Nuclear Energy in France: Lessons to Learn for India

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1. **Nuclear Energy in France:**

a. **Overview:**

France is considered to be one of the greatest pioneers in the nuclear energy sector. But all this development started from the first oil shock. In 1974, just after the first oil shock, France decided to expand rapidly the country's nuclear power capacity. This decision was taken in the context of France having substantial heavy engineering expertise but few indigenous energy resources. Nuclear energy, with the fuel cost being a relatively small part of the overall cost, made good sense in minimizing imports and achieving greater energy security. As a result of the 1974 decision, France now claims a substantial level of energy independence and almost the lowest cost electricity in Europe. In 2007 French electricity generation was 570 billion kWh gross, and consumption was about 447 billion kWh - 6800 kWh per person. Over the last decade France has exported 60-80 billion kWh net each year and EdF (Electricite de France) expects exports to continue at 65-70 TWh/yr, to Belgium, Germany, Italy, Spain, Switzerland and UK. Imports are relatively trivial. France has 59 nuclear reactors operated by EdF, with total capacity of over 63 GWe, supplying over 430 billion kWh per year of electricity (net), 78% of the total generated there. Total generating capacity is 116 GWe, including 25 GWe hydro and 26 GWe fossil fuel. France has an extremely low level of CO_2 emissions per capita from electricity generation, since over 90% of its electricity is nuclear or hydro. In mid 2010 a regular energy review of France by the International Energy Agency urged the country increasingly to take a strategic role as provider of low-cost, low-carbon base-load power for the whole of Europe rather than to concentrate on the energy independence which had driven policy since 1973.

The below figure Shows France's Nuclear Power Plants and their locations:

b. <u>Economies:</u>

France's nuclear power program has cost the country FF 400 billion in 1993 currency, excluding interest during construction. Half of this was self-financed by Electricite de France, 8% (FF 32 billion) was invested by the state but discounted in 1981, and 42% (FF 168 billion) was financed by commercial loans.

In 1988 medium and long-term debt amounted to FF 233 billion, or 1.8 times EdF's sales revenue. However, by the end of 1998 EdF had reduced this to FF 122 billion, about two thirds of sales revenue and less than three times annual cash flow. The net interest charges had dropped to FF 7.7 billion by 1998. In 2006 EdF's sales revenue was EUR 58.9 billion and debt had fallen to EUR 14.9 billion. The cost of nuclear-generated electricity fell by 7% from 1998 to 2001 to about EUR 3 cents/kWh, which is very competitive in Europe.

The back-end costs (reprocessing, wastes disposal, etc) are fairly small when compared to the total kWh cost, typically about 5%. EdF early in 2009 estimated that its reactors provide power at EUR 4.6 cents/kWh and the energy regulator CRE (Commission De Regulation De L'Energie) puts the figure at 4.1 c/kWh. The weighted average of regulated tariffs is EUR 4.3 c/kWh.

Power from the new EPR units is expected to cost about EUR 5.5 to 6.0 c/kWh. From being a net electricity importer through most of the 1970s, France now has steadily growing net exports of electricity, and is the world's largest net electricity exporter, with electricity being France's fourth largest export. (Next door is Italy, without any operating nuclear power plants. It is Europe's largest importer of electricity, most coming ultimately from France). The UK has also become a major customer for French electricity. France's nuclear reactors comprise 90% of EdF's capacity and hence are used in load-following mode and are even sometimes closed over weekends, so their capacity factor is low by world standards, at 77.3%. However, availability is almost 84% and increasing.

c. Current Status of Projects and Technological Developments:

