear energy, the advocates of nuclear renaissance take argument of this situation and claim that at least, nuclear power has a major role to play in countries or regions where it is already developed and that are ready for more – altogether in the technical, economic and political sense. Although there is no evidence from the past of a clear advantage in terms of energy security and mitigation of greenhouse gas emissions for countries operating large nuclear fleet,[26] the idea is worth consideration for the future.

Then comes the case of France. With 78% of its electricity production provided by nuclear power plants, the country has pushed the use of nuclear energy as far as it could be using current technologies. Its "all electric, all nuclear" plan, which remained the pillar of its energy policy since the programme started in the mid 1970s, has no equivalent in the world. The analysis of the real contribution of this development to France's energy security, and now climate policy, therefore provides a unique benchmark for similar plans currently discussed in other countries.

The original myth of energy independence

The idea that developing a domestic fleet of nuclear power plants would provide "energy independence" to the country by cutting down its dependency on oil became a decisive argument to launch a large programme of PWR reactors just after the first oil shock in 1973. The argument is still, 35 years later, the cornerstone for most decisionmakers' support for nuclear energy in France.

Yet the reasoning was biased from the beginning. In 1973, electricity production was only the fourth sector for French oil consumption, with 11.7% of the total (including non energetic uses), well behind transports (24.4%), residential and tertiary use (25.7%), and industry and agriculture (21.3%). This was actually the reason for promoting, as a complement to the construction of reactors, the extension

[26] The archetypal example being, of course, the United States that are the world leaders of both greenhouse gas emissions and nuclear electricity generation, with respectively more than 20% and around 30% of the world total in 2007.

of the use of electricity in sectors where this would be achievable, first the industry then the residential and tertiary sectors (through electric heating).

The substitution of nuclear power plants to fossil fuel-fired ones successfully brought down the share of electricity production in the French oil consumption down to 1.5% by 1985. By that time, about 30 reactors out of the 58 PWRs currently operating had been started-up. It is also the time when the counter oil shock, in 1986, put an end to ambitious energy efficiency policies that had been developed for the previous years following the oil shocks of 1973 and 1979. Altogether, the intensity of efforts on the demand side in the industry, residential and tertiary and transport sectors, related to the evolution of oil price, had much more influence on the level of French oil consumption than the nuclear programme alone.

This is true in both ways. Between 1973 and 1985, the reduction achieved in the power sector was only half of that obtained from the combined efforts on demand in the industry and residential and tertiary sectors. But the laxity of these policies from 1986, and the global lack of demand side policy in the transports sector reverted the decreasing trend to a growth of oil consumption up to now. According to the Ministry of Industry, the contribution of oil in terms of French final consumption reached a peak of 94 Mtoe in 1973 and went down to 74 Mtoe in 1985. The constant increase trend ever since has just brought the contribution of oil back to the record level of 1973, with 93 Mtoe in 2007 (see the part on evolution from the past years in Figure 9, below.) The actual dependency on imported fossil fuel is even higher if one considers that over the same period, the contribution of gas to French final consumption went up from 10 Mtoe in 1973 to more than 40 Mtoe in 2007.

Nuclear programme is nevertheless still considered a major contributor to French energy security in official reports. According to Government accountancy, it has brought French energy independence up from less than 25% to more than 50% – 50.4% exactly for the year 2007. This figure is based on a controversial choice to calculate the energy independence (the ratio between the energy domestically produced and consumed by the country) in primary rather than final energy: this allows for the two-thirds of primary energy used in nuclear power plants that are actually lost as heat in the atmosphere to be accounted for as produced… and consumed.

It is of course paradoxical that this large amount of wasted energy (roughly of the same order as the total oil use in the French transport sector) plays a positive role in the calculation. The absurdity shows when one considers that replacing French nuclear power plants, which reach a 33% efficiency, with less efficient plants would actually increase the official energy independence, while replacing them with hydropower and windmills, both assumed to have 100% efficiency, would bring it down to a mere 30%.[27]

Therefore it appears much more realistic to use a calculation based on final energy produced and consumed in the country. This implies, however, to make some choices in the calculation on how to account for energy losses, electricity exports, etc. Depending on those, published estimates range from less than 10% to 18% independence.[28] This is more consistant with the fact that nuclear power, after all, only accounts for 75% or more of the electricity produced in France, and electricity in turn only accounts for around 20% of French final energy consumption.

The difference between the two calculations is central to understand the huge gap that could develop between the importance given to nuclear power when discussing energy and climate options, and its real impact.

It should be noted that the authorities introduce other bias to enhance the role of nuclear power when they reduce energy security to the simple measurement of an ‘energy independence’ ratio. The first one is to discard any similarity when reasoning on security of supply of oil and uranium. On one hand, 99% of the oil used in France is imported and most of it (around 90%) is refined in France. On the

[27] It is interesting to note that even the planned improvement of new reactors performances, should these reactors replace the current ones with all things even, would have a negative impact on the calculated energy independence: this would drop from 50% to 48% if using the European Pressurized water Reactor (EPR, aimed to reach 36% efficiency) for replacement, and 42% if using hight temperature reactors reaching 50% efficiency or so.

[28] See in the first part of this chapter Global Chance’s calculation of a 14% energy independence ratio for France in 2007.

other hand, 100% of the uranium used in France is imported since the last French mine closed in 2001, and most if not all of it is enriched and fabricated into nuclear fuel in France. Yet nuclear electricity is accounted for as domestic production, while oil use is accounted for as imported energy, one reason given being the difference in the number and nature of supplying countries.

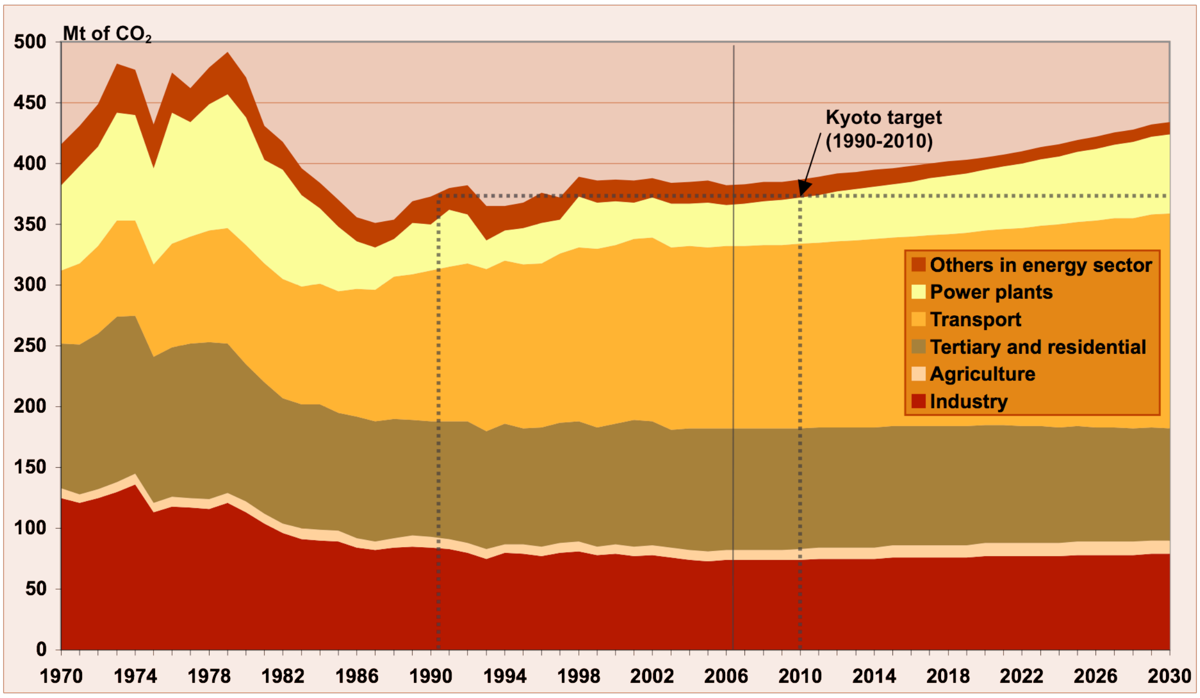
The second bias is to ignore any energy security issue besides the security of supply at the boarders, as if the domestic energy system were not impacting on the risk of energy shortage for end-users, which is what energy security is really about. The highly concentrated organisation of the electric grid that goes with nuclear power is not neutral regarding the potential for grid failures and their consequences. This systemic effect was involved in the very large extent, compared to the neighbouring countries, of the electric blackout following a record-breaking tempest in December 1999.[29] Moreover, the high dependency on nuclear power plants to 'fuel' the French economy and society with indispensable electricity creates, in addition to the remaining vulnerability to oil imports at least for transports, another serious vulnerability.

The inherent limits to the substitution logic

The failure of nuclear power to provide France with real energy security stresses the limits of an approach to energy policy that is based on technological substitution. Although this was obviously not intended at the time when the programme was decided, this rationale of substituting nuclear power to fossil fuels has been later extended to the growing issue of mitigating greenhouse gas emissions.

Figure 8 shows how the substitution mechanism applies to the evolution of greenhouse gas emissions – and more specifically to the CO_2 emissions from energy production and use, which are those concerned with nuclear development and account for roughly three quarters of France's total GHG emissions.[30]

Figure 8 **Past evolution of CO_2 emissions from energy production and use in France by sector and projection in a "business as usual" scenario (1970-2030)**



Source: Observatoire de l'énergie, DGEMP, 2008

29 More than 3.4 million households were left without electricity at the peak, of which more than 500,000 for at least 5 days. In 25 departments (or about one fourth of the total territory) it was more than 50% of the population that was affected.

30 The CO_2 emissions shown in the figure are those calculated by the Energy Observatory, with a slightly different method than the official United Nations Framework Convention on Climate Change (UNFCCC) method.

The figure clearly shows the impact of the development of the nuclear programme from the start-up of the first French PWR in 1977. But the decrease is also due, for a great part, to the efforts during that period on the demand side. These efforts drop dramatically in 1986 and from then, the growth of energy demand as a whole results in more increase of new fossil fuel consumption than is substituted by new nuclear reactors. Once all nuclear power plants are in service and an upper limit of substitution is reached, there is no more counterbalance to the overall growing trend.

The relatively low level of French GHG emissions, compared to similar countries, was taken into account to attribute its share of burden to France as part of emissions reduction for the European Union in the framework of the Kyoto Protocol. As a result, the French objective under the Protocol is only to maintain its level of emissions in 2008-2012 compared to their 1990 level (one should note that the choice of this year of reference, when emissions were peaking after the steady decrease of the 1980s, was already quite favourable for France).

But the trend, according to the 'business as usual' scenario published in 2008 by the Directorate general for energy and primary materials (DGEMP), is a constant growth of emissions for the next years and up to 2030 (Figure 8.) Consequently, France with all its nuclear power plants is not on the right tracks to respect its Kyoto assignment regarding CO_2 emissions.

This situation has nothing to do with some kind of nuclear phase-out. On the contrary, the DGEMP scenario assumes that, beyond the start-up in 2012 of the EPR under construction in Flamanville, more EPRs will be constructed to compensate for the shutdown of ageing reactors, so as to maintain all the way until 2030 a total installed nuclear capacity of 65.4 GWe, compared to 63.3 GWe in 2008. This is hardly 'business as usual': it represents about 52 GWe of nuclear reactors to be replaced between 2015 and 2030, roughly an average of 2 EPR reactors per year. The problem is that maintaining the nuclear capacity brings no more substitution but drains resources away from other energy options, while the rest of the energy system just grows.

Nuclear in France and the 'Factor 4'

Obviously something different will be needed if France is to aim not only for maintaining, but furthermore reducing its GHG emissions. It has actually set for itself a very ambitious goal for the long term with the 'Factor 4' concept.[31] This objective is based on the assessment by IPCC on projected temperature rise depending on global GHG concentrations. As it was put by the French Prime minister Jean-Pierre Raffarin at the opening of the 20th plenary session of the IPCC in Paris in 2003, "global GHG emissions must be halved by the year 2050"; for France, "this is equivalent to a fourfold or fivefold cut in emissions."[32]

The objective has been incorporated in French law through the Energy Policy Act n° 2005-781 of 13 July 2005 and its Article 2, which states that "tackling climate change is a priority of the energy policy, which aims to reduce by 3% per year on average French GHG emissions." Moreover, "France supports the establishment of a twofold cut objective for world GHG emissions by the year 2050, which implies, given the different level of consumptions between the countries, a fourfold to fivefold division of emissions for the industrialised countries."

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[31] This application to greenhouse gas emissions is derived from the much broader 'Factor 4' concept introduced by E. U. von Weizsäcker and A. Lovins in a 1997 report to the Club of Rome, *Doubling wealth – halving resource use* (Earthscan Publications Ltd).

[32] The reasoning behind is as follows. The equilibrium of temperatures on the low side of projected warming by the year 2100 (i.e. a temperature rise of 2°C or less) implies, according to the models, that GHG concentrations are stabilised at 550 ppm by the year 2050, which roughly correspond to a stabilisation at 450 ppm of CO_2 alone.
This, in turn, implies that annual emissions in 2050 would have to amount to no more than 14.7 Gt of CO_2, roughly half of the current level of emissions. This corresponds to 2.3 t of CO_2 per person per year based on the current word population of 6.5 billion people. If this burden had to be shared on the basis of an equitability principle, France and its current 61 million inhibitants would be entitled to 138 Mt of CO_2 emissions, compared to French emissions of 382 Mt of CO_2 for the year 2006.
Finally, this target of 138 Mt of CO_2 emissions in 2050 is assumed to be about one quarter of a projected growth of French emissions up to 550 Mt of CO_2 in 2050 if prolonging the current trend up to then. The factor four has later been further interpreted as a need to reduce emissions in 2050 to a quarter of their reference level in 1990.

It should be underlined that this self-compulsory objective was set prior to any elaboration of a French official energy and climate scenario matching this factor 4 goal. In fact, the first prospective scenario demonstrating a path to reach a 4-fold reduction of French CO_2 emissions by 2050 was published by an independent group of energy experts, négaWatt, in 2003. This scenario, updated in 2006, is based on a comprehensive implementation of energy sufficiency and efficiency on the demand side and of renewable energies on the supply side.[33] It therefore considers no need to build new nuclear reactors, even for replacing the existing ones when they shut down: it stresses that achieving the potential efforts to curb down energy demand is necessary *and* sufficient for keeping it to an absolute level of primary energy which the potential of renewables can reach on the long term.

On the contrary, official scenarios that have been developed since are bound to some continuity with the nuclear power precept. In that sense, they fully illustrate the potential contribution of this energy to meet long term energy and climate objectives.

The first 'factor 4' study commissioned by the Ministry of economy in 2004 was published in 2005.[34] The authors are themselves very cautious with the results, as the long-term part of the scenario (up to 2050) is based on a model of equilibrium between energy supply and demand that is built on the rules of the past while the need for real rupture is recognised by all experts. The model favours the share of electricity in final energy and that of nuclear power in primary energy, but that is a "possible factor 4 scenario" which "might not be the most desirable, the most economic or the most likely".

This scenario, which actually achieves a 3-fold reduction of emissions between 2000 and 2050 – considered as a sufficient burden for France inside a 4-fold reduction of emissions of the developed countries – envisions an increase of French nuclear electricity, up to 420 TWh in 2050. Yet this compares to some 480 TWh of nuclear electricity by 2050 in the 'trend' scenario. Why it takes less nuclear power to reach important reduction goals? Because the main difference lies in the overall electricity production, respectively foreseen at 690 TWh in the 'factor 4' scenario against 890 TWh in the business as usual case.

The most important lesson is there: curbing energy demand is the main key to curbing CO_2 emissions. The scenario adapted from this first study and presented as 'factor 4' scenario by the Ministry of industry in 2005 therefore envisions an average decrease of 0.6% per year through 2050, bringing the final energy consumption down to 116 Mtoe from 159 Mtoe in 2000 (figure 9.) This decrease is remarkably comparable to that envisioned in the négaWatt scenario, demonstrating that the development of a low carbon energy supply based on renewables or nuclear energies is a secondary choice which is meaningless if not preceeded by a primary priority on reducing energy demand.

Unlike the négaWatt scenario which sees an immediate and progressive decrease of final energy consumption, the official scenario, however, concludes that curbing the demand is not realistic in the short term. It therefore postpones any inflexion to 2020 or even 2030. With less time remaining towards 2050 but the same level to reach, this obviously requires a much steady decrease, in the order of 1.7% per year between 2030 and 2050. The scenario has been deemed an unrealistic vision, for it fails to justify why it considers a slight inflexion impossible today but sees a steeper one possible 15 years later.[35]

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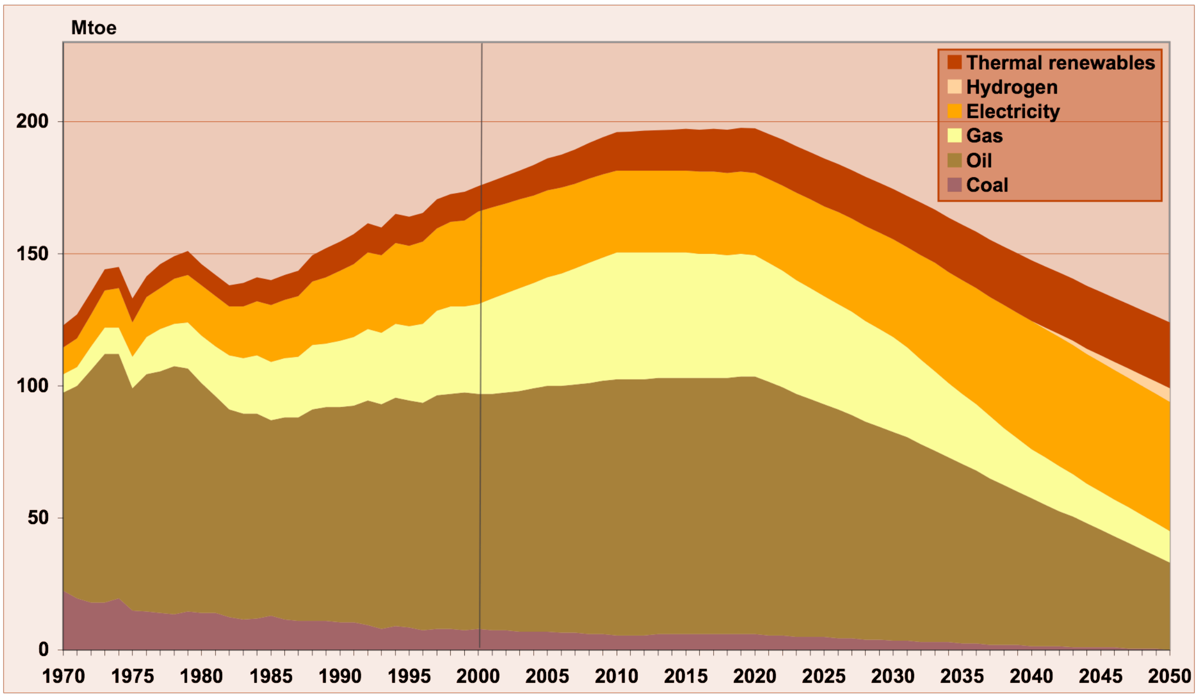
33 négaWatt, *Scénario négaWatt 2006 - Pour un avenir énergétique sobre, efficace et renouvelable*, Document de synthèse, December 2005.

34 Enerdata / LEPII, *Etude pour une prospective énergétique concernant la France*, commissioned by the Observatoire de l'énergie, Direction générale de l'énergie et des matières premières, Final report, February 2005.

35 Commission Particulière du Débat Public on the project of a first EPR at Flamanville, *Rapport de restitution du groupe de travail dit "Bilan prévisionnel RTE"*, February 2006.

Figure 9 **Past evolution of final energy consumption in France by energy and projection in a "Factor 4" scenario (1970-2050)**



Source: Observatoire de l'énergie, DGEMP, 2006

Late developments of official consultancies to the Government on French energy and climate 'factor 4' strategy have notably insisted on the marginal role of nuclear power as compared to energy demand policies[36] and the need to curve the trends as soon as possible.[37] The most recent advice, provided by a commission chaired by a former director of the energy department in the Ministry of industry and former CEO of Cogema, Jean Syrota, states that "reaching a division by 2 or 4 of GHG emissions by 2050 would hardly be compatible with leaving them unchanges between now and 2020."

These findings are reflected in the basis of the 'energy/climate package' passed by the European Council in March 2007, which sets goals for 2020 as a key condition to reach long term objectives, and establishes a link between the reduction of emissions (20% cut by 2020 compared to 1990), the development of renewable energy (20% of energy supply by 2020) and the effort on the demand side (20% reduction of energy consumption by 2020 compared to the projected trend).

Nuclear power: an obstacle to change?

The first French official 'factor 4' scenario matches none of these objectives. The meaning of these intermediate targets, in the case of France, is that relying on nuclear power to maintain the relatively low level of French CO_2 emissions in the short term does not dispense with the rapid implementation of strong policies on the other parts of the energy system as key for reducing the emissions on the longer term. But the basic philosophy of the French 'factor 4' scenario is that such policies aiming at reducing energy consumption or developing decentralized renewable energies could not deliver in the short term. This actually suggests that the whole technical, economical and political organisation of the French energy system around the "nuclear pillar" is an obstacle to the deep changes needed to face energy security and climate change challenges.

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36 Ch. de Boissieu (Dir.), *The Factor 4 Objective: addressing the Climate Challenge in France*, Report from the Working Group on "Achieving a fourfold reduction in greenhouse gas emissions in France by 2050", Ministère de l'économie et des finances and Ministère de l'écologie et du développement durable, August 2006 (free English translation of the authentic version of the report.)

37 J. Syrota (Dir.), *Perspectives énergétiques de la France à l'horizon 2020-2050*, Rapport de la commission Énergie, Centre d'analyse stratégique, February 2008.

The Syrota commission of the Centre d'analyse stratégique (CAS), which pointed that need for rapid changes apart from pursuing the development of nuclear power, developed a series of energy scenarios combining these policies to reduce CO_2 emissions. The scenarios, which use two different sets of well established models (Markal and MedPro/Poles), compare reference or trend situations with voluntarist policies that are seen as the most efficient ones in realistic limits. The performances of these scenarios regarding the 2020 European targets and the national 2050 target are summarized in Table 7, which also includes the scenario developed by négaWatt.

Table 7 Comparison of CO_2 emissions, energy efficiency, share of renewable energies and use of nuclear energy in 2020-2050 scenarios for France

Scenarios[a]			CO_2 emissions (evolution /1990)	Energy efficiency (/2006[b])	Renewables (% of total primary energy)	Nuclear power (Twh and % of total electricity)
2006			+1%	0%	n.d.	428.7 (78.3%)
2020	CAS	Ref. Markal	-3%	+13%	n.d.	431.3 (70.6%)[d]
		Vol. Markal	-23%	+6.6%	10.4%	549 (82.1%)
		Ref. MedPro-Poles	+3.5%	+1%	8.1%	431.3 (70.6%)[d]
		Vol. MedPro-Poles	-21%	-16%	9.8%	439 (65.8%)
	négaWatt		-26%	-18%[e]	19%[e]	209 (53.7%)
2050	CAS	Ref. Markal	+2.5%	+35%	n.d.	n.d.
		Vol. Markal	-52%	0%	15.4%	731.6 (78.4%)
		Vol. MedPro-Poles	-58%[c]	-38%	16.2%	453 (59.8%)
	négaWatt		-75%	-41%	70%	0 (0%)

a. Scenarios include reference (or trend) versus voluntarist scenarios ('Ref.' and 'Vol.') based on two different sets of models: the Markal model used by a team of the Ecole nationale supérieure des mines de Paris (ENSMP) and the MedPro and Poles models used by Enerdata.

b. The European objective of 20% of reduction of final energy consumption by 2020 compared to a projected growth is assumed to be equivalent to 14% of reduction compared to the demand in 2006.

c. Excluding carbon capture and sequestration (CCS).

d. The reference for 2020 is the projection of electricity supply published in 2007 by RTE.

e. The authors of the négaWatt scenario rather refer to primary energy consumption and to the share of renewables in final energy. Regarding energy efficiency, the decrease from 2006 reaches 24.3% in primary energy; the difference in 2020 négaWatt's own reference (or trend) scenario is -31.9% in primary energy and -26.6% in final energy. Regarding renewable energies, they represent 22.4% of final energy consumption in 2020.

Source: CAS, 2008, based on ENSMP, Enerdata; négaWatt, 2007

The quantitative output of such prospective analysis should be cautiously considered due to the high level of uncertainty of the models and arbitrariness of some hypothesis. However, this summary of scenarios' results sheds an interesting light on the overall performance of energy and climate strategies embedding the nuclear option:

- the fact that CO_2 emissions rise in both models' reference scenarios, although they maintain a stable level of nuclear generation, recalls that a strong share of nuclear power is no guarantee against a negative trend;
- the comparison suggests an adverse effect of a high level of nuclear generation on the development of energy efficiency and renewables. In particular, the scenario with the highest development of nuclear power (Vol. Markal, +71% in 2050 compared to 2006) is also that with the least effort on final energy consumption (only coming back down in 2050 to its 2006 level)

and renewables (remaining with 15.6% far off the 2020 target even in 2050)[38]… and the least efficient of the voluntarist scenarios for cutting CO_2 emissions;

- conversely, it can also be noted that none of the scenarios published by the CAS reaches the same level of energy conservation and the same share of renewables than the négaWatt scenario, which excludes new nuclear reactors… and reaches more reduction of CO_2 emissions;
- finally, the performance of CAS scenarios, which all include an increase of nuclear power production, remains short of a 4-fold reduction of CO_2 emissions by 2050. The 2.1 to 2.4 reduction reached is deemed by the Syrota commission as a realistic maximum. The report therefore calls, instead of a further domestic effort, for diminishing France's commitment in the framework of a burden sharing within European Union of a European factor 4 objective (which is of course misleading, since France's factor 4 objective is already based on the application to the French population of a worldwide per capita target).

In addition, the CAS report acknowledges for significant biases in the models that clearly both increase the weight of nuclear energy in the calculated energy mix and its role in reducing emissions. Firstly, the models mostly calculate average energy supply and demand without including potentially significant variations through time. This is especially important for the macroeconomic modelling of the electric system in France, marked by a massive use of this form of energy – which can't be stocked on such a scale – for heating in buildings.[39] The huge variability of heating needs influences the needs for electricity generation through days and seasons.

The variation between the yearly peak and low of French electricity demand increased from 27 GWe in 1978 (between a minimum of 12 GWe and a maximum of 39 GWe) to 57 GWe in 2007 (between 32 GWe and 89 GWe), mostly as a result of the development of electric space heating that was decided together with the nuclear programme. By ignoring this structuring factor, the models used by the CAS do not account for its important economic and environmental impacts. Covering a large part of varying electric needs with nuclear power plants over the year actually combines periods when their capacity is higher than demand so they lose profitability, and periods when it is far from sufficient and a massive support of fossil fuel thermal plants is needed.

Also, the models do not provide an acurate representation of decentralized energy sources, especially those with the highest efficiency. The scenarios, according to the CAS report itself, give excessive importance to centralized sources like nuclear energy because they underestimate the potential for developing renewables and combined production of heat and power (CHP) – exactly those the most needed according to bottom-up scenarios like négaWatt.

The nuclear lock-in of the energy system

In summary, these models that have been developed in a context of supply oriented energy policies based on centralized technologies fail to give a fair representation of energy alternatives. The irony of the CAS report conclusion that without a high share of nuclear power France could not meet its long term energy and climate goals, while the scenarios actually show that this would not succeed, is typical of how the importance given to nuclear power locks in French long term energy policy.

The idea of a competition between the current energy system and a new policy based on energy efficiency and renewables is denied any relevance. Instead, the French authorities advocate the complementary nature of renewables and nuclear power to form a mix of carbon free energy supply. They claim that their support for nuclear electricity does not prevent other developments. Recent evolutions of the French energy debate on some key issues reveal on the contrary that clear choices against renewables or energy efficiency come with nuclear projects.

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[38] Although, due to the high level of energy demand compared to other voluntarist scenarios, this relatively low share of renewables in primary energy corresponds in absolute terms to a higher level of production than in the voluntarist scenario produced with the other model (Vol. MedPro-Poles).

[39] Electric heating represents around 10% of the total electricity consumption in France, and 30% of the consumption of households. About 7 million of flats and houses, or more than 29% of all lodgings, use electricity for heating. In 2007, 70% of new lodgings were equipped with electric heating.

This shows for instance in the very low development, if compared to the potential, of CHP or proven renewable energies like wind power.[40] The development of CHP practically came to an end in 2002 due to the end of public support, and there is no plan to back this technology. A report commissioned by the Ministry of industry in 2007 concluded that any development of CHP should be cautiously limited to the most efficient plants and underlined a potential waste of public money, judging that it would be more economic to invest in new nuclear reactors.[41] The decentralized development of windmills is limited by the instability that it can induce on the highly centralized French electric network. Also, any increase of wind power, which must be used when the wind blows, would reduce the share of baseload electric demand covered by nuclear power plants and therefore erode their economics. The government's clear intention is to constrain the development of wind power to a limited, controllable number of large plants instead of using the whole potential of the French territory (estimated to be the second highest in Europe).

There are even stronger hidden effects of competition between nuclear power and energy efficiency. This is particularly true with choices to be made regarding heating in the residential and tertiary sectors. Heating needs in buildings represent more than 20% of French CO_2 emissions and a clear consensus has emerged in recent years that the factor 4 objective implies strong changes in the consumption of this very slow evolving sector. This includes both a large programme of rehabilitation of the thermal performance of existing ones and the introduction of strong new constraints of thermal performance for new buildings. In October 2008, the introduction in a project of law of a plan to impose a level of 50 kWh/m^2/year of primary energy for space heating in new buildings forced political reactions in defense of the nuclear industry: this level could not be reached in new buildings using electric heating from thermal (nuclear and fossil) plants, which has the lowest overall efficiency of heating systems. The debate underlined the contradiction between the urgent need for a policy to reduce the huge wasting of energy in that sector and the will to maintain a supply-side policy favouring nuclear power.

