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.

[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

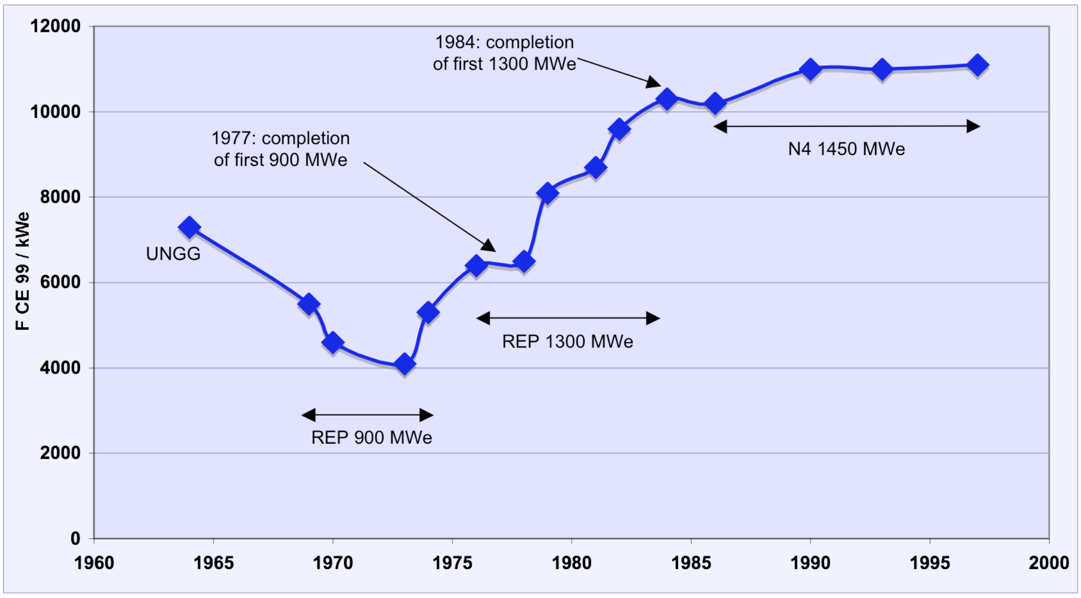
The French nuclear industry has thus a fairly faulty record when it comes to the technologies it chooses to develop. Another regular pattern has been the failure of new equipment to match planned performance. New plans for reactors or fuel-chain plants have usually been promoted through economic justification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

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.