The first eight power reactors developed by France were gas-cooled, as championed by the Atomic Energy Authority (CEA), but EdF then chose pressurised water reactor (PWR) types, supported by the new Eurodif enrichment capacity. Choosing a reactor type that has proved to be very durable, capable of running consistently with minimal problems, was obviously very important. Apart from one experimental fast breeder reactor (Phenix), all French units are now PWRs of three standard types designed by Framatome - now Areva NP (the first two derived from US Westinghouse types): 900 MWe (34), 1300 MWe (20) and 1450 MWe N4 type (4). This is a higher degree of standardization than anywhere else in the world (there was another large fast reactor –Superphenix – commissioned but subsequently closed down). This can be contrasted with the experience in the USA (over 100 reactors, all of which are essentially different) and Japan (a similar-sized programme to France, but with a much greater number of reactor types). The degree of standardization has undoubtedly created substantial economies of scale for the French industry and cut power generation costs.

Another key element of French energy strategy has clearly been developing Areva to cover the whole of the fuel cycle. It is possible to have a nuclear programme without the attendant fuel cycle infrastructure, therefore relying on the world market. But with a lot of reactors and industrial capability, it makes sense for France to cover at least some of the areas with domestic supply. French uranium mining has now ended, so investments have been made in good uranium deposits around the world and mines subsequently developed, for example in Africa and Canada. Conversion, enrichment and fuel fabrication facilities have been developed at home, and have excellent export capability.

It is, however, the back end of the fuel cycle where the French approach has been different from much of the world. A closed fuel cycle based on reprocessing and recycling of mixed oxide and reprocessed uranium fuel has been adopted. Although the economics of a closed-loop fuel cycle have often been questioned, the closed cycle could be seen in light of the French holistic view of the fuel cycle and waste management. From this point of view, usable fissile material should be recycled to minimize the amount of high-level waste that must, eventually at least, go to a deep geological repository.

d. License renewal:

Most of France’s 900 MWe reactors all had their lifetimes extended by ten years in 2002, after their second 10-yearly review. Most started up late in 1970s to the early 1980s, and they are reviewed together in a process that takes four months at each unit. A review of the 1300 MWe class followed and in October 2006 the regulatory authority cleared all 20 units for an extra ten years operation conditional upon minor modifications at their 20-year outages over 2005-

14. The 3rd ten-year inspections of the 900 MWe series began in 2009 and run to 2020. The 3rd ten-year inspections of the 1300 MWe series run from 2015 to 2024.

In July 2009 the Nuclear Safety Authority (ASN) approved EdF's safety case for 40-year operation of the 900 MWe units, based on generic assessment of the 34 reactors. Each individual unit will now be subject to inspection during their 30-year outage, starting with Tricastin-1. In December 2010 ASN extended its licence by ten years, to 2020.

In July 2010 EdF said that it was assessing the prospect of 60-year lifetimes for all its existing reactors. This would involve replacement of all steam generators (3 in each 900 MWe reactor, 4 in each 1300 MWe unit) and other refurbishment, costing EUR 400-600 million per unit to take them beyond 40 years. EdF is currently replacing steam generators at two units per year, and plans to increase this to three units in 2016.

e. <u>Uprates:</u>

In the light of operating experience, EdF uprated its four Chooz and Civaux N4 reactors from 1455 to 1500 MWe each in 2003. Over 2008-10 EdF plans to uprate five of its 900 MWe reactors by 3%. In 2007 EdF announced that the twenty 1300 MWe reactors would be uprated 7% from 2015, within existing licence limits, and adding about 15 TWh/yr to the country’s nuclear output. France has also exported its PWR reactor technology to Belgium, South Africa, South Korea and China. There are two 900 MWe French reactors operating at Koeberg, near Capetown in South Africa, two at Ulchin in South Korea and four at Daya Bay and Lingao in China, near Hong Kong.