Historical and prospective analyses of France's energy and climate policies clearly show that other priorities than the sempiternal stance on nuclear power must be developed in order to meet the country's medium and long term goals. However, the analysis also shows that the disproportional importance given to nuclear power makes it hard to grasp those real priorities. Moreover, it suggests that under the influence of nuclear power, the whole energy policy is trapped in some mechanisms and constraints that hinder appropriate shifts in the energy system, irremediably leading the country to failing to its own commitments. Although current level of CO_2 emissions create the illusion of a successful policy, the lack of further decrease comes as a warning. France appears well on track to show that long term negative impacts of this nuclear lock-in outweight positive impacts of nuclear substitution.

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[40] According to RTE, the French production of electricity from renewable energies other than hydroelectricity reached 7.8 TWh in 2007 (or 1.4% of a total of 544.8 TWh), of which 3.8 TWh from 960 MWe of thermal plants using renewable fuel and of photovoltaic, and 4.0 TWh from 2,250 MWe of wind power.
The capacity of electricity generation from CHP is around 4.7 GWe in the end of 2007, of which only 0.7 GWe have been installed between 2002 and 2007.

[41] Inspection générale des finances and Conseil général des mines, *Rapport sur les installations de cogénération sous obligation d'achat*, Report to the Ministry of economy, finance and industry, January 2007.

Focus 02 Electric heating: not so virtuous!

> *"We have a serious problem with electric heating in France. It was a mistake to develop it. One could think it was possible to do it because we have a very large nuclear fleet, but then it leads to peaks of electric consumption in winter time. […] It is French folly to aim for transforming electricity into heat, a nonsense from the point of view of thermodynamics."*

Nathalie Kosciusko-Morizet, Secretary of State for ecology, interview in *Le Monde*, 1st October 2008

The 'all electric, all nuclear' wave on which France had ridden since the 1970s in the name of its 'energy independence', and which had led to extensive use of electric heating based on joule effect, received a sizeable new justification from the mid-1990s in the shape of nuclear power's more or less complete lack of emissions of CO_2, the main greenhouse gas. It was an excellent sales pitch for the heating salesmen and EDF alike.

However, matters were not so simple. Even in France, where nearly 80% of electricity is nuclear-generated, electric heating requires the use of fossil-fuel-generated electricity with its attendant CO_2 emissions – in winter, the peak heating demand is very often met by fossil-fuel generation. As a result, the Environment and Energy Management Agency (Agence de l'environnement et de la maîtrise de l'énergie – ADEME) and EDF announced average emissions of 180g per kilowatt hour for domestic electric heating over the period 2000–04. This represents a modest saving by comparison with modern gas heating (<10%), although a more significant one as compared with oil heating (40%), as Table 8 shows.

Table 8 Comparison of the CO_2 emissions of different methods of heating in France not involving electricity exchanges with European countries

Method of heating	CO_2 emissions per kWh	Δ compared to electricity
Electric heating in France supplied by the *national* generating fleet*	180 g	—
Natural gas*	195 g	+8%
Domestic heating oil*	310 g	+72%

*Assumptions: electric heating efficiency = 1, gas boiler efficiency = 0.95, oil boiler efficiency = 0.85.

Source: ADEME / EDF, 2005

In short, a France self-sufficient in electricity shows a saving in CO_2 emissions, albeit a modest one. **But what about the present situation, now that Europe has pressed ahead with its internal electricity market?**

The electricity consumed by domestic heating in France is not only French: it is European. Moment by moment, the network manager finds the cheapest available electricity on the European market. ADEME and RTE, the Gestionnaire du Réseau de Transport d'Electricité (operator of the national electric grid), which manages France's electricity network, have calculated the effects of the opening of this market on CO_2 levels per kilowatt hour of electric heating, as shown in Table 9.

Table 9 **Comparison of the CO_2 emissions of different methods of heating in France in the context of the European electricity market**

Method of heating	CO_2 emissions per kWh	Δ compared to electricity
Electric heating in France supplied by the *European* generating fleet	500 to 600 g	—
Natural gas	195 g	-60% to -67%
Domestic heating oil	310 g	-38% to -48%

Source: ADEME / RTE, 2007

The table shows that, in the context of the European market, electric heating becomes a catastrophe in CO_2 emission terms – with emissions two-and-a-half to three times as bad as they would have been if gas boilers rather than convection heaters had been installed in our houses! Installing heat pumps does admittedly bring an improvement in CO_2 levels. But such pumps must achieve an average annual performance coefficient of a factor of three to achieve performance comparable to gas heating, which is not the case for the air/air pumps which are at present the most widely sold.

The French nuclear dream: promises for disillusion

Nuclear energy might be marginal on a world-wide scale, but see how successful it can be in France, from an economical, industrial or environmental perspective! In view of such benefits, why not follow the French path?

The idea deserves consideration: what lies behind the repetitive vulgate of an industry selling its technical and economical success, claiming that it guarantees French energy independency, protects the climate, controls its waste and preserves the environment, that it is safe against terrorism, etc.?

What is the reality of the French nuclear experience in terms of industrial policy, safety, proliferation, waste management or economy? This chapter explores, on each of these issues, the gap between the talks and the facts.

Global Chance

Basics

The nuclear industry in France – An overview

French scientists contributed to the main stages in the discovery of radioactivity and its properties. Right after the Second World War, the country embarked on a nuclear development programme – initially military and then civil. The nuclear industry's organisation is still heavily based upon the structures created at this key period, even if their status has developed.

The Commissariat à l'Énergie Atomique (CEA – Atomic Energy Commission), set up in 1946, was charged with overseeing the research and development, up to the industrial stage, of all the processes necessary for the military programme and subsequently for nuclear electricity generation, including the uranium extraction and fuel manufacture (upstream) stages and the management of spent fuel and waste (downstream). A branch of the public research body CEA was created to manage all its industrial activities, mainly through the Compagnie Générale des Matières Nucléaires (Cogema – General Company for Nuclear Materials), a private company set up in 1976. In 2001 this merged with Framatome, the nuclear reactor builder, to create the Areva group.

Electricité de France (EDF), a company also established in 1946 by the nationalisation of the numerous state and private companies that existed at the time, was first and foremost responsible for overseeing the development of the electricity supply across the country. From the 1960s and even more from the 1970s, this development relied very heavily upon the construction and operation of nuclear reactors. Today EDF operates all 59 nuclear reactors in service in France. In 2005–06 EDF ceased to be a public enterprise entirely controlled by the State and was privatised, although the State retained a controlling share.

In 1991 the Agence Nationale de Gestion des Déchets Radioactifs (Andra – National Agency for Radioactive Waste Management), and in 1998 the Institut National de Radioprotection et de Sûreté Nucléaire (IRSN – National Institute for Radiological Protection and Nuclear Safety, known until 2002 as the Institut National de Protection et de Sûreté Nucléaire, IPSN), were formed from internal departments of the CEA. The IRSN is a public expert body responsible in particular for supporting the Autorité de Sûreté Nucléaire (ASN – Nuclear Safety Authority). The latter, which for a long time remained an internal department of the Ministry of Industry, has gradually evolved: after initially coming under the joint responsibility of the Ministry of the Environment and the Ministry of Health (under the name of Direction de la Sûreté et de l'Information Nucléaire (DSIN – Department of Nuclear Safety and Information) and then of Direction Générale de la Sûreté Nucléaire et de la Radioprotection (DGSNR – General Department of Nuclear Safety and Radiological Protection)), it has been an independent authority since 2006.

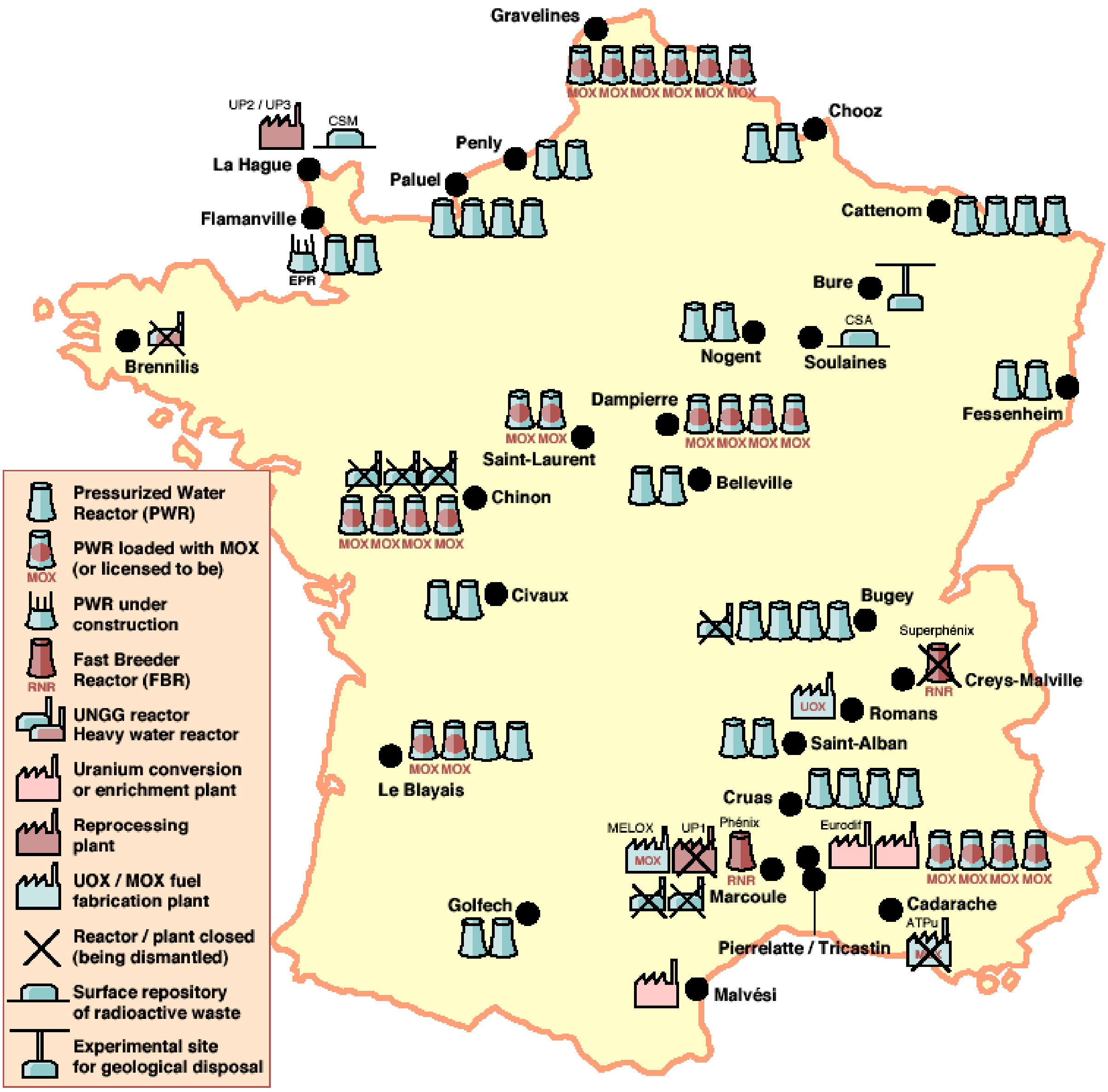
The first nuclear reactors operated by EDF from the end of the 1950s belonged to the natural uranium/graphite/gas (UNGG) line, initially developed by the CEA to produce plutonium. These reactors, as well as several industrial-scale prototypes tested as part of the development of other lines during the 1960s, have now been shut down and are being dismantled. In 1973 the French authorities opted for a massive development of the pressurised water reactor line, using low enriched uranium. The 58 pressurised water reactors now operated by EDF on 19 sites were for the most part put into service from 1977 until the end of the 1980s. A new reactor in this line, the EPR, is under construction at Flamanville. France has also developed the rapid neutron reactor (RNR) line with two reactors: Phénix, still operated by EDF, and Superphénix, which was finally shut down in 1998.

The French nuclear industry has moreover endeavoured to control all stages of the nuclear process. The CEA developed a uranium mining industry from the 1950s, although the last French mine closed in 2001. The various stages of uranium conversion are carried out for the most part at the Pierrelatte/Tricastin site, where in 1976 France also established an enrichment plant, Eurodif. Finally, the manufacture of enriched uranium oxide fuel (UOX) is carried out in the FBFC factory at Romans-sur-Isère.

Particularly characteristic of France is its establishment of the various stages of a plutonium industry. Reprocessing began in 1957 in the plant at Marcoule, which essentially fulfilled military demands and closed in 1977; since 1966 it has also been carried out at La Hague, whose capacity has gradually been increased in response to French and foreign requirements. In addition, the industry has acquired the capacity to manufacture mixed uranium/plutonium oxide fuel (MOX), first at Cadarache with the ATPu, closed in 2003, and then at Marcoule with the Melox plant, which entered service in 1995.

The decision to conduct reprocessing has a significant effect on the options for radioactive waste management. Solutions exist for the least radioactive waste: low- and medium-level short-term waste is stockpiled at the Centre de Stockage de la Manche (CSM – Manche Disposal Centre) near La Hague, opened in 1966 and closed in 2003, and the Centre de Stockage de l'Aube (CSA – Aube Disposal Centre), opened in 1992. But the search for solutions for all long-term waste continues – most notably research into geological disposal for the most active waste in the underground laboratory at Bure. Meanwhile the waste and nuclear material awaiting long-term solution is accumulating in more or less perpetual temporary storage facilities at the various sites, in particular at La Hague.

Figure 10 Principal sites associated with the nuclear industry in France (2008)



Source: WISE-Paris

Industrial policy

Beyond the ideal image of a highly successful industry

> *"Thanks to our experience with nuclear energy and our nuclear technologies, France is a major player in that strategic sector. […] France has always taken its responsibilities. These techniques that it has a recognized and respected mastery of deserve to become available to the nations."*
>
> **Bernard Kouchner, Minister of Foreign Affairs,**
> ***Les Echos*, 29 April 2008**

The success story of the French nuclear programme, as related by the nuclear industry and successive governments, conveys a strong image of highly skilled engineering and far-sighted industrial policy. This glittering image is surprisingly far from the reality of 50 years or so of development of nuclear energy in France, which has been marked by a history of technological dead-ends, failed industrial challenges and planning mistakes.

But the successive mistakes of the state-controlled industry have never been acknowledged, either by the state or the industry. At least, not in public terms, or only sketchily. On the contrary, while problems have been fiercely disputed behind close curtains, and some corrective actions taken, the public discourse has always remained as much as possible one of denial of any failure. The pursuit of the nuclear choice, declared once and forever the major pillar of French energy policy, is worth the price of covering, politically and financially, some dramatic reassessments.

Better pay the expenses than confess faults: the case for reprocessing

The future of French industry, or even of nuclear energy worldwide – as much as it is highly influenced by the French showcase – was actually mentioned in an official document as the main reason for maintaining existing reprocessing plans when they had just been critically reassessed, in 1985. Reprocessing had originally been developed for other purposes. In 1958, the first 'plutonium factory' (*usine de plutonium*), or UP1, was built and operated in Marcoule to produce raw material for the French nuclear weapons programme. Later, with the second plant, UP2, in La Hague opening in 1966, came the original rationale for civilian reprocessing as the core of a large programme of fast breeder reactors. Superphénix, a 1,250 MWe sodium-cooled fast breeder reactor (FBR) was ordered in 1976, and the following years reprocessing contracts were signed with EDF and foreign companies with the intention to fuel that programme. In 1976, CEA chairman, André Giraud, forecasted 540 such FBR units to be operated worldwide by 2000 – of which 20 would be in France – and 2,766 by 2025, because of increased tensions on uranium resources. By the end of the 1970s, an advisory report to the government planned that at least 40 GWe, or 25% of the total French nuclear-installed capacity by 2000 (which it also highly overestimated) would be provided by reactors of the same type as Superphénix.[42]

[42] Not a single order of FBR the size of Superphénix has been placed or is currently planned in the world.

A further step was taken with the ordering of new builds in La Hague, including the extension of UP2 into UP2-800 for reprocessing of EDF's light water reactor (LWR) fuel, and the addition of a new reprocessing plant, UP3, dedicated to the reprocessing of foreign LWR fuel. Ratified within days after the election of François Mitterrand, in May 1981, the decisions were seen as a fait accompli by the industry. Yet by that time, the forecasts on the price of uranium and the related development of fast breeder reactors had already been proved totally wrong.

The large-scale reprocessing plans had lost their ground. But instead of adapting them, the industry developed a new justification for them. A technological option that had been previously discarded provided a way out of this industrial dead-end. The separated plutonium would be used in existing LWRs in the form of mixed-oxide fuel, or MOX, blending 5% or more of plutonium with depleted uranium. This shift in justifying unchanged developments planned at La Hague was made as early as 1982. The choice was strongly criticised internally, and a report by a member of CEA to a consultative body for the French government, the CSSIN (Superior Council for Nuclear Safety and Information) concluded in 1982 that "interim storage (40 to 100 years, or more) of light water reactor spent fuel followed by geological disposal (non-reprocessing option) is infinitely less costly than the reprocessing option", adding that "recycling plutonium in light water reactors is an economic aberration."[43]

In 1985, an internal assessment conducted by the Ministry of Industry with a working group gathering industrial players to support the MOX programme showed no clear advantage to this option. Yet it led to the final decisions launching a 'reprocessing-recycling" scheme to a commercial scale, namely the completion of the new reprocessing plants in La Hague, the building of a commercial MOX fabrication plant in Marcoule (MELOX), and a contract between EDF and La Hague's operator Cogema (now Areva) covering the reprocessing of 8,000 tons of spent fuel over the 1990-2000 period.

An internal report by the department of fuel management of EDF, in 1989 – or two years after the first loading of MOX fuel in one of the utility's reactors – summarised the process.[44] It explained that "in 1982, when it appeared that the development of [fast breeder] reactors was to be postponed for a long time, EDF had to reassess the situation to know whether recycling plutonium in light water reactors would present sufficient advantages to legitimate pursuing the reprocessing programme", which would only be the case if uranium prices were high, a condition that did not materialise. The higher costs than planned for reprocessing and MOX fuel fabrication made it even worse. Every part of the assessment became negative, except for the conclusion: "given the investments already spent, even with the significant drop of MOX fuel competitiveness compared to natural uranium, the reprocessing option should be maintained […]. Questioning it has no economic basis, yet it would have a strong impact in the world, harmful to the whole nuclear industry." In other words, the increased operational cost of € 350 million over ten years, according to the low estimate of EDF at that time (to which one could add the investment costs of the reprocessing and MOX fuel plants), is a convenient price to pay to preserve a good image of the industry…

The 'reactor line war': France's late choice for US LWR technology

The French national utility would not lose the case against the fuel chain industry every time. Strategic discussions had started as early as the 1950s between the two industrial giants created in the first year after the end of the World War, in 1946: Electricité de France (EDF) and the Commissariat à l'énergie atomique (Atomic Energy Commission, CEA). The CEA was in charge of developing the use of nuclear energy in France, which it did in tandem with its other task, of running the weapons programme. Its industrial branch, later to become the publicly owned, private status company Cogema, developed technologies covering the whole fuel chain. EDF gathered French generating capacities and was in charge of developing them and the electric network to power economic development on the whole territory.

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43 J.L. Fensch, *Finalités du Retraitement*, Report presented to the Conseil Supérieur de la Sûreté Nucléaire, Paris, 1982.
44 J. Beaufrère et al., *Combustible MOX – Aspects techniques, économiques et stratégiques*, 24 November 1989.

EDF began generating nuclear electricity in six reactors operated with natural uranium (UNGG, moderated with graphite and gas-cooled), started between 1963 and 1972, totalling a capacity of 2,375 MWe.[45] The CEA had developed this technology mostly because of the high-grade quality of the plutonium produced in its low burn-up fuel, and intended to base any further development of nuclear generation on the same kind of reactors. EDF developed another vision and favoured the technology promoted by the US company Westinghouse of light water reactors using low-enriched uranium.

The choice between the two technologies turned into a tug of war between the two branches of the industry, intensifying throughout the end of the 1960s and the beginning of the 1970s as plans to launch a large nuclear programme gained political momentum. The issue, known as the "reactor line war", is for instance documented in successive reports by the French Consultative Commission for the Production of Electricity of Nuclear Origin (PEON), adviser to the government on the competitiveness of proposed nuclear power stations.

A first report in 1964 put UNGG reactors, which were assumed to produce electricity at the same cost as oil-fired plants (but expected to gain in competitiveness), at the core of a nuclear programme. The report estimated that LWRs would have lower investment costs but these would be levelled out by higher fuel costs, therefore "nothing allows [us] to conclude that the kWh costs would be more economic using US techniques." The main problem with LWRs was that the French industry would have to rely on US technology for both the reactors and uranium enrichment.

The government decided in 1967 to pursue the UNGG programme, with an order to be passed for two units at Fessenheim. The 1968 PEON report took note of that decision, but insisted on the need to wait for feedback on the first large units, and noted how economical the LWR designs were, although it pointed out yet again their tie to the US monopoly on uranium enrichment at that time. The report advised the development of studies to build an enrichment plant for French and European needs.

The 1969 PEON report took note of the decision to postpone UNGG orders and proposed the launching of a programme of five LWR units of 700 to 900 MWe, through buying licences of foreign designs. UNGG had become uneconomic in comparison. By the way, an inter-ministerial committee in January 1969 had decided on the launching of a "diversification programme" through a series of low-enriched uranium reactors. The report also recommended the construction of an enrichment plant, based on gaseous diffusion technology. Finally, the 1973 and 1974 reports were centred on LWR technology, in order to be consistent with the government decision to launch a massive programme of pressurised water reactors (PWRs) by the turn of 1973-4.

The final decision was therefore contrary to the will of the CEA, which had argued as long as it could against the change to a foreign technology – and almost won the case in favour of pursuing the UNGG programme. Nevertheless EDF's preference proved right, put in the perspective of today's status of nuclear reactors worldwide, where LWRs clearly dominate the fleet with 88 percent of the total installed capacity,[46] and natural uranium-based designs are largely on the decline and outdated.

Yet one interesting result of the CEA's blindness to LWR technology is that the French programme launched in 1974 had to be developed based on the Westinghouse licence, which had been granted to the French reactor constructor Framatome. It was 1982 before the franchise ended and Framatome was commercially regarded as the genuine designer of the reactors it built. By that time, 50 of the 58 units operated by EDF had been constructed or were still under construction... under a US licence.

Uranium enrichment: dead-end choices

This is not the only time the industry branch of the CEA, later Cogema in 1976, and Areva in 2001, developed technological options that had to be reviewed. Some choices that it made on the front-end

[45] This does not include two reactors operated by CEA in Marcoule, G2 and G3 (43 MWe each), started for plutonium production and later used also by EDF to produce electricity.

[46] As of the end of 2006, the world installed capacity totalled 368.8 MWe, and included 242.3 MWe of pressurised water reactors and 83.9 MWe of boiling water reactors (BWR), or 326.2 MWe for the two categories of LWRs together.

of the fuel chain also proved erroneous. When the decision to base a large nuclear programme on LWRs emerged, the need to be independent of the then US monopoly on low enrichment of uranium triggered plans for a French uranium enrichment plant that could also serve the whole European nuclear industry.

The US had developed uranium enrichment on the basis of a gaseous diffusion technology for isotopic separation. The French plant, operated by the Eurodif consortium, was designed and built to start operation in 1979 on the same technology, which CEA had already developed for a first plant operating for the military programme. An alternative technology, based on ultra centrifugation, had been developed after the war and was implemented at the same time in other European countries by the Urenco company, as well as in the then Soviet Union. This technology proved robust and effective, and much less energy-intensive. (The Eurodif plant consumes up to 15 TWh of electricity per year, a centrifugation plant of the same size would use around 50 less times less.) It also has lower construction times and investment costs and is more easily adaptable to enrichment needs. It can also be used to re-enrich reprocessed uranium if needed, which gaseous diffusion plants could not do without technological problems.[47] It is overall more competitive, and has clearly become the leading technology on the enrichment market.

The CEA had planned to replace the gaseous diffusion plant by a very advanced technology of enrichment by laser. The process, called SILVA in France, was also developed under the name AVLIS in the US (atomic vapor laser isotope separation), where the corresponding R&D programme was abandoned in 1999. The CEA, on the contrary, further developed it and still claimed in the early 2000s that the process would be ready to replace the Eurodif plant when needed and would come at a lower cost than other enrichment technologies. The official plan remained to use either gaseous diffusion or laser technology for a new plant.

The plan failed. In 2004, Areva launched the process to license and build a new enrichment plant at Tricastin to gradually replace, as of 2012, the existing Eurodif plant. This plant is to be based not on renewed gaseous diffusion or on a new laser process, but on the centrifugation technology that, turning its back on everything it had said up to then, Areva noted as “currently considered by every expert as the best performing technology for uranium enrichment”, pointing out the huge difference in energy consumption as a clear advantage.[48] The laser process, it also said, “has proved a theoretical capacity to enrich uranium, but using it on an industrial scale brings unavoidable costs given the current status of technology and available materials.”

As France never developed a R&D programme on centrifugation, choosing this technology means Areva has to buy it from its designer, Urenco. Areva bought 5 percent of ETC, the Enrichment Technology Company, the Urenco subsidiary which owns the design and sells centrifuges. However, because of the highly sensitive status of this technology regarding proliferation risks, Areva did not get access to the design. In other words, 30 years of industrial development of French-owned enrichment technologies came to an end to use Urenco’s black boxes, like anyone else.

A reality systematically short of projected targets

The French nuclear industry has thus a fairly faulty record when it comes to the technologies it chooses to develop. Another regular pattern has been the failure of new equipment to match planned performance. New plans for reactors or fuel-chain plants have usually been promoted through economic justification based on highly optimistic assumptions – sometimes necessary to win the case – that could not be met in reality.

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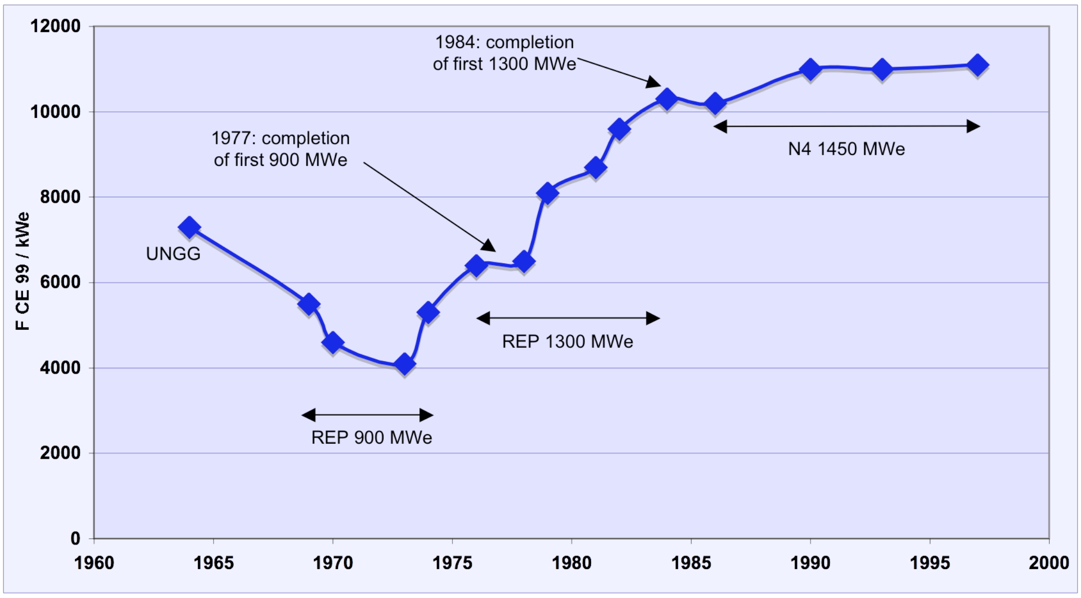
[47] The choice of gaseous diffusion for Eurodif therefore appears to run counter to the reprocessing plans developed at the same time in France.

[48] The huge electricity consumption of the gaseous diffusion process has not been a problem as long as EDF, with its excess nuclear capacity, could provide cheap electricity in exchange for some enriched uranium – a sort of mutual dumping allowed by the state. It is likely that diverging interests causing this agreement to end have played a role in Areva’s decision.

Although the phenomenon surely started from the beginning of the military-civilian programme, it only became apparent as new projects started to be discussed in public reports as industrial options. The PEON reports are among the first documents to trace the gaps between paper projects and reality. The evolution of the investment costs for new reactors, for instance, shows an escalation, with each report taking feedback into account – and the reason why real costs were actually higher than projected. Altogether, projected investment costs have gone up 3.3 percent per year over the period, when the 1968 PEON report projected a decrease of 3 percent per year (Figure 11.)

Figure 11 **Investment costs considered in PEON and DIGEC reports, 1964-97**



Source: CDP, 2000

It all started with the construction of the first reactor of the 58 LWR series, Fessenheim, which took two more years than planned. The PEON report noted in 1977, the year of its start-up, that "the norms currently used in terms of a period of construction, determined before the real start of the nuclear programme, at a time when the regulatory context and the quality processes were strongly different, are very tight"… This brought the financial burden of interest payments from 23 percent up to 32 percent of the total investment cost. The same report noted that Fessenheim and Tricastin real construction costs had actually gone up 7 percent and 13 percent compared to projected costs.

