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in the French electronuclear industry**

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The performing interaction between institutions and technology in the French electronuclear industry.

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Among the various traditional “grands programmes” typical of the French public intervention in high-tech industries, the nuclear programme is often considered as one of the major successes. About 60 nuclear reactors have been built between 1970 and 1998. Altogether they generate 80% of the electricity produced by the state-owned monopoly at a competitive cost. Moreover, the French nuclear industry ranks first on the world market of nuclear equipment and services. Such performances are all the more contrasting with those in the other OECD countries, where costs have dramatically increased while many projects never went ahead: since the 1980s, a number of electricity companies decided to stop their risky investments in nuclear equipment in many countries. Such a performance is attributable to an appropriate institutional set-up, which has been able to enforce all the technological learning needed to the implementation of this kind of radical complex and large-sized innovation. This appropriate set-up associated together (i) a strong political support, (ii) a state-owned electricity monopoly strongly endowed with engineering resources and identified to national interest, (iii) a very concentrated electromechanical manufacturing industry which supplies all the public procurement as well as (iv) an influent R&D public agency. Beyond this set-up, the success was due to the safe regulatory stability and the avoidance of past bureaucratic failures in technological policy and efficient coordination allowed by long-term organisational arrangements on standardised reactor series.

However in recent years, the French national nuclear system, as composed of the whole set of institutions and relations between organisations in this sector¹, is affected by different exogeneous shocks. In disorder those shocks are the European power markets liberalisation legislation, the persistence of the world-wide nuclear market depression, the competition of a new power generation technology (gas turbine), and the globalisation and concentration of the world-wide electromechanical industry. The national nuclear system cohesiveness is questioned, because it is forced to adapt to this new environment. But it resists thoroughly: French transposition of the new European electricity legislation, which could have

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¹ National nuclear system as a sectorial part of the National System of Innovation (or a meso-system of innovation) could be considered as such, if it is considered within its relations to its institutional environment.

dramatically upset internal relations, has been very limited in scope in order to preserve the capability to pursue the nuclear option.

We shall argue two points. First, because of two specificities of the nuclear technology – technological risk creating social acceptability problems and regulatory instability, and embedment in complex and large-size equipment implying long lead-time and complex learning - there is a fit between the French set made of institutions, organisational patterns and the technological regime of this industry. This does not mean that any alternative institutional and organisational sets would have had lower performances in other political circumstances than the social opposition to nuclear technology, but that the French set has satisfying performances because it has allowed protection of the nascent technology from political and regulatory shake up and the establishment of an efficient user-supplier partnership relation.

Second, the French nuclear system is a clear case of co-evolution of technologies and institutions. Generally speaking, techniques emerge from specific forms of industrial organisation but, once set up in a performing way, they contribute to maintaining the dynamics of these forms of this organisation (Nelson, 1988; Coombs & al, 1992). As far as electricity generation and network technology are concerned, the technological trajectory (increase in unit size, economies of scale, etc.) has effectively been oriented in the past by the organisational choices with respect to the creation of vertically integrated monopolies. In return, the technological dynamics reinforced the organisational form and the need for tight relationships between equipment suppliers and electricity companies: institutional path-dependency (North, 1988) has resulted from both the increasing efficiency of the institutional set-up to exploit technological progress opportunities and the growing interdependencies between institutions. As argued by Hirsh (1988), this organisation has also contributed everywhere to the initial commercial dissemination of the nuclear power technology, since a regulated monopoly is the only company able to invest large amount of risky capital with very long lead-times. In the French case, moreover, this involvement was comforted by the traditional role of the national public monopoly to pursue industrial and social policies (Frost, 1991).

But the coherence between technology and industrial organisation vanishes as soon as technical progress slows down or socio-economic environment changes (Nelson, 1988). So, in the power industry of many OECD countries, the social acceptance crisis of nuclear technology as well as the emergence of the much less capital-intensive gas turbine relax the co-determination and open up the institutional choice. Conversely, in France, the performances of the nuclear program help to maintain the nuclear option, thus justifying the preservation of the existing industrial organisation and institutional scheme. In order to characterise the joint institutional and technological dynamics of the French electricity supply industry we distinguish two stages: first the efficient adaptation of institutions and industrial relationships to the nuclear as a new technology, and second the influence of technological features on the industry structures changes.

1. The performance of the French public model: the compliance of the institutions with the requirements of nuclear technology

Nuclear technology is a complex and capital-intensive technology, requiring considerable development and learning delays on stable time limits. It also presents specific technological risks with strong symbolic charges. In all the industrialised countries, it originally benefited

from a favourable selection environment: highly structured public research and development, monopolistic organisation of the electricity industry, a high technological dynamism in the electromechanical industry world-wide, and an atmosphere of enthusiasm for science and technology values.. Standardisation was favoured through the innovation process. It consisted in initial creation of variety at both world-wide and national level thus favouring competition and emulation. It was then followed by a race to the equipment size and the early selection on the international market of a dominant design, the American Light Water Reactors (LWR).

However, changes in social environment in the industrial democracies have dictated that technology should be able to adapt to increasing safety demands and subsequent regulatory requirements. Barriers to equipment completion and regulatory instability have disrupted the various learning processes. Against this background of instability, the most effective national nuclear systems were doubtless those that have been able to avoid instability and to allow the reactor technique to be standardised (Finon, 2000). France was in this position for three reasons: strong public and centralised institutions, the capacity of the national nuclear system to open to foreign technology adoption, and efficient user-producer relations.

1.1. The industrial and economic performances

The importance of the sales and the control of the economic costs reflect the technological and industrial success of the French nuclear industry since 1970. The French industry has built a nuclear capacity of 62 000 MW in France and 6 000 MW in foreign countries, that represents 22% of the world-wide nuclear capacity (outside the former Soviet block). It has developed the technologies and invest in the equipment for the whole nuclear fuel cycle from the uranium mine, the isotopic enrichment to the fuel reprocessing. In the seventies it also took the leadership in the technological development of second generation reactors, the Fast Breeder Reactor (FBR), before the cancellation of OECD countries programs in the eighties.

- **Control of construction cost and time limit**

The economic control of nuclear technology is shown in investment costs that are dramatically less than those recorded in other industrialised countries: comparisons of official reference costs gathered by the OECD on the same basis of calculations indicate a level of 80% to 100% less than in other countries (Table 1)². Since the seventies, costs increases were recorded because of increases in the stringency of standards and site restraints, but they were much less than would otherwise have been the case. This is mainly due to the type of regulatory interventions, the protection from the public arena troubled by site opposition and division of the public opinion on this matter, and the capacity to organise and manage series contracts and to standardise the technology, as it will be analysed. During the industrial and technological learning period, the French investment costs increased by 54% between 1974 and 1984 (Crowley and Kaminski, 1985) before its stabilisation, to be compared to an increase by a factor three in Germany and in the USA between 1969 and 1982 (Thomas, 1988)³.

² Official reference costs gathered by the IEA-OECD are partly political figures but their evolution reflects the evolutionary situation of this type of investment in each country. Moreover the relative positions of each countries reflect those of the current costs. Concerning the French current costs, subsidies might be suspected. But the fact is that the national utility – EDF - did not receive subsidies, beside the guarantee given by the State to EDF for its borrowings on the financial markets which can be considered as implicit subsidies.