Given Below in the table is the list of the Nuclear reactors presently operating in France with their current ratings:

Class	Reactor	MWe net, each	Commercial operation
900 MWe	Blayais 1-4	910	12/81, 2/83, 11/83, 10/83
	Bugey 2-3	910	3/79, 3/79
	Bugey 4-5	880	7/79-1/80
	Chinon B 1-4	905	2/84, 8/84, 3/87, 4/88
	Cruas 1-4	915	4/84, 4/85, 9/84, 2/85
	Dampierre 1-4	890	9/80, 2/81, 5/81, 11/81
	Fessenheim 1-2	880	12/77, 3/78
	Gravelines B 1-4	910	11/80, 12/80, 6/81, 10/81
	Gravelines C 5-6	910	1/85, 10/85
	Saint-Laurent B 1-2	915	8/83, 8/83
	Tricastin 1-4	915	12/80, 12/80, 5/81, 11/81
1300 MWe	Belleville 1 & 2	1310	6/88, 1/89
	Cattenom 1-4	1300	4/87, 2/88, 2/91, 1/92
	Flamanville 1-2	1330	12/86, 3/87
	Golfech 1-2	1310	2/91, 3/94
	Nogent s/Seine 1-2	1310	2/88, 5/89

	Paluel 1-4	1330	12/85, 12/85, 2/86, 6/86
	Penly 1-2	1330	12/90, 11/92
	Saint-Alban 1-2	1335	5/86, 3/87
1450 MWe	Chooz B 1-2	1500	12/96, 1999
	Civaux 1-2	1495	1999, 2000
	Total (58)	**63,130**	

f. Regulation & Safety:

In France, the General Directorate for Nuclear Safety and Radiological Protection (DGSNR) is responsible for monitoring the Regulations and safety concerns of nuclear energy systems. It was set up in 2002 by merging the Directorate for Nuclear Installation Safety (DSIN) with the Office for Protection against Ionizing Radiation (OPRI) to integrate the regulatory functions and to "draft and implement government policy."

In 2006 the new Nuclear Safety Authority (Autorite de Surete Nucleaire - ASN)), an independent body with five commissioners, became the regulatory authority responsible for nuclear safety and radiological protection, taking over these functions from the DGSNR, and reporting to the Ministers of Environment, Industry & Health. However, its major licensing decisions still need government approval.

Research is undertaken by the ISRN (The Institute for Radiological Protection & Nuclear Safety), which was also set up in 2002 from two older bodies. ISRN is the main technical support body for ASN and also advises DGSNR.

There have been two INES Level 4 accidents at French nuclear plants, both involving the St Laurent A gas-cooled graphite reactors. In October 1969, soon after commissioning, about 50 kg of fuel melted in unit 1, and in March 1980 some annealing occurred in the graphite of unit 2, causing a brief heat excursion.

g. Decommissioning:

Decommissioning is the dismantling of a nuclear power plant and decontamination of the site to a state no longer requiring protection from radiation for the general public. The main difference from the dismantling of other power plants is the presence of radioactive material that requires special precautions. Thirteen experimental and power reactors have been decommissioned in France, nine of them first-generation gas-cooled, graphite-moderated types. There are well-developed plans for dismantling these (which have been shut down since 1990 or before), However, progress is delayed due to the lack of availability of sites for disposing of the intermediate-level wastes and the alpha-contaminated graphite from the early gas-cooled reactors. In April 2008 ASN issued a draft policy on decommissioning which proposes that French nuclear installation licensees adopt "immediate dismantling strategies" rather than safe storage followed by much later dismantling. The policy foresees broad public information in connection with the decommissioning process.

Materials arising from EdF's decommissioning include:

- 500 tonnes of long-liver intermediate-level wastes
- 18,000 tonnes of graphite
- 41,000 tones of short-lived intermediate-level wastes
- 105,000 tonnes of very low level wastes.