The series also demonstrate the failure of the projected decrease in investment costs as was expected with the increased scale of the reactors. The 1976 report, for instance, expected a 24 percent decrease in the investment cost for 1,300 MWe reactors compared to the 900 MWe of the first series. The average costs used throughout the PEON series, incorporating the return of experience of real costs, actually went the opposite way, with the cost for 1,300 MWe around 68 percent higher than that for 900 MWe reactors. The increase also applied to the next series of 1,450 MWe, with a further 25 percent.[49]

The problems did not decrease with experience. Construction of the four last reactors entered in service, of the 1,450 MWe type, also called N4 series, started between 1984 and 1991 (two units in Chooz and two units in Civaux). Yet they were connected only between 1996 and 1999, or after an average of 10.5 years. Moreover, safety problems forced them to an early shut-down and their official industrial service only started in 2000 (Chooz) and 2002 (Civaux), that is respectively 15.5 and 12.5 years after their construction started!

[49] The average costs used in PEON and DIGEC reports are respectively, converted in 1999 FRF then in Euros, 777 €/kWe for 900 MWe, 1.311 €/kWe for 1,300 MWe, and 1.646 €/kWe for 1,450 MWe.

Construction times and investment costs are not the only problems experienced with reactors. Another big difference between projected calculations and real operation comes from the load factor of EDF's reactors. Due to the excess capacity created by the planning mistakes of the 1970s and 1980s, the reactors cannot be used as much as they are technically available. While their full capacity cannot cope with the high peaks of demand linked to electric heating at some times in winter, it is largely in excess for long periods of time throughout the year. The average load factor of EDF's reactors is in the range of 75 to 80 percent, compared with load factors of 85 percent or even 90 percent reached by reactors in some countries – in other words, EDF looses 10 percent profitability by comparison. Nevertheless, EDF has constantly presented projections of a load factor above 80 percent, especially for new reactors, whose competitiveness is calculated using such optimistic figures.

Another area of failure has been the export of nuclear reactors. The high figures detailing planned development of nuclear capacity in France were assumed to be part of a similar development worldwide which did not happen. The projections almost got to a ten-fold order of error, with André Giraud's forecast, as CEA chairman in 1976, of 4,000 reactors operating worldwide by 2000 – against a real figure of 440 units. France's nuclear technology was to be involved in this international development – and the industry spoke of a massive potential for exports. When the French programme of LWR was launched, the manufacturing capacity for the large components of nuclear reactors was based on the assumption that France would export, on average, one unit for each unit built at home. In real terms, before the EPR order by Finland in 2005, the French industry eventually exported only nine units to four countries (Belgium, South Africa, China and South Korea), all based on its oldest 900 MWe design.

The lack of a comprehensive public assessment of projects has allowed the industry to produce over-optimistic justifications of its plans in a very systematic manner. Furthermore, the lack of reassessment procedures to compare implemented projects with their targets has prevented any learning process. The industry's promises, no matter how unrealistic, are still the basis for public discussion of its projects. Based on controversial hypotheses regarding key factors such as its planned lifetime (60 years) or its fuel performance well above the current licensed levels, the European Pressurised Reactor (EPR) project provides the most recent example.

The choice of this 'evolutionary' design is constrained by structural factors related to maintaining the competencies and motivation of the French nuclear industry while managing the time gap between the past programme of reactors and their potential renewal.

In the end of 2003, a French government's White Book on energy policy outlined four options, with no given preference order, to manage the replacement of nuclear reactors. These included the anticipation of the need for a first EPR; the potential to extend current reactors' lifetime while waiting for the next 'generation' of reactors; the acceleration of development of this new generation; and finally the possibility of waiting until when new reactors would really be needed and buying the best technology on the international market. In particular, there was concern over the EPR's large capacity – not fit for the smaller electricity grids of new countries – and its evolutionary design, less innovative yet more complex than some of its current competitors. Also, new reactors could emerge in the next 15 years that would definitely make the EPR outdated.

The first option has been chosen two years later without any comparative assessment being presented. Therefore, instead of the visionary cliché promoted by the French industry and government, constraints inherited from past mistakes have been decisive in the choice to anticipate the building of a first-of-its kind French EPR, rather than there being any analysis of the potentially negative impact of that structuring decision.

Focus 03 From planning to structural mishap

Some key decisions about the evolution of the French nuclear programme were based on dramatically faulty forecasting. The main example is the development of a large fleet of light water reactors (LWRs) decided in 1973-4. Based on unrealistic previsions of electricity demand, these decisions have had the strongest and most long-lasting impact on the national nuclear and energy policies.

The PEON reports series documents the projection of electricity consumption, showing how the forecast for any given year evolved from one report to the next (Table 10). In fact, France's official experts, like those in most western countries at the same time, based any planning on a forecast of very high increase, roughly based on a doubling of the electricity consumption every ten years. In 1964, they forecast 103 TWh in 1965, thus 205 in 1975 and 410 in 1985. What happened instead was a significant slowing in the rate of electricity demand compared to economic growth. The projection for 1985 was not less than 33 percent higher than the eventual real consumption, at 303 TWh. The decisive report for the launching of the "Messmer programmes" (from the name of the then prime minister), published in 1973, forecast 750 TWh of electric demand in 2000, an overestimate by 75 percent of the real demand, set around 430 TWh.

The divergence between this "rule" and the real evolution of demand was plain as early as the end of the 1970s. Yet the last reports of the PEON series still projected the building of a huge nuclear capacity, to reach 158 GWe by 2000 (of which around 40 GWe of FBR reactors of the Superphénix type…). And a corresponding rhythm of construction was maintained all through the first half of the 1980s, only coming almost to a halt by 1985, when 54 reactors of the 58 LWRs now in operation (totalling 63.8 GWe) had already been built or at least ordered.

In fact, while some countries gave up parts of their programmes and cancelled some projected reactors,[50] EDF did not abandon a single order. As a result, France is marked by a structural overcapacity of nuclear power that is still in effect, impacting on nuclear economics and preventing demand-side management and development of renewables in the electricity sector.

Table 10 Electricity consumption forecasted in PEON reports, 1964-79

Year of prevision	Electric consumption in France – forecast (TWh)							
	1960	1965	1970	1975	1980	1985	1990	2000
1964	72	103	150	205	290	410		
1968				210	300	400		
1970				200	285	400		
1973				195	280	400		750
1974						355-420		
1976						365		
1978							350-450	
1979							400-450	530-700
Real	**72**	**102**	**140**	**181**	**249**	**303**	**349**	**430**

Source: CDP, 2000

[50] For instance, no less than 138 reactor units were cancelled in various stages of planning and construction in the US, compared with 103 reactors in operation.

Focus 04 The loss of competencies

"The whole point in anticipating the building of a 'first-of-a-kind' is to bring the industrial system back with the capacity and competence."

Head of Nuclear Engineering Dept, EDF, about the EPR in Flamanville, in a public meeting of the national debate on the project, Paris, 29 November 2005

The national public debate that preceded the licensing of the French EPR project in Flamanville shed light on the main reason for building it at a period when, as opponents pointed out, no additional nuclear production was needed. EDF made it very clear through public meetings that, although the company forecast no problem in selling the new reactor's electricity, production of energy was not the main rationale behind the project. On one occasion, a high representative of EDF's engineering department even acknowledged that the EPR project might turn into a negative financial balance in the short and mid-term, but claimed it was still a decisive step in EDF's industrial strategy for the longer term.

The main reason why EDF is building the EPR is the desperate need to maintain industrial, organisational and engineering competences that widely erode. The company intends to pursue its singular strategy and remain the only nuclear operator with the ability to build its own reactors. The international window provided by the building of an EPR in France is also said to be vital for Areva, which warned during the public debate that "in the absence of new orders, the French nuclear engineering community would lack the critical size, the necessary means and mobilisation to maintain its technological superiority"…

The competency issue is mostly one of human resources. The pyramid of ages of the French nuclear workforce is strongly influenced by the history of the nuclear programme, with large numbers hired in the fast growth phase and then a standby phase. This results in a generational gap between the skilled scientists, engineers and technicians that developed the French nuclear fleet into its current status, and the new workforce that will have to build and operate reactors to replace the existing ones. (And which will also, to make things more complicated, have to manage their inheritance in terms of waste disposal and decommissioning…) On the one hand, about 40 percent of EDF's current staff in reactors will retire by 2015; on the other, there is a lack of graduates with the relevant qualifications following years of reduction in the number of students interested in nuclear studies.

Encouraging large numbers of new engineers and technicians to embrace a career in the nuclear industry would not solve the problem, as they would need to be trained and learn from operational experience. Already, operational problems arising from the shortage of competence renewal, which EDF's Inspector General for Nuclear Safety pointed out in his annual report for 2007 as "the first management concern", are apparent at all management levels and all sites in the whole nuclear sector (and not only in EDF).

Finally, the issue extends to organisational and industrial considerations, such as the capacity to cast the largest pieces of the reactor vessel of an EPR. The only plant, owned by Japan Steel Works, that could forge ingots of the needed size (450 tonnes) up to now will provide components for the Finnish and French EPRs. Only in July 2008 Areva announced that it would proceed with the investment needed to upgrade its Chalon forgery to produce components for future EPR orders.

Focus 05 The problems of EPR projects

"It is difficult to build a nuclear power plant."

François Fillon, French Prime Minister, 30 May 2008

The problems experienced on both the EPR construction sites of Olkiluoto in Finland (OL3) and Flamanville in France show how difficult the building of a nuclear power plant can be, given the level of specification to meet and the skills required. In both cases problems have started at early and supposedly less complex stages of construction such as the pouring of concrete and the welding of steel. Yet the companies involved – Areva as supplier, Bouygues as subcontractor for construction works, EDF – are considered among the best in the field. Nuclear reactor construction proves hard to manage even for the cream of the French nuclear and construction industry.

The construction of the first EPR started in October 2005 in Finland, and problems began very soon. Two and a half years later, the project is at least two years behind schedule. The Finnish nuclear safety authority STUK made clear, highly critical statements about the supplier's responsibility for the delay. In a report published in July 2006, STUK considered that "the time and resources needed for the detail design of the OL3 unit were clearly underestimated when the overall schedule was agreed upon", and that "major problems involved project management", pointing to the insufficient guidance of subcontractors with no prior experience in nuclear power construction. STUK also comments that "the incompetence in the constructor role becomes obvious in the preparations for concreting of the base slabs."

In early 2007, STUK had listed 1,500 safety and quality problems with the project, including critical ones, and considered it possible that all the problems had not been detected. Most pieces of the pressure vessel, the pressuriser and steam generators had been badly manufactured. The future operator, TVO, has also complained, its project manager recalling in February 2008 that at the time, Areva had submitted only half the plans for the EPR.

The work building the second EPR started two years later in Flamanville. There again, problems were evident from the beginning. On 3 December 2007, on the very first day of concrete pouring on the site, an inspection carried by the French nuclear safety authority, ASN, concluded that the quality control procedures for the base slab concrete were "unsatisfactory". Some basic specifications had not been respected and the right procedures had not been followed for concrete mixing, pouring, and test sample filing. Another inspection, ten days later, showed erroneous assumptions and violations of regulations as regards the potential interaction of the building works with the two operating units, suggesting a deeper lack of basic safety culture.

Further inspections carried on during the first half of 2008 found a series of anomalies that led ASN to point to "a lack of rigor in the construction of the building site, difficulties in the management of external subcontractors and organisational deficiencies." Finally, on 23 May 2008 ASN took the very unusual decision to stop the concreting of all safety relevant parts of the plant. A long series of inspection reports listed very serious errors affecting the quality of concrete – too porous in some parts; the quality of repair of subsequent cracks; the incorrect following of specifications in welding etc. On 17 June 2008, ASN authorised a conditional restart of the concrete work, based on a commitment by EDF to upgrade quality control and organisation.

Safety

An evolution laden with risks

> *"Even a minor accident could be a disaster, because it could question the acceptability of nuclear energy in France, and perhaps in the world."*
>
> **Bruno Lescœur, Executive Vice President, EDF, biennial general meeting of the World Association of Nuclear Operators (WANO), Berlin, 13-14 October 2003**

The nuclear accidents at Three Mile Island (1979) and Chernobyl (1986) have demonstrated the potential for catastrophic events at nuclear power plants. While they had a significant impact in preventing the development of nuclear programmes in a large number of countries, they did not affect the French nuclear industry much. The pioneers of the French nuclear programme had so confidently promised that a major accident could never happen in France that it developed a sense of immunity which partly remains. French nuclear facilities are painted as some of the safest in the world, and the industry carefully sustains the idea that "a Chernobyl-like accident is not possible in France."

What could actually happen is not easy to predict. It is important, first, to note that the technology, organisation and systems of control used in the French nuclear facilities are not really different, taking into account some national specifics, from those in place at least in other western countries. Like anywhere in the world, nuclear accidents are not "impossible" in France, say safety experts, but might rather be "improbable". This fundamental difference opens a whole field of discussion over the likeliness of events, from how they could be assessed to what level of risk is acceptable.

From impossible accidents to acceptable risks and consequences

There has been no catastrophe in the world leading to a large radioactive release with consequences like massive evacuations and land contamination since Chernobyl. There has been no major accident, in the sense of an accidental event in a nuclear facility with immediate, large and serious consequences for workers or populations and the environment, in France. Does that mean that safety has improved worldwide and that it is even better in France?

While any accident proves a safety failure, the contrary is not true. A lack of accidents only indicates that, though potential failures in the safety of nuclear facilities could exist, allowing a tree of events to develop into a major accident, they have not yet occurred in real life. The demonstration of safety relies on a double objective: reaching "acceptable risks" and "tolerable consequences". This is increasingly based on probabilistic safety analysis (PSA), which consists of calculating possible trees of events and their consequences in a given range of probability. This approach provides the reassuring appearance of a very comprehensive and systematic assessment, but is bound to the inherent uncertainty of models as compared to real life.

In short, it is not possible to take into account every single event or combination of events within a certain range of probability (e.g. one chance out of one million per year) so as to exclude any other situation. It seems overconfident to consider a priori the full scope of factors, such as design errors, construction and manufacturing problems, material defects, internal and external events, deficiencies of documentation and voluntary or involuntary violations of rules and procedures. This is particularly true when thinking over the plants' lifetime of tens of years, which brings changes in the internal organisation and external conditions that might not be foreseen, and is also affecting the behaviour of components through ageing in a way that can't be fully predicted.

Moreover, the calculation of consequences relies on assumptions about the response of some components to certain situations that can only be theoretical until the event really happens. This is especially an issue for safety components reserved for the most severe events, such as the melting core management system proposed for the EPR ('corium catcher').

It is therefore important to learn as much as possible from existing events. The numerous incidents that occur in nuclear plants throughout the years without triggering a major accident tend to promote a complacent feeling in the industry that the lessons learnt from Three Mile Island and Chernobyl have improved the level of safety up to really acceptable levels. One can note, however, that the Three Mile Island warning did not prevent the Chernobyl catastrophe from happening. Also, the improvements that actually took place after Chernobyl could not change the design of existing plants, but only involved back-fitting and upgrading of some equipment and the strengthening of procedures and training.

New safety standards and old reactor designs

This is particularly true for the French nuclear power plants, which were decided, designed and constructed in a very standardised way over a very short period of time (see Table 11.) The 42 first units of the LWR programme (36 reactors of 900 MWe and eight reactors of 1,300 MWe), or three-quarters of the currently operating reactors, have been ordered in one decade (between 1970 and 1980) and put in service over the same time (between 1977 and 1987). It took only three more years to order and seven more years to build 12 units of the 1,300 MWe type. Finally, only the realisation of the last four units of 1,450 MWe was stretched out, with orders placed between 1984 and 1993 and start-ups in 2001.

The core of the French reactors programme was thus planned more than 25 years ago, too early for any feedback from the reference accidents of 1979 and 1986 to be deeply integrated in plant design. The Three Mile Island accident, because it happened in a nuclear reactor of the same technology that France used to develop its own power plants, was taken very seriously in France. A group of experts appointed by the Ministry of Industry proposed some reinforcements in the operators' theoretical and practical training, some equipment was reinforced and the rules and procedures were strengthened. The accident is recalled as a shock to the French nuclear industry. As stated by one of the most prominent safety experts of the time, Pierre Tanguy, "weaknesses of the earlier safety approach were revealed" and it "blew the idea" of most people in the nuclear community that a major accident was nearly impossible.[51]

However, it was too late to change the basic design of reactors, as 46 of them were already in operation or at least under construction when the French safety experts drew lessons from Three Mile Island in 1981. Accordingly, the major change introduced instead was the reexamination of emergency planning through the Plans d'urgence internes (PUI) and the Plans particuliers d'intervention (PPI) to include the event of a core meltdown with radioactive release outside of the plant. Similarly, the accident triggered the development of new methods to assess the risk in accidental situations, taking better account of multiple defects and human errors.

[51] P. Tanguy, Director of IPSN, "L'impact de Three Mile Island", in *Les réalités de la sécurité nucléaire après Three Mile Island*, Proceeding of an information meeting, Paris 9-10 June 1981, SFEN, 1981.

Table 11 The French programme of Light Water Reactors (LWR)

Type	Number of units	Power plants (nb units)	Order	Grid connexion	Industrial start-up
REP 900 / CP0	6	Bugey (4) Fessenheim (2)	1970 – 1974	April 1977 to July 1979	Dec 1977 to Jan 1980
REP 900 / CP1	18	Blayais (4) Dampierre (4) Gravelines (6) Tricastin (4)	1974 – 1980	March 1980 to Aug 1985	Sept 1980 to Oct 1985
REP 900 / CP2	10	Chinon (4) Cruas (4) Saint-Laurent (2)	1975 – 1980	Jan. 1981 to Nov 1987	Aug 1983 to April 1988
REP 1,300 / P4	8	Flamanville (2) Paluel (4) Saint-Alban (2)	1975 – 1980	June 1984 to July 1986	Dec 1985 to March 1987
REP 1,300 / P'4	12	Belleville (2) Cattenom (4) Golfech (2) Nogent (2) Penly (2)	1980 – 1983	Nov 1986 to June 1993	April 1987 to March 1994
REP 1,450 / N4	4	Chooz (2) Civaux (2)	1984 – 1993	Aug 1996 to Dec 1999	Jan 2001 to Dec 2001
EPR (1,600)	1	Flamanville (1)	2007	—	—

Source: based on CEA, *Elecnuc*

Having worked heavily on learning the lessons from Three Mile Island, the worldwide nuclear industry responded very defensively to the Chernobyl disaster, by pointing out that it was a "Soviet accident" waiting to happen due to specific defects in technology and organisation, and outrageously downplaying the human and environmental consequences. The French authorities were the most defensive, up to the point of denying any impact from the large radioactive cloud that flew over Europe on French territory (thus refusing to take any measures regarding the consumption of food or water, etc.), an attitude remembered in the collective consciousness as the false statement that "the cloud had not passed the French border."

Yet the accident weighted the evolution of safety requirements to be imposed on new reactors, at French as well as international level. As soon as the early 1990s, only two orders of the last series of French reactors – the N4 type of 1,450 MWe – had been completed when official safety experts already saw them as outdated. A director of IPSN (now IRSN) noted that "the conception of the N4 units […] dates back to the first half of the 1980s […]. Today, it appears to all concerned players that a significant improvement in the safety of future units is needed, as compared to those currently in operation."[52] As recalled in parliamentary hearings in the early 2000s, the French nuclear safety authority (now ASN) stated as early as 1995 that it would not be acceptable any more to build N4 reactors, as the reference safety requirements had evolved, in the sense of higher exigencies, since their conception in the early 1980s.[53] The need for a higher standard of safety was the reason for developing a new design, leading to the EPR project developed with Germany.

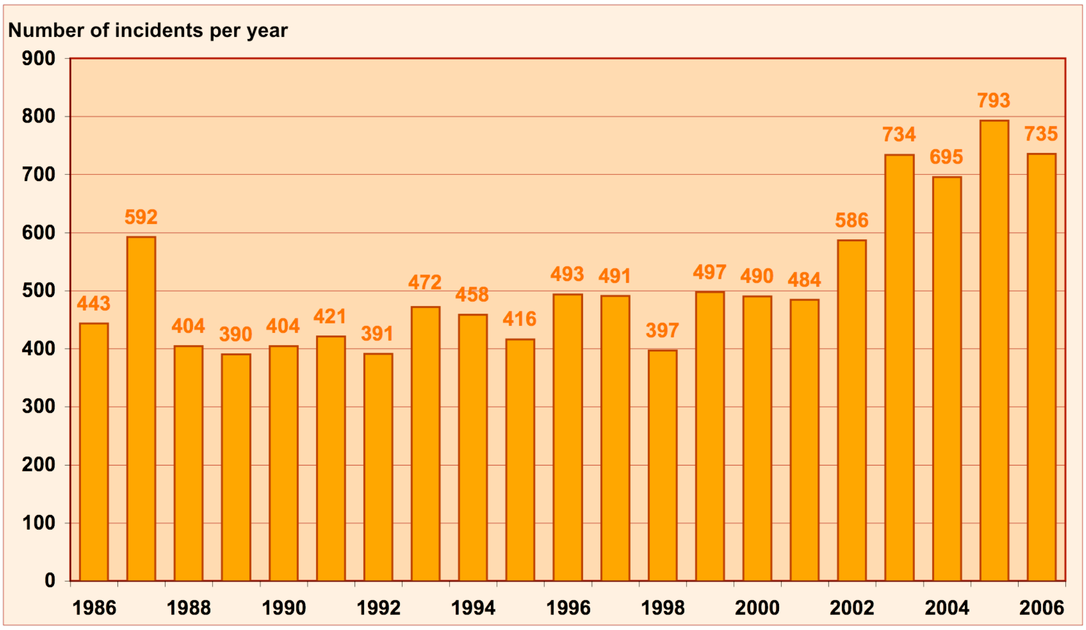
[52] D. Quéniart, Director for safety of IPSN, "La sûreté dans les années 1990", *Revue Générale Nucléaire*, n°5, Sept-Oct 1991.

[53] Ch. Bataille, C. Birraux, *La durée de vie des centrales nucléaires et les nouveaux types de réacteurs*, May 2003, OPECST, from the hearing of B. Dupraz, Director of the Energy division, EDF, on19 December 2002.

Distorsion in the public account of safety events

Yet the same reactors that would not be constructed now because they are seen as insufficiently safe are said to operate with an acceptable level of safety. This view is largely based on the statistics of events that are considered relevant for safety by operators and the authorities. The operators of 200 nuclear facilities in France declare a very large number of events every year, with EDF alone declaring between 10,000 to 12,000 of them,[54] of which 700 to 800 are considered "incidents" or "significant events" (see Figure 12.) These are regularly analysed by IRSN and then discussed in internal meetings with EDF and ASN to prepare their classification and draw lessons for the prevention of operational risks.

Figure 12 Significant incidents in French nuclear power reactors, 1986-2006



Source: *Residual Risk*, 2007, based on IRSN

The database of these events and their analysis is not publicly available. According to a report citing the director of the nuclear safety department of IRSN,[55] approximately 200 events are considered "outstanding" every year (244 in 2006), and 100 are retained in the framework of national feedback. On average, around 20 events each year are seen as precursors, in the sense that they put into jeopardy several lines of defense and could have led under other circumstances to a serious accident. Finally, between two and three events usually undergo a detailed in-depth analysis by IRSN.

Unfortunately, there is no indication given about the existing link between this statistical analysis and the classification of events using the International Nuclear Events Scale (INES) regularly published by the ASN (see Figure 13.) The number of events recorded on the INES scale in France through the years shows very important variations which found no technical explanation. It is difficult to find trends in these statistics. According to an analysis presented in the ASN annual report for 2005, a remarkable one is that the more recent plants (by technology and by operational age) encounter more incidents than the older ones, with an average of 10 incidents per 900 MWe per year, increasing to 12 per 1,300 MWe per year and 13 per 1,450 MWe per year.

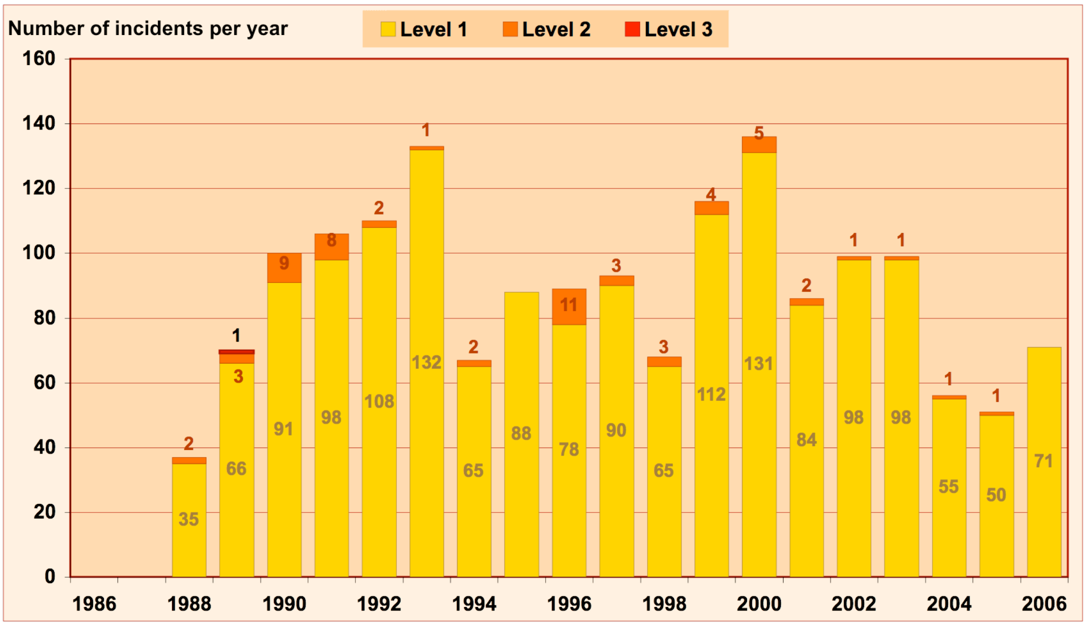
[54] Although a large majority of them are related to safety, it must be noted that these include safety, radiation protection and environmental protection events (respectively 73.7%, 22.2% and 4.1% for the year 2005).

[55] M. Schneider (Dir.), *Residual Risk – An Account of Events in Nuclear Power Plants Since the Chernobyl Accident in 1986*, May 2007.

A cumulative 10,786 significant events have been declared in French nuclear power plants between 1986 and 2006, of which 1,615 were rated INES Level 1 and 59 Level 2. Only one event was rated Level 3. The ASN reported 764 events declared by EDF for 2007, of which 56 were rated at Level 1, and none at higher level. In addition, between 50 and 200 events are reported each year for fuel chain facilities, other nuclear facilities and transports.

The problem with the INES scale is that it tends to distort the reporting and classification of events as compared to their real importance in terms of safety. While the number of reported events almost doubled between 1998 and 2005, the number of events rated 1 or more on the INES scale went down from 136 in 2000 to 51 in 2005… In other words, there is a trend of a steady increase in the number of events (from 7.1 per reactor per year in 2000 to 10.8 in 2007), but the number of those which seem important using INES criteria is decreasing.

Figure 13 INES rated incidents in French nuclear power reactors, 1986-2006



Source: *Residual Risk*, 2007, based on IRSN

The International Atomic Energy Agency (IAEA)'s INES defines events as "deviations" (Level 0), "anomalies" (Level 1), "incidents" (Level 2) "serious incidents" or "near accidents" (Level 3) and "accidents" (Levels 4 to 7). The criteria used to rate safety events on the INES scale are complex but mostly based on the potential for immediate radiological consequences to workers, the public or the environment rather than the measurement of how close the given situation came to very serious damage or the weaknesses in the safety system that could be pointed even by minor events.

As a consequence, some events that were close to developing into serious accidents but did not thanks to one hazardous factor – or some events that might be taken as early warnings or as precursors of serious incidents – are given a low level on the scale compared to other events with minor implications in terms of flaws in the lines of defence but immediate consequences. Accordingly, a negative side-effect of the INES rating might be that operators tend to feel relief when an incident closes without immediate consequences rather than concern about the fact that a 'near-miss' situation could have developed.

The Forsmark incident, which happened in Sweden in July 2006, illustrated the potential significance of such a 'near-miss' scenario, although there were no direct radiological consequences. After a short circuit in an outdoor switching station of the grid near the nuclear power plant had caused the emergency shutdown of the reactor, a complex set of events led to subsequent failures. The incident clearly revealed a weakness in the plant's design and, according to some experts, the reactor was just a few minutes away from a Chernobyl-scale scenario.

Only one "accident" in the sense of the INES scale was ever registered in France. On 13 March 1980, on the gas-cooled unit of Saint-Laurent-A2, a local defect of the cooling system due to the fatigue of some components inside the reactor vessel led to the total fusion of two fuel elements and the partial fusion of two others. Even incidents rated at Level 3 are very rare. One is the fire in radioactive waste (bituminised sludge from reprocessing) at La Hague storage facilities in 1981.

Another serious incident took place in Bugey on 14 April 1984 that would probably be rated Level 3 today, but was not at the time. A defect in the design of electric cables linked to the control-command system led to their failure, causing a complete blackout of unit 4 of the plant. The safe shutdown of the plant absolutely required the use of alternate electricity sources provided by two diesel engines, of which the first one could not be started when needed – leaving the second backup engine as the last and only safety line before a fusion of the core. On 16 August 1989, another incident was rated at Level 3 in Gravelines-1, when it was found that the reactor had been operated for about one year with inappropriate screws, causing a severe degradation of the protection system against overpressure of the primary circuit.

Worrying lessons from a whole range of incidents

The authors of the *Residual Risk* report obtained in 2007 from IRSN a commented selection of the most significant incidents for safety on French nuclear reactors between 1986 and 2006 which shows how much this criteria might differ from the INES scale: eight of the 18 incidents selected by IRSN were only rated Level 1 on the INES scale, and one was not even rated.

