



THE FRENCH EXPERIENCE IN NUCLEAR ENERGY: REASONS FOR SUCCESS

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Abstract

Nuclear energy for France represents a viable option in meeting energy demands in the near and medium terms due to few energy resources and dependency on imported oil. Basic decisions to launch the French nuclear program, successive series of PWRs installed and standardization due to technical progress are highlighted in this paper.

1. FRENCH NUCLEAR PROGRAM

After the oil crisis of 1973, French Authorities elected to adopt nuclear energy on a wide scale since France has few energy resources and was heavily dependent on imported energy, especially oil. But, to avoid escaping from one dependency only to fall into another, the authorities insisted on French control of all the aspects of development, from the entire fuel cycle, to the design, construction, and operation of nuclear power plants.

Basic decisions made to launch the French nuclear program were:

- To build a large number of plants employing a single technology. After experimenting with several types of reactor (gas graphite, heavy water, light water), Electricité de France (EDF) selected the PWR technology as the ideal model.
- To mobilize the necessary industrial capabilities and concentrate them in the hands of only a few participants: these participants were given long term objectives and assured of the continuity of the program. In response, they invested in human resources and industrial facilities necessary to ensure the success of the program.
- To establish a complete and consistent set of codes and standards to facilitate regulation.
- Finally, to develop the programme through series of identical units, to benefit from the standardization.
- A license agreement was signed between Framatome and Westinghouse for the Nuclear Steam Supply System (NSSS).

However, standardization does not mean frozen technology and a stepwise evolution was chosen, each step corresponding to an updated standard incorporating improvements due to technical progress and experience.

The successive series of PWRs installed in France were:

(i) The 900 MW(e) series (three loops);

- This series based on a twin-unit configuration was initiated by 2 units at Fessenheim and 4 units at Bugey contracted for in 1970 and 1971, before major expansion of the nuclear program.

- The first «program contract» (CP1) was signed in 1974 for 18 practically identical units, the only differences being due to the site conditions.
- The second multi-unit contract (CP2) was signed in 1976 for 10 units identical to the CP1 units except for the turbine hall, which is laid out axially instead of transversely, with respect to the reactor building.

(ii) The 1300 MW(e) series (four loops);

- The program continued with the signing of contracts in 1977 and 1979 for 20, more-powerful units of the 1300 MW(e) class including:
- 8 units of the P4 type
- 12 units of the P4 type, similar to the P4 but with a reduction in the size of the buildings, as a result of civil works optimization.

(iii) The 1450 MW(e) series (four loops);

- Four units of this N4 series have been ordered. They correspond to the latest development of French technology, with a completely French design and new types of steam generator, reactor coolant pump and turbine. The first two (Chooz B1 and B2) were connected to the grid in 1996 and 1997 respectively. Civaux 1 was connected at the end of 1997. Civaux is expected to come into operation by the end of 1998.
- During this period a complete and convenient nuclear fuel industry from uranium mining, conversion and enrichment to spent fuel retreatment was also developed.
- In brief, the French nuclear power program today is leading to gratifying results: 57 PWR units are in operation and 1 unit is under construction. About 75% of French electricity is produced by nuclear power with an availability factor above 80% and with a high degree of safety.
- Moreover, 9 units or nuclear islands, directly derived from the 900 MW(e) series have been exported by French nuclear industry, and are now in operation in Belgium, South Africa, Korea and China. Two other units of the same class were ordered by China at the beginning of 1996.
- Figure 1 shows the construction program with coupling dates of the French and exported nuclear units for the 27 last years.

2. ECONOMIC ACHIEVEMENT

2.1. Standardization

The key word for nuclear competition is "STANDARDIZATION". In fact, it is a series effect allowing such standardization and resulting from the continuity, extent and rhythm of the program and from multiple units siting.

A standardized design reduces engineering costs, licensing problems, equipment prices, construction time and site costs. The standardization of components avoids delays in procurement and on site installation and more generally, the risks and contingencies are significantly decreased with the number of identical units.