³ Various American analyses, such as Jasper (1987) and Morone and Woodhouse (1989) have studied the

Table 1: Comparison of Nuclear Investment Reference Costs* in Various Countries in 1984, 1992 and 1997 (in current \$ / kW)

	USA	Japan	Germany	France	United Kingdom
1984	1,860-2,800	1,405	1,429	870	nd
1992	2,320-2,500**	2,938	3,417	1,658	3,540-4,080
1997	2,079**	2,828	nd	1,988	nd

* Include interests during the construction, discounted decommissioning costs.

** Official American costs for 1992, like those of 1997, are purely for information, as they do not relate to any specific projects. In some nuclear projects, investment costs reach \$4000/kW.

Source: IEA-OECD– Projected costs of generating electricity-1986, update 1992, update 1998.

The construction time⁴, which is a major cost and risk factor for such a capital-intensive equipment has been controlled for the reactors of the different series; only the first ones in series with new design have been affected by some delays. Mean construction times remained virtually stable in France from the beginning of the industry until about 1986 and have increased only slightly after because of the planned slowdown of the construction rates and the bigger reactor size (1300 MW instead of 900 MW). An international comparison shows that the mean construction time is around five years and ten months for the reactors starting commercial operation before 1985, and seven years after with a relatively low dispersion). In the same time, in the USA, the mean construction time jumped from five years before 1974 to eleven years before 1985 and twelve years and half after, with a very important dispersion (Table 2).

Table 2 : Construction Time* of French and American Nuclear Power Plants

Year of start of operation	Pre-1974	1974-79	1980-85	1986-1995	Post-1995
FRANCE					
Average (months)	69	71.2	73.0	87.2	176*
Minimum(months)	52	61	59	76	96*
Maximum(months)	86	76	100	96	204*
Number of plants	6	6	29	20	4
UNITED STATES					
Average (months)	57,6	86	131.7	156.0	276
Minimum(months)	41	56	86	109	-
Maximum(months)	87	130	201	220	-
Number of plants	28	38	26	25	1

* Defined as period from construction start to commercial operation (handover to utility)

** Effects of the construction problems on the new N4 series of four 1450 MW PWR

Source : Figures from IAEA (1995). Nuclear power reactor in the world- April 1995 Edition

In Germany, the average construction time jumped from six years and half before 1980 to eleven years and half with a low dispersion, but it came back to the preceding level for the last three reactors (Thomas, 1988). Beyond this contrasting picture, a special attention has to be

different national records in nuclear construction. They have clearly pointed out the regulatory problems occurring in many countries, in particular in the USA, and the lack of standard design, which limited the effects of the learning curves.

⁴ The construction time is defined as the period between the construction start and the commercial operation. It does not include the licensing time, which became very long (with some adverse cost effects) in countries with open procedures and non-standardised reactors as the USA, Germany and Japan.

given to the delays of the last French series of four 1450 MW-reactors which, since 1990, have faced important learning problems before the handover to the national utility. This is due to their radical new design. Still, the average construction time has increased to fourteen years.

Performance levels in operation, although sometimes affected by generic faults, which needed long and scheduled in advance shutdown for maintenance and/or improvement, are also satisfactory. The availability rate for the 900MW-reactors series had reached 79% in 1988 after the learning period. It then decreased to 72% in 1992 reaching 81%. The 1300MW-reactors which were successively commissioned after 1984 have had to wait 1993 for reaching a performance of 80% after the resolution of generic defects⁵.

- **Good performance on the international nuclear market**

The French nuclear industry presents also a good performance on the international market of nuclear equipment and services since 1975. It a 30% reactor market share on this period with sales of eight reactors on a very tight but competitive market (that represents 7370 MW on 25330 MW)⁶. Among the specific set of competitive advantages on this market (Walker and Lönnroth, 1983), cost efficiency, demonstration of technological capability and industrial organisation at home have contributed to the gain of exports contracts.

Competition on the nuclear export market escapes entirely to the electro-technical manufacturers' cartelisation which has regulated the heavy electric equipment world market until the end of the eighties (Epstein and Newfarmer, 1980; Thomas and McGowan, 1990). Many expectations have been put by dominant electro-technical groups (Westinghouse, General Electric, Siemens, AEG, Hitachi, Toshiba, etc) as by entrants from the heavy mechanical industry (Babcock & Wilcox, Combustion Engineering in the USA, BBC in Germany, Creusot-Loire in France, Mitsubishi in Japan) in this new market. A substantial part of supplier countries' output of nuclear equipment, material and services was expected to be traded internationally. A margin of spare capacity was installed in most reactor supplier equipment to take account of the export trade. But after 1980 the reduction of the export prospects intensify competition between reactors suppliers

**Table 3. Market shares of the nuclear equipment export markets
between 1975 and 2000**
(see at the end of the paper)

Nuclear equipment trade involves more than the exchange of hardware and technology. It involves cheap finance, the supply of nuclear fuel cycle service, industrial assistance, training. Purchasers seek also long term assurances that the supplier countries will act as a reliable partner in the development of the recipient's nuclear industry, as it was clearly the requirements of importing countries (Brazil, South Korea, China, Taiwan). Moreover the

⁵ Because the over-capacity of the French power system, a part of the fleet of reactors have not been used to their maximum of availability until very recently. The availability indicator takes into account this aspect.

⁶ Without taking into account the contracts signed by the joint venture ABB-CE (ex-Combustion Engineering) and the Korean heavy electric equipment supplier (KHIC), with the Korean electricity board during the nineties, the Framatome's market share on the 25 year period rises to 37%. Framatome sold two reactors in South Africa in 1975, two in South Korea and two in China in the eighties and again two in China in the nineties.

suppliers are supposed to respect the overall limits set by the non-proliferation treaty and, in a context of intense competition, the manner which safeguards of the treaty and other arrangement are interpreted has been occasionally an element of the competition in the seventies and the beginning of eighties. For these reasons, the framework within which nuclear sales are negotiated by commercial enterprises tends to be established through bilateral negotiations at the highest level between governments. The French nuclear industry has without doubt benefited from the government's enthusiasm for promoting nuclear sales, but it was also the case for the German suppliers in the seventies and for the dominant American ones.

Besides the political influence also the industrial competitive advantage of the French supplier help the gain of export contracts by two important aspects. First it could propose cheap bids by the help of standardisation effect by always proposing the standard 900 MW-PWR used for the units built in the first series ordered in France between 1972 and 1985⁷. It is the logic outcome of a policy initially based on the idea that, for the smallest supplier countries, competing effectively in open markets with the giant US manufacturers induced economies of scale in production through concentration of the reactor supply, and standardisation in design and series effects. Second the reactor supplier can use the national electric utility's efficient engineering know-how for the general supervision of the building process on site in the foreign countries; it also can associate all the nuclear fuel services in the offer.

1.2. Centralised organisations and institutions of the French nuclear system

The network of actors responsible for developing nuclear energy is a close-knit one, and was for some considerable time closed to political influences and managed on a centralised basis. This has had a considerable importance for putting in place a massive public policy program in an area, which has led to huge controversies in other countries. Since 1975, the three key actors are Electricité de France (EDF), the public electricity enterprise, Framatome, the reactor seller and the Atomic Energy Commission (CEA) the nuclear research and development agency, , which also owns the COGEMA, the nuclear fuel company. The Ministry of Industry played a central role in co-ordinating and taking decisions on most industrial structuring features. This organisational model is deeply rooted in the tradition of the "grands programmes", which was a principal characteristic of the French national system of innovation until the eighties.