The selection shows how various factors can affect the safety of French nuclear facilities, as the 18 incidents cover the whole range of root causes: from design errors and defective components to inappropriate procedures and human errors.

Some incidents illustrate the potential weakness of the probabilistic approach, as in the case of the Blayais-2 incident of 1999. The unexpected strength of the storm that struck France on 27 December 1999 was such that it led to a combination of two critical conditions: a centennial flooding of the plant and the loss of the external electric grid. This led to an emergency shutdown while some key safety equipments (injection pumps, containment spray systems…) were unable to work, and any human intervention was perilous because of storm conditions. Each of the events had been separately considered to fall within the range of probabilities to take into account, but not their simultaneous realisation. Also, the incident led to a reassessment of flood protection provision at all sites, which concluded there was a need for higher maximum flood design levels and better protection at the Belleville, Bugey and Chooz nuclear power plant sites.

This highlights the difficulty of predicting at the time of conception of a reactor the whole range of probability of internal and external events that could happen throughout its entire life. The probability of severe climatic events, in particular, must be reassessed, taking into account the local impact of ongoing climate change. An improvement in methods of assessing seismic hazard has also led to some reassessment of the major seismic events to be considered at some sites, which in turn has triggered a reassessment of how key equipment withstands stress. This applies to EDF reactors that undergo a large programme of back-fitting, and also to other facilities, particularly the oldest ones, built under very lax anti-seismic requirements. The MOX fuel fabrication plant of ATPu, in Cadarache – on the seismic fault of Durance – was eventually closed in 2003 following years of pressure by ASN because of its insufficient anti-seismic design.

These selected incidents also illustrate how the high level of standardisation of EDF reactors can lead to generic failures, some of the events affecting all 58 reactors in operation. The most serious was probably the problem of sump clogging, a phenomenon that could strongly affect the recirculation of primary cooling water needed in the case of a large loss of coolant accident. The problem, already known on foreign reactors with similar designs as early as the beginning of the 1990s, was acknowledged to affect all 34 units of the 900 MWe series as of December 2003.

Generic faults were still found on EDF reactors in 2007. On 26 February 2007, the ASN issued a note concerning all 58 reactors, after it was found that error margins had not been taken into account during periodic tests of key safety devices – while with the margin of error some tests might have been counted as having failed. This incident received a Level 1 INES rating.

Also in 2007, a very serious problem appeared with an extensive plugging of tube sheet penetrations, affecting a large number of reactors. The phenomenon could affect up to 80 percent of the tubes of concerned reactors and is estimated to increase by five percent per year. The problem will have serious economic consequences as it reduces the power output of the generator, and it raises safety concerns because it increases the sensitivity of the tubes to vibratory fatigue and can lead to tube cracking, as already happened at the Cruas power plant. In addition, in February 2008, following a problem of tube leak in Fessenheim-2, the ASN requested EDF to proceed before September 2008 with the plugging of all steam generator tubes in all reactors affected by a generic fabrication defect of anti-vibratory supports – the number of reactors and tubes has not been made public.

Although the French nuclear facilities enjoy a good record of a very low number of accidents or serious incidents as rated on the INES scale, an analysis of the increasing number of events seen as significant for safety, some of them close to really severe situations, points to an increasing risk of catastrophe. The time is long gone when French official safety experts could pretend that the risk of a major accident was so low that it could be ignored. The rising number of issues with key equipment in the 58 reactors, and the increase in potential events needing to be considered sheds a worrying light on the real level of safety in the French nuclear industry.

Focus 06 1986-2006: twenty years of significant incidents in France

Although not much publicised because of their low rate on the INES scale – based on immediate radiological risk rather than intrinsic safety criteria – many significant events occur in nuclear reactors and fuel-chain facilities that show serious flaws of design, quality, procedures and systems, with the potential to trigger a dramatic event. France is no exception to that rule. The 2007 *Residual Risk* report, by an international team of independent experts, obtained from IRSN a selection of some of the most significant of those near-miss and precursor incidents in France for the period 1986-2006. Below is the summary by the report authors of these 18 selected events, presented in chronological order:

■ **12 January 1987, Chinon-B3** (not rated on INES scale). The particularly cold conditions during the winter 1986-87 led to the freezing of several materials and systems significant for the safety of the unit, in particular at the level of feed water intake from the Loire river.

■ **16 August 1989, Gravelines-1** (INES Level 3). The mounting of an inappropriate type of screws onto pressure relief valves on the primary circuit would have rendered the overpressure protection system inefficient. The valves would have opened and closed significantly later than under design basis conditions. The operators did not agree to the Level 3 rating and initiated, in vain, a procedure to get it downgraded to Level 2.

■ **30 October 1990, Cruas-4** (INES Level 1). The explosion of a 6.6 kV commutator caused a fire that entailed the loss of one of the two electrical safety circuits. The destruction of the commutator was caused by the degradation of elastic washers due to the exposure to heat. Subsequently, the second line was found to be affected in the same way.

■ **23 September 1991, Bugey-3** (INES Level 2). A leak was identified during the decennial primary circuit pressure test on the support of the control rod drive mechanisms that was going through the reactor vessel head.

■ **29 January 1994, Bugey-5** (INES Level 2). The reactor was shut down and the primary coolant level was decreased to working level in order to carry out some maintenance operations. The water flow level at the primary pumps and the motor intensity fluctuated for eight hours without any operator intervention. The technical specifications explicitly require close supervision of these parameters under these operational conditions because fluctuation can indicate the degradation of the primary pumps leading to their potential loss and thus the risk of core degradation. The safety authorities identified "significant malfunctioning": the manual was erroneous, the operators had not received any specific training for this "particularly delicate" operation, the situation has been considered falsely as "normal and safe", the visit of the safety engineer in the control room did not lead to any corrective action.66 The event had originally been given an INES 1 rating.

■ **12 May 1998, Civaux-1** (INES Level 2). While the unit was shut down, a 25 cm diameter pipe cracked open due to thermal fatigue and a large leak (30 m3 per hour) occurred in the primary cooling circuit. It took 10 hours to isolate the leak. An 18 cm long crack was on a weld was identified. The unit, which is one of the four most modern French reactors (N4, 1500 MW), had been operating only for six months.

■ **10 June 1999, Tricastin, then identified on all 58 EDF units** (INES Level 1). Polyamide cages, non-qualified for accidental situations, instead of metal cages have been built onto ball bearings of coolant safety injection pumps. First identified at the Tricastin site, the problem turned out to be spread over all of EDF's nuclear power plants.

■ **11 March 1999, Tricastin-1** (INES Level 1). Following a series of organizational and human errors, a technician has penetrated into a protected, highly radioactive area of the reactor (red zone) and has received a dose of about 340 mSv (17 times the current legal limit for worker exposure).

■ **27 December 1999, Blayais-2** (INES Level 2). The unusual storms at the end of 1999 led to the flooding of the Blayais nuclear power plant site. Certain key safety equipments of the plant were flooded, for example the safety injection pumps and the containment spray system of units 1 and 2. The electrical system was also affected. For the first time, the national level of the internal emergency plan (PUI) was triggered.

■ **2 April 2001, Dampierre-4** (INES Level 2). Following human and organizational errors, the correct core loading scheme has not been implemented. The situation could have led to a criticality risk.

■ **21 January 2002, Flamanville-2** (INES Level 2). The installation of inappropriate condensers due to an inappropriate procedure led to the simultaneous loss of several control-command boards and systems while the unit was operating as well as to the destruction of two safety significant pumps during the shut down sequence.

■ **24 December 2003, all 900 MW reactors** (INES Level 2). The misconception of the reactor sump filters induced the potential risk of debris blocking the cooling function in case of the need for recirculation under post-accident conditions. The problem has been subsequently identified not only in all of the French 900 MW reactors but also in many other plants around the world.

■ **24 January 2004, Fessenheim-1** (INES Level 1). Following the erroneous operation of an auxiliary circuit valve, ion exchange resins68 have been introduced into the primary cooling circuit. Their presence could have threatened the integrity of the primary pump joints as well as the proper functioning of the control rods. Both elements are essential to control and shut down the reactor.

■ **22 March 2004, all 58 EDF reactors** (INES Level 2). An insulation default at an electrical switchboard, experienced on unit 2 of the Penly nuclear power plant, was triggered by a steam leak close to electrical equipment that was to be qualified to resist accidental conditions. The non-conformity of the cabling has been subsequently identified on all of the French nuclear power plants and led to large-scale verification and remediation operations.

■ **16 May 2005, Cattenom-2** (INES Level 1). The sub-standard of the secondary coolant pump power supply cabling led to a fire in the electricity funnel. As a consequence one of the two safety circuits had to be disconnected. The operator EDF triggered its local (Level 1) internal emergency plan (PUI) The technical emergency center (CTC) has been activated for a few hours. The nuclear safety authorities issued a nine-line press release. Details of the event have never been published.

■ **7 April 2005, Gravelines-3** (INES Level 1). During the year 2006 the operator has noticed the presence of provisional pieces of equipment on both of the reactor protection control command lines. These pieces were applied during the previous reactor outage and had been left there by mistake. Under accidental conditions certain automatic sequences would not have taken place in a normal way.

■ **30 September 2005, Nogent-1** (INES Level 1). A certain number of material failures added to a human error during the restart of the reactor led to the hot water and steam penetrating the four rooms containing the control command boards of the reactor protection system. Under normal conditions these rooms are independent from each other and should never be put in danger simultaneously. In the case of an accident, this incident could have made it difficult for the operator to bring back the reactor into safe state. EDF has activated its internal emergency plan and the nuclear safety authority ASN activated its national emergency organisation for a few hours. ASN issued a 10-line press release.

■ **21 December 2005, Chinon-B, four units** (INES Level 1). An ill-conceived surveillance of the tertiary cooling water intake canal led to its significant silting up. The collapse of the sand hill could have led to the heat sink loss of all four reactors.

Focus 07 The EPR, supposed improvements versus new vulnerabilities

> *"The design of EPR ensures the high level of safety that is required worldwide for the future nuclear power plants."*
>
> **Areva, *EPR, un choix stratégique*, brochure,February 2004**

Lessons from Three Mile Island and Chernobyl came too late to bring in-depth modification of the design of the 58 reactors currently operated by EDF. Although they consider them as safe as was required at the time of their conception, the operator as well as the authority have recognised for more than ten years that these reactors would fail to meet current safety standards applied to new reactors.

From the mid-1990s, the French nuclear industry developed, together with the German and then alone, the EPR design as a response. This reactor builds upon the designs of the latest French and German concepts, respectively N4 and Konvoi, and seeks to reinforce their safety by adding supplementary and redundant features instead of deeply reviewing the designs. This approach has been qualified as "evolutionary", as opposed to more "revolutionary" reactor concepts developed in other countries – and the EPR might be the less innovative amongst new "evolutionary" designs like the US reactor AP-1000, which has developed more passive safety features.

The reinforcements of the EPR design, as compared to its predecessor N4, mostly consist of an increased thickness of containment, a multiplication and improvement of the backup system, or the adding of water in the primary circuit, as well as improvements in the operational procedures and automation of control and command. All of these tend to reduce the probability of a scenario leading to a core fusion. The overall goal is to reduce such probability by a factor of ten, from a "guaranteed" level of one chance out of one million per reactor per year for existing plants to one chance out of ten million. Nevertheless, as if to acknowledge that even this reduction of the probability remains hazardous, the main innovation of the EPR is a "core catcher" designed to receive and let cool down the melted corium in case of a major accident, with the aim of preventing any large radioactive release outside the plant in such a scenario.

The EPR design is therefore based on the same principle that accidental events can be fully projected in probabilistic trees, an assumption even more problematic given the planned lifetime of 60 years for new-built EPRs.[56] Also, the complexity of the safety systems involved makes their assessment subject to high uncertainty, as they cannot be fully tested except in the unfortunate case of a real accident.[57] Some key elements of the EPR safety case, like the efficiency of the core catcher, the prevention of hydrogen explosions in case of a core fusion, or the behaviour of the automated system of control-command, remain prone to controversy. Also, the level of performance intended for the reactor raises some new safety issues. In particular, the behaviour of fuel elements that would reach the very high burn-ups targeted could not be fully guaranteed with existing technologies.

Finally, it should be noted that the safety of a reactor is also that of the whole fuel-chain that it needs, the overall level of safety being that of the weakest part of the system. The EPR brings no improvement as it will rely on the same front-end and back-end technologies as existing reactors. On the contrary, the higher fuel performances that it aims for will induce new safety and radiation protection problems at all stages of fuel management.

Altogether, the ten-fold reduction in probability of a major accident in the reactor appears neither sufficiently assessed given the uncertainty regarding key features, nor sufficiently comprehensive in view of the limits of the probabilistic approach on one hand, and the need to consider the safety of the full system on the other hand. As compared to the potential field of innovative safety systems, one can doubt that the EPR design fits the evolution of safety requirements in a century – the time scale that would separate the shutdown of an EPR started-up in 2020 from the 1980s conception of the N4 reactor which it is based upon.

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56 The probabilistic approach also fails to cover the scope of malevolent acts that could reasonably, after 9/11, lead to thermal and/or mechanical loads superior to those arising from accidental situations.

57 For instance, the resistance of the containment to the high pressure of an accident could be tested, but not coupled with the high temperature that would go with such pressure.

Focus 08 Is France prepared for a major accident?

France has chosen nuclear weapons and nuclear electricity generation, and has maintained that choice. As a result, France's territory contains over 35 nuclear sites[58] and is criss-crossed all year long by numerous consignments of radioactive material being transported by rail or road.

Safety and security systems invariably have limitations. So one question remains, which we could put like this: "What if there was an accident?" Though the authorities have long considered this question at best preposterous, at worst seditious, nonetheless we believe that it is worthy of attention. Indeed, one is entitled to believe that a country that opts for nuclear has a duty to adopt appropriate emergency and public security measures. Since the chance of a major accident occurring is not zero, one must be prepared for it. So, what do the authorities have to say on the subject?

The official plan is explained on the website of the Autorité de Sûreté Nucléaire (the French Nuclear Safety Authority) – www.asn.fr. Unfortunately, this does not appear very up-to-date, as the institutional changes which gave rise to the ASN in 2006 are not taken into account. The key measures and above all the 'doctrine' for the management of a crisis have barely evolved at all.

According to the plan, if a major event occurs, the operator is to alert the prefect of the *département* concerned and the ASN. The ASN will evaluate the situation and "advise" the prefect, who will take the decisions. He or she is the keystone of the plan.

The population, once alerted by a special siren, is supposed to follow these rules: take shelter (there is no longer any mention of containment), listen to the radio, do not use the telephone too much, leave the children at school and await instructions. The prefect, meanwhile, activates the Plan Particulier d'Intervention (PPI, specific intervention plan) for the nuclear site concerned. Of course, this PPI is supposed to have been prepared in advance and updated at least every five years. Simulations are sometimes carried out in order to test the arrangements.

From theory to practice…

The management of a nuclear crisis thus relies essentially on advance preparation, flagging up of the actions to be undertaken by the various actors, and prior information. However, the doctrine has many intrinsic weaknesses; in particular it is a long way from reality.

The 10km rule. PPIs are drawn up on the basis of a zone within a 10km radius of the nuclear installation. The ASN explains that this limit was set on the basis of a range of accident scenarios, and that beyond the 10km limit the authorities would be able to organise a second line of response when needed. However, the few accident scenarios published by independent experts call this rule into question. Weather conditions are a major factor in the speed of dispersal of radioactivity. The least that should be done is probably to take account of the geographical locality and observed weather patterns.

Preparing the inhabitants. People living within the aforementioned 10km limit should normally all have received a leaflet telling them what to do in case of an alert: shelter indoors, do not flee, do not go to pick up one's children, listen to the radio in order to hear instructions. Depending on the *département*, leaflets are distributed more or less regularly and new arrivals are thus not necessarily informed. In the case of tourists, visitors etc, it is up to their hosts to convey the information – which does not generally take place. The PPI is a public document, theoretically available at the prefecture to citizens who want it. Those who have tried to obtain a copy can bear witness to the difficulties encountered.

Warning sirens. Each nuclear site is equipped with sirens to warn of accidents. The inhabitants are supposed to recognise the signal and act accordingly. However, during simulations organised by the

[58] Counting only the principal sites. In particular, France has 58 pressurised water reactors on 19 sites, several nuclear research centres comprising numerous industrial and research installations, plants such as La Hague, and waste storage centres. The total count runs to over 200 installations.

authorities, it is regularly noted that the sirens are not audible far enough away and do not really cause any reaction.

The Flamanville PPI

The 1998 Flamanville PPI (which was the one available to the public in 2007 – it should normally be revised every five years) offers a good illustration of the difference between doctrine and operational reality. A PPI describes the area, the number of inhabitants, the factories, schools etc, and lists the available means for potential evacuations, the roads to be used or to be blocked, the assistance that can be mobilised, the reception centres and so on.

Quite apart from the generally outdated nature of this PPI, however, the bizarre approximations that it contains are astonishing. For example, the tourist coach companies are duly listed along with the number of vehicles they possess – all assumed to be available. But at any normal time, of course, the coaches are not in the garage awaiting the alert with a driver alongside. Moreover, a few discussions with the employees concerned make it clear that they do not consider themselves to be ‘requisitionable’ and that their first instinct would be to go to fetch their families.

Again, people seriously contaminated as a result of an accident are supposed to be transported to Cherbourg hospital, which has a specialist unit – with only a few beds. For a *département* which includes a nuclear power station and the plant at La Hague, this is clearly inadequate. Moreover, the PPI does not mention which personnel will be sent on site like the ‘liquidators’ at Chernobyl. Would it be the fire service? The army?

What about iodine tablets?

Everybody has heard of the need to take iodine tablets in the event of a nuclear accident where radioactivity has been dispersed. The taking of stable iodine, to saturate the thyroid gland and prevent it from fixing the highly volatile radioactive iodine (iodine 131) released during an accident, is one of the measures used to protect populations. But this policy has some limitations:

- Firstly, only residents of the 10km zone around sites are supposed to keep iodine at home.
- Stocks of iodine tablets are obtainable from pharmacies but will only be distributed on the order of the authorities. It is easy to imagine the resultant panic and the queues at dispensaries. We can only hope that an accident will not be so ill-mannered as to happen in August.
- People will probably have difficulty taking the pills at the right time, and in the correct dosage, although these are important parameters and an overdose can be harmful.
- Finally, and above all, iodine merely protects the thyroid from iodine 131 – and if there is an accident many other radioactive elements will be released into the environment.

Post-accident management

After a major accident, and the implementation of the first emergency measures, comes the post-accident period, with the need for radiation protection and public health measures, bans on food or water consumption, evacuations, decontamination and so on. On this topic, the special dossier in the ASN journal *Contrôle*, published July 2008 (issue 180), makes interesting reading.

The editorial by the Director-General of the ASN is crystal clear: “In order to carry out the mission entrusted to it on the instructions of the Prime Minister in June 2005, the ASN has established the steering committee (CODIRPA) to manage the post-accident phase of a nuclear or radiological accident. […] This committee has the mission of developing a national doctrine on this subject – a doctrine which is still lacking not only in France, but also in most countries with nuclear energy.”

One could go on adding examples and illustrations showing that in France today too little account is taken of the possibility of a major accident to enable serious preparation. It is of course a complex and costly undertaking to be permanently ready for a situation considered to be very unlikely. But the discussion about our country’s level of preparation must take place, because ‘improbable’ is not synonymous with ‘impossible’.

Focus 09 Growing safety concerns in the fuel chain

The incidents at Tricastin and Romans-sur-Isère in July 2008, involving uranium spilling into the environment at nuclear facilities related to uranium conversion and enrichment and fuel fabrication, showed that nuclear safety is not only about nuclear power plants.

The risk of major accident in case of core fusion is specific to nuclear reactors. This scenario is seen as the most extreme, in terms of potential damage, that could happen on nuclear facilities. As such, it focuses most of the attention paid to safety in terms of R&D programmes, regulations, safety studies, etc. In France, after nuclear facilities had been operating for more than ten years, the plan to develop nuclear reactors to produce electricity led to the first regulations specific to nuclear activities, a 1963 decree that defined the status of "nuclear basic installation" (installation nucléaire de base, INB) and introduced a framework centred on the control of the risk of criticality.[59] The basic safety requirements, defined by orders called "fundamental safety rules" (règles fondamentales de sûreté, RFS) dealing with various issues, were introduced much later for other nuclear facilities than nuclear reactors. The RFS relating to the approach for considering the risk of plane crashing, for instance, was introduced in 1980 for reactors, and only in 1992 for other facilities. The same delay applied to other issues such as seismic risk. The MOX fuel fabrication unit ATPu, which was eventually shut down in Cadarache due to unsufficient seismic design, is only one of many facilities that were built up to the mid-1980s without sufficient regulation on that point.

In addition, the high level of variety of nuclear facilities other than power plants, as opposed to the standardisation of EDF reactors, makes it even more complicated to develop a thorough assessment and control of all relevant risks in all facilities.

When WISE-Paris published, in the aftermath of 9/11, estimates on the risk of radioactive releases "up to 67 times the equivalent of Chernobyl"[60] at La Hague reprocessing plants in the case of a plane crashing on one spent fuel storage pond, it seemed like this was a brand new issue. One of the immediate answers from Areva was that this was absurd, as "there is no risk of chain reaction in such a facility, unlike in reactors"… The assessment was based on US safety authority NRC's calculations that 50 to 100% of fuel rods could catch fire from their own thermal output if the pool was emptied, as could happen in the case of a plane crash or other events (explosion, seism, etc.). Commissioned by the Ministry of Industry to analyse the issue, the IRSN concluded that "only" 10% of the fuel inventory might burn, which still meant a release six times larger than the Chernobyl accident! The inventory of radioactive materials at La Hague, where all spent fuel from EDF reactors, and high and intermediated level waste arising from their reprocessing is stored, is such that the potential for radioactive release in case of an accident might exceed that of a single reactor in the worst case.

Any facility involving the storage of radioactive materials presents a risk which is a combination of the potential danger linked to the radioactive inventory and the vulnerability of the plant to scenarios leading to the release of some fraction of this inventory – taking into account that containment systems are generally not as large in those facilities as they are for reactors. The same applies to the transport of nuclear materials and waste.

The historical development of the French nuclear industry around various sites, and the extension of the services it provides to every step from front-end to back-end of the fuel chain, creates a whole range of hazards that have long been dealt with as secondary while the prime focus was on reactors. Moreover, the decision to develop industrial reprocessing and plutonium re-use leads to a qualitative and quantitative increase of risks, as it implies more manipulation, transport and storage of more dangerous materials.

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59 This decree remained for more than 40 years the main regulatory framework for nuclear activities, until it was eventually included in a comprehensive nuclear law untitled "law on nuclear transparency and security" passed in June 2006.

60 This "equivalence" was based on the content of Caesium-137 to be released, as this radionuclide represents around 75 percent of the long-term collective dose from the Chernobyl accident.

Focus 10 Pressure on performance and safety

> *"The drop of the availability factor is an alarm signal for safety and is a wake-up call: are we paying sufficient attention to staff competence as well as to maintenance quality and material ageing?"*

Pierre Wiroth, Inspector General for Nuclear Safety and Radiation Protection, EDF, January 2008

The economic performance of nuclear facilities relies on such factors as their level of availability or the cost of maintenance. The need for profitability might therefore reduce the safety of the plants, for instance by delaying refurbishment or shortening technical controls. This particularly applies to French nuclear power plants, which already see their economics limited due to their huge overcapacity – and are subject to generic problems due to their high level of standardisation. For instance, in an internal note of 2001, EDF's financial department directorate estimated the loss of profitability at €76 million per percent point of productivity.[61]

EDF reactors have always shown a relative load factor. This combines the availability factor (the time when the plant is ready to produce) and the use factor (the actual production when available). EDF reactors have historically experienced a low use factor because of their excess capacity at large periods of insufficient demand. This, for instance, led to a worldwide unique pattern of reactor management where some units were shut down at weekends, particularly in summer. The constraints induced on the fuel assemblies were one of the potential causes of the unexpected failure of a highly unusual number of fuel rods at Cattenom in 1999-2000, which remains largely unexplained.[62]

Weekend shutdowns have supposedly ceased. However, over 40 units are still operated on load following mode, which could have unforeseen consequences on the fatigue of some components of the plants. Meanwhile, some problems have appeared that affect the technical availability of EDF reactors. Although it remains low, with 77.3 percent cumulated over the reactors' lifetime, the availability has been in constant progress during the last few years, with an increase from 80.4 percent in 2000 to 83.6 percent now, bridging some of the gap with the 90 percent availability or so that the reactor fleet achieves in some countries. But it dropped to 80.2 percent in 2007, clearly on technical grounds.

The main cause is a generic problem of plugging of the tube sheet penetrations of steam generators, that reduces the power output through cuts in the heat-exchange capacity, and could lead to tube cracking in huge numbers. EDF estimates that it will take until 2010 to solve this problem, which needs chemical cleaning. Only five to six units can be industrially treated each year, and 15 of the 900 MWe and 1,300 MWe have already been identified as affected, while some still wait for inspection. This would cost, according to EDF, another 2 percent of availability at least in 2008 and 2009. Yet another problem could further weight availability, as ASN ruled in February 2008 that an "anti-vibratory support default" has to be corrected in all affected reactors, the number of which has not been made public.

These are only the latest examples in a long series of generic problems that have affected the operation of EDF reactors. The negative side of standardisation is that it multiplies problems in large parts of the reactor fleet – and has associated high costs. An example of this link between safety and economy is the series of reinforcements of seismic withstanding after the ASN reassessed in 2003 the level of seismic hazard that had to be taken into account. This involved heavy refurbishments being required at specific points on some reactors, including anchoring points and metallic structures. EDF's reluctance led to the commissioning of a working group between the operator, ASN and IRSN to discuss in detail the exact level of reinforcements on each reactor involved.

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[61] The figure must be higher now, following the increase of electricity prices in recent years.

[62] The problem had affected a total of 92 fuel rods in 28 different fuel assemblies (out of 193 assemblies with 264 rods each). This compares to an usual figure of a few rods failures at most in all French reactors in one year.

Another issue where economic pressure and safety can diverge is the search for fuel performance. The goal there is to improve the quantity of energy delivered by each fuel assembly, to allow a reduction in the number and intervals of outages for reloading of the core. EDF reactors were designed for nominal fuel burn-ups of 33 GW.d/t (gigawatt day per ton) which could be reached after a few years, then regularly improved up to 55 GW.d/t currently for uranium oxide fuel (UOX) – although not as quickly as EDF had wanted to. The operator plans to reach even higher burn-ups, both in currently operated reactors and in the future EPR reactor, for which the economic case is based on the hypothesis of a 70 GW.d/t burn-up.

The problem, on the safety side, is to keep control of the behaviour of fuel rods with increased burn-up. The concern with plutonium-uranium fuel (MOX) has for many years prevented ASN authorising a burn-up increase for that specific fuel from 42 to 47 GW.d/t. Fuel rod failures, among other problems, might be the start-up for some accidents. The zircalloy currently used for cladding is not resistant enough to reach the high burn-ups aimed for UOX fuel. The industry developed a new alloy, named M5. The first ever cycle of a full reactor reload cladded with the new M5, in 2002 in Nogent-2, had to be stopped because of primary fluid contamination following a record 39 rod failures on 23 assemblies. Although it remains unclear whether M5 cladding was a root or secondary cause, ASN suspended any extension of its use until full investigations.

Finally, cost-cutting impacts in many ways on operational safety. One recurring concern is the ever-growing use of external, underqualified and untrained workers for various maintenance tasks on nuclear power plants. The management of stocks recently arose as a new concern. EDF's inspector general for nuclear safety and radiation protection insisted in its report on the year 2007 on the problems raised by the massive reduction of costly replacement pieces.[63] He explained that it had become hard for sites to get those pieces when needed, reporting astounding cases where pieces had been unmounted to be replaced and were eventually put back in place due to the lack of spare parts.

[63] *Rapport de l'Inspecteur Général pour la Sûreté Nucléaire et la Radioprotection 2007*, EDF, January 2008.

Security

An industry incapable of adapting to the post-9/11 world

> *"Security measures offer no real guarantee against the kind of kamikaze actors."*
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> **French Ministry of Defence internal memo, cited by *Libération*, 12 September 2001**

For the nuclear industry, security, or protection against malicious acts, is a preoccupation that runs parallel to safety, or protection against accidents. In both cases, the objective is to prevent nuclear installations from being exposed to the situations foreseen, and to limit by design the possible consequences to these installations if these situations occur in spite of everything. While the logic of prevention is necessarily different with respect to chance events and deliberate actions, the two areas overlap at the level of installation design.

Unlike accident scenarios, malicious acts are by definition intended to produce the desired level of damage. A key issue in the field of security is therefore to identify threats judged to be "credible", by evaluating (in particular through intelligence) the interest of groups or individuals in targeting a nuclear installation and the means that they could employ.

The impractical challenge of evolving threats

Here the nuclear industry runs up against a fundamental difficulty inherent in the fact that threats evolve over time, whereas the degree of protection that installations have is essentially fixed for their whole lifespan when they are designed. If threats develop which exceed the load level built into the design, protection must henceforth rely on prevention alone.

In France, the authorities have chosen not to make any information available on "design basis threats", in other words the types and levels of credible threat of a malicious act against which nuclear installations should be protected. These details are covered by the secrecy rules protecting national security – "defence secrecy". As a result, we do not know whether these threats have been re-evaluated, and if so in what way, since the attacks of 11 September 2001 in the USA.

Nonetheless, it is incontestable that this date marked a major turning point. Previously, it appears that the threats taken into account were limited by a principle extending nuclear deterrence to any action against nuclear installations carried out with clearly identified foreign support. In the context of the time, only small-scale attacks had to be allowed for in the design under these conditions.