EdF puts aside EUR 0.14 cents/kWh for decommissioning and at the end of 2004 it carried provisions of EUR 9.9 billion for this. By 2010 it will have fully funded the eventual decommissioning of its nuclear power plants. Early in 2006 it held EUR 25 billion segregated for this purpose, and is on track for EUR 35 billion in 2010. Areva has dedicated assets already provided at the level of its future liabilities. Decommissioned Power Reactors in France are as given below:

Reactor	Type	MWe	operational
Chooz A	PWR	300	1967-91
Brennilis	GCHWR	70	1967-85
Marcoule G1	GCR	2	1956-68
Marcoule G2	GCR	40	1959-80
Marcoule G3	GCR	40	1960-84
Chinon A1	GCR	70	1963-73
Chinon A2	GCR	200	1965-85
Chinon A3	GCR	480	1966-90
Saint-Laurent A1	GCR	480	1969-90
Saint-Laurent A2	GCR	515	1971-92
Bugey 1	GCR	540	1972-94
Creys-Malville	FNR	1240	1986-97
Phenix	FNR	233	1973-2009

2. <u>Factors that lead to the French Nuclear Success story:</u>

Some of the major factors that Helped France attain its now level of success in the Nuclear energy can be summarized as below:

- **Strong government role in energy policy making**

  In the face of insufficient energy sources, substantive engineering expertise and a sound science and technological base, turning to nuclear power became an almost natural choice. Strong government support to nuclear power translated into a rapid expansion of the nuclear infrastructure. No noteworthy public debate or scrutiny of the nuclear programme is documented before 1999. Of course, there were some anti-nuclear groups, such as the Friends of the Earth, Societes de Protection de la Nature etc. By mid-1975, several influential French newspapers, such as Le Figaro, had raised concerns over questions of radioactivity, risk of nuclear accidents, nuclear waste, and the like. A large and even violent demonstration against construction of the FBR Super-Phenix at Creys-

Malville took place in June 1977. In France, support for nuclear power fell from 74 per cent in 1974 to 47 per cent in 1978. Yet, France continued to experience growth in its use of nuclear power. Al this was attributed to the Strong role of the government in framing and supporting their energy policy throughout.

- **Use of Standardized reactor design and technology**

The Standardization of nuclear reactor technology has obviously brought many advantages to France. The first of these has been the economic benefit of allowing industrial processes to be standardized for serial production of components and systems. Secondly, it has helped in easy dissemination of experience across the plants and in case of any fault detected in one plant, rectification has been quickly possible along the entire fleet of reactors. In fact, standardization or the 'common plant template' has significantly enhanced the possibility of probabilistic safety analysis and enabled easier maintenance and operation.

- **High Emphasis on maintenance and safety records**

As we have seen in the earlier section, the French nuclear establishments have accorded a high level of importance to maintenance of nuclear plants from the point of view of nuclear safety. After capital and fuel related costs, 60 per cent of the remaining budget is allocated for maintenance tasks and the plant engineers are subjected to rigorous training at the EdF's specialized Maintenance Preparation and Qualification Centre for PWR Systems (Cetic). All reactors undergo a review after every ten years and, in most cases, lifetimes of the units have been extended by ten years above the initial projected operation period, mostly with minor modifications.

- **High public support**

The understanding in the French public that its nuclear programme brings the benefit of energy independence has translated into a high support for it. With a high level of emphasis on nuclear safety, France has managed to avoid any serious nuclear mishap. This unblemished safety record also feeds into the public support for nuclear power. In 2006 with the enactment of the TSN (Transparency and Nuclear safety Law) Law, the government also increased the transparency of its nuclear programme. The right to information on nuclear facilities was strengthened by supplying a legal framework to the Local Information Committees (CLIs, which were set up in 1981) and by establishing a High Committee for Transparency, in order to provide for discussions at national level. This reinforced the faith of the general population in the nuclear power.

- **Monopolistic rule of EdF**

The Nationalization Law of 1946 established EdF as the primary importer and exporter of electricity transmission within all of France and outside. EdF is also the leading exporter of electricity in Europe. It exports 13 per cent of its total production to Britain, Switzerland, Italy and Germany. At the same time, EdF has a monopoly over electricity generation. In fact, EdF is the world's second largest electricity producer. Owned completely by the state, it has managed with the help of government subsidies to provide cheap electricity to the French industrial users as well as to the residential and commercial sectors. This has not only enabled the nation to attract foreign investment but also helped maintain a high level of public support for nuclear power. EdF's monopoly has allowed it to evolve its own tariff levels which have been touted as an advantage of the national nuclear programme to forge national unity.