- **The public electricity enterprise**

EDF was nationalised in 1946. The decision was taken to create a single integrated monopoly in order to overcome the failure by private enterprises to develop major equipment in a co-ordinated way, and to pursue the objectives of industrial and social development. This function has remained despite the passing of decades (Frost, 1991). The offer of equipment and fuel to the national utility has always been considered by the government to be mastered, especially for the purpose of consolidating the electromechanical construction industry and promoting national technology. The utility strongly identified itself to this mission. The size

⁷ For instance the reactor price of the last French-Chinese deal (the sale of the Lingao reactors pair in 1997) is under the official nuclear reference cost (without interest during construction) in France: \$1458/kW, instead of \$1636/kW which refers to the more complex 1450 MW-N4 design and a small series sale.(IEA-OECD, Projected costs of generating electricity, update 1998, Paris, OECD)

of EDF (present turnover of \$ 30 billions) gives it large capacity for action. On the opposite of many electricity utilities in the world, it has a vast engineering department (about 4,000 members of staff) and develops large-scale research and development activity by its RD division in partnership with manufacturers. These resources have allowed it to master the construction of complex equipment and to dictate the direction taken by its suppliers' activities in the field of innovation.

- **The equipment supply industry**

During the 1950s and 1960s, unlike the American and German industries, which were concentrated and technologically dynamic, French equipment suppliers were small and widely scattered, and depended on foreign licences. There were no firms capable of offering power station in turnkey contract. The firms were protected by public procurement rules but were subject to EDF's technical choices and to its willingness to keep several suppliers in competition with each other. Under these conditions, the sector was not concentrated until the end of the 1960s. Since 1975, the industry was definitively concentrated: on Alstom, a subsidiary of CGE (later Alcatel) for the supply of turbo-alternators under the General Electric and Brown-Boveri licences, and on Framatome, subsidiary of Creusot-Loire group, which supplied the nuclear reactors under the Westinghouse licence until 1985. The ownership of the capital of Framatome, divided after 1985 mainly between the Atomic Energy Commission (35%), EDF (10%) and CGE (40%)⁸, gave the State an important right of veto.

- **The Atomic Energy Commission**

As in Great Britain and the United States, the pioneer countries in nuclear developments, the government created in 1945 a public body known as the Commissariat à l'Énergie Atomique (CEA) The CEA had very wide-ranging responsibilities for developing both civil and military applications for nuclear energy. The CEA always aimed at placing itself in the centre of the network of industrial actors involved in the development of reactors and fuel cycle techniques. By vocation, it strongly advocates national technologies. (Scheinman, 1965 ; Nau, 1974). In 1970, the industrial choices made (abandonment of national reactor technology) led to a review of its responsibilities, but without the radical changes that similar bodies underwent elsewhere (UK, USA, Italy, etc.). Together with its RD functions on new types of reactors, it in fact preserved a strong industrial involvement in all sections of the nuclear fuel cycle, with its subsidiary COGEMA, and a significant stock participation in the reactors seller FRAMATOME. In addition, it holds the capacity of expertise on which is based the decisions of the ministerial safety authority, and has retained its military activity, with the result that its legitimacy is continuously maintained in the civilian nuclear activity.

- **Modes of co-ordination**

The nuclear programme is written in the context of a long centralised tradition of public involvement and planning that has little exposure to politics and, as such, allows very long industrial programmes to be fulfilled (Zysman, 1982 ; Cohen and Bauer, 1986). A decisive role also has to be attributed to the technocracy, composed of engineers belonging to the "Corps d'Etat" (Corps des Mines, Corps des Ponts). Strongly identified to the national

⁸ The Creusot-Loire group bankrupted in 1984.

interests, their members have overall responsibility at the ministerial authorities (especially Ministry of Industry), and are strongly represented in EDF's, the CEA's and the nuclear sector businesses' heads and top-management staffs. Given the French fuel poverty, since the Suez crisis in 1956 and the oil crisis in 1973, the reduction of the French energy dependence became the cardinal objective. In this sociological context, from 1956 to 1981, a commission bringing together the various parties in the government and industry (the PEON Commission) made the major determinant choices relating to nuclear policy in a closed way. Those choices have been subsequently endorsed by the Government.

In the same way, the nuclear safety authorities, which had a crucial role to play in the development and stabilisation of techniques, remained integrated into the bodies responsible for promoting nuclear technology (Ministry of Industry, the CEA) until 1999. The regulatory style was part of this centralist tendency, as was the simplicity of licensing and control procedures and the willingness to make the safety rules foreseeable.

- **The result: an inexorable industrial momentum**

After a first stage made of conflicting learning, the nuclear policy gains an irresistible industrial momentum. The first period of the civil nuclear effort was nationalist by nature. Developments related to the Uranium Naturel-Graphite-Gaz (UNGG), reactor technique, which was originally developed by the CEA for military plutonium production. Eight reactors, (with a total capacity of 1,600 MW), were ordered and built between 1955 and 1970 by EDF being its own industrial architect. After five years of conflict between EDF and the CEA, the resignation of General de Gaulle in 1969 allowed American LWR techniques to be adopted, as EDF wished to adopt them in order to benefit from the dominant design advantages (Bupp and Derian, 1978).

The second period (1970-1975) was marked by the construction of the first four Pressurized Water Reactors (PWR) (under Westinghouse licence) and two Boiling Water Reactors (BWR) (under General Electric licence), and by industrial concentrations supervised by the ministry. In 1975, The government chose a definitive industrial rationalisation with a single supplier of PWR reactors (Creusot-Loire and its subsidiary Framatome) thus eliminating the CGE⁹.

The third period (1975-1983) was impulsed by the oil shock of 1973. It was marked by the construction of several series of standardised PWR reactor, with an average of five orders per year despite the initial lack of learning. Unwavering political support, and the centralised institutions, protected the development of equipment against the effects of social opposition. In this same dynamic, the technological effort invested in the development of the Fast Breeder technique was increased by the construction of the SuperPhenix prototype between 1978 and 1986, with the aim of becoming the leader of the second generation of reactors. Given this strong industrial momentum, the last period (1983 onwards) was marked by a long slowing in the frequency of orders (one reactor every two years between 1986 and 1992) in spite of significant EDF's overcapacity, and by the adoption of a new design (the 1,450-MW N4 type), not subject to the Westinghouse licence.

⁹ The two BWR orders to CGE were cancelled by 1975. In exchange CGE concentrated all the turbo-alternators manufacturing.

1.3. Relevant industrial choices

French nuclear industry has developed from an initially weak industrial basis, comparatively to the American and the German industries. Conversely, the British nuclear program was based on an analogous set of institutions and organisations but has shown poor performances (see box 1). This may suggest that good industrial and technological choices at relevant time allow the creation of a performing nuclear industry able to compete with the leading ones. These appropriate industrial and technological choices are:

- The adoption of the American dominant technology,
 - The user's renunciation of a dominant relationship over suppliers.
- **The adoption of the American dominant technology.**

In such a set of institutions and organisations, the risk could have been to favour “nationalist” goals to the detriment of industrial and commercial realism as some French technological programs in the sixties overran (supersonic aircraft Concorde, big computer with the Plan Calcul, Aerotrain in railways, etc.) (Cohen and Bauer, 1986 ; Zysman, 1982). The French nuclear industry has been less affected by technological nationalism essentially because of the EDF influence. The presupposition that mastering a national reactor technique would give a local industry an advantage in world-wide competition did not have the same resounding in France and in Great Britain. In France, the public company and the industrial firms preferred being in the dominant technological stream, by relying on the supposed capacity of American industrial leaders in electrical equipment supply to master the technology of reactors, rather than remaining bound to the CEA's UNGG technique and its drawbacks. Despite the pronounced anti-American sentiment that characterised the de Gaulle period (1958-1969), EDF was able to refuse to take on new UNGG reactors between 1963 and 1969¹⁰ before the governmental decision.