Since then, the design basis of installations has been essentially, if not totally, determined by external attacks or internal situations of accidental origin, liable to cause mechanical or thermal stresses greater than those caused by limited malicious acts.

During the 1980s and 1990s, France witnessed several attacks on its electrical industry. Most aimed to destroy pylons of high-tension transmission lines. The most notable, however, hit the Superphénix reactor on 19 January 1982. Activists opposed to the breeder reactor project attempted to destroy the reactor, then under construction, by attacking it with heavy weaponry. They failed to hit their precise target, but out of five rockets fired, four hit the reactor – three hitting the containment building and one a lifting system. The damage was estimated at around 100,000 francs at 1982 prices (€15,000). The perpetrators, who had obtained the necessary equipment from actual terrorist groups, were never found until one of them confessed of his own accord 22 years later.[64]

Weapons of the type used, while rare and hard to obtain at that time, have become commoner and more accessible in the last twenty years, as is shown by their being used increasingly often in heavily armed attacks on armoured money convoys. Thirty years after the first French reactors entered service, the threats that need to be taken into account today bear no resemblance to those of that time.

After the World Trade Center attacks, any scenario involving twenty or so people prepared to sacrifice their lives has to be considered as plausible. Obviously this includes the use of hijacked airliners to hit installations – which, whether reactors or fuel manufacturing or processing plants, have not been designed to withstand such an impact.

This fact clearly shows the limitations of the essentially probability-based approach to the design basis of installations. Faced with the risk of malicious acts, a different approach is required. Security thus depends upon an evaluation of the potential dangers. This, as the IPSN (now IRSN) explained after 11 September 2001, involves an estimation of risk based on the identification of the system's sensitivity (ie the potential for a release of radioactivity) combined with its vulnerability (how difficult it is to cause such a release).[65]

Blackout on evaluation and mitigation

No public evaluation exists of the potential consequences of an airliner crashing into one of EDF's 58 reactors. Following an independent assesment published by WISE-Paris in the context of the debate aroused by 9/11 on the potential consequences of such a crash on the fuel ponds at La Hague, an official evaluation by IRSN concluded that if such a scenario occurred it could bring about the release of up to 10% of the radioactive inventory of the fuel in one pond. The release of around 1.5% of the caesium contained in one pond would correspond to the caesium released by the Chernobyl accident.[66]

However, this scenario is not the only one to be taken into account – intruders must also be considered. According to what little information is available on this subject, exercises carried out by the French special security forces have highlighted the poor extent to which nuclear installations are protected against an attack. At another level, Greenpeace anti-nuclear activists have on several occasions been able to carry out protests actually inside power stations, evading security for several hours and reaching sensitive areas of the installations.

At the same time, insider collusion may enhance the effectiveness of malicious acts. Several incidents have shown how vulnerable nuclear installations are in this respect. One incident at the Bugey power station in 2003, which went totally unnoticed by the public, illustrates this vulnerability. On 12 June 2003, during a strike at the site, the mere closing of a hatch triggered a sequence of security system activations, culminating in the automatic shutdown of unit 2 as a result of the activation of the turbo-alternator group protection systems. It is easy to see the potential danger of such an action if the perpetrator had intended to cause more serious harm.

Moreover, nuclear installations are not the only elements to be taken into consideration. The very numerous transports of radioactive material – and especially nuclear material (uranium and plutonium) – resulting from the industry's activities can be seen as so many hard-to-protect "mobile installations". There is a risk both of an attack aiming directly to disperse the material being carried by a transport,

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[64] The rocket launcher, an RPG-7, and the rockets were obtained from the German RAF (Red Army Faction) group via the Belgian CCC (Communist Combatant Cells) group, according to one of the perpetrators, Chaim Nissim, in a book published in 2004.

[65] IPSN, *La protection des installations nucléaires contre la malveillance* [The protection of nuclear installations against malicious acts], note of 30 October 2001.

[66] In other words around 26kg, which according to international estimates was responsible for three-quarters of the overall long-term collective dose caused by the accident.

and of an attempt to hijack these materials in order to use them subsequently for a “dirty bomb” or, if nuclear material is involved, to make a nuclear weapon. This risk of misappropriation also exists for all installations that have a significant stock of radioactive material.

Faced with these different risks, how well is the French nuclear industry protected? Planned with reference to threats which are now superseded, the industry appears badly adapted in terms of the design of its installations as much as in its general organisation. As we have seen, the reactors and plants have not been designed to resist the sorts of attack that can now be envisaged. Nor has their location: for example, the centralisation of all reprocessing activities at La Hague gives rise to long transport journeys from the reactors. Even more so, the distance between La Hague, which separates plutonium, and the MOX fuel manufacturing plant at Marcoule which uses it, bears witness to the priority given to economy (in terms of minimising the volumes transported)[67] over security.

Would it have been possible to predict better the way in which threats have evolved? This question is a very difficult one to answer. On the other hand, one might ask how capable the nuclear industry is of adapting. While some parameters are fixed – such as the design basis and the general design of the installations, other factors may be developed in such a way as to reduce the system’s vulnerability or sensitivity to the risks of attack.

External security measures have undoubtedly been strengthened – both in the short term, such as the temporary deployment of radar and anti-aircraft missiles to protect the installations at La Hague or in the Rhône valley, or more permanently. On the other hand, the authorities have given no indication of any possible adaptations at the level of the industry.

On the contrary, nothing seems to have changed, even in the most at-risk areas. So, in spite of the anxieties aroused by nuclear transports crossing the country, these transports continue, apparently under the same conditions. The industry’s chosen path of reprocessing, of separating plutonium and reusing it in twenty or so of EDF’s reactors, which increases the number of transports even while exacerbating their intrinsic danger, has not been revised at all in terms of the security factor. These choices, moreover, result in the long-term accumulation of very large amounts of radioactive material in temporary, low-security storage, by comparison for example with underground stores such as could be implemented in the space of a few years. One again, this issue does not appear to trouble the industry.

In reality, it is by choice that protection relies above all upon external arrangements, so as to dismiss any calling into question of the industrial system’s design and direction. Detecting preparation for actions by surveillance of the national territory, and preventing those actions from being carried out through the intervention of security forces, are therefore key.

Secrecy, a substitute for security?

One consequence of this doctrine is the enforcement of a maximum level of secrecy. Of course, as the ASN explained as early as the end of 2001, counter-terrorist protection measures “like the studies conducted into the resistance of nuclear installations to a terrorist act, cannot, by their very nature, be publicly communicated”.[68] Details of them must not be disseminated. But the doctrine implemented by the nuclear industry and the French authorities implies any security flaw in the design of the industrial system should be accepted, so long as that flaw can be kept secret!

Having become the first line of defence, secrecy must be protected at all costs – or at least the appearance of secrecy. By this logic, no explanation is possible; nor even any serious expression of doubt. No internal analysis is disseminated outside the circle of those privy to the secret, and any criticism from outside is immediately denounced as playing into the hands of potential terrorists.

Soon after 11 September 2001, several members of Global Chance involved in a working group on France’s energy security inside the Commissariat Général au Plan (French planning commission)

[67] Marcoule is near the enrichment plants that produce the depleted uranium which makes up over 90% of the MOX fuel, as against 10% of plutonium.

[68] DGSNR, Annual Report 2001.

proposed that it should include a consideration of the relative resistance of different energy systems to malicious acts (particularly in terms of their degree of centralisation and of the networks on which they depend). The representatives of Cogema (now Areva) and EDF in particular refused point blank to discuss the resistance of different installations to different kinds of attack, bringing the group's work to an end.

This logic can tip over into absurdity when it attempts to keep secret elements that are under the eyes of the public, such as the timetables and itineraries of nuclear material transports, which regularly take the biggest public roads in an easily identifiable form. Again, the lack of any guarantee as to the resistance of present-day reactors to a crashing airliner can hardly be considered a secret.

Deadlock on updating security standards

The same policy now extends to the new EPR reactor project. In 2005-06 the dedicated commission organising a national public debate (Commission Particulière du Débat Public, CPDP) on the Flamanville project censured a paragraph of the contribution by the Sortir du Nucléaire network which cited a note from EDF in support of its doubts as to the reactor's ability to withstand an airliner crash. The problem was the Network's proposal to circulate this note – seen as a "compromise" of defence secrecy, even though the note, classified as "confidential" by EDF, had already been leaked into the public domain.

The dossier submitted to the national public debate thus included contradictory statements, discussion of which was forbidden by defence secrecy. In the context of a democracy, however, it seems vital to assess the EPR in these terms and so to determine what progress it represents in comparison with present-day reactors. The crisis which this incident instigated notably led, in the context of the public debate, to the creation of a working group on freedom of information in the nuclear field.[69] This group acknowledged that, while defence secrecy is an indispensable element of nuclear security, its exact role in the protective arrangements, and thus its limits, remain subjects for debate.

The progress of the debate on the EPR reactor exemplifies the doctrine which gives more importance to secrecy about the EPR's degree of resistance to new terrorist threats not anticipated by its design basis, than to consideration of how to address these threats better at the design stage of a new reactor. Security still ranks low down the list of both short- and long-term priorities, as the industry's preferred vision of the reactors of the future shows.

This vision is in line with international work on the 'fourth generation', a catch-all term which encompasses all reactor concepts, whether new or resurrected, that make a break with the models which currently dominate the industry worldwide.[70] This work is carried on in particular in the context of the Generation IV International Forum, which brought together the "world's top nuclear experts" to define the objectives to be reached and select the most suitable concepts to achieve them.

The objectives, set in April 2001, prioritise safety and above all the management of uranium and waste. Moreover, five of the six design concepts chosen in 2002 rely on a 'closed cycle', not only of plutonium but also of the minor actinides. This choice of designs which require more complex management involving the separation of the most dangerous materials reflects the lack of concern about the terrorist threat.

France's participation in the Forum gives priority to the liquid sodium-cooled fast breeder reactor family. The nuclear industry's objective in this context is to have a prototype put into service in 2020 that would dispel the sense of failure produced by the 1998 closure of the Superphénix breeder reactor, which belonged to this family. This choice, synonymous with a potential worsening of the nuclear system's vulnerability and sensitivity to terrorist threats, shows the French nuclear industry's profound inability to carry out the increasingly urgent updating of its security doctrine.

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[69] Commission Particulière du Débat Public on the project of a first EPR at Flamanville, *Rapport de restitution du groupe de travail dit "Accès à l'information"*, February 2006.

[70] Known as 'second-generation' reactors, while the reactors developed from these designs, such as the EPR, are referred to as 'third-generation'.

Focus 11 Nuclear reactors as 'pre-deployed weapons'

> *"There is no regulatory system in the world that can guarantee that a power station will not be damaged by a crash involving a large aircraft."*

Jérôme Goellner, Assistant Director, DSIN (now ASN), quoted in *Les Échos*, 13 September 2001

To some experts, nuclear reactors appear to be 'pre-deployed nuclear weapons'. The idea suggests that a successful attack on a nuclear reactor would cause devastation comparable to that unleashed by an actual atomic bomb. In reality, the same instantaneous force as produced by a nuclear explosion would not be liberated, but the impact of the massive contamination that the destruction of a nuclear reactor could cause would be just as great.

Can this vision, chilling as it is, be regarded as realistic? The question was barely asked before 11 September 2001. But the attacks carried out in the United States that day clearly changed everything. The question of nuclear reactors' degree of resistance to airliner crashes, which people were simply not considering only a few days before, became a major preoccupation over the following period. The debate which developed at that time in France, rapidly stifled by the convenient pretext of "defence secrecy", brought no reassurance.

In fact, the traditional response to the question of a threat to French reactors – as far as that risk was actually taken into account – lay in the military doctrine of nuclear deterrence, since it was thought that an attack on this scale could only be organised at a military or paramilitary level, with the direct support of a foreign government. The country in question would be laying itself open to the same response – a nuclear strike – as if it had actually aimed an atomic weapon at France. But as soon as it was possible to imagine such an attack being carried out by a group not associated with a foreign government, as 9/11 showed, this doctrine fell apart.

An important consequence of this doctrine had been that any large-scale attack was ruled out of consideration when drawing up the design basis for nuclear installations. This was essentially based on the constraints that could result from accidental external impacts, assessed in terms of probability – since the only malicious acts judged plausible at the time would not have an effect greater than that of the earthquakes or chemical explosions that were taken into account. By this reasoning, only an accidental light aircraft crash seemed probable enough (over one change in a million per reactor per year) to insist that a reactor be designed to withstand it. The impact of such an aircraft bears no resemblance to an airliner crash, particularly when one takes account not only of the collision but of the burning of its fuel.[71]

The 'plausibility' of terrorist attacks on nuclear installations using airliners loaded with aviation fuel is unfortunately no longer in doubt, any more than the fact that such an attack could have catastrophic consequences if it succeeded in hitting one of the 58 reactors operating in France (or anywhere else in the world). What is more, reactors are not the only nuclear installations at risk (to say nothing of the fact that other industrial installations could also be targeted). For example, nuclear fuel cycle plants and the various storage and stockpile sites for radioactive material sometimes have a larger radiological inventory than reactors, without enjoying a level of protection equivalent to that provided by a reactor containment building. This is particularly true in the case of the irradiated fuel storage ponds at La Hague, as the debate of autumn 2001 revealed.

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[71] The thermal energy that would potentially be released by the burning of between 20,000 and 200,000 litres of aviation fuel (two-thirds of the maximum fuel payload of the Airbus A320 and A380 respectively) is much greater than the 2,300 to 19,000 megajoules of kinetic energy that these aircraft would have (on the basis of their maximum weight and speed).

Today's official response – apart from preventing any public analysis of the situation from developing, by invoking official secrecy – consists of reassuring the public that such an attack would be stopped before it reached its target, thanks to intelligence systems and alert and reaction plans: fighter aircraft would be mobilised to intercept any threatening airliner and shoot it down if necessary, after confirming the threat and going up the chain of command according to an established protocol. All the same, in the case of La Hague, radar-guided surface-to-air missiles were deployed close to the site for a time.

The vulnerability of existing installations and the impossibility of adapting them to a threat that postdates their design create a very difficult situation for the authorities. Any discussion beyond platitudes is impossible. The questions that one might want to ask as to the effectiveness of these preventative measures against an attack like 9/11, or about the possible resistance of installations to other conceivable types of massive attack and about the prevention of these, receive no reply beyond the need for secrecy.

The question is – or should be – framed differently in the case of new installations. One might therefore have thought that new requirements for protection against malicious acts would have been set out, or at least discussed, before new projects were built. Nothing could be further from the truth. The EPR reactor whose construction has been authorised at Flamanville was designed in the 1990s to the standards current at the time. In terms of air crashes, it has merely benefited from Franco-German cooperation to incorporate into the design basis resistance to a military aircraft crash (which was considered more likely in Germany in light of the accident statistics for aircraft from American airbases).

The lessons of 9/11 have not led the authorities to review the design basis requirements. They have been content to ask the operator to carry out studies on resistance to an air crash outside the design basis process, without making this a regulatory obligation. The final results of these studies are not publicly available. EDF states about the EPR that "in consequence of several additional precautions decided after 2001, it is capable of resisting airliner crashes."[72] The constructor of the EPR, Areva, and the authorities do not contradict this. Nevertheless a leaked provisional document, published by numerous sources even though covered by defence confidentiality, seems to suggest that "crashes" does not mean "all crashes", or in other words that in some cases the EPR might not be able to withstand the kinetic shock. Moreover, no information exists regarding evaluation of the combined effect of impact and heat, and still less on the consideration of other design basis threats, even the list of which is secret. Conceived at the end of the 20th century, the EPR does not seem ready to face the dangers of a new century inaugurated by the collapse of the Twin Towers.

[72] EDF, *Débat public 2005/2006, Projet Flamanville 3 – Construction d'une centrale électronucléaire "tête de série EPR" sur le site de Flamanville – Le dossier*, document submitted to the public debate, July 2005.

Focus 12 Transports, a weak link in the nuclear chain

Hundreds, if not thousands of packages of radioactive material criss-cross French territory every day, mostly intended for medical or industrial purposes not involving nuclear power. These numerous journeys do of course pose some security problems, particularly in terms of the risk of misappropriation, since some of them contain sources that could be used in a 'dirty bomb' (combining a conventional explosive device with a radioactive source in order to spread contamination).

But the main security issue with transportation concerns the more significant transfers of radioactive material generated by the nuclear industry, and in particular the transportation of nuclear materials used in fuel (which are the same as those used in nuclear weapons, although usually of a different grade and form). On average, there are over four transports of such materials on France every day.

Each of these carries enough material to qualify, if it were stationary, as an *installation nucléaire de base* (INB – regulated nuclear installation, the French term for a nuclear facility significant enough to require a certain level of regulation). Any vehicle park, railway station or service station where one of these transports stops also effectively becomes an INB, albeit without having any of the protection required by this specific regulatory status. This is the root of the problem: beyond its walls, the nuclear industry needs to put in place protective measures suited to a mobility which by its very nature weakens the traditional mechanisms. For example, the containment barriers are necessarily less thick and the restrictions on public access less controllable than in the case of a fixed site.

Some of these transports are vital to the functioning of the nuclear industry. However, France has made industrial choices which hugely increase the risks, by developing reprocessing and plutonium reuse activity, not only for its domestic purposes but also for foreign clients.

This increase in risk is in the first instance quantitative. The very principle of separating and reusing plutonium implies additional transports between the places where the various stages in this cycle are carried out. The increase is all the greater in that, for other reasons, these locations are spread all around the country – in particular the spent fuel reprocessing and new plutonium-based fuel manufacturing plants, located respectively at La Hague in the North-West and Marcoule[73] in the South-East, and so necessitating a journey right across the country.

The increase can be measured by calculated the total number of kilometres covered by packages of nuclear material containing plutonium, or even the kilometres covered by the tonnages of plutonium involved in the different transport stages (expressed respectively as 'package kilometres' and 'tonne plutonium kilometres' – see Figure 14). By this method it can be estimated that, in a typical year of flows generated by the industry, over 250,000km are covered on French territory by transport packages containing plutonium. In addition to uranium transports further up the fuel cycle, the choices associated with plutonium reuse lead to a trebling in tonne kilometre terms of transports related to the lower part of the cycle, half of it attributable to domestic and half to overseas users.[74]

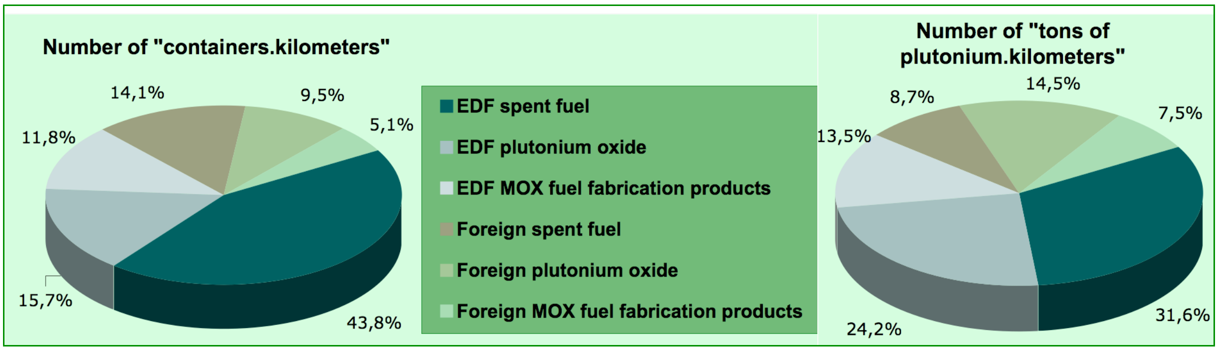
The increase is also – and perhaps above all – qualitative. In accordance with the stages in its reuse, plutonium is transported in forms very different from the one form encountered in the absence of reprocessing. In this instance, plutonium remains included within the matrix of spent fuel in which it was formed. Its reuse entails an initial transport of the separated plutonium to the MOX manufacturing plant, in the form of oxide powder, then a transport of non-irradiated MOX fuel to the power station that is going to use it. Finally, the spent MOX, hotter and more radioactive than conventional spent fuel, is transported to La Hague for storage. These different forms represent an additional sensitivity in terms both of the risk of misappropriation of material and of the potential impact if they were

[73] Two other plants, now closed, used to receive plutonium separated at La Hague: Cadarache, even further to the South-East than Marcoule, and Dessel in Belgium.

[74] These figures, representative of the beginning of the decade, are tending to fall as a result of the halting of massive imports of foreign fuel with the gradual ending of all the big foreign reprocessing contracts.

dispersed. This applies particularly to the first two forms which, in the classification of transported nuclear materials, belong to the best-protected category of non-irradiated nuclear materials.

Figure 14 Total transports[a] linked to the plutonium industry (2003[b])



a. The total level of nuclear material transports in France is here broken down into French and foreign material, and according to the main transport stages after discharging of the fuel (transfer of irradiated fuel to storage, transfer of separated plutonium from reprocessing to the MOX manufacturing plant, transfer of the products of the MOX manufacturing process (including waste from manufacturing). This total is calculated in terms of two scales:
• the estimate in 'package kilometres' corresponds to the total number of kilometres covered by packages of material of each of the categories included
• the estimate in 'tonne plutonium kilometres' relates the distances covered to the quantities of plutonium transported, according to the average content of each category.

b. The estimates presented have been produced by WISE-Paris in terms of a 'standard' year – in other words one representative of the average flows of material associated with EDF's reprocessing services and with foreign customers (before the decline in the latter activity).

Source: Estimates from WISE-Paris, 2003

Moreover, transports of this category of material go by road, unlike the other categories which are generally carried by rail. The idea, in view of the particular threats to which these sensitive transports can be exposed, is to enable greater flexibility in their organisation and to offer possible alternatives in the event of a known threat. Of course, this choice of policy is not a neutral one in terms of the risk of an accident and of the potential for the public to be exposed.

An intense controversy has developed in the last few years around the security of these transports and the associated risks. Greenpeace in particular observed that the transports between La Hague and Marcoule, amounting to one or two transfers of 150kg of plutonium over more than 1,000km every week, were taking place at fixed days and times and following a regular route – to the point that the organisation was able to observe the transports and reconstruct their timetables and itineraries. In 2003, in a spectacular action intended to call attention to this situation, Greenpeace blockaded a lorry carrying this plutonium in the middle of Chalons-sur-Saône, where it was preparing to spend the night in a barracks.

The logic of secrecy dictates that no failing can be acknowledged. The authorities accordingly turned the burden of responsibility on its head: the problem was not that these transports were regular and completely identifiable on the public highway, but that Greenpeace was making this information public. Those in charge of security thus maintained that the system of protection was based above all on intelligence, in the sense that it was precisely when observing the transports to obtain this information on timetables and routes that a malicious group would be spotted. So, they went on, Greenpeace's activity was indeed spotted; conversely, the publication of the information that the organisation had collected would enable a genuine malicious group to prepare an attack without attracting the attention of the intelligence services.

By the same logic, the authorities maintained that the straightforward immobilisation of the lorry did not show any weakness in the onboard protection systems, but on the contrary demonstrated the effectiveness of the decision-making chain, since rapid identification of the nature of the group had enabled certain methods of defence (whose nature is unknown) not to be brought into play. It is true that the Greenpeace activists were wearing visible signs that they belonged to the organisation. But what would happen if actual terrorists adopted a disguise of this sort?

The controversy also extends to the possible consequences of an attack on these transports. In several successive reports since 2003, the independent British and French experts of Large & Associates and WISE-Paris have analysed the risks of a plutonium release in the event of an accident or a malicious act. These studies note that while the IRSN considers “that a transport accident could not cause a rupture in the container” of the type used (FS47) – a point on which they cast doubt elsewhere – the same institute has published test results showing that this container would not withstand the impact of a rocket, a type of weapon plausibly accessible to organised sub-national groups.[75]

It seems relatively clear that actions intended expressly to cause damage, if they succeeded in their goal, could have a major impact on the integrity of the containment and result in significant releases of plutonium powder. Quite apart from the socio-economic impact of contamination, the health consequences could be serious, in view of the acute radiotoxicity of plutonium. Inhaling just a few dozen microgrammes (less than one ten-millionth of the contents of a transport) is enough to trigger lung cancer with certainty. For example, Large & Associates estimate that a zone of 250km^2 could be affected, which in an urban area would represent around 125,000 inhabitants, with some 500 resultant fatal cancers.

More broadly, analysis of the infrequent published explanations of the French approach to the security of nuclear material transports suggests a failure fully to apply the recommendations of the International Atomic Energy Agency (IAEA), even though these recommendations precede 11 September 2001 and there are currently calls for them to be revised. The particular attention aroused by an exceptional transport of 150kg of American military plutonium from La Hague to Cadarache[76] in October 2004 led to a double standard: the visible security measures for this transport, including a heavily reinforced escort and the guarding of all the bridges, tunnels etc on the route, seemed to have nothing in common with the light measures applied every week to the French transports.

However, one anecdote calls into question the seriousness of the highly conspicuous arrangements deployed in this media-friendly context. Parked in order to refuel at a service station previously ‘secured’ by the arrival of armed personnel, the lorry could be seen and approached, with nobody on board, in the midst of the petrol pumps… Besides, the measures deployed for the occasion have remained exceptional: transports of plutonium and other nuclear materials subsequently recommenced in the same form as before. Barricaded behind their defence secrecy, the authorities show no sign of developing their doctrine on the security of these high-risk transports.

[75] The seizures occasionally carried out by the police show that modern weapons, capable of striking a vehicle travelling at 80km/h at a range of several hundred metres, are in circulation in some quarters.

[76] This plutonium was transported for the manufacture in Europe of four MOX fuel assemblages intended to be tested in an American reactor, with the aim of adopting this procedure generally as a means of eliminating the 34 tonnes of military plutonium declared surplus by the USA.

France, a pyromaniac fireman of proliferation

> *"We've got it in France, why can't they have it in Morocco?"*
>
> **Nicolas Sarkozy, President of the French Republic, Speech delivered at Marrakech, October 2007**

The risk of proliferation, in other words the misappropriation for military purposes of the infrastructure, equipment, technologies and materials of civil nuclear programmes, has not traditionally loomed large in the debates on nuclear power in France. While public opinion and political decision-makers appear, as elsewhere, to be anxious about the risk of escalation in nuclear arms at the global level, for the most part their analyses seem to disconnect this issue from the questions raised by the development of the French nuclear industry.

French nuclear plans: detached from proliferation issues?

In the first place this risk is completely ignored as far as activities in France are concerned. In a country which had a military nuclear programme before embarking on a civil one, the interaction between the two raises few questions. The idea that the nuclear installations operating in France might help the development of nuclear programmes in other countries seems incongruous. For example, it is likely that very few French people know that since 1974 Iran has had, and still has, a 10% share in the Eurodif uranium enrichment plant at Tricastin.[77] What is more, when in the midst of the Iranian enrichment crisis a report on proliferation recalled this state of affairs in detail, it was largely ignored by politicians and the national media.[78]

Likewise, the consequences in terms of proliferation have very rarely been a subject of debate where French nuclear technology export projects are concerned. During the 1970s and 1980s, France showed itself generous in this area. Most of the official and unofficial nuclear-armed countries enjoyed its help. The development of the Israeli nuclear weapon relied on French technology, as did the Iraqi programme which was abandoned after Israel itself destroyed the Osirak reactor, of French origin. The South African programme, too, benefited greatly from French support.

Even the reprocessing of spent fuel, a proliferating technology *par excellence* whose origin is obviously the military need to obtain separated plutonium, raises but little concern. When the Carter administration decided to stop reprocessing in the USA in 1977, because of its proliferating nature, France embarked on a massive programme of commercial reprocessing at La Hague. At the same period, it was not opposition in France, but rather a US veto, which stopped France from delivering a reprocessing plant to Pakistan.

This indifference continues. When in 2007 the economic media announced as the "contract of the century" the draft agreement for Areva to supply two reactors to China, it mentioned the difficulties arising from China's insistence on extending the contract to encompass fuel management, including a reprocessing technology transfer. This news did not create much of a stir, and there was no public follow-up on the refusal announced by Areva – which was perhaps motivated more by commercial than geopolitical logic. Similarly, the nuclear cooperation accords signed by France with India, an officially nuclear-armed country but not a signatory of the Non-Proliferation Treaty (NPT) have attracted very little public attention. India's military programme has clearly been reliant on the diversion of civil cooperation, although it is blacklisted by the international community. The

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77 By way of the Atomic Energy Organisation of Iran's 40% holding in Franco-Iranian consortium Sofidif, which in turn holds 25% of the multinational group Eurodif, whose principal shareholder is Areva. The dividends that Iran has accumulated, estimated at several tens of millions of euros, are frozen in French bank accounts in consequence of the international restrictions linked to the Iranian enrichment programme.

78 Schneider, M., *The Permanent Nth Country Experiment – Nuclear Weapons Proliferation in a Rapidly Changing World*, Report commissioned by the Greens/EFA group in the European Parliament, March 2007.

cooperation established between France and India in the nuclear field, formalised by a joint declaration in February 2006, has aroused no debate. It has a counterpart in the shape of a draft agreement between India and the USA whose ratification, in comparison, was debated in Congress and more widely for over a year.

Salesman of the French nuclear industry

The President of the French Republic, Nicolas Sarkozy, has willingly put on the mantle of salesman for the French nuclear industry since he came to power in mid-2007. In particular he is pursuing a policy of actively promoting nuclear power, accompanied by the offer of cooperation, in the countries of North Africa and the Middle East, where the aim is above all to maintain influence by offering an alternative to cooperation with the USA.

This posture aroused opinion for the first time when France offered to deliver an EPR reactor to the Libya of Colonel Gaddafi, who was received with great ceremony at the Elysée palace in autumn 2007; a nuclear cooperation agreement was signed between the two countries. But France has also in recent months signed similar agreements with a number of other countries in the region – Algeria, Jordan, Morocco, Tunisia, the United Arab Emirates (UAE) – without giving rise to the same reaction.

