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CONSTRUCTION TIME OF PWRs

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ABSTRACT

The cost of electricity generated by nuclear power is greatly affected by the capital cost, which is dependent on the construction time of the plant. This work analyses the construction time of PWRs in several countries with different market structure and licensing experience. Countries which succeeded to establish a more collaborative environment among utilities, constructors, regulators, and energy planners through effective partnerships were able to build PWRs in shorter times. The construction time in Germany, France and Russia was around 80 months and in Japan, about 60 months. The envelope of 95% of the cases includes a range between 50 and 250 months of construction time. The evaluations show that construction time of PWRs has been longer for countries that did not hold the technology to build their own reactors, and depended on contracts with foreign suppliers. The nominal power of the reactors was considered a measure of plant size, technology complexity and standardization. Countries with standardized reactor designs (France, Japan and Russia) were able to build plants in shorter times.

1. INTRODUCTION

The growing world demand for energy, considering the concerns with the climate changes and the raising electricity generating costs increased the interest in the construction of new nuclear power plants. Today, there are 443 nuclear plants in operation around the world, which respond for 17% of the total global electric power capacity [1]. Considering that 267 plants are PWR (Pressurized Water Reactor) or VVER (Russian PWR), they correspond to more than half of the power reactors in operation [1]. The cost of building power plants has increased over time in real terms [2-5]. Regarding the nuclear power generation, capital cost is around 60 to 80% due to equipment and components with the required nuclear quality, site infrastructure, and complex electromechanical assembling tasks. Construction time overruns increase also costs when prices of commodities, engineering services, and other construction factors are constantly increasing as they happen today [6-8].

It is important to understand the determinants that cause higher costs and specifically longer construction times. Earlier studies and data available identified large differences between countries for both cost and construction time which can only be explained considering several variables such as plant size, technology, date of construction start, and the institutional structure involving vendors, utilities, and regulatory bodies responsible for licensing [1-8].

This paper discusses aspects that affect the construction time of PWR plants taking into consideration data available in the literature [1]. The paper starts presenting the main possible determinants of construction time for nuclear power plants, followed by the data about construction times. It then discusses possible correlation between the data and determinants, and finally presents the conclusions.

2. POSSIBLE DETERMINANTS FOR INCREASING CONSTRUCTION TIME OF PWRs

The construction cost of nuclear power plants depends on many different determinants as suggested by different authors[2-7]: design revisions during construction, large plant size and complex large-scale technology, lack of standardization, serialization and modularization, plant safety and environmental concerns, prevention of accidents and risks, change in regulatory standards during construction, and actions of environmentalists and nuclear opponents. There are technical and institutional issues involving vendors, utilities, regulators and the public. From these possible cost determinants we select in Table 1 those that can influence the construction time of PWRs and classified them in three broad groups: technical, regulatory, and institutional.

The technical determinants are all applicable to the construction process. Sources of delays on construction times are design revisions during construction, inefficient methods of construction, plant size, and plant complexity. During the 1970s the amount of steel, concrete, length of pipes and length of electrical cables increased between 25 and 50 % for plants of similar nominal power. We add to the list experience of contractors and constructors because of the diversity of countries that has built PWRs. The absence of design experience of local firms contracted to deliver specific parts of the project of a nuclear power plant may also cause delays in the construction process.

Table 1. Some important determinants of construction time of nuclear power plants

Technical determinants
Design revisions
Large plant size and complex large-scale technology
Lack of efficient methods of construction such as standardization, serialization, modularization, etc
Experience of contractors and constructors
Regulation determinants
Complex licensing procedures
Delays in the licensing permits
Level of public participation
Economic and institutional determinants
Additional costs due to design changes or other causes
Commercial decisions that delay the construction
Market characteristics
Political decisions that interrupt the construction
Partnership in licensing, construction and operation

The other determinants may be classified as regulatory or institutional. Nuclear power regulatory procedures are complex and in many countries require several permits [9]. During the 1970s they became more stringent during the construction of many nuclear power plants. Delays in issuing those permits may have increased construction times.

The last group of determinants encompasses economic and institutional issues. The structure of the institutions affects how technical, economic and licensing issues are resolved [2,3]. An important factor is how much partnership between the main actors is found in the process of licensing, construction and operation of nuclear power plants. Cost overruns cause delays and affect future commercial decisions. Delays and design changes usually mean additional costs such as future replacement power and financing charges that require new negotiations and business evaluations. Cost overruns usually change how a project fits in the electricity market and commercial considerations may postpone its completion. All these factors have impact on construction duration.

3. CONSTRUCTION TIME OF PWRs

We start presenting the data available about the construction time of PWR power plants. The data have been collected from the IAEA report which presents general and technical information about nuclear power plants under construction, operation, or shutdown, and performance data about those under operation [1]. The important variables available in the data set are the dates of beginning of construction and of commercial operation, nominal power, countries, utilities, and builders. The nominal electric power is chosen as an important variable for the analysis because it can be related to several technical determinants such as plant size, standardization and plant complexity.