In Great Britain, technological nationalism in the nuclear field has put the industry at a serious disadvantage. The influence of the nuclear agency on the government prevented the LWR from being adopted by the public company, less legitimate than EDF, on two successive occasions (1965 and 1974). In addition it caused the very premature launch of the new British Advanced Gas-cooled Reactor (AGR) technique in 1965 to avoid LWR adoption with eight programmed order, and this in turn caused numerous industrial and technological difficulties (see box).

However, the abandonment of the gas-graphite UNGG reactor did not signify in France the end of the technological and industrial nationalism that was ardently defended by the CEA. But a series of compromises was reached between the industrial and commercial realism to which EDF and the reactors manufactured were required to submit on the one hand, and the continual technological push of the CEA on the other hand.

¹⁰ At the same time, EDF was allowed to circumvent the ban imposed on the transfer of American technology to France to allow familiarisation with it. It had two PWR reactors constructed successively by Framatome in Belgium, at Chooz in 1962 (230 MW reactor) and at Tihange in 1967 (670 MW reactor) in the framework of two French-Belgian joint ventures.

BOX 1
The British nuclear program

In Great Britain nuclear technology has been promoted by a similar network of actors than in France, that is, a public electricity enterprise with a high level of engineering capacity (the CEGB), a fragmented equipment industry which by 1970 was concentrated around two vendors (GEC and NEI), and a nuclear agency (the Atomic Energy Authority or AEA) which exerted a very significant influence.

The British nuclear programme was the first to develop in the world, being based during the first stage on the graphite-gas Magnox stations, 27 of which were successfully built between 1954 and 1970 (4,200 MW). The second stage, on the other hand, was very poorly managed. The AEA, which was very active in the study of several different types of reactor (Magnox, AGR, heavy water, FBR), tried to impose its own technological choices prematurely in order to prevent the CEGB from adopting the American LWR technique in 1965. A programme for eight 660-MW AGR reactors was launched on the basis of technological knowledge that was too limited. The orders were allocated between three weakly integrated consortia, and the result was an industrial fiasco (costs doubled, construction took between 10 and 13 years, availability levels were mediocre) (Burn, 1978; Williams, 1980). Despite this fiasco and the development of the oil resources from the North Sea, however, the nuclear option remained credible. The choice of national technology was again retained in 1974, against the wishes of the constructor GEC and the CEGB's preference for PWRs. The AEA insisted on a programme of heavy water reactors, replaced in 1978 by the order for two now fully mastered AGR reactors. At the beginning of the 1980s, the decision was finally taken to switch to PWRs for building one reactor per year, but a unique reactor was finally ordered in 1988. Because industrial learning, it cost twice a similar reactor built in France.

This led to the choice to “Frenchify” the PWR reactor in the context of a tripartite programme (CEA-Framatome-EDF) between 1977 and 1982, mainly in order to finally escape from the American government control on the exportation of nuclear reactors under American licence. This led also to the commitment to build the prototype Fast Breeder SuperPhenix in 1978, in spite of the increasing bleak future of the international nuclear market (Finon, 1989). When the decision was taken, none of these choices supposed increased costs for the manufacturer or for EDF¹¹, which could accept easily to sacrifice to the “national technology” support.

- **The utility's renunciation of a dominant relationship over suppliers**

In Great Britain, the public company preferred preserving competition between electrical equipment suppliers to save on costs. Industrial policy was not in favour of a rapid concentration of the electrical equipment industry. Orders for the eight AGR reactors were sent to three weakly integrated consortia in 1965. After the 1970s' concentrations of electrical equipment suppliers (GEC and NEI), concentration of the reactor manufacturing was not achieved until 1973 in spite of the technological fiasco.

In France until 1975 EDF, which had been dominating its national suppliers from the beginning, shared the same belief in preserving competition between suppliers (Frost, 1991). However, during the 1960s, this approach came into obvious contradiction with the requirement to concentrate the industry. Although between 1968 and 1970 it encouraged polarisation around two or three groups in electromechanical equipment, it subsequently wished to keep them in competition on the national market. When the government imposed complete concentration in 1975, in accordance with the concept of “national champion”, EDF had to agree to alter this pattern. The industrial concentration was criticised because of the profit that the monopoly supplier was likely to realise from its serial sales. EDF, however,

¹¹ For example, EDF financed only one quarter of the total cost of SuperPhenix (\$ 3,5 billion), one half having paid by foreign partners and the last quarter from the public budget.

admitted that the gains allowed by the series effect and standardisation resulting from this concentration largely offset the advantage that could have been taken by bringing two national reactor suppliers into opposition.

The evolution of the user-supplier relation has also been marked by indirect effect of the adoption of technology under Westinghouse licence. In fact, it limits the user's interference inside the design of reactors and their components. French series of PWR until 1985 were strictly under the Westinghouse design for the 900 MW and the 1300 MW size. In the UK, by comparison the utility participation to the design of the successive AGRs is pointed as one of the factors of the industrial fiasco (Thomas, 1997). So EDF brought its strong management capacity to monitor building works, but without power to destabilise designs.

1.4. The capacity of the industrial organisation to standardise nuclear technology

The level of technological and industrial performance of the French nuclear industry can be broadly explained by the capacity to standardise the very large reactors and alternators in the context of series orders and to master the way in which works are carried out. These grouped orders allowed the components and the "design" of the whole to be standardised to a significant degree, the benefits of the series effect to be the limited lead-times for licencing with a predictability of the procedures and the learning associated with each change of design to be reduced. Two factors condition this capacity for standardisation: regulatory stability and industrial concentration.

First, the institutional closeness of all the safety authorities, which shows in a flexible regulatory style, has allowed the technique to be stabilised through the stability of safety rules for each series. In other countries (USA, Germany, Japan, etc.), the learning process has been curbed by the difficulty in anticipating regulations and the impossibility to stabilise the techniques because of recurrent changes in safety rules. These rules were applied to reactors under construction, causing a back-fitting requirement thus inducing very costly alterations. The average number of worked hours for the building of a plant has sextupled between 1967 and 1980 in the USA

Second, the presence of a single reactors seller, together with that of a single large electric operator with major engineering potential, has allowed the successful completion of series of reactors in the context of several major contracts (so-called CP1, CP2, P4, and P'4).

Table 4: Contracts of Series of Standardised PWRs

Contracts	Signature	Number of reactors	Unit capacity	Characteristics
Prog. 70	1970-1974	6	900 MW	Westinghouse design
CP1	April 1974	18	900 MW	3 loops of steam-generators Coupling of pair of reactors
CP2	December 1975	10	900 MW	Decoupling of pair
P4	December 1975	8	1300 MW	Westinghouse design
P'4	August 1980	12	1300 MW	4 loops of steam-generators
N4	1984, 1987, 1991, 1993	4	1450 MW	French design

Being its own industrial architect, EDF was in the best position to organise the interface between the reactor and the electric part of the station. At the same time, as just noted, Framatome's dependence on a foreign licence limited EDF's involvement in the design of reactors under the four major contracts. The decision was explicitly taken to adhere rigidly to the Westinghouse design. The role of EDF was however no less essential: it was in charge of the rigorous checking procedures for equipment delivered, the quality control procedures, and the effective site management of building works.