On every occasion, these agreements are negotiated without any form of prior debate, and announced as a *fait accompli*. The government, through the mouthpiece of it Foreign Minister Bernard Kouchner, has justified this policy once and for all: "the demands of countries who want to benefit from this clean, inexpensive energy are legitimate." He calls for a "new nuclear era […] synonymous with collective security and shared prosperity"![79]

The President and his government seems to see no connection between their policy of encouraging the development of nuclear power in some of the most unstable parts of the world, and the problem of proliferation. But the revelations about the clandestine network around one of the key individuals in charge of the Pakistani military nuclear programme, the successive crises in North Korea and Iran, and (to some) the breaking of the Indian embargo begun by the United States are seen on the international stage as worrying signals.

The arrangements put in place to prevent the development of military nuclear programmes are being tossed aside one by one. France is wrapping itself in virtue by advocating a strengthening of the guarantees against proliferation around three 'imperatives':

- not to export "any technology to countries which do not respect their obligations" (in the context of the NPT or UN Security Council resolutions)
- to apply to "the exporting of enrichment and reprocessing technologies […] much stricter criteria" than to the exporting of reactors and fuel, and to offer countries access to a "multilateral supply mechanism" (fuel bank) for which France would, of course, be one of the main suppliers
- "only to export non-proliferating, ie light water, reactors" – exactly the main technology that France is offering for export.[80]

Obvious weakness of guarantees

These proposals, not without commercial ulterior motives, display extreme naivety. Many countries have benefited from technology imports (including of French technology) while avoiding their international obligations. Some countries have acquired enrichment technology without officially importing it. Finally, while pressurised water reactor technology has not been diverted to military ends by countries which have chosen more direct means, it is still not intrinsically non-proliferating.

It is precisely the obvious weakness of guarantees of this sort that has led to the present crisis. The international non-proliferation regime appears "on the point of imploding", in the words of Joschka Fischer, the former German Foreign Minister. In this context, the mere fact of suggesting that nuclear

[79] Bernard Kouchner, *Les Echos*, 29 April 2008.
[80] B. Kouchner, *ibid*.

technology can be developed, with no danger and for the benefit of all, in any country that shows itself tractable enough, is tantamount to playing with fire.

The French attitude is all the more open to criticism in that the 'need' to resort to nuclear power in the countries concerned is questionable. None of them has the regulatory system, the capacity of expertise and inspection, the qualified personnel, the maintenance infrastructure or even the grid capacity. The ASN, which underlined the importance of this issue in January 2008, estimates that it would take around 15 years to develop the necessary structures to operate a nuclear reactor in a country that was starting from scratch. The French Government has set up an agency, Agence France Nucléaire International, within the Commissariat à l'Énergie Atomique (Atomic Energy Commission) to help the countries concerned to "prepare the institutional, human and technical environment" that they will need.

A reactor such as the EPR, with a power rating of 1,600 MWe, is too large for the needs and the grid capacity of countries whose total installed capacity is currently between 1,900MWe (Jordan) and 6,600MWe (UAE). Jean Syrota, the former president of Cogema, has commented that "other reasons than the desire for efficient and rational management of an electricity system must therefore be found."[81] These countries undoubtedly have access to other energy options more in keeping with their capacities and needs, and without the same risks.

The real intentions of countries entering into the cooperation proposed by France should therefore be considered with caution. Similarly, the far from negligible potential for political destabilisation in these countries, including the risk of terrorist groups getting hold of sensitive material or equipment, or indeed of hostile political movements gaining control of the installations, must be taken into consideration. By pretending to be unaware of these problems, the French authorities are pursuing an irresponsibly inflammatory policy towards the risk of proliferation.

[81] J. Syrota, "L'avenir du nucléaire civil", *Politique étrangère*, 2008/1, spring 2008, pp. 161-171.

Focus 13 Plutonium stockpiling, a signal for proliferation

Like every other country that has developed this technology, France became involved in reprocessing irradiated nuclear fuel in order to produce the plutonium necessary to develop a military arsenal. These countries then continued the activity for civil purposes to supply their breeder reactor programmes. While the USA abandoned civil reprocessing in 1976-77 because of the technology's very high risk of proliferation, France embarked on a programme of reprocessing of the fuel from its pressurised water reactors at La Hague, confirmed and extended in the mid-1980s with the launching of a programme to reuse the plutonium separated in the same reactors in the form of MOX fuel.

Large-scale separation of military plutonium began in 1958 and finished between 1991 and 1993, by which time about six tonnes had been produced in total.[82] Allowing for the quantities used up in tests and processing losses, the present stock can be estimated at around five tonnes. The civil nuclear programme brings much bigger quantities into play. The total quantity of civil plutonium stored in France, including all forms, stood at 294.2 tonnes at the end of 2006, according to France's latest official declaration to the IAEA (Table 12). This constantly changing total has probably exceeded 300 tonnes since that date.

This stock includes in particular unprocessed plutonium in the stocks of unreprocessed irradiated fuel, stored to await future reprocessing, and also separated plutonium stored to await reuse. It includes a proportion of plutonium of foreign origin in each category – though this proportion is falling rapidly as the reprocessing contracts with foreign electricity companies gradually come to an end. The most worrying point is the growth in the stock of separated unirradiated plutonium, theoretically awaiting reuse but actually piling up on the shelves. Although the official doctrine, ever since MOX fuel was first introduced into EDF's reactors in 1987, has been to preserve a "balance of flows" between the amounts coming from reprocessing and the amounts being reused, the un-reused stock, which stood at zero at the time, has grown more or less continuously to a total of 52.4 tonnes at the end of 2006. To this must be added a total of 29.7 tonnes of separated plutonium belonging to foreign customers.

The nuclear industry has long allowed this plutonium to build up while rejecting any concerns about the potential military implications of this stockpile. Areva used regularly to state that this plutonium could not be used to make a nuclear weapon, but this relied on semantics: according to the classification introduced by the USA, this plutonium is considered to be of "reactor grade", as opposed to the plutonium known as "weapons grade" used for weapons. The difference lies in the isotopic composition and in particular the level of odd-numbered isotopes responsible for the fission reaction (plutonium 239 and plutonium 241).[83] While this difference means that it is preferable to use the latter, it does not at all imply that it is impossible to use the former.

The IAEA, responsible for non-proliferation inspection on behalf of the UN, has expressed its position on this point very clearly, stating that it considers "any plutonium derived from fuel irradiated at a high burn-up, and of whatever composition except for plutonium containing over 80% of plutonium 238, to be usable in a nuclear weapon".[84] Pressed on this point during the national public debate on nuclear waste management in 2005-06, the directors of Areva admitted for the very first time, in a reply to the experts of Global Chance, that it was technically possible to use the plutonium separated at La Hague for military purposes. Claiming to have "no specific competence in the design or production of nuclear weapons", Areva referred to an article by the former Assistant Director General of the IAEA, Bruno Pellaud, to recall that not one of the more than 2,000 nuclear explosions carried out worldwide since 1945 had used reactor-grade plutonium, while admitting that it "could in principle be

[82] This figure is an average of available estimates which run from 4.3 to 7.8 tonnes.

[83] Plutonium derived from the reprocessing of irradiated fuel from modern reactors is "degraded" by the high burn-up fraction. Weapons-grade plutonium, which contains over 90% of fissile isotopes, is made from fuel that has been only slightly irradiated.

[84] Hans Blix, then Director of the IAEA, in a letter of 1 November 1990 replying to Paul Leventhal, President of the Nuclear Control Institute.

used to produce a bomb but [that] the practical difficulties are considerable”.[85] The criticisms advanced over many years have never said otherwise.

The IAEA estimates the “significant amount” of plutonium, in other words the rough amount from which, taking account of the conversion processes, it cannot be technically ruled out that a bomb could be produced, to be 8.5kg. The stock of plutonium stored at La Hague in oxide powder form, which would be the most readily usable for this purpose, is around 50 tonnes, equivalent to nearly 5,900 bombs.

Table 12 Development of stocks of plutonium stored in France (1996-2006)

State of stock (at 31 December of the year)	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1. Separated plutonium in the reprocessing plants	43.6	48.4	52.0	55.0	53.7	51.1	48.7	48.6	50.7	49.8	48.6
2. Separated plutonium being manuf./in half-finished products[a]	11.3	12.2	11.8	13.0	14.8	14.1	15.0	13.3	12.7	14.4	12.7
3. Plutonium contained in unirradiated fuel/manuf. products[a]	5.0	6.3	6.8	8.2	9.2	9.9	12.7	13.2	12.8	15.9	19.6
4. Separated plutonium stored in other installations[a]	5.5	5.4	5.3	5.0	5.0	5.4	3.5	3.5	2.3	1.1	1.2
Total unirradiated plutonium stored in France[c]	**65.4**	**72.3**	**75.9**	**81.2**	**82.7**	**80.5**	**79.9**	**78.6**	**78.5**	**81.2**	**82.1**
(i) Of which plutonium belonging to foreign organisations	30.0	33.6	35.6	37.7	38.5	33.5	32.0	30.5	29.7	30.3	29.7
(ii) Plutonium in one of the above forms (1 to 4) abroad	0.2	0.2	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Total unirradiated plutonium belonging to France[c]	**35.6**	**38.7**	**40.3**	**43.5**	**44.2**	**47.0**	**46.4**	**48.1**	**48.8**	**50.9**	**52.4**
1. Plutonium in spent fuel/ reactor sites[b]	65.0	66.7	74.9	80.0	82.6	89.4	91.6	94.1	96.4	99.1	94.6
2. Plutonium in spent fuel/ reprocessing plants[b]	88.0	88.8	83.4	79.2	81.3	83.3	89.8	96.5	101.8	105.9	110.9
3. Plutonium in spent fuel/ other sites[b]	0.0	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	6.6
Total plutonium stored in spent fuel in France[c]	**153.0**	**156.0**	**158.8**	**159.8**	**164.4**	**173.2**	**181.9**	**191.1**	**198.7**	**205.5**	**212.1**
Total stored plutonium (irradiated and unirradiated)[c]	**218.4**	**231.1**	**234.7**	**241.0**	**247.1**	**253.7**	**261.8**	**269.7**	**277.2**	**286.7**	**294.2**

a. Rows 2 and 3 essentially correspond respectively to the plutonium held in the manufacturing plants and the power stations (other than in the reactors); row 4 includes plutonium separated for research purposes.
b. Rows 1, 2 and 3 essentially correspond respectively to the plutonium in discharged fuel still at power station sites, transferred to a reprocessing plant, and stored in research facilities.
c. Totals calculated by WISE-Paris, not given in the official declarations.

Sources: 1994–95 – French Secretary of Industry, 1997 ; 1996–2006 – declarations to the IAEA (InfCirc), 1997–2008

[85] Response to the questions of independent experts in the context of the Groupe de Travail sur l’Accès à l’Information (working group on access to information), reproduced in the report on the work of this group, *op.cit*.

In the first instance, the size of the stocks and of the plutonium flows resulting from the adoption of reprocessing and MOX presents a direct risk of proliferation associated with the danger of diversion. The misappropriation of only a thousandth of the quantities handled in a year by the reprocessing plant at La Hague and the MOX fuel manufacturing plant at Marcoule would give the perpetrators more than this ‘significant amount’. The authorities have provided no details as to the accuracy of the flow measurements in these plants, that would enable us to know whether such a misappropriation would be detected, or after how long. Various precedents worldwide, and even in France (namely the inventory of the former ATPu MOX plant at Cadarache), have shown that “materials unaccounted for” (the discrepancies noted in the account of material coming in and going out) can reach this order of magnitude. On each occasion, the explanation given blames an accounting error or an undetected technical accumulation during some stage of the process. Nevertheless, when questioned as part of the 2005–06 public debate, the director of the department responsible for this monitoring within the IRSN stated that if a genuine loss was ever detected, this information would not be made public.

Beyond this direct risk, the stockpiling of ‘civil’ separated plutonium sets a very bad example internationally. The national electricity provider EDF, which legitimises a nonetheless technically and economically questionable reprocessing policy, bears a large share of the responsibility for this. The operator is undoubtedly the foremost producer of separated plutonium in the world today, and holds a stock of 26 tonnes, or over 3,000 times the ‘significant quantity’, stored in oxide powder form at the La Hague site. By completely covering up this aspect of proliferation in France, while promoting the extension of reprocessing internationally, the French authorities and nuclear industry are sending out an extremely dangerous signal on the international stage.

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.

[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).

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

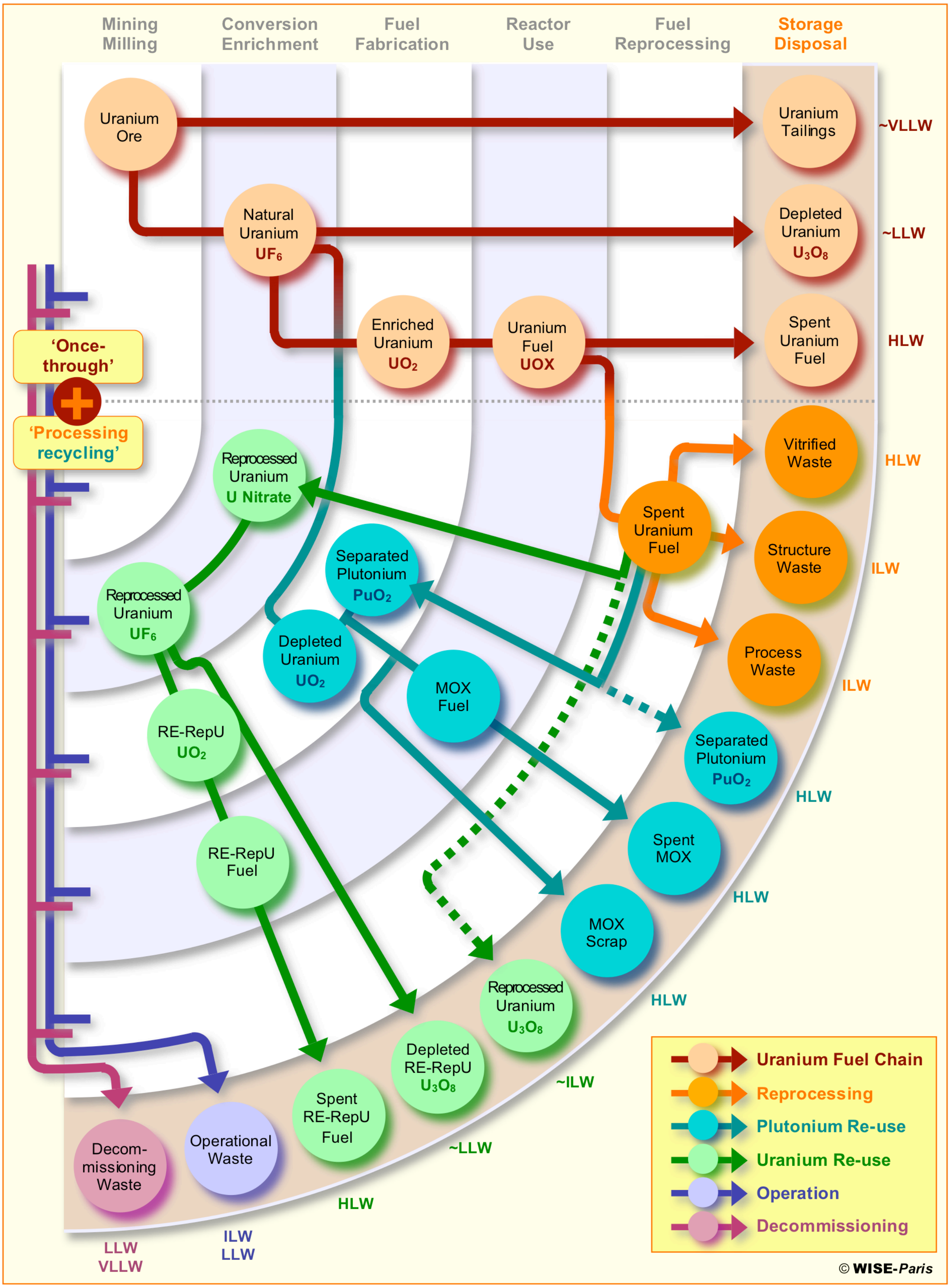
One issue rarely discussed when it comes to “reduction” is the range and size of the inventory to be managed. France defines six classes of radioactive waste on the basis of their concentration and the lifetime of their radioactivity. (Long, short and very-short lived; high, intermediate, low and very 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.

[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



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.

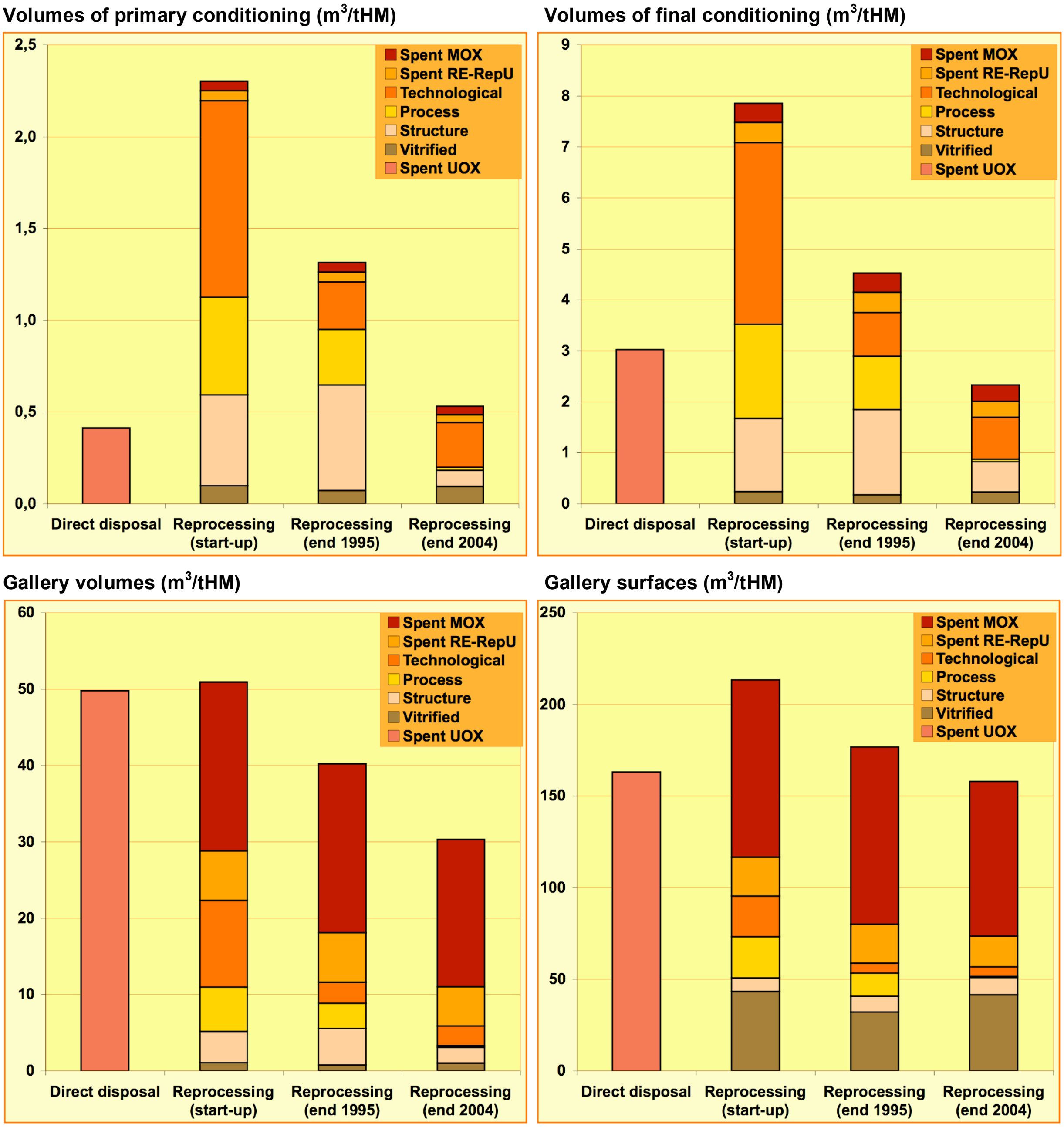
The failure of waste volume reduction plans

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]**



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).

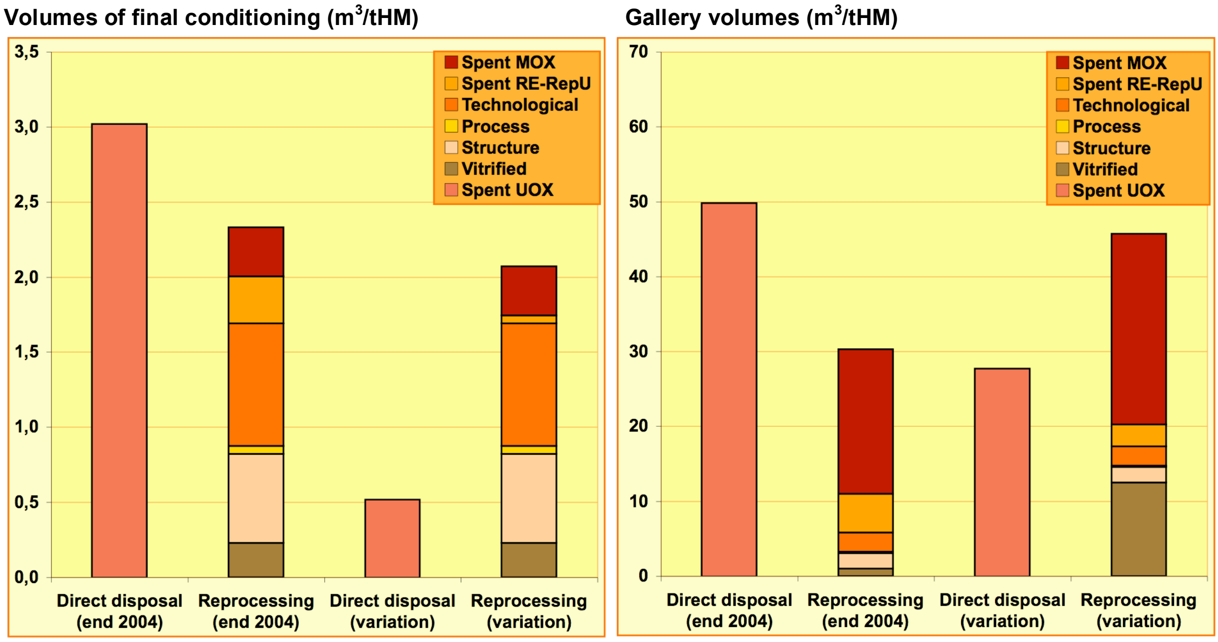
Source: WISE-Paris for the International Panel on Fissile Materials (IPFM), 2008, based on Andra, 2005 and IRSN, 2006

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]



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

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.

[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

<table>
<tr><td></td><td></td><td>LL – Long-lived</td><td>SL - Short-lived</td><td>VSL – Very short-lived</td></tr>
<tr><td></td><td>Period
Activity</td><td>> 30 years</td><td>≤ 30 years
> 100 days</td><td>≤ 100 days</td></tr>
<tr><td>HL
High Level</td><td>> 10^8 Bq/g</td><td colspan="2">Under study
Art. 3 of the law of 28 June 2006
1 laboratory for geological disposal: Bures</td><td rowspan="4">Management by radioactive decay</td></tr>
<tr><td>IL
Intermediate Level</td><td>≤ 10^8 Bq/g
> 10^5 Bq/g</td><td>Under study
Art. 3 of the law of 28 June 2006</td><td rowspan="2">Surface disposal[a]
1 closed facility:
Centre de Stockage de la Manche (CSM)
1 facility in operation:
Centre de Stockage de l'Aube (CSA)</td></tr>
<tr><td>LL
Low Level</td><td>≤ 10^5 Bq/g
> 10^2 Bq/g</td><td>Study of dedicated subsurface disposal</td></tr>
<tr><td>VLL
Very Low Level</td><td>≤ 10^2 Bq/g</td><td colspan="2">Dedicated surface disposal
1 site in operation: Morvilliers
Limited recycling for some categories</td></tr>
</table>

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.

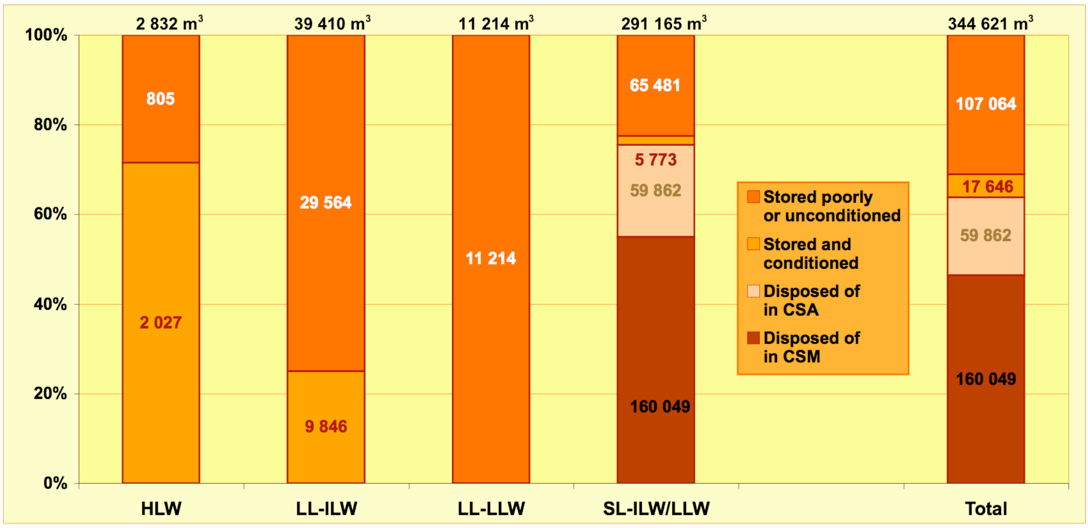
About 64 percent of the waste volume has been disposed of, 5 percent is stored with primary conditioning, and 31 percent with insufficient or no conditioning (see Figure 18). Although solutions exist for the disposal of short-lived low and intermediate level waste, representing 85 percent of the total, 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.

[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.

Economy

Twisting global economics

"The difficulties that France is facing to secure its energy supplies in a satisfying way could only be solved in the medium term through largely turning to nuclear power: it is the only energy that can bring timely responses to the problems of costs, commercial bill, security of supply and national independency."

D'Ornano Report (justifying the launching of the 1973 Messmer programme of new reactors), 1974

"The era of cheap oil is over. Nuclear power is more than ever an industry with a future and an indispensable energy. […] The EPR generates electricity which is 30 to 50% cheaper than that generated by a gas or coal fired thermal plant. One can become an electricity exporter although one has neither oil nor gas. This is an historical chance of development."

Nicolas Sarkozy, President of French Republic, Speech delivered in Creusot (France), announcing the decision to build a 2nd EPR, 3 July 2008

Nuclear power is claimed to be a key positive feature of the French economy, both contributing to national energy security and providing abundant and cheap energy for French industry and households. Though one can hardly pretend to grasp the full balance of the nuclear option's positive and negative impacts on the whole economy, basic facts are there to show the gap between the perpetual stream of rhetoric from the nuclear industry and reality.

No clear competitive breakthrough

The idea that France's nuclear choice is good for the national economy is deeply rooted in many people's minds – and a strong belief of most politicians and economic leaders in the country. But what clear advantage has it got? In brief, France's economy did not perform better than those of comparable countries, but rather below average for the European Union, where countries with no nuclear power enjoyed higher GDP growth rates.

The benefit, if any, could just not be seen at such a global level. So one might look for a more specific indicator. The ongoing use of "energy independence" as a key argument to promote the use of nuclear power in France points to the French energy bill, i.e. the commercial balance between French energy imports and exports, as the most relevant indicator.

Failed protection against imports at any cost

Avoiding costly imports of energy is a major goal for the nuclear programme. The development of a 58 reactor fleet seemingly eased the energy bill in a significant way, bringing it down from €28 billion in 1984, risen from just €3 billion in 1973, to €10 billion in 1988. But that is not in keeping with the fact that oil imports, the major contributor to the energy bill, have always been on the increase – and still are. In other words, the fall by 250 percent of oil prices in 1986 and their relative stability in the next years were the main reason for the drop in the energy bill.

Nuclear power's contribution appears very large, responsible for around 78 percent of the electricity produced in France in 2007. But in fact, electricity represented only 20.7 percent of the final energy consumption in France in 2007. And that is even though the French have the highest consumption of electricity per capita in the European Union. Taking into account the large share of nuclear power actually used for electricity exports, the overall share of nuclear power in the national consumption of final energy is rather more in the range of 14 percent, corresponding to 286 TWh.

No wonder then that France's final energy is provided over 70 percent by fossil fuels (oil, gas and coal), a situation which does not show much difference with comparative countries. If reducing oil dependence had been the real target, the development of nuclear power plainly failed. Already the largest consumer of oil in the early 1970s, the transport sector has developed to such an extent that its 70 percent increase in oil consumption largely outweighs the impact of nuclear substitution in the power sector.

The continuous increase in oil consumption, driven by the transport sector, brought French dependence on oil to a peak of 48 percent of final energy consumption in 2007. The limitation of nuclear power in face of this growing dependence on imports showed as early as the end of the 1990s in a jump in the energy bill. The current oil crisis further highlights the failure of nuclear power's promise to avoid a new shock like that of 1973 to the French economy, cruelly pushing up the energy bill to record levels close to €50 billion, a threshold most likely to be broken in 2008 (Figure 19.)[93] With €44.8 billion in 2007, the government recently noted, the energy bill brings down the overall commercial balance of France from a benefit of €5.6 billion without energy to a loss of €39.2 billion.[94]

The impact of nuclear substitution, however, should be taken into account. This is obviously highly dependent on what one considers the nuclear reactors to be substitutes for. The French Ministry of Industry used to base any such calculation on a "substitution rule" where any nuclear generation would replace that of an oil-fired plant with a 38 percent efficiency ratio (corresponding to the old thermal plants of the 1970s). This method was used up until 2001, when France gave up this specific energy accounting and adopted the international IEA accountancy standards, to artificially increase the weight of nuclear substitution in the energy balance.