3. Lessons for India:

As we all have seen and read in the recent times, the projections of the Indian Planning Commission, state that India will need three to four times more electricity generation capacity in the next two decades compared to what it has today. Nuclear power has been envisaged as an important contributor to the country's future energy mix. NPCIL has plans for construction of eight PHWRs of 700 MW capacity each based on indigenous technology, four FBRs of 500 MW also based on indigenous technology, and six large capacity LWR parks to be set up with foreign collaboration to make a total of 63 GWe from nuclear generation by 2031-32.The details of these projects were depicted in my earlier mid-term report on "Nuclear Energy in India". For India's ambitious nuclear plans to materialize, We will have to take several steps at home as well as engage with foreign suppliers to make the most of the opening we has achieved with the waiver granted by the NSG in 2008.

We need to develop an active policy to support the development of the indigenous nuclear industry which will also indirectly boost international cooperation. We know that, the costs of nuclear power, especially developed with a foreign partner, can be lowered by localization of the nuclear supply chain and technology transfer. But for this the local industry must be supported through fiscal concessions, simplified regulatory and administrative processes etc. so as India embarks on this new mission to strengthen its nuclear power industry in the country, it needs to learn from the experiences of other countries who have developed huge nuclear programmes with much success. France stands out in this category and it will be an important partner in India's nuclear expansion plans owing to its ability to provide fuel and reactors. Another factor that tends to support the case is the similarities that India and France share on the nuclear front:

- The first of these is their completeness of scope and mastery over the entire nuclear fuel cycle. From the front end to the back end activities, both nations have indigenous capability at every level of nuclear activity.
- Secondly, both programmes have been supported by a long-term vision and staunch government commitment. They have weathered changes in political leadership but the focus on nuclear power has been maintained.

Thus we can conclude that India can learn a lot of lessons from France that can help it in developing its nuclear programme with much success.

Lesson 1:

The most important lesson that India can draw from the French nuclear energy experience pertains to the importance of energy security for a nation. The oil shock in the early 1970s awakened France to its high level of energy vulnerability owing to the large-scale dependence on fuel imports. The government was then jolted into finding ways of securing energy independence and turned to nuclear power. For India, a country that faces a huge energy deficit, low domestic availability of fuel, but which today has many years of operating experience in nuclear power, the option of nuclear electricity is particularly relevant. We cannot expect nuclear power to completely bridge the energy shortfall, but it can make a substantive contribution to our overall energy production and in an environmentally sustainable manner. Energy security is essential for the overall national security and India cannot afford to relax on this front.

Lesson 2:

France today has a nearly 80 per cent dependence on nuclear energy. With such a high level of dependence on only one energy source, the country seems to have fallen into the same trap which it tried to once escape during the oil shock once again. This scenario of overly dependence on nuclear energy makes it vulnerable to the shutdown of reactors since the loss of generation from one or more high capacity reactors threatens major loss of energy production. In recent times, such a situation was faced by the country in the summer of 2009 when a strike by power workers and ongoing repairs at some units put a third of French nuclear power stations out of action and the country was forced to import electricity from the UK. The lesson here for India then is that it must develop as diversified an energy mix as it can. Given the huge energy demands of the rapidly developing nation, the country cannot afford the luxury of depending on only one source of energy. It needs to tap every fuel source including placing a heavy emphasis on energy efficiency and conservation. Only then can the country assure itself of true energy security.