In the other major industrialised countries (USA, Germany, Japan), the fragmentation of the electricity industry and the presence of numerous industrial groups competing against each others limited both the possibility of standardising the reactors and the users' capacity to monitor the building works. In the United States, the reactors construction were all different in practical terms, with one type of reactor per constructor (1 BWR, 3 PWR) and different adaptations of design to suit each company's needs and the regulator's demands.. This can be explained by the fragmented electricity industrial structures (180 utilities) with four competitor industrial groups (General Electric, Westinghouse, Babcock & Wilcox, Combustion Engineering) involved in nuclear engineering. The "utilities", which were small and did not have any capacity to manage building works¹², depended on the major industrial architects (Bechtel, Stone & Webster, etc.), who were paid on the basis of "cost plus" contracts. Consequently, they had little if no incentive to rationalise the management of the projects subjected to continual regulatory changes (S. Thomas, 1988). Absence of standardisation and of series effect, difficulties in reducing the destabilising effect of back fitting: the contrast with the French nuclear system shows the importance of industrial centralisation and of the quality of the user-producer relation in the successful commercial dissemination of nuclear reactor techniques. But this comparative interpretation would be incomplete if it was disconnected from the social and institutional environment, namely the social acceptance of the nuclear technology and the safety regulation organisation and style. If the USA, Germany, Japan, etc. had not been plagued by regulatory instability it is not possible to infer clearly the specific and rigid requirements for success: would they be long established skills in the heavy electrical industry, the size of the utilities, etc? In its reference comparative analysis, S.Thomas(1988)the key factor appears to lead in the quality of the supplier-user relation. It is eased by the engineering capacity of the utility, but it does not necessarily require a vast organisation: it does need skill at managing the complexities involved, at having the technical leadership of nuclear projects and an ability to manage and control the various activities involved.

Even if there is no such thing as an optimal organisational model, nuclear technology requirements fit well with the institutional matrix of the French national system of innovation. The centralisation, the regulatory stability, a capacity for industrial planning, and the highly co-ordinated effective industrial relations favoured its efficient development. Finally, beyond the paradox of an industrial success founded on foreign technology, namely the Westinghouse PWR, the producer-user relationship which has been structured around three successive temporarily stabilised designs by few series contracts has been the determining factor in the learning dynamics.

¹² One exception was the Duke Power Company, which successfully mastered the construction of its equipment.

2. The capacity of resistance of the French electronuclear institutions to exogenous shakes

Both the technological, industrial and institutional environment of the French electronuclear system have dramatically evolved with the last 15 years.

- As with other public utility sectors, the electricity supply industry (ESI) of economies have been progressively facing radical reforms whose key element is the replacement of monopoly with competition. In the European Union, the Directive 96/92 compels the countries to liberalise their ESI. This challenges the traditional user-producer relations in the electric equipment market. Competition in the ESIs has strong influence on the generators' criteria of equipment choices, on their participation to R&D expenses and to the long learning processes in new nuclear technologies. The new competitive environment is not favourable to nuclear investment for two main reasons: the high capital intensiveness of the equipment, which imposes long pay-out beyond private producers' profitability horizon, and the specific risks perceived by the investors (regulatory risk, political risk of shut-down and nuclear phasing-out)¹³.
- Regarding the electrical techniques and components, the past stop of nuclear reactors dissemination in the OECD countries induced a technological re-orientation of the major equipment suppliers towards the new Combined-Cycle Gas Turbine (CCGT). Thanks to its rapid efficiency progress, its low capital intensity, its low demanding user's engineering capacity, CCGT technology has been progressively chosen by an increasing number of electric utilities in the world because it fits with the new competitive environment ;
- Regarding the evolution of industry structures, there has been a significant concentration of the world-wide electrical equipment sector (Ninni, 1992; Tait, 1999). Only few groups have resisted or wanted to remain in the power equipment business, some of them (ABB, Westinghouse) leaving the power equipment business for more profitable fields of information technology and communications: General Electric, Alstom (before GEC-Alsthom, a joint venture of the French Alcatel group and the British GEC group) which bought the ABB's electric equipment division in 2000, Mitsubishi, and Siemens which acquires the Westinghouse's electric division in 1998. They have dramatically increased in size and globalised their activities as a results of all the mergers and acquisitions. Between 1994 and 1998, these big four (which were six between 1990 and 1998) concentrated more than 96% market share of the worldwide CCGT sales and 61% market

¹³ The impact of the capital intensiveness is linked to different features such as: 1) the unitary amount of capital to invest (about \$ 2 billion per plant to be compared to the \$150 million for a CCGT of 300MW), 2) the construction lead-time which can reach from seven to ten years to be compared to the two to three years for a CCGT thus imposing an unprofitable capital immobilisation with a significant regulatory risk, 3) an important licensing procedure and 4) in a deregulated market, a long preparation of insurance contract against the construction risks. These last two aspects of the transaction costs which are important for the nuclear reactor building are limited for CCGT projects, while there are significant but not so important for coal conventional plants.

However competition is not unfavourable to nuclear technology in every aspect: the distinction between existing equipment and capacity development has clearly to be done. Ownership of nuclear reactors and efficient operating skills are important advantages for a competitor on liberalised power markets because of their low variable costs. So one can observe in the USA an important interest for buying existing nuclear assets, with an important exchange value, and for extending the lifetime of the plants after scrutiny of the safety authority. (See The Electricity Journal, October 1999, volume 12, n°8)

For an analysis of the consequences of the liberalisation of the electrical industries on the nuclear development, see International Energy Agency (1998), Nuclear power: sustainability, climate change, and competition, Paris: OECD; and OECD-Nuclear Energy Agency (2000), Nuclear power in competitive markets, Paris, OECD.

share of the steam turbine sales¹⁴. As a consequence, these concentration and globalisation movements also lead to the abolition of the national frontiers and a certain standardisation of the electricity generation technology around the CCGT .

- The nuclear equipment industry which is mainly inserted in the electro-technical industry has been largely affected by these movements whereas the level of the reactor market activity (which remained very low during all the nineties) maintained a pressure towards the concentration. Major exits are observed through the sale of nuclear activities to the specialised nuclear suppliers. Indeed, Westinghouse's nuclear division and ABB-CE, the nuclear subsidiary of ABB, have both been sold in 1998 and 1999 to the British nuclear company BNFL; Siemens decided in 1999 to merge its nuclear division with the Framatome's nuclear activities in a common subsidiary controlled by the latter. as a result, the worldwide nuclear reactor industry is mainly concentrated in three companies, General Electric in the electro-technical industry, Framatome and BNFL in the specialised nuclear enterprises group, with a minor place for AECL (Canada), Minatome (Russia) and some Asian licensees suppliers (Mitsubishi, Toshiba in Japan and KHIC in South Korea) with protected national markets.

Submitted to these external shocks, industrial organisation benefited in France from strong elements of institutional path-dependency rooted in the nuclear option. Our hypothesis is that the realms of legitimising conventions and the intertwining of industrial and bureaucratic interest allowed the conservation of the integrated organisation of the ESI, as this system produces performing results in the nuclear development, which is considered as important for the national interest. This then avoids the future dilution of nuclear supporting institutions, as the comparison with the UK situation, where the ESI liberalisation has clearly dilutes them will show. However increasing globalisation and regional integration of the French economy has slackening effects in the relations between the parties in the national nuclear system. While the persistence of public acceptance of the nuclear technology and the condition of competition between electrical techniques in the liberalised electricity markets do not allow any optimistic prospects for nuclear equipment in the OECD countries on the mid-term, the institutional answer has been a recent re-concentration of the French nuclear industry inside the public sector and outside the increasingly globalised French electric equipment industry.