According to the French experience, practically all the benefits of standardization are obtained with series of about 10 units. Another factor of cost reduction is size of units. As mentioned, the successive series of PWRs built in France are in the range of 900 MW(e), then

1300 MW(e) and now 1450 MW(e). A few years ago, an EDF study showed that for the same total output, a series of 1450 MW(e) units would be about 15% cheaper than a larger series of 600 MW(e) units constructed in the same 10 year period.

The benefits of standardization are:

- Easier relationships with the Authorities;
- Minimized technical risks;
- Extensive research and development;
- Concentration of means and tools;
- Controlled backfitting of improvements;
- Reduction in design, manufacture, erection and commissioning durations and costs;
- Improvement of plant operation;
- Easier management and reduction of spare parts;
- Easier maintenance;
- Maximizing experience feedback.

The French nuclear program is schematically shown below:

- 600 reactor years of cumulative operating experience;
- 80% Of the electricity generated in France;
- Availability factor above 80%;
- Full mastering of all engineering and manufacturing activities;
- Continuity Constant improvement through experience and modern technologies;
- 220 steam generators, 220 reactor coolant pumps, 70 reactor vessels, 10 000 fuel assemblies.

This lead to:

- good public acceptance;
- excellent safety results;
- economical competitiveness;
- reliable long term partner for international cooperation.

2.2. Financing of French nuclear program

Financing for the PWR program amounted to about half of EDF's investments over the last 20 years. The resulting debt is judged normal for a large utility like EDF, which has replaced all of its power plants and dealt with a large increase in electricity demand during the same period.

Out of the total nuclear program amount (about 400 billion French francs excluding interest during construction), 50% was self-financed, 8% was directly financed by the State owner of EDF and the remaining 42% was financed through loans in France or on the international market. Such loans benefited of French Government guarantees.

In 1988, medium and long- term debts totaled 230 billion French francs. Now its debt is decreasing yearly and by the end of 1997, the EDF debt, essentially due to the nuclear program was 126 billion French francs, corresponding to 68% of its sales revenue and the debt interest of 3% of the sales revenue.