Lesson 3:

France has largely been conducted without any major public scrutiny. While on the one hand, this has allowed a greater degree of consistency and steadiness in French nuclear policy, it has also led to allegations of nuclear power being made viable in the country only through government subsidies. So the third lesson to be learnt by India is, as the Indian nuclear programme undertakes a rapid expansion, it must open itself to a greater amount of transparency so that it can operate in a more democratic fashion and escape or avert potential allegations of commercial non-viability. This is important for the sake of reinforcing public support for the nuclear programme.

Lesson 4:

The fourth lesson to be learnt from the French experience is the need for high public support for the nuclear programme so that it acquires the character of a national venture which is based on a broad-based consensus. Only then can issues such as land acquisition, environment impact assessments, which have the potential to become contentious be carried out smoothly. In France, for instance, through the period 1970s to 1990s, the nation perceived its nuclear programme as a symbol of national pride and realized its importance as a contributor to energy independence. During this time, the French were able to bring about this mindset not only by the safe, consistent and cheap production of nuclear electricity but also through a conscious and well planned education campaign that included encouraging the common man to visit nuclear plants and related industrial facilities. This helped alleviate public fears about nuclear power and reduced the distance between 'high technology' and the common man.

Lesson 5:

The fifth lesson to be learnt is that the government should play a major role in supporting the programme. This is required to provide clear and sustained policy support for the development of nuclear power as well as ensuring its public acceptance by explaining the relevance of nuclear power in the country's larger energy mix and its affordability in terms of pricing. It needs to work with transparency, fairness and strictly by the rules of the game. Any inkling of unfairness could lead to a trust deficit in the public and lead to an anti-nuclear sentiment. In contemporary times, when the media maintains a close watch over the government, nuclear policy will not be the only domain of the government. Public perceptions about risks to public health and environment will have to be accounted for and the government would be well advised to launch public awareness campaigns to undertake perception management. Efforts must be made to disseminate facts on the Indian energy situation in general, its linkages with economic and social development, and the specific advantages of nuclear energy in the Indian energy mix. The existential risks in the nuclear sector must be addressed by explaining how the government and the nuclear industry seek to mitigate them.

Lesson 6:

The next most important lesson to be looked into is that the nuclear industry must provide the highest standards of nuclear safety if the promise of large-scale generation of nuclear electricity is to be realized. The ability of the French nuclear programme to avoid any major mishap generated continued support for itself from the government and the public. In India, until now, the government has managed the entire nuclear programme, including operation of nuclear power plants. With the entry of private players envisaged in the future, adequate terms of reference will have to be drawn for optimum public-private partnership with an apt level of investment risk being borne by private sector investors. Therefore, efficient and responsive nuclear governance will be critical for an expanding nuclear programme in India.

Lesson 7:

India needs to build a pool of skilled labour and manpower. A consistent availability of skilled and trained manpower is essential for the nuclear sector. As generations of technicians, engineers and researchers who joined the nuclear industry at the time of major construction activity retire, replacements have to be systematically planned to preserve the knowledge and know-how as well as work on new designs.

Lesson 8:

An effort is required to deal with the problem of nuclear waste. France confronted this problem after twenty years of large-scale energy generation. But, it has become an issue important enough today to bring about a dip in public support for nuclear power in the nation. If India is to avoid this, serious thinking on the selection of site and construction of geological repository to house high level, long-term waste must begin now in order to reassure the public on this important matter. And public support will depend upon transparency and education programmes in this field.

4. Conclusion:

In this phase where India may very rightfully require an energy revolution to meet its demands of the future, we need to carefully plan before determining the future energy mix. With the explosion in the population, mounting demands, lacking indigenous fuel sources and changing climate issues we, don't have much time to get the plan right. We need to develop the proper resources to curb our lack of energy security. Nuclear power is one big opportunity that if harnessed properly can work wonders for India.

The cost of not having energy or power to meet our needs and demands is a much higher cost than the cost of power prevailing so we need to focus all our resources and talents to help develop the plans that can set the right pace for the development numbers we are eyeing for.

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