2.1. The stability of the nineties

During the nineties, the relations between the main players remained quite stable in France. Two nuclear orders have been placed by EDF in 1991 and 1993 in spite of the electric overcapacity, thus supporting the manufacturer. Since 1991, anticipating the need of replacement of EDF's nuclear reactors in the long term, Framatome has been working on the design of an advanced PWR, the so-called European Pressurised water Reactor (EPR), with financial support from EDF and technological support from the CEA. This project also responds to its positioning strategy on the future world reactor market with a technique competing with the new ABWR of General Electric. In the near future the slight power industry reform (see below) preserves the government means to promote the EPR prototype realisation and to organise its financing, for preparing the first orders planned around 2010.

¹⁴ China, India, South Korea, Japan, Russia, which all consider their power engineering industries as crucial supports of national development are also rivals of the big four both for their domestic markets and sometimes in some emerging markets, notably in conventional equipment.

In parallel the industrial and technological resources which have been acquired by the French nuclear industry gave some impetus to break up the nationalist industrial insulation. The government let Framatome establish an alliance in 1990 with Siemens to develop the EPR, initially in view of its common commercialisation on the world market. This technological venture leads in 1999 to the merger of the two companies' nuclear divisions.

As for the public nuclear agency, the CEA is protected by the legitimacy of its military activities and the cohesiveness of the "Corps d'Etat" to which the CEA top managers belong. Altogether, this avoided any attempt to radically re-organise it. Actually, a thorough evaluation in 1989 did not even recommended such re-organisation. The only significant evolution in RD relations has concerned, since 1985, the participation of the technology users (EDF, COGEMA, Framatome) into the financing of RD projects decided jointly with them¹⁵.

The closure of SuperPhenix FBR prototype in 1998 has questioned the RD priorities. But the abandonment of the FBR priority does not significantly modify neither the public nuclear RD, nor the CEA's role within the French technological policy, whereas, at the exception of Japan, public nuclear RD has strongly declined in the other major industrialised countries since 1985.

Table 5 – Evolution of Public Nuclear RD Budgets*

(in millions \$ and in constant prices 1996)

	1985	1990	1996
USA	1079	628	116
Japan	2056	2565	2821
Germany	996	251	70
France	670	514	594
UK	427	171	15.8

*without nuclear fusion

Source – IEA, Energy Policies of IEA countries - 1998, Paris, OECD.

The long-term policy issues (climate change, nuclear waste management) justify maintaining nuclear RD despite the bleak future of the world-wide nuclear capacity development on the mid-term. The redefinition of according objectives (such as the reduction of waste volumes by new types of reactor, new nuclear fuels, "sustainable" nuclear reactor, etc.) is still under discussion in 2000. But the stability of the power and nuclear industries in the next years should allow avoiding dramatic decline.

2.2. The nuclear option, main element of institutional path-dependence in the French electricity reform conservatism

Differences in approaches to liberalising and restructuring the ESI have resulted in a diversity of reforms among the many countries that have implemented their own reforms. Both the structures of the industry prior to the reform and the institutional environment, among which the nuclear option, condition the attractiveness and the extent of liberalisation reform (Glachant and Finon, 1999). France and the UK had quite similar industrial structures.

¹⁵ In 1995, for instance, industrial users brought \$ 220 millions to the civil nuclear budget of the CEA which amounts at \$ 870 millions (1995 Annual Report).

Nuclear power promotion was a common goal of the two governments but it impacted very differently on the choices of industrial structures, market rules and institutions.

2.2.1. The French conservative reform of the electricity supply industry

France opted for institutional conservatism with no radical restructuring and no creation of any kind of organised market. France chose to limit competition to bilateral contracts between producers and industrial consumers (one third of the retail market) through the third party access provision to the national utility's transmission network. Indeed, it preserves vertical integration as far as possible under public ownership. Instead of a full vertical de-integration, there is only a transparent separation of the transmission and system operation within EDF, which then has to ensure non-discriminatory access to the transmission network. The creation of a regulatory commission with credible powers is supposed to guarantee fairness in the competition. Since there is neither significant structural changes nor creation of organised markets, competition will take the form of market contestability. However, EDF keeps its over-dominant position, which should dissuade potential entries.

The reform, voted lately in 2000, has been designed mostly to preserve intact the role of the state-owned monopoly as an instrument of public policy in different areas, mainly the energy policy with nuclear option. Moreover it gives legal means to create a market-niche for new nuclear equipment. The Law contains articles giving the ability to the government to control the evolution of the overall electric production capacity and its technology mix. Indeed, it sets up a five-year programming procedure which has to be debated (and voted) by the Parliament. It allows the government to tender for the construction and the operation of specific additional generating capacities whose technology will be clearly specified, with long-term guaranteed outlets and bid-price payment for the winners. The law creates also a fund financed by a tax on every generated kWh so as to support all the expenses devoted to public interest missions. So it could be used to finance the over-cost of the new nuclear units production in the market-niche.

On the opposite, pioneer of power liberalisation in Europe the UK opted in 1990 for a radical restructuring, the creation of a centralised day-ahead spot-market, privatisation of the public utility CEGB, and a mix-policy of defence of the nuclear power and promotion of CCGT. The activities of the CEGB have been split between four companies: three generators among which one public nuclear producer, and one transmission company. The British government commitment in the nuclear option to limit dependence from coal mines influenced the restructuring and the transitional dispositions for supporting the nuclear power production (Thomas, 1996). The British government organised institutional devices to support existing nuclear production and protect eventual new nuclear investment. One measure, the Non Fossil Fuel Obligation (NFFO), was the requirement that the distributors must buy specified proportions of their power from non-fossil sources (i.e. nuclear power and secondarily renewables). A second measure was the payment of a tax on electricity purchases (the Fossil Fuel Levy or FFL when then represented around 10% of the final electricity price) financing the expected high operational costs of existing reactors (including the provisions for decommissioning) and particularly the over-costs of eventual future reactors¹⁶. But in fact these arrangements were more fragile than the preservation of the utility's vertical and horizontal integration opted in France to protect the nuclear option.

¹⁶ Same as with FFL, these non-fossil electricity was known to be exclusively nuclear power at that time but it progressively included renewable. Nuclear Electric, the public nuclear producer, earned through this FFL more than £1 billion each year which represented 40-50 % of its income

2.2.2. Past industrial performances as elements of institutional conservatism

The past institutional arrangements in electricity have had an influence over the technological and industrial performances. Those performances systematically self-reinforce in France the institutional arrangements which allowed them while the institutional environment is itself very receptive to them and able to occult inefficiencies. On the contrary, the British institutional arrangements became more fragile as much as technological and industrial inefficiencies appeared while the neo-liberal ideology was progressing in the 80s participating to such “instability”.

Obviously, in France, the nuclear power technological and industrial success did legitimise both the size and the state-owned status of EDF. These two characteristics have allowed the development of high-levelled engineering competencies and stable strategic decisions, which exploit a range of economies of scale. They could be presented as acting in the long term in favour of consumers (Bouttes and Lederer, 1991). But in the same time, the technocratic decision process and the political consensus surrounding the success of the nuclear power program hide inefficiencies and maladjustments. Economic effects of generic flaws, counterpart of positive series-effects, are occulted, as the absence of economic improvements with technological changes (size increase to 1300 MW and 1450 MW, use of mixed uranium-plutonium fuel)¹⁷. Maladjustment costs are also ignored: as the national nuclear system is not easily adaptable, excess capacity resulted from the poor ability to adapt to the dramatic slow-down of power growth: in 1990, it could be estimated at 12 000 MW out of a total 54 000 MW nuclear capacity by that date¹⁸.