A more reasonable basis for comparison, as shown by the trends of generating capacity in the European Union, should be to consider the substitution of nuclear reactors to gas-fired power plants. The amount of natural gas needed to generate 310 TWh in order to deliver the equivalent 286 TWh of final electricity to French consumers that nuclear energy provides would amount to 47 Mtoe. This would represent an increase of € 10.7 billion of gas imports, based on the € 9 billion for the actual net import of 41.3 Mtoe of gas by France in 2007. However, this is an upper value for the need of gas in such a "what if" calculation. The French nuclear programme had a negative influence on other policies which could have been much more developed had another energy pathway been chosen as of the 1970s – renewable energies for heating and electricity, improved efficiency of buildings, etc. – reducing the final energy needs to provide the equivalent energy services to those provided by nuclear power. Also, the massive development of electric heating could have been avoided, and a significant part of that heating could have been much more efficiently provided by gas-based central heating systems instead of gas-fired stations and electric heating – again, reducing the amount of gas needed to provide the same service.

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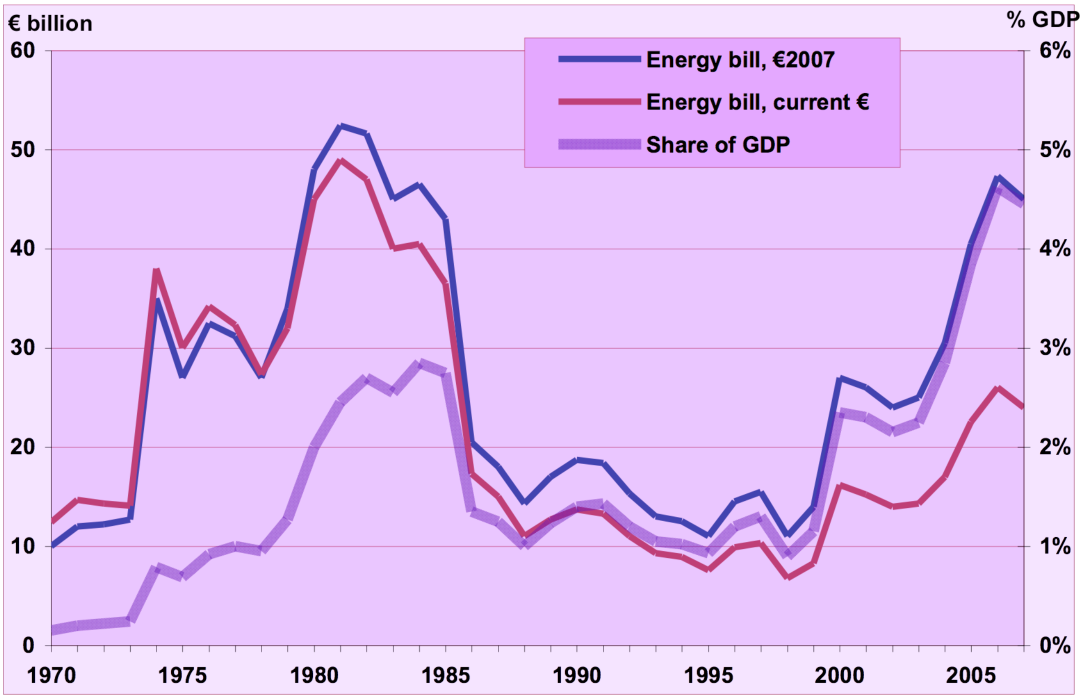
93 In particular, if the further increase of oil prices in the first half of 2008 is confirmed in the second half. The small decrease of the energy balance in 2007 as compared to 2006 is essentially due to the combined effects of a mild winter and a strong change of € against $.

94 Direction générale de l'énergie et des matières premières (DGEMP), *Facture énergétique de la France en 2007*, June 2008.

Figure 19 **French energy bill and its share of GDP, 1970-2007**



Source: DGEMP, 2008

Electricity exports: the soaring cost of overcapacity

So much for the protection provided by the use of nuclear power against rising imports of oil and gas at increasing costs. Yet another claimed line of contribution is the commercial benefit from electricity exports. France has always been since 1981 a net exporter of electricity, with a strong increase to reach 50 TWh by 1991 and a peak record of 77 TWh of net export in 2002. The average net exchange went down to 56.8 TWh in 2007 through the combined stabilisation of a small decrease of exports and increase of imports. This level is not matched by any country in Europe.

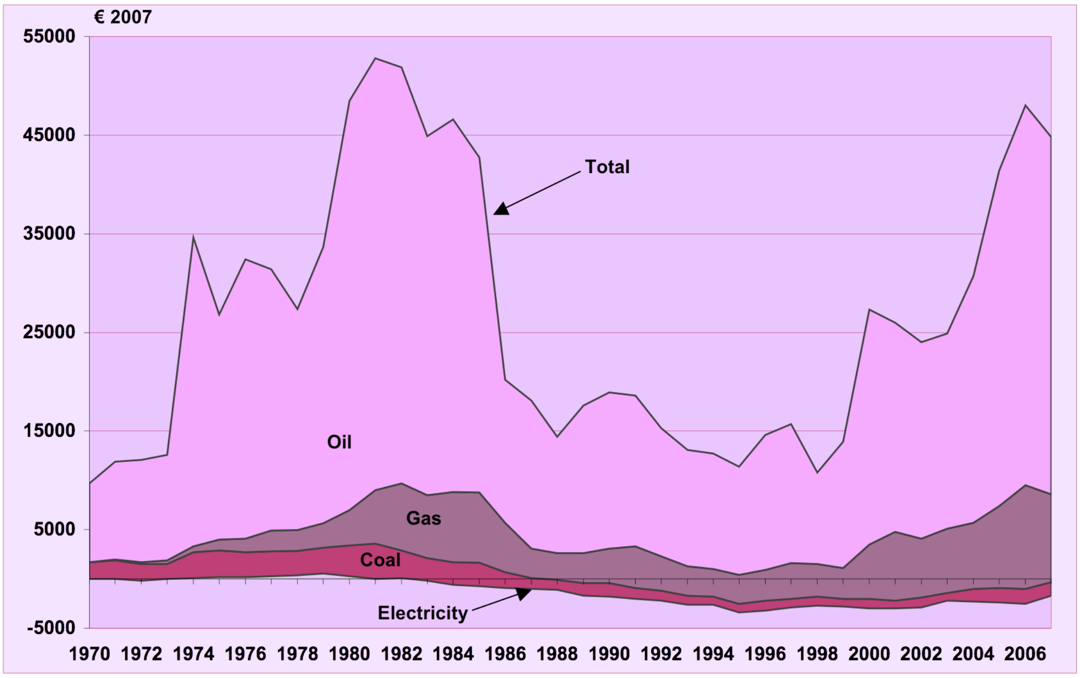
The electricity exchanges, accounting for a net export of 4.9 Mtoe, remain actually marginal compared to the oil and gas net imports of 130 Mtoe in 2007 (90 Mtoe of oil and 40 Mtoe of gas). This reflects in the breakdown of the French energy bill by source, which shows the very low contribution of electricity (Figure 20.) However, the pattern of electricity exports, as shown by the fact that they remain very high, even though the economic burden of oil and gas imports is rising, has nothing to do with energy security. Their driver is the overcapacity of French nuclear power plants.

Faulty forecasting of electricity consumption, which did not rise as sharply as promised, and the lack of timely adaptation of the planning of construction of nuclear power plants, resulted as early as the mid-1980s in a large overcapacity of the French nuclear fleet, which could be estimated at 12 to 16 nuclear reactors. The total installed power generating capacity reached 115,9 GWe as of the end of 2007, of which 63,3 GWe was nuclear power. This compares to a peak demand of 89,0 GWe in 2007, but also a minimum demand of 31,6 GWe, respectively in mid-December and mid-August, the main reason for this huge gap being the extensive use of electric heat in French buildings.

The technical and economical need for the nuclear reactors to operate as much on a base-load basis as possible implies that their production is in excess for large periods of time throughout the year. Exporting electricity was therefore a mean to use some part of the overcapacity and pay for the stranded investment costs. In the mid-1980s, EDF started long-term contracts of base-load electricity supply to foreign utilities in Belgium, Switzerland, Germany, Italy, Spain and the UK, offering very low prices and very high guarantees of supply. The profits claimed from those contracts by EDF and the government are doubtful and commercial data have never been provided to confirm them. On the contrary, independent assessments show that official income from exports remained below the official cost of nuclear generation, and suggest that power exports generated major losses estimated at €0.8 billion to €6 billion per year (through 1995-2001).[95]

Meanwhile, the continuous increase of peak demand brings some changes of priorities. Many of the long-term contracts were not renewed when they ended in 2005, and the need for imports linked to periods of high demand has increased. The electricity price can get much higher on the European market during such periods than it is when the French oversized nuclear plants have excess electricity to sell. The commercial balance of electricity exchanges remains positive but is evolving in a negative way. The mean prices of electricity exchanges for the years 2006-2007 show import prices between two and a half and three and one-tenth higher than export prices – a ratio to consider with some caution, as the range of prices from base-load to peak demand is much more extended and the physical exchanges seem to include the use of French lines for transit between neighbouring countries (mostly Germany to Switzerland).

Figure 20 French energy bill broken down by energy source, 1970-2007



Source: DGEMP, 2008

No clear pattern of electricity prices

Besides energy security issues, nuclear power was chosen on the grounds of its supposed competitiveness. Governmental estimates have regularly claimed that nuclear power plants were the cheapest available option for electricity generation in France, providing the country with the lowest electricity prices in Europe.

Prices of electricity for households are below the average prices in the European Union, but not the cheapest. Also, the price taken into account for France is that of the regulated market, excluding higher prices found on the small deregulated share of the market. For many reasons, this regulated tariff decided by the government does not necessarily reflect the full cost of nuclear power generation.

France comes third of EU-15 in the Eurostat comparison of electricity prices in the European Union, based on a standard household consumption of 3,500 kWh (Figure 21.) As for any comparison of that kind, the realness of assumptions behind the "normal" conditions considered in all countries is the key.

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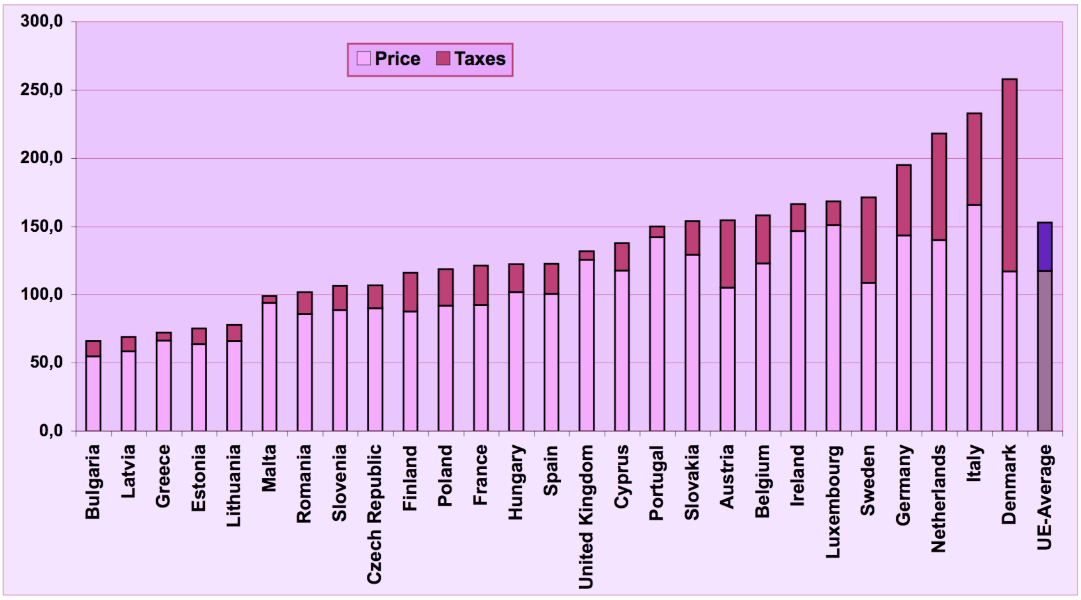
95 A. Bonduelle, *Exportations de courant électrique : qui perd, qui gagne ?*, commissioned by Greenpeace France, Inestene, November 2002.

Another comparative study, by National Utility Service Consulting, ranked France sixth, with higher prices in 2006, and ninth in 2007 for industrial customers on the deregulated market – out of 14 countries, of which ten were European. Also, this study notes, "all European countries have reported their energy markets as being at their most volatile in several decades with this trend continuing in the future".

The good ranking of France is thus partly due to the predominance of a maintained regulated market, somehow disconnected from the real costs: energy planning, electricity generation and regulated tariffs are all managed by the state. Yet another factor should be taken into account when it comes to customers: how much one household has to pay depends on the price but also the amount it needs. One mean to improve the economics of French nuclear plants has been to develop the use of electricity, especially through a massive development of electric heating in the residential sector. With 145 TWh of electricity consumption in this sector, households use on average more than 7,000 kWh per year, or twice the "normal" condition considered for comparison in the Eurostat study.

Figure 21 Electricity prices for households in EU-25, as of 1st January 2007[a]



a. Prices in € per 100 kWh, for a yearly consumption of 3,500 kWh including 1,300 kWh at night.

Source: Observatoire de l'énegie, based on Eurostat, 2007

One key to nuclear economics is the higher share in the cost of nuclear power plants, as compared to other plants, of the investment. As both the regulator of electricity prices and the full owner of EDF, the French government could freely plan the rhythm of the return of capital costs, overcoming one of the main obstacles to the construction of nuclear reactors in deregulated economies. Moreover, this integrated framework, completed by the state ownership of the R&D body CEA and the operator Areva, allowed for large public funding in support of the nuclear industry in many ways, including very extensive R&D developments – up to the financing of industrial size prototype fuel cycle plants – ,costs linked to the electricity grid, adaptation of taxes, guaranteed loans with low rates, etc. This all points to the need to look for complete costs rather than drawing conclusions from prices…

Behind prices, the real costs

Government assessments of the projected costs of nuclear power plants started with the publication of the first report in 1964 by the PEON commission, followed by ten reports up to 1979 and replaced from 1981 on by the publications of the DIGEC, a department in the Directorate for Energy and Raw Materials (DGEMP) in the ministry in charge of energy [see Focus]. These official assessments have been regularly challenged on grounds of their methodological flaws and the oriented choice of hypothesis.

However, due to a lack of strong criticism of the nuclear option in the main government parties, it was not until 1997, almost 25 years after the choice in favour of a large number of pressurised water reactors had been made, that pursuing this option was challenged for the first time within the government after the victory of a left-wing alliance including the Green Party in general elections. This resulted in the first major attempt to draw a global public assessment of the economics of the nuclear option in France.

A report was thus commissioned, in May 1999, by the Prime Minister to Jean-Michel Charpin, Benjamin Dessus and René Pellat (then respectively Director of the General Planning Commission, director of a pluri-disciplinary programme on energy in the CNRS, and High Commissioner for Atomic Energy), to conduct "a study concerning the economic data of the entire nuclear industry" and "a comparative analysis of the various methods of generating electricity", taking the "full costs" into account for all options, including "all of the factors on which a public decision must be based: inherent competitiveness, externalities and long-term effects."

The report compiled data from the industry (EDF, Areva…) and had them analysed by experts inside and outside the industry to draw the economic balance of the existing nuclear fleet of 58 PWRs over its planned lifetime. The overall cost, not discounted, of investment (including specific R&D), operation and fuel (including front-end and back-end, up to final waste disposal) was estimated in the range of €418 to 446 billion (original costs are expressed in FrF of 1999), depending on assumptions on the reactors' lifetime and on the back-end. It showed the importance, in undiscounted calculations, of operation (€184 to €197 billion over 40 to 45 years) and fuel-chain costs (€124 to €144 billion) compared to the capital cost (€99 to €103), which is the dominant factor in discounted cost.

Finally, the report compared prospective scenarios up to 2050, introducing a mix of options on the demand side policy (high or low evolution of energy consumption) and on the supply side, from reinforcing the nuclear share in the energy mix to lowering it to a base-load level, or replacing out-of-date reactors with other sources of energy, mostly modern gas turbines. Calculations showed that economics could not strongly point to a cheaper option between pursuing the nuclear programme or replacing ageing reactors with alternative thermal power plants, e.g. gas-fired ones. How this result might differ if it took into account the changes in economic conditions since 2000 is not obvious. One might think at first that rocketing oil and gas prices would give a real advantage, in these official calculations, to the nuclear option, but large increases in reactors' costs or uranium prices could very well equalise the two options.

However, this growth of all energy costs reinforces what was already the main conclusion of the Charpin-Dessus-Pellat report. Low-demand scenarios appeared less costly in any case than high-demand scenarios, with the level of demand making a much higher economic difference than the energy mix for a given level of energy demand. Therefore – and even more so with today's cost conditions – energy efficiency should be a primary priority of any sustainable energy policy, while the choice of nuclear energy among alternatives for electricity generation should only be a secondary issue. Furthermore, the report concluded that the equivalent of the average difference between high- and low-demand scenarios, amounting to some €2 billion per year, could be spent on energy savings without losing any money. Again, a higher figure might be appropriate now, given today's energy costs.

Closing a vicious circle

The report was the first publication of its kind in the nuclear field to gain positive comments from most players, from the government to the industry, the political parties, trade unions and NGOs. At a time when no new reactor was on track, it gave a rare opportunity to review the priorities of the French energy policy. What happened next was the opposite: successive governments since 2001 have chosen to keep nuclear energy on the spot, and given priority to the construction of a new reactor, the first EPR. Although EDF insisted that its project was not driven by immediate priorities in energy needs but was reponding to its industrial strategic goal to maintain its capability to build nuclear reactors, and admitted that it might be a loss maker, the administrations advising the government produced reference reports to justify the need for an EPR on the energy side and to show that it would be competitive.

After more than 30 years of rhetoric, the myth of the nuclear role in French competitiveness has become stronger than reality. Policy makers and their official advisers appear caught in a vicious circle, where new official assessments must confirm the same results – even though they might be repeating previous mistakes – while their conclusions encourage decisions increasingly remote from reality. The announcement by President Nicolas Sarkozy, as of 3 July 2008, that a second EPR will be built in France in the future, as the best response to the shock of oil prices on the French economy, takes this surreal policy even further.

Focus 17 From “too cheap to meter” to too expensive to tell?

The forecast of American nuclear proponents in the 1950s – that nuclear power would be “too cheap to meter”, in other words that the cost of metering would exceed the cost of production and delivery to the customers – demonstrates how confidence in the technology produced a skewed vision of its economic performance.

From the very beginning, the nuclear industry has always promoted itself as being one of the cheapest options for electricity. In fact, the planned costs have most of the time been unrealistically low, due to a series of repeated biases in economic assessments, including forecasting mistakes, over-optimistic technical assumptions, systematic use of the best suited economic values, extensive use of accounting methods favouring nuclear power, etc.

The French Consultative Commission for the Production of Electricity of Nuclear Origin (PEON), gathering 31 high-level experts from the administration and the industry, advised the government from the end of the 1950s to the end of the 1970s on the projected costs of new nuclear projects. It produced 11 reports from 1964 to 1979. Then the Department of Gas, Electricity and Coal (DIGEC) in the Ministry of Industry took over with a series of studies prepared with a working group of administration and industry experts on the “reference costs” of electric power. It produced eight reports from 1981 to 2004.

These reports invariably advised in favour of the nuclear option, and backed continuous support from the government to new reactor projects, from the launch of the PWR fleet with the Messmer programme in 1973-4 to the decision to build a first EPR in Flamanville in 2005-6. A quick historical glance shows how much this process has been flawed all the way along, and decisions made on a succession of unrealistic assessments.

To start with, PEON reports, which based their economic analysis of the need for new power capacities on forecasting of electricity consumption, have systematically overestimated the growth in demand. The 1973 report, which was key to the launching of the French nuclear programme as it stands now, overestimated electricity demand as close as in 1975 by 7.7 percent (real consumption reached 181 TWh instead of the forecasted 195 TWh), in 1985 by 32 percent (303 TWh real against 400 TWh planned) and in 2000 by 75 percent (430 TWh real against 750 TWh planned).

The same 1973 report, fifth in the PEON series, included for the first time in the cost calculation of new nuclear reactors the cost of nuclear waste management, neglected before. Yet it included neither the decommissioning costs, which were not taken into account until in the 1977 report, nor the R&D costs, which were considered for the first time in the 1993 DIGEC report.

It is also noteworthy that the investment cost assumed for a new PWR in the 1973 report was the lowest ever in the PEON-DIGEC series. The report used, based on the return of experience of the first generation of French reactors (natural uranium, graphite and gas, UNGG), an investment cost of 4,000 FrF96. After the construction of the first reactor in Fessenheim, which took two more years than expected to complete, the assumption used in the 1977 report rose to 5,200 FrF96. The investment costs used in the next reports increased, each time, to catch up with real costs that were invariably higher than the projected ones.

As the reports included the fuel costs and compared new nuclear reactors with other options, their assumptions about the prices of oil, gas or uranium played an important role. The PEON and DIGEC reports, like many others, constantly got it wrong when predicting the prices of primary energy materials, with all reports before 1973 forecasting low price rises, then all reports before 1986 forecasting high ones. More recently, 1997 and 2003 DIGEC reports have assumed high oil prices that nevertheless remain far off the actual increases.

Similar mistakes in forecasting uranium prices provided a faulty basis for very important decisions in the period 1975-85. The peaking of uranium prices in 1975-9 (from 25 $2007/lb$U_3O_8$ in 1973 to more than 110 $2007/ lb$U_3O_8$ in 1977) resulted in a forecast of high prices for the next decades that proved wrong, as prices on the uranium market fell as soon as 1980 to 40 $2007/ lb$U_3O_8$ and remained very low for the next 20 years (below 20 $2007/ lb$U_3O_8$ between 1988 and 2003), only climbing again in recent years to reach a new peak at 120 $2007/ lb$U_3O_8$ in 2006, from which they went down to below 60 $/ lb$U_3O_8$ in mid-2008. Meanwhile, the French government decided, based on projected prices for uranium more than twice those later realised, to launch the fast breeder reactor Superphénix in 1977, and the large-scale policy of spent fuel reprocessing and plutonium re-use as MOX for PWRs in 1985. The two-fold mistake on uranium prices, though, was key to giving PEON's and then DIGEC's own calculations a positive economic result instead of a negative one.[96]

Another regular bias is the systematic use of the best range of technical and economical hypotheses regarding the performance of new reactors. In its 1997 report, DIGEC concluded that new nuclear reactors would reach a better performance, by a narrow margin, than modern thermal plants using gas. However, this was only the case when piling up a series of assumptions on the economic conditions of investment and operation of a new reactor, each of them unlikely to be met in real conditions. For instance, the investment cost had to be scaled down by ordering ten reactors instead of one, an unrealistic assumption in the context of overcapacity of the French electric system. Also, the new reactor needed to reach a load factor of 85 percent, an unrealistic assumption given the fact that the French PWRs never exceeded an overall performance higher than 80 percent of load factor. Applying the more realistic assumptions of 20 percent higher investment cost for a single order instead of a series, and of a 75 percent load factor for a new reactor would wipe out the supposed competitiveness of a new nuclear reactor. Yet this is only shown in a table in an annex of the report, while the conclusions for the decision-makers are based on the over-optimistic scenario.

The last report of the series, published by DIGEC in 2003, proved even more controversial than its predecessors, mostly due to a lack of transparency in its preparation. Its calculation of the projected cost for a first EPR benefited from the usual kind of assumptions: investment cost based on a ten-series order, higher load factor of 90 percent, and even a fuel performance of 70 GW.d/t, although reaching this level is highly unlikely.[97] But the report went even further, introducing highly controversial unit costs by using the cover of industrial and commercial secrecy.(It argued that new competitiveness between industrial players required protection of their sensitive data. Accordingly, DIGEC proposed that the unit cost for each energy be discussed between DIGEC and each operator rather than in a working group.) Discussions between DIGEC and Areva provided unit costs for EPR construction and reprocessing far below those provided, only a few years before, by the same operator to the authors of the Charpin-Dessus-Pellat report: 1,043 €/kWe instead of 1,320 €/kWe for the construction cost, and 450 €/kg for reprocessing instead of 870 to 1,500 €/kg. Such hypotheses were highly criticised in the working group and outside it for lacking credibility and appearing "tailor-made" to respond to the political will of a positive result for nuclear competitiveness.

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[96] It can be added, regarding the decision to launch Superphénix, that the rationale for developing a plutonium-based industry was aimed at reducing the pressure on the natural resource of uranium, in the context of over-optimistic projected installed capacities. The 1974-6 PEON reports forecast 158 GWe of installed nuclear capacity in France by 2000, or more than two and a half times the actual capacity of 63 GWe.

[97] The performance of fuel, expressed in burn-up of "power days per tonne" (GW.d/t), refers to the quantity of nuclear fuel needed to produce a given energy in the reactor. Increased performance means a decrease in the outage time for reloading the reactor, and a decrease in the quantity of nuclear material to handle, both described as favourable in terms of economics. 70 GW.d/t is well above the current 55 GW.d/t reached in the current fleet, and a number of technical and safety issues would have to be resolved before such a burn-up could be authorised and reached in a French reactor.

Focus 18 EPR costs: high and rising

> *"Olkiluoto is often presented as a showcase of an open process in a democratic country. The process might have been democratic, but the information that the democratic decisions were based on has turned out to be false and misleading."*
>
> **Greenpeace Finland, Olkiluoto-3 Factsheet, March 2008**

With one order placed in Finland and one in France, the EPR, a 1,600 MWe reactor based on French and German design, is the first reactor being built in Western Europe for more than 17 years (28 years outside France), and the first of the so-called "third generation" to be built in the world.

Olkiluoto-3 was predicted by the Finnish power company Teollisuuden Voima Oyj (TVO), in the early stages of licensing, to cost €2.5 billion and take four years to build. With the choice of EPR, a reactor with a higher capacity than that initially sought for, the contracted price went up to €3.2 billion, with a fixed price, and the agreed construction time became four and a half years. As of mid-2008, delays in the construction work, plus increased prices of raw materials and possibly other factors, led to estimates of cost overruns up to €1.5 billion, putting overall investment cost at around €5 billion. After two and a half years of construction, it is estimated that construction might actually take seven years. It is likely that French economic players, not Finnish ones, will have to pay for the direct cost increase. However, this delay in delivery will also hamper the whole electricity sector in Finland, resulting in higher prices for Finnish electricity consumers for a total cost that heavy industry in Finland (as a large consumer of electricity) estimated to reach about €3 billion in 2008-12. Moreover, though the Finnish EPR is presented as a truly market-financed private investment, the French export credit agency, Coface (usually covering export projects in countries presenting a financial risk) and a bunch of public banks ensure a very low interest rate, specific guarantees and favourable financial terms for the project.

The French EPR project is set in a different context. Its operator, the French utility EDF, has decided to develop it mostly for industrial – i.e., not energy – reasons linked to its strategic goal to keep the capability to build its own reactors in the future. On one occasion, during the national public debate that preceded the formal decision to build the reactor (although the political decision had already been made by the government and the parliament), EDF admitted that given the status of the electric system, this strategic industrial choice might represent a financial loss.

EDF forecast the generation cost of its new reactor to reach 43 €2004/MWh. In the document filed to the national debate, the utility insisted that this cost included the whole R&D cost for developing the EPR technology. This cost, presented to the public in 2005, was 44 percent higher than that published less than two years before by the DIGEC in its advisory report to the government on "reference costs", which underpinned the government decision to launch the project… EDF had to explain the difference between its cost estimate and the very low DIGEC estimate of 29.9 €2004/MWh (published as 28.4 €2001/MWh). The main difference came from the impact of a series (ten orders in DIGEC assumptions) compared to a single order, with EDF calculating that for ten EPR the cost would lower to 35 €2004/MWh. The remaining difference, still a 17 per cent increase, is explained by a series of favourable technical and financial hypotheses in the DIGEC report that EDF would not endorse, including: economic life of 60 years in DIGEC lowered to 40 years by EDF (although EDF aims for a technical lifetime of 60 years, never reached yet), assumptions more conservative and "in line with international accounting rules" by EDF than by DIGEC, etc.

Yet EDF's calculation still uses some assumptions pointed out as unrealistic or very uncertain by critics of the 2003 DIGEC report, such as the burn-up increase, the load factor (based on an availability factor of 91 percent) or the time of construction, 57 months (four years and three terms) – a figure already doubtful after the suspension for one month of on-site work by the nuclear safety authority ASN, due to problems very similar to those earlier experienced by the Finnish project. It is likely that reality won't justify the optimistic estimates, and the real cost of EPR will inevitably increase from the figures used in the licensing phase. In the press release announcing the formal launching of the EPR project in May 2006, EDF mentioned that the complete cost of the EPR might rise to 46 €2005/MWh, due to changes in context like the price of steel, setting the construction cost at $3.3 billion, i.e. 10 percent more than the figure of "around €3 billion" presented by EDF in 2005 to the public debate. The latest figure published by the economic press, as of July 2008, sets the construction cost estimate at €3.4 billion.