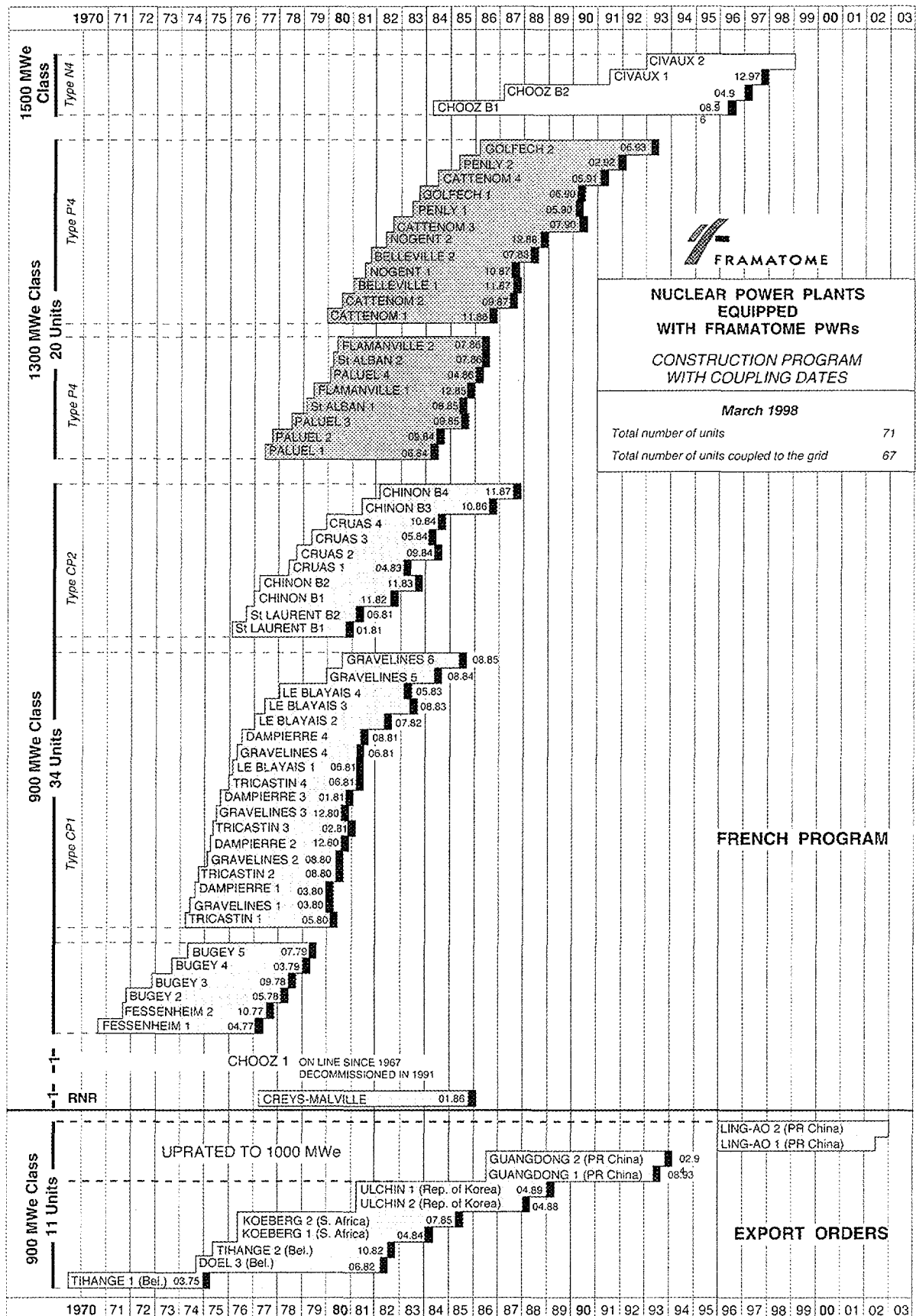


FIG. 1. Construction program with coupling dates of the French and exported nuclear units for the 27 last years.

TABLE I. BASE LOAD GENERATION COSTS IN FRANCE

	NUCLEAR	GAS	COAL
PLANT (MW)	2x1450	2x650	2x600
YEAR OF COD	2005	2005	2005
OVERNIGHT COST (FRF/KW)	8700	3950	7150
INVESTMENT COST (FRF/KW)	11020	4370	8290
LOAD FACTOR (%)	85	90	90
ECONOMIC LIFETIME (YEARS)	30	25	30
GENERATION COSTS (FRFcents/KWH)			
INVESTMENT	12.7	4.9	8.9
O & M	3.4	2.2	4.5
FUEL	4,3/4,8	12,0/21,1	8,8/12,9
TOTAL	20,7/21,2	19,1/28,2	22,2/26,3
<i>FUEL ASSUMPTIONS</i>	<i>20/25\$/lbU3O8</i>	<i>2/3,9 \$/M BTU</i>	<i>40/50 \$/T CIF</i>
<i>USD/FRF EXCHANGE RATE</i>	<i>5/6,5</i>	<i>5/6,5</i>	<i>5/6,5</i>

3. WHAT FUTURE FOR NUCLEAR IN FRANCE?

Today, thanks to the amortization of most of the nuclear units into service, EDF can deliver low cost electricity to its customers; its goal is to maintain nuclear power plants in service as long as possible.

When the time comes to renew the park, nuclear power plants will compete with gas or coal-fired units. About every three years the French ministry of electricity issues a report giving the "reference costs" for units to be implemented in the future. The last report - DIGEC 97 - shows that, although coal and gas may challenge nuclear in some cases due to low fuel costs, nuclear energy remains a solid option (see Table I). It is up to all French nuclear actors to prepare now the nuclear units of the future to keep their costs (investment, O & M, fuel) as low as possible.