For that matter, there is an important contrast between the French and the British case. Whereas the public electricity company succeeds in the UK in increasing its economic performances during the 1980s, the defaults of its equipment policy will strongly contribute to its full break-up (both vertically and horizontally). It has not the possibility to refer to the success of the nuclear program: the reactors production (20% of the total in 1990) is modest comparatively to the EDF's one. At that time, negative liberal critics regarding state-ownership were rather strong and powerful. They emphasised a number of factors that have led to inefficiencies such as the systematic over-estimation of electricity growth forecasts, the over-investment and the excessive, if not blind support of nuclear power. More generally, they have denounced the public management inefficiencies (Vickers and Yarrow, 1988). Numerous learning difficulties with turbo-alternators of 500 MW ordered between 1965 and 1980 and the construction of AGR reactors give arguments to the critics. Even if the Thatcher

¹⁷ The drawback of the reactor standardisation is the vulnerability of the nuclear reactors fleet to generic flaws. The standardisation advantages have been real, but economic risks associated to those flaws have rarely been assessed. They impacted at three times on different components, steam generators, control rods, etc. with important costs (losses of production, repair costs of hundred of millions of F per reactor). The closed decision process tends also to occult the adverse effects of engineers' beliefs. As such, the reactors' size increase between the 900 MW-reactors and the 1 300 MW reactors did not produce the expected reduction in investment costs while it reduced availability performance; the latest type of reactor, the so-called N4, has shown some important learning problems which have, up until now, not been clearly analysed. Be that as it may, the overall efficiency of the program is considered as largely compensating every drawback of the system rigidity.

¹⁸ Excess capacity has been occulted by the accelerated decommissioning of recent conventional plants, the promotion of electricity usages and the contracts on electricity exportation (60 TWh of net electricity exportation in 1998)

Cabinet was strongly supporting nuclear power, those mistakes warned enough people who do not defend against the privatisation in 1988.

In France, though, the past technological and industrial success acts in favour of the preservation of the vertically integrated utility and more generally of a protected institutional arrangement. As such, the preservation of the conditions to promote nuclear power to build new units and favour learning on a new type of advanced PWR was considered as a priority, even if it had to be associated with institutional conservatism.

2.2.3. The institutional requirements of the nuclear option as regards to electricity competition

Nuclear equipment is very demanding in terms of safety and investments. As such it is not an attractive technology for private investors in a competitive electricity industry, knowing that other power generation technologies meet more easily the investors' criteria in this environment, as already mentioned. The nuclear plants will not be selected by the private producers competing in an energy price environment whereas prior to the reform a monopoly would have selected it. High capital intensiveness and risks are probably not a definitive obstacle to invest in a competitive environment as can be observed in the oil industry for the exploration investment. But the economic risk must be assessable and the expected profit at the level of the risk. For lenders, nuclear investment risk is not assessable in every dimension and the competition in power generation does not let large profit margins. So, two solutions are possible so as to maintain the nuclear option in relation to political goals. The first one consists in maintaining vertical companies with only a provision of third party access to network, which maintain an important legal captive market and create a strong dominant position on the competitive segment. The second one consists in separating the nuclear generation from the liberalised power market by creating a regulatory market niche.

In France conservatism has plaid in favour of the first solution. The introduction of effective competition at the generation level, which would impose divestiture, and privatisation of nuclear assets along the way followed by the British ESI would suppose massive changes in the technocratic and political culture which is still based on two beliefs to this respect:

- the necessity to maintain within the same State-owned producer the operation of nuclear equipment so as to guarantee high levels of safety, given that 80% of the French power production is based on the fleet of nuclear reactors ;
- the unacceptability to depend significantly on fuel importation for the electricity generation, while competition should favour much less capital intensive technology as CCGTs which would furthermore require massive gas importation.

This last postulate is backed to the technocratic culture which, unfamiliar with risk, tends to dramatise the vulnerability of any dependence situation, thus justifying the preservation of the state-owned vertically integrated monopoly. By contrast other countries poorly endowed in fuel resources (Spain, Italy, Sweden) have implemented radical reforms of their electricity industry without being so influenced by sensitiveness to the dependence risk.

2.3. The preservation of the French electronuclear institutions : avoiding their dilution under the competition and globalisation shakes

The resistance to the competition paradigm avoids the risk of dilution of the nuclear institutions after the instauration of power competition, as it has been observed in the UK. However evolution should be seen more complex because of the necessity of adaptation to external changes: the French ESI is included in the increasingly integrated and liberalised European power industry and the French electromechanical industry does not escape to the globalisation of this sector.

2.3.1. The importance of avoiding the competitive shake-up in the ESI

The British contrast sets off the positive influence of institutional conservatism in the electricity reform upon the stability of French electronuclear institutions in the nineties, as for the future. If keeping opened nuclear option had clearly oriented initial choices of restructuring the power industry in the UK, afterwards the competition paradigm has progressively eroded rationales for the nuclear support. The NFFO niche rapidly became no more than a mechanism to ensure that the existing nuclear power plants were used to their full extend instead of promoting the construction of new plants. In 1994, after a review on its policy, the government decides a moratorium on new nuclear construction and announces privatisation of the AGRs and PWR assets. The rationale was the prospect that existing AGRs could potentially generate at low costs but that new plants are financially risky and uneconomic. After privatisation British Energy, the new private nuclear producer, does not effectively need any support. NFFO and the fossil fuel levy subsidisation were removed by 1998. But no investor shows any interest for new nuclear equipment.

The reform introducing competition has also eroded the nuclear institutions by its own logic in the UK. The promotion of the competition, which is the main mission of the regulator, implied to favour entries, and so to encourage new entrants to invest in CCGTs thus considered appropriate for this new competitive environment¹⁹. In other words, the development of competition brought government to encourage the dissemination of another technology. Moreover the choice of the major generators to invest massively into CCGT turned upside down the relationship between purchasers and suppliers. There is no preference for national equipment suppliers anymore since orders are won through a tendering process: the joint venture GEC-Alsthom indeed wins less than 20% of the tenders²⁰. The major generators have also abandoned their own RD activity for new electrical techniques and the financing of public nuclear RD projects. The nuclear agency, already transformed in public commercial establishment in 1986, was strongly affected by the breakdown of the joint public and private RD financing²¹. Among these ruins the nuclear fuel company BNFL survives firstly by the reactor fuelling market. It is the only company staying active within the British nuclear industry²².

¹⁹ For this goal, long term contracts (15 years) were allowed between developers and distributors in tension with the principles of the jurisprudential competition rules.

²⁰ ABB and Siemens were the main winners.

²¹ The nuclear public R&D budget decreases dramatically from \$ 170 millions in 1990 to \$26 millions in 1996. Source : International Energy Agency.- Energy Policies of IEA Countries.- 1990 and 1998.

²² It took the opportunity of the sale of their nuclear divisions by Westinghouse in 1998 and ABB in 1999 to vertically integrate from the nuclear fuel to the reactor supply. Still, BNFL has little hope to have reactor sales outlets in the UK. It took the opportunity of the sale of their nuclear divisions by Westinghouse in 1998 and ABB in 1999 to vertically integrate from the nuclear fuel to the reactor supply. Still, BNFL has little hope to have reactor sales outlets in the UK.