Side economics: downplaying associated costs

"Compared to other energy sources, nuclear power is behind in the trend towards the liberalization of energy markets. The heavy investment and research costs, the long time lag before payback, the uncertain evolution of technologies, the problem of reprocessing and waste, and the sensitivity of public opinion on security issues, all point to high industrial and financial risks that require some State involvement. […] The State control over the public industrial players in [French] nuclear industry is key to guarantee the competitiveness of nuclear power, notably through public R&D financing."

Report of the Seminar "Energy and Society", Ecole nationale d'administration (ENA), Promotion Copernic, 2002

The cost of a nuclear reactor, as discussed in the case of the EPR, includes the investment cost and the operation cost but also many associated costs in the front-end or the back-end of its construction and operation. These include direct costs, like R&D costs, the costs linked to the fuel chain, and the costs raising from the inheritance of nuclear power – radioactive waste management and decommissioning. There are also indirect costs which might be significant, especially those arising from implementing the appropriate technical and organisational framework, like the costs of the high-voltage electric grid or the costs of assessment and control of safety and security. Official estimates usually neglect or downplay such costs.

R&D costs

The total R&D costs in public support of the nuclear industry in France can hardly be calculated due to a lack of sufficient data and the difficulty of separating out costs regarding the overlap between civil and military applications, or the share of fundamental research in CEA later used for nuclear developments. It proves even harder to identify the respective R&D costs associated with the various technologies developed in nuclear generation and the fuel chain.

Altogether, at least half of the costs of nuclear power R&D have been covered by CEA public funding. The total R&D expenditures of CEA for the civilian nuclear programme since its creation in 1946 were estimated for the Charpin-Dessus-Pellat report as €24.7 billion (FrF 162 billion) as of the end of 1998.

Economic Costs of Reprocessing in France

In France, the costs associated with the fuel chain are framed by the structural choice to reprocess – at least partly – spent nuclear fuel. The strategic decision to launch the large scale reprocessing of spent fuel from PWR reactors was taken at the end of the 1970s, at a time when uranium spot prices reached a peak that was not reached again until the end of 2006, with the price already down to half that record level as of the mid-2008. The assumption that uranium prices would, contrary to what actually happened later, remain high and rising justified a fleet of fast breeder reactors, with Superphénix as the first order, then the construction of a reprocessing plant and later a MOX fuel fabrication plant to separate and re-use the plutonium from PWRs in PWRs.

The decisions have been made, and Superphénix, La Hague UP2-800 and UP3 and Marcoule MELOX have been built, although the economic rationale, as in the terms set out by the industry and government themselves at the time of high uranium prices, had disappeared with the end of that uranium peak.

Superphénix undoubtedly proved a big loss. Ordered in 1976, the 1,200 MWe reactor was connected to the grid in 1986. It experienced various technical and administrative problems until it was permanently shut down from 1996 and its decommissioning decided in 1998, eventually achieving no more than a 7 percent load factor, with a mere gross production of 8.6 TWh over its short lifetime. The overall cost of Superphénix has been estimated as €9.7 billion (FrF 64 billion) by the Court of Auditors (Cour des Comptes) in 1996, very close to the estimate provided by its operator, the European consortium NERSA, in 1998, at €9.8 billion (FrF 65 billion, of which FrF 38 billion being paid for by EDF). Yet this does not include the stranded R&D cost and a potential rise in the future costs for decommissioning and waste management, including the storage and future disposal or reprocessing of the two cores fabricated for the reactor, one irradiated and one non-irradiated.

The case for reprocessing and MOX fabrication could be laid out just as clearly, if the global economics of the plutonium industry were discussed in an open way. The Charpin-Dessus-Pellat report commissioned by the prime minister in 1999-2000 offered a rare occasion to do so. Using real and projected costs provided by the industry, the report compared the global costs of the current nuclear fleet under various assumptions, including the status quo on reprocessing and MOX on one hand, and the theoretical scenario of a choice for direct disposal of spent fuel from the beginning of the French PWR programme. Although embedding favourable assumptions on future costs linked to reprocessing, like those of La Hague decommissioning, the report concluded that the choice of the French government in favour of reprocessing represented an increase in average generation cost of about 5.5 percent per installed GWe over the reactors' lifetime. In other words, not developing reprocessing from the start would have provided total savings of €25 billion (FrF 164 billion).

In 2003, the official DIGEC report on reference power costs acknowledged, that "for the time being, the low prices in the front-end of the fuel cycle (natural uranium and enrichment services) do not justify the reprocessing of spent fuel on purely economic grounds." But while it recognised the conclusions of the Charpin-Dessus-Pellat report as "representative of the current economics of the fuel cycle", the DIGEC used instead projected costs for the period 2025-85 (corresponding to the reprocessing of the spent fuel of a future EPR reactor). The assumptions, based on confidential discussions between Areva and DIGEC, proved less than half the costs calculated in Charpin-Dessus-Pellat (450 €/kg of reprocessed fuel instead of 1,000 €/kg or more under various assumptions). No explanation was given for cutting by half the investment and operation costs of a future reprocessing plant as compared to La Hague, apart from a clear statement on its political origin by DIGEC: "the cost of reprocessing used in the study is the cost objective needed to guarantee the competitiveness of reprocessing compared to the direct disposal option."

This fools' game of using unrealistic assumptions to preserve the appearance of an equivalence of costs between reprocessing and direct disposal might not be played for long by EDF. With more than 8,000 tHM of spent fuel stored at La Hague, representing 99.8 percent of the material stored in advance of reprocessing as of 31 December 2007, the French utility is faced with financing most of reprocessing costs. In 2007, in the first phase of working discussions preparing an update of DIGEC's 2003 report, EDF explained in a working document that it "expects the new [reprocessing] facilities to allow for some gains in productivity," but that "one must remain cautious about the final impact on reprocessing costs" and therefore, "EDF regards the values used in the report as a low estimate."

Since 1995, EDF has assigned in its accounts a zero value to its stocks of separated plutonium – as well as to its stocks of reprocessed uranium – and made it publicly clear that, if a market existed for separated plutonium from PWR fuel, "the price would be negative". EDF is for instance charging the Dutch utility EPZ (which has its fuel reprocessed in La Hague but no means to reuse the plutonium) for taking its plutonium – rather than paying for it. The liberalisation of the electricity sector presses EDF to lower its costs, including those linked to the plutonium industry. While the reprocessing and MOX contract signed for seven years in 2001 had already included an option for 2008-15, EDF only signed on to a provisional one-year follow-up agreement with Areva in April 2008.

Decommissioning and Waste Management

The reprocessing option has a strong impact on waste management policy and costs estimates. The key issue in cost calculations is the burden of final disposal of very long-lived and highly radioactive waste, set to be a geological repository by the 2006 law on radioactive waste management. Although large uncertainties prevail in this matter, refining the design is not necessarily bringing the costs down, as illustrated by projected costs published by Andra. Its estimates of the total cost of a geological disposal rose from €14.7 billion in 1996 to a range of €15.9 billion to €58.0 billion in 2003.

This 2003 estimate conveniently concluded, in line with the claim that reprocessing is reducing waste volumes, that ending reprocessing in 2010 would more than double the cost of final disposal as compared to reprocessing all spent fuel. The bias was however obvious: in the first case, the cost accounts for the disposal of all nuclear material discharged from the reactors; in the second case, on the contrary, more than half of the total plutonium and uranium inventories are transferred to an hypothetical next generation of reactors, and none of the cost arising from the management of the waste this will produce in the future is accounted for.

As the 2006 law would require dedicated funds from the operators to cover long-term costs of waste management, the Ministry of Industry set up a group with the operators to reduce the range of uncertainties in Andra's estimates. The group concluded with lower-cost estimates for the total reprocessing scenario, in the range of €11.5 to €12.9 billion. The Cour des Comptes stressed in a subsequent report that the study failed to deal with major uncertainties on the waste site, its design and inventory or size, as some of the main cost factors remained very high. It insisted that the reduced costs displayed were caused by an announced strategy that had yet to demonstrate its technical and political feasibility.

Many factors have still to be taken into account that will lead to higher costs of disposal than the current estimate. Calculation is based on the availability of a repository by 2020, but the programme is already some years behind schedule. The final conditioning of some categories of waste, representing some of the largest volumes has yet to be designed, as well as some concepts of galleries. Finally, some of the separated nuclear materials assumed to undergo indefinite reuse will eventually go to final disposal.

Long-term liabilities also include the decommissioning of one of the world's largest infrastructure of nuclear power plants, research centres and facilities of all kinds. The Court des Comptes has calculated liabilities pending on the three main operators (EDF, Areva and CEA) to a total of €65 billion (undiscounted) as of the end of 2004. This includes the decommissioning of PWRs, for which a provisional estimate of 15 percent of the investment cost is used, but also the huge costs of decommissioning reprocessing plants. However, a part of this cost might be lifted from the operators and transferred to public funding. In 2004, the provisions calculated by Areva for the decommissioning of its facilities dropped from a total of €12.2 billion to €8.0 billion thanks to a bailout agreement with CEA transferring to the state the decommissioning responsibility for the Marcoule reprocessing site in exchange for a lump sum payment by Areva of €427 million plus a commitment to a future payment of €158 million.

Structural costs

To estimate structural costs linked to the development of nuclear energy is out of reach of a simple independent analysis, for obvious methodological reasons including the difficulty of setting a limit to costs attributable to the nuclear industry and the lack of data on structural costs in general. Nevertheless, nuclear energy generates some specific infrastructural needs that can be identified and discussed on the basis of a few examples.

One obvious need linked to nuclear power is that of the appopriate electric grid to transport and distribute the electricity generated by nuclear power plants. Of course, an electric grid would be needed in any case to distribute electricity to consumers, yet the highly centralised repartition on the territory of nuclear power casts some specific needs. This is illustrated by the case of the EPR project in Flamanville, where the introduction of a third massive unit producing electricity on the site requires an additional high-voltage line to help evacuate energy from the site and transport it to areas of consumption. Although the projected line would provide a larger benefit to consumers than the evacuation of the EPR production, these benefits could be obtained through other options, some of them at a lower cost. A large part of the investment cost to build this 150 km, 400 kV line, estimated at €240 million, is therefore directly attributable to the EPR project.

The global investment costs for the development of the electricity grid (transport and distribution) from the 1970s up to 1997 has been estimated by a working group for the Charpin-Dessus-Pellat report to reach more thant €75 billion, of which more than 10 percent is for the very high voltage grid. By the turn of the century, around €2.9 billion was spent each year for developing the grid, of which 0.5 billion was for the very high voltage grid. Based on those costs, the report introduced a difference of €6.8 billion over the period 2000-2050 in a low-electricity-demand scenario, in favour of a non-nuclear, decentralised power system compared to a status quo nuclear fleet.

Structural costs such as those arising from the organisation of safety and security are even more difficult to assess. These cover, for instance, a large part of the IRSN budget – amounting to €276 million in 2006 – dedicated to public expertise and advisory work on radiation protection, nuclear safety and security issues. Or that, of course, of the nuclear safety authority, ASN and its decentralised control means in the French regions, around €50 million. The specific activities of security forces to protect nuclear facilities and transports should also be included.

Democracy

A long-lasting undemocratic choice

"Since forty years the big decisions concerning the development of the French nuclear program are taken by a very restricted group of personalities that occupy key positions in the government or in the top administration of EDF, CEA and the few companies involved in the program. The approach remains unchanged in spite of the change of ministers thanks to the permanence of these personalities (…)."

Georges Vendryes, former French representative on the International Atomic Energy Agency (IAEA) Board of Governors, *IAEA Bulletin*, autumn 1986

France's 'choice' of nuclear power has been anything but democratic. Such fundamental decisions as the launching of a massive programme of pressurised water reactor (PWR) construction, given the go-ahead in 1973-74, the development of breeder reactors with the ordering of Superphénix in 1976, and the establishment of spent fuel reprocessing and the 1985 decision to extend it with the reuse of plutonium in MOX fuel, have all been taken on the basis of internal work by senior civil servants and the industry, without any procedure of public evaluation or debate.

With the notable exception of the presence of a Green Party environment minister in the Government from 1997 to 2001, the ministers in charge of the nuclear portfolio, the economy, industry, health and the environment have invariably proclaimed their unfailing support for the nuclear industry, so ensuring that the sector's industrial ambitions are promoted on every front.

Without going into a detailed historical analysis, this situation has its roots in the particular political context of France after the war, which saw the coming together, in a way unique in Europe, of the Gaullist right and the Communist-dominated left over the principle of national independence. Nuclear technology, first in the military, then the civil sphere, has become one of the main vehicles for this principle. The main parties of government, ensured overwhelming domination of parliament by virtue of the electoral system, have remained unanimously faithful to this pro-nuclear policy for over 60 years.

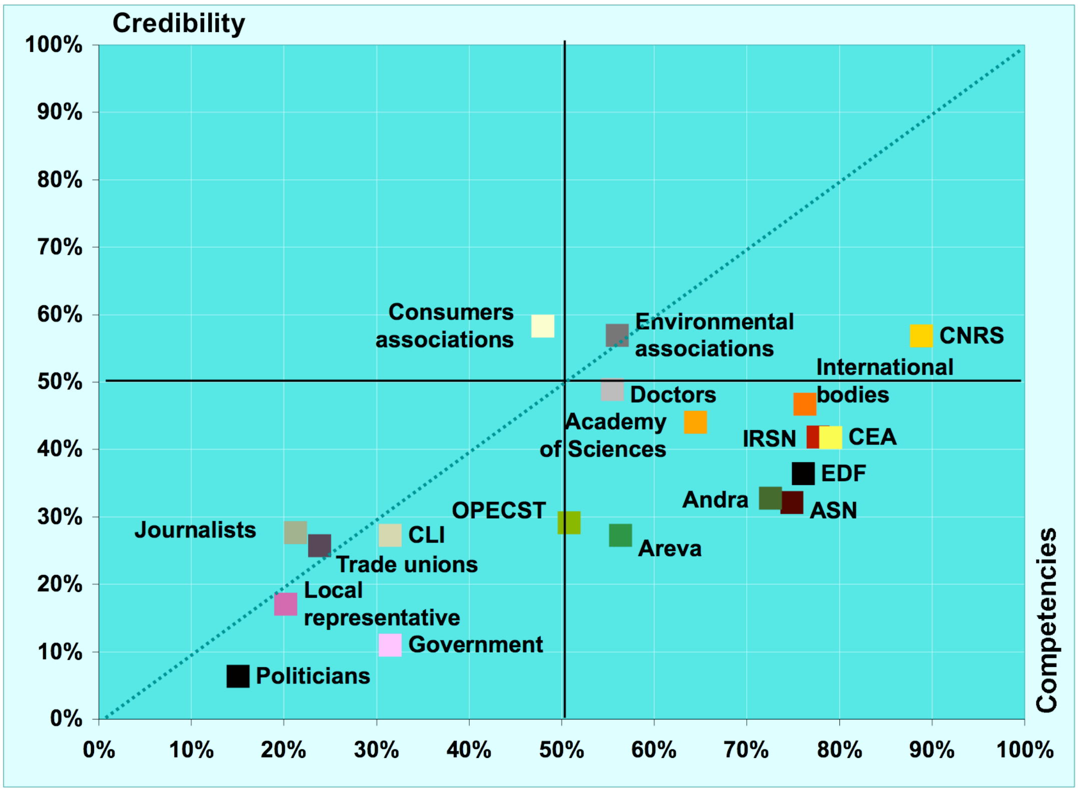
As a result, the rare parliamentary debates enshrine the illusion of a national consensus (with a few variations) on the pursuit of the nuclear programme. The same arguments around energy independence, the price of energy and (nowadays) greenhouse gas emissions are trotted out again and again without ever being seriously analysed. The rare evaluations conducted by parliamentarians, in particular through the Office Parlementaire d'Evaluation des Choix Scientifiques et Technologiques (OPECST – Parliamentary Office for the Evaluation of Scientific and Technological Decisions) have certainly noted gaps in safety or the management of nuclear material and waste, but with very few exceptions they maintain an explicit, preconceived support for the French nuclear programme.

Public mistrust

The attitude of the political establishment, and in particular that of parliamentary representatives, contrasts very strongly with the state of public opinion – at least as measured by the various surveys that have been conducted on this topic. The nuclear industry sometimes boasts that it has the support of the French people, especially when it comes to selling the French nuclear model abroad. But the reality is quite different.

The most interesting opinion polls from this point of view are those which compare the state of public opinion on the nuclear issue in various countries. In 2005, a study by the IAEA found that only 25% of French people questioned were in favour of new nuclear power stations (compared to a figure of 40% in the USA, for example, although on a par with the Germans at 26%), with 50% in favour of the retention of the existing power stations with no new ones being built, and 16% for the closure of the existing ones. A poll published by the European Commission in 2007 confirmed these findings: only 28% of French people came out in favour of an increase in the role of nuclear energy in order to combat climate change, as against 59% in favour of a decrease in the nuclear industry's share of energy production. Interestingly, the French are very close to the average figures for the 27 countries of the European Union (30% and 61% respectively).

Figure 22 Credibility and competence index[a] of the main actors in the French nuclear industry[b,c]



a. 'Credibility index' here denotes the percentage of positive opinions recorded in response to a question as to whether the various actors tell the truth about nuclear power; similarly, 'competence index' denotes the percentage of positive responses recorded to a question as to whether the various actors are competent with regard to nuclear power.

b. Under this heading are grouped a very diverse range of bodies (institutional and otherwise) and of professions or functions, either specifically active in the nuclear field or involved in it as part of a broader field of activity.

c. CLI: Commission locale d'information; CNRS: Centre national de la recherche scientifique; OPECST: Office parlementaire d'évaluation des choix scientifiques et technologiques.

Source: Based on 2007 IRSN Barometer (survey of November 2006)

This situation is all the more remarkable in that the dominant pro-nuclear discourse is only weakly counterbalanced. Numerous groups and associations, united in coalitions opposing specific projects (the EPR reactor, burial of waste) and more widely since 1997 in the Réseau Sortir du Nucléaire (Get Out of Nuclear Network), oppose the nuclear industry domestically. But their media influence and their political importance remain very limited. France is desperately short of critical, independent expertise on the whole range of nuclear issues: organisations such as Global Chance that produce counter-analyses of the official evaluations can be counted on the fingers on one hand.

The 'barometer' of French public opinion on the risks that is published regularly by the IRSN repeatedly shows that the numerous official sources of thinking and analysis favourable to nuclear power suffer from a chronic lack of public confidence (see Figure 22.) None of the institutions promoting nuclear power achieves a public opinion rating of over 50% in terms of both competence and credibility.

A closed institutional framework

How can we explain this disconnect between the wishes of the people and the direction taken by policy? One of the main reasons is the existence of an institutional system which actually allows these decisions to evade any democratic scrutiny. Apart from a handful of targeted laws, the most important of which, in 1991, focused on the focus of research into the management of radioactive waste, the entire development of the nuclear industry took place without any specific legal framework until legislation on nuclear transparency and security was adopted in June 2006. None of the major decisions about the programme between the 1960s and the 1980s was even put to a parliamentary vote, to say nothing of specific public consultation processes.

On the contrary, all the key decisions were taken behind closed doors by the country's technocratic elite, with the Corps des Mines (Corps of Mines) playing an especially key role. This state body, comprising around 700 engineers selected from among the best students of the most prestigious technical institutes, is well placed to fill all the key positions relating to the nuclear portfolio, whether as ministerial advisers, senior civil servants or managers of the sector's businesses. Those in charge remain in post when the political leadership changes, or else are replaced by another member of the Corps. In this way the direction of nuclear policy – whether in terms of nuclear power's central role in the country's energy policy, choices about the development of different nuclear technologies, or decisions on the opening, closing or development of facilities – is never exposed to the winds of political change, but goes on following the long-term vision set out by the Corps des Mines.

Recent developments, but no real progress

Nevertheless, nuclear power could not remain forever protected from the gradual rise of the principles of freedom of information and public participation in decision-making that has occurred across environmental issues as a whole. The nuclear sector's encounter with the procedures established under the aegis of the Commission Nationale du Débat Public (National Commission for Public Debate) raised many people's expectations, with two dossiers put out to national debates in 2005-6. Unfortunately, these hopes were dashed. While the organisation and the content of the debates confirmed the potential value of open procedures in improving the analysis and common understanding of the dossiers, the arrangements betrayed their limitations as regards any real influence on decision-making mechanisms.

In the first debate, which focused on EDF's projected construction of an EPR reactor at Flamanville, the situation was very straightforward. The construction of this reactor, the first of its type and supposedly a necessary preparatory step in the renewal of the French nuclear fleet, was included in energy blueprint legislation which Parliament had voted through even before the national public debate began. In the second debate, focusing on nuclear waste management, the period of public debate seemed to produce great advances towards a shared vision of the problem – a necessary precondition for the identification of genuinely acceptable solutions. But the process culminated in legislation adopted in June 2006 which, although it represented some progress by comparison with the bill as it existed prior to the debate, nevertheless represented a retreat from the conclusions that emerged from the debate.

The two debates also highlighted the nuclear field's unique approach to freedom of information principles. After the progress of the debates ran into difficulties caused by the lack of precise replies to some key questions raised by those involved and the public, a working group was set up, comprising representatives from the administration and the companies concerned, along with a few independent experts. This produced several proposals to improve the definition of the scope of commercial and defence secrecy, along with the justification for it and the explanation of its application; but as far as we are aware these proposals have had no concrete repercussions.

The most recent developments confirm that, beyond peripheral improvements and some fine words about the implementation of transparency, at a fundamental level the situation has hardly improved at all. The obstacle to making any progress is exemplified by the consultation set in motion by the French President in summer 2007 in the context of the Grenelle Environment Forum, which brought together the administration, communities, employers, unions and environmental protection groups. Although energy policy and climate change clearly form one of the main fields of work which need to be brought to a legislative conclusion in autumn 2008, from the outset the President deliberately excluded from this any discussion of the nuclear aspect!

Conclusion

In view of its original ambitions and the considerable technical and economic efforts that it has required, the huge French nuclear programme developed between 1975 and 2000 shows a particularly disappointing balance sheet. The perennial trumpeting of "France's energy independence" does not stand up to analysis, given that France's per capita oil consumption in 2007 was higher than that of its large neighbours, and that the contribution of nuclear power to overall consumption was a mere 14% while oil products accounted for 49%.

Admittedly, nuclear power's contribution does reduce France's dependence on gas and coal, but oil dependence is by far the most restricting factor in terms of energy security. Moreover, with more than 80% of its electricity being of nuclear origin and reliant on a single technique, the pressurised water reactor, the French electricity system has created a new source of vulnerability for itself.

In overall economic terms, the 'all electric, all nuclear' approach which has been the cornerstone of French energy policy for the last three decades – and which continues to be so, in the face of all economic and practical reason, with the EPR reactor construction programme – has brought France no particular advantage, for example by comparison with Germany. On the contrary, the nuclear monoculture has left France a long way behind in renewable energy development and has obstructed its efforts towards energy efficiency, particularly where electricity is concerned.

Faced with the consequences of an increase in greenhouse gases, the proponents of nuclear power present it as the essential solution in that it emits much less carbon dioxide than the combustion of oil, gas or coal. But on closer inspection it becomes clear that this miracle cure is nothing of the sort. It is true that nuclear electricity generation contributes to the reduction of greenhouse gas emissions – but even in the extreme case of France, this reduction amounts to at most an estimated 15-20% of total emissions. While this figure is not negligible, it needs to be balanced against all the risks posed, and pollution generated, by the whole complex and dangerous nuclear power system, with its power stations, its fuel plants and its radioactive material transports – both now and in the long term (dismantling of the installations, management of the radioactive waste).

Nuclear power is liable to suffer serious accidents that may affect extensive areas for long periods of time. No satisfactory solution has been found for the management of long-term waste. Finally, proliferation remains a major risk for global security and it is dishonest to maintain that a country can be equipped with civil power stations without a military use being possible.

Moreover, nuclear power can only contribute to the production of electricity, which (adding all sources together) represents only around 20% of a developed country's end-user energy consumption. The remainder comes from the petrol and diesel burned in cars and lorries, the oil or gas used to heat buildings and power industrial production – and also from biomass and solar energy (of course hydro and wind power produce electricity).

The unavoidable fight against greenhouse gas emissions therefore requires, first of all, a policy of energy saving and research into greater energy efficiency. Next, it calls for a greater reliance on renewable energy.

The continuation of present-day global energy consumption trends runs up against insurmountable obstacles and leads to a developmental impasse, accentuating the inequalities between rich and poor countries and contributing to social breakdown. Economic and social development can only be held back, if not made impossible, by energy insecurity (in terms of physical supply faced with geopolitical constraints, rising prices, increasing scarcity of resources in the medium term, and risks both technological and posed by external stresses of all kinds) and by the degradation of the local environment (by pollution and accidents) and the global one (through climate change). The rising price of oil is already wrecking the most fragile economies. Besides, 'business as usual' scenarios of the energy future clearly highlight the political, economic and environmental impasse to which they lead.

Energy security and environmental constraints pose a considerable challenge for social and economic development on a global scale. The limiting of energy consumption is now the policy most urgently in need of adoption, in that it has the greatest potential to develop, is applicable to all sectors and in every country, is the best instrument with which to combat climate change, and can help slow down the depletion of fossil fuel resources and ensure that a growing proportion of energy demand is met by renewable energy. It can also contribute to economic development by reducing expenditure on energy and by creating new business activities and employment. It is a key imperative of energy and economic policy.

This fundamental change in the energy paradigm which gives priority to demand rather than to supply profoundly alters the citizen's relationship with the energy system. The need to provide an 'energy service' instead of an 'energy supply' brings new actors to the fore: businesses, communities, households, and professionals in the construction, transport and manufacturing industries, in agriculture and in the service sector. Cities and local authorities become key drivers and promoters of these new policies.

By applying such a strategy, industrialised countries can reduce their energy consumption to a significant degree. Developing countries need to increase theirs, but they can do so at a much slower rate than that undergone by rich countries in the past, with the damaging consequences we know all too well. For most countries, including major energy producers, the reduction of energy consumption will represent their main national energy resource for the decades to come.

Europe can play a lead role in promoting this policy: indeed both its energy security and the fight against climate change oblige it to. The March 2007 European Summit's decisions on the "three 20 per cents" (energy efficiency, renewable energy and greenhouse gas emissions) and the "energy package" presented by the European Commission are an encouraging signal within the European Union. But the "burden sharing" between Member States remains to be organised, and this will be the touchstone of their individual political will.

In this context, and considering what is at stake in terms of the climate risk, energy security and economic and social development, nuclear power's real contribution will continue to be marginal for Europe. Conversely, the physical and geopolitical risks that further expansion of the technology in its present state would entail are so great that the balance of benefits and drawbacks is very clearly against such an expansion. Moreover, nuclear power requires massive centralisation of the energy system, based on high-output power stations, whereas technological progress is increasingly concerned with an energy system based on decentralised actions and initiatives in the fields of energy efficiency, renewable energy and combined heat, cooling and power production.

About Global Chance

Global Chance is a non-profit organisation gathering scientists and experts who share the strong belief that a better balanced developement of the world can and must arise from growing awareness of the threats weighting on our global environment.

In the face of these threats, Global Chance puts its members' competencies together to serve a pluralist and contradictory public expertise, so as to identify and promote new and positive collective answers in various fields – scientific and technical, economic and financial, political and regulatory, social and cultural. It also aims for such answers to be inspired by solidarity between the North and the South, humanism and democracy.

The organisation has regularly published its views in *Les Cahiers de Global Chance* since 1992 (two issues per year), but it is also participating in the public fora through its members' publications and their individual implication in various debates.

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Benjamin DESSUS

Engineer and economist, Benjamin Dessus started working in Marcoussis labs on quantum electronic and lasers before he joined the R&D department of EDF. He entered the AFME (Agence Française de la Maîtrise de l'Energie, later to become ADEME) when it was created in 1982, and directed its technical services until 1987. He then joined CNRS where he directed successive interdisciplinary research programmes (PIRSEM, Ecotech, ECODEV) on energy and environment. He contributed meanwhile to the elaboration of the climate strategy of the Global Environment Fund (GEF) and was from 1991 to 1994 a member of its Scientific and Technical Advisory Panel; from 1994 to 2003 he chaired the Conseil scientifique et technique of the Fonds Français pour l'Environnement Mondial (FFEM). A recognized expert of energy and nuclear issues, he was co-author of the Charpin-Dessus-Pellat report on the prospective economic evaluation of the French nuclear option, published in 2002, and published a large number of books, including *So Watt ? L'énergie, une affaire de citoyen* (with Hélène Gassin, Ed. de L'Aube, 2004).

Bernard LAPONCHE

Born in 1938, Bernard Laponche is an independent consultant, expert on energy and energy efficiency policies. An engineer from the École Polytechnique, State Doctor in Science, and Doctor in Energy Economics, he worked in the nuclear reactors Department of the French Atomic Energy Commission (CEA) during the 1960s and 70s, and was active during this period in the workers union CFDT. He was Director of Planning and then Director General of the Agence Française de la Maîtrise de l'Énergie (AFME, which has since become ADEME) from 1982 to 1987, then co-founder and director of the International Conseil Energie (ICE) consultancy firm from 1988 to 1998, and technical advisor on energy and nuclear safety to Dominique Voynet, Minister of Territorial Planning and the Environment, in 1998 and 1999.

Hélène GASSIN

With a master degree in Sciences and Techniques applied to the management and the environment, Hélène Gassin joined Greenpeace France in 1998, where she was in charge the energy campaign up to 2006. She ran numerous campaigns and initiatives which involved following through international negotiations, lobbying through the preparation of European directives or French laws, coordinating conferences and public debates as well as NGOs networks. She authored a number of articles on energy and policy issues and published *So Watt ? L'énergie, une affaire de citoyen* (Ed. de L'Aube, 2004) with Benjamin Dessus. Now established as independent consultant on energy and environment issues, she is also co-initiator of the organisation Tandem – Construire ensemble une culture de l'environnement (build together an environmental culture).