So the British case demonstrates that, as the upset of industrial organisation in centralised ESI has devastating effects on the nuclear institutions and relationships. Conversely, the absence of such an upset in France should contribute to their stability in the general context of liberalisation and globalisation.

2.2.3. Uncertain futures and statist reconcentration answer

Despite the preservation of the integrated public utility, the relationships between participants of the French nuclear system are somehow affected by the European economic integration, the globalisation and increasing concentration of electric equipment supplies. Reinforcement of financial and strategic links between industrials involved in the nuclear industry inside the public sphere has been the answer to future uncertainties.

- **The relaxing of the relationship between EDF and the equipment supply industry**

The relationships between EDF and the reactor manufacturer are relaxing for different reasons:

- The 1992 European Directive on “public procurement” opens these markets to international competition, thus prohibiting national preferences.
- There should not be any effective need for new nuclear plant within the next 15 to 20 years for the French electricity market is mature if not in excess capacity. If it does not open opportunities of CCGT development on one hand, it also does not favour new nuclear projects.
- EDF is obliged to adopt a competitive behaviour: It has to respond to the threat of foreign entries on the market and it aims at massively investing in Europe for controlling companies and extending its market share.

The 1999 internal reorganisation within EDF illustrates such strategy. Its newly created Commercial Division (“pôle clients”) ranks first supplanting the Generation Division (“pôle industrie”) and its engineering department regarding strategic power and influence on the traditional EDF’s equipment push. EDF pursues an aggressive internationalisation. As a consequence, it is less invested with support of the French nuclear and electromechanical industry. Subsequently, EDF is not as enthusiastic as it used to be in ordering a prototype EPR which would suppose to go partly alone to great expenses, given that new reactors would not have to be ordered before 2015. Besides, EDF aims at taking advantage of its existing amortised nuclear assets by working on the extension of their lifetime over the expected 30 years to 40-45 years, that postpones the renewal of the French reactor market. More generally, possible institutional convergence of the French power industry with the other European ESIs during this latency could question prospects of new nuclear order by that time.

- **Progressive break-up between the national nuclear system and the globalised French power equipment industry**

The restructuring of the nuclear industry responded to the growing concentration of the international electromechanical industry, the long-lasting depression of the international nuclear market and the subsequent sales by some major companies of their nuclear divisions (namely Westinghouse and ABB). The traditional nationalist and technocratic logic behind the persevering nuclear momentum has recently induced a separation between first the nuclear

industry re-confined into the statist-industrial area and second the equipment supply industry fully involved within the global market.

Alcatel, which owned 44% of Framatome shares without having the full control, decided in 1999 to get out the nuclear activities by selling its capital share. Since 1985, under the influence of the State-engineers bodies, successive governments have refused to let it take over the full control of Framatome, to the respect that French technology could be sold out if opportunities of strategic alliances were going to force it. Facing such a resistance, Alcatel focuses on its electrical equipment activities, essentially gas turbines on which it is strongly involved in its joint venture with the British GEC, and without any support from orders on the national market. Globalisation of Alsthom increased: by the end of 1999, GEC-Alsthom (now Alstom) decided to rationalise the whole range of its activities by merging their electrical equipment activities with ABBPower, the two companies aiming to regroup their technological resources for performing their innovation activities. Ultimately Alstom buys all the ABB Power's assets in April 2000.

Framatome is subsequently replaced in the public area. As far as Framatome was in line with the nationalist logic, the Ministry of industry was allowing its relative strategic autonomy. For instance, Framatome has been able to pursue a diversification strategy towards activities in the field of the "connectic" which now represents half of its turnover. But it has kept close eyes on the strategic alliance with Siemens, which was in 1989 originally based on the only joint conception of a new type of reactor for sales outside Europe. It also has raised objection to the Framatome's will of purchase of Westinghouse Nuclear in 1998. It accepted the merger of Framatome's and Siemens' nuclear divisions in 1999, because the French part is clearly dominant (with two thirds of the joint venture assets). After all, in 1999, Alcatel's withdrawal resulted in a situation where both COGEMA and the CEA were given the control of Framatome²³. It corresponds to a take-back from the State which aims at protecting the French technological and industrial resources in the nuclear activities in the hope of a new world-wide nuclear market take-off.

3. Conclusion

French nuclear industrial performance has benefited from the specific institutional set-up associating together the public power company, the equipment supply industry, the nuclear agency and the government. But the main explanations of the industrial performance are quite contingent as shown by the comparison with the British nuclear developments where a similar set-up is not associated to good technological and industrial performances. Industrial concentration and proximity of the nuclear supplier and the user are not a sufficient condition for good performances.

The domination of the national utility has allowed French industry to rank in the dominant technological stream at the right time by following its preference for adopting the American LWR technique under licence. This choice has created a layer around the adopted technology which has avoided the intrusion of the user and the nuclear agency in the reactor manufacturer's learning process while not impeding to benefit from the user's important

²³ The new Framatome stock sharing in 2000 is the following : COGEMA 34% ; CEA-industrie 32% ; EDF 11% ; Alcatel 14%, for Framatome salaries, 5% (with a rest of 4% to share).

engineering capability in the control of the building work of large and complex equipment. As a consequence of centralism, the presence of this single buyer associated to the regulatory stability have created the conditions of technological development and dissemination (standardisation, effects of series) both making industrial performances possible. Success was mainly obtained on industrial grounds: a foreign technology was basically used, while “pure” French technological developments (the new N4-PWR design and the FBR) have not been convincing.

Technology and institutions have mutually interacted: after having favoured the industrial success of the nuclear technology dissemination, the desirability of the nuclear option contributes to the preservation of the electricity industry organisation. Nuclear option justifies the slow and limited scope for liberalisation, which then avoids the dilution of the national nuclear system. Its structures remains an exception in the industrial world regarding both the electricity area (preservation of a quasi-monopoly maintaining strong engineering activities) and the nuclear R&D organisation. It will thus help to keep in France the same technological trajectory in power generation, which is based on complex large-sized and capital intensive technology. The risk is to become isolated from the rest of the other industrialised countries by developing new nuclear technologies if there will be no new take-off of nuclear technology dissemination in the mid-term. This raises one issue: how far is it possible to introduce more flexibility into the nuclear system without breaking it up, knowing that its force lays in its cohesiveness maintained by equipment realisations?

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Table 3 : Market shares of the nuclear equipment export market between 1975 and 2000
(in MW of capacity)

Year of the order	1975-1980			1981-1990			1991-2000			Total		
	Number	Capacity	Share	Number	Capacity	Share	Number	Capacity	Share	Number	Capacity	Share
General Electric		0			0		2	2630**	21 %	2	2630	10.5 %
Westinghouse	4	3600	54 %		0			0		4	3600	14.2 %
ABB and Combustion Engineering		0		2	1900	30.5 %	6	5700**	46 %	8	7600	30 %
AECL-Canada		0		1	650	10.5%	4	1300	10.5 %	5	1950	7.8 %
Siemens-KWU	1	1230	18.4 %		0		1	950	7.5 %	2	2180	8.5 %
Framatome	2	1850	27.6 %	4	3660	59 %	2	1860	15 %	8	7370	29 %
Total	7	6680		7	6210	100%	15	12440	100%	29	25330	100%

Source : CEA-ELECNUC Data Base 2000.

* Without cancelled orders.

** In consortium with Asian or local suppliers (Hitachi-Toshiba, KHIC) with minority shares.