Other variable considered important is the country where a plant is built because it can be related to different regulation environment and institutional structure. The countries variable also allows one to identify attempts to build PWRs with more standardization and serialization. Other variables to be considered are date of construction start or completion which could give information about the evolution along the years. Previous studies presented interesting trends about construction time and cost along the years [1,2,5]. Figure 1 presents the results from Ref. 1. During 1980 and 2000 the time required for building reactors were longer. The average construction time of nuclear power plants between 1976 and 2009 was 92 months or 7.7 years with a maximum of 10 years between 1996 and 2000.

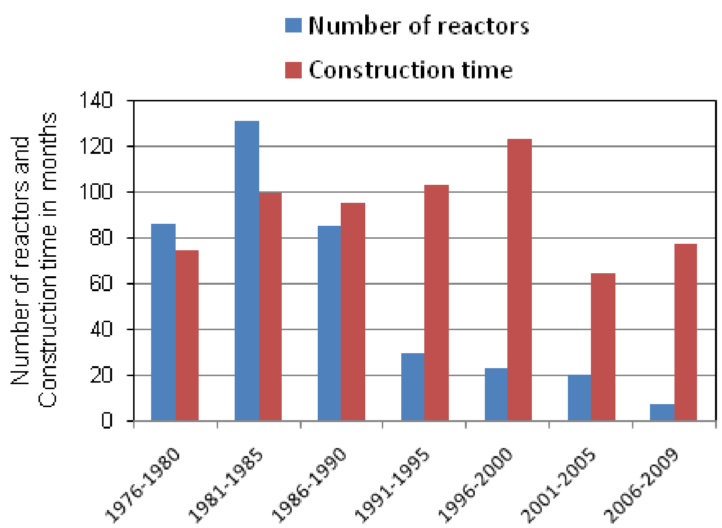

Figure 1. Construction time and number of nuclear power plants (PWR, BWR, Candu, etc) along the time. Source: Ref. 1.

Defining the period of time between the beginning of the construction and its initial commercial operation as the plant construction time, Figure 2 presents its values for all PWR in operation in the world as function of the nominal electric power. The data present large spread: for 95% of the plants, the construction time is in the range from 50 to 350 months. Reactors with higher nominal power present wider ranges than lower power reactors. The red line represents a curve fitting, by minimum squares, of the average construction time. The standard deviation of the fitting is around 41 months.

The construction time of the PWR plants depends on specific problems that occurred during the construction period. In Figure 2 some reactors present very long construction times which may not be representative of actual construction duration. In most cases, the reasons can be related to political or commercial decisions that interrupted the construction for several years. They cannot be excluded from the set because political and institutional structure of countries are possible determinants for construction time, but since the data presented in Figure 2 are independent, some statistical approach can be used to treat the extreme cases. The Chauvenet criterion [13] shows that several plants present very long construction times, and are presented in Table 2. With the exception of the Mochovce-2, in Slovak, whose construction time was around 16 and a half years, all plants have large sizes, with nominal power above 1000 MWe and construction times, in most cases, higher than 20 years. Since it is not the purpose of this article to discuss specific plants, they were removed from our data base.

Considering the remaining plants and separating them in two sets, where the first one includes reactors with power below 800 MWe and the other set composed by the remainder reactors, their construction times are presented in Figure 3. The envelope of 95 % of the cases includes a range between 50 and 250 months of construction time. Also, for reactors with power below 800 MWe, the construction time does not show any variation with the power, while for higher power reactors, the construction time increases about 8 months for each increase of 100 MWe in power.

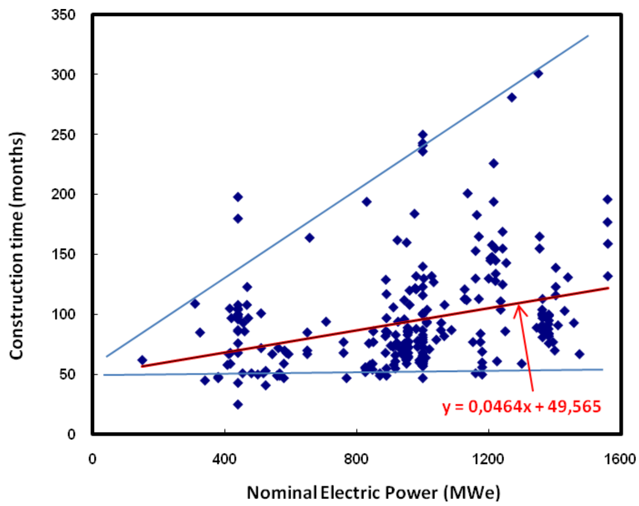

Figure 2. Construction time for all PWRs in operation

Table 2. Nuclear plants with excessive construction time.

Reactor	Country	Operator	Constructor	Nominal Power (MWe)	Beginning of construction	Commercial operation	Time (months)
ANGRA 2	Brazil	ELETRO-NUCLEAR	KWU	1350	Jan/76	Feb/01	301
KALININ-3	Russia	REA	FAEA	1000	Oct/85	Nov/05	241
VOLGODONSK-1	Russia	REA	FAEA	1000	Sep/81	Dec/01	243
MOCHOVCE-2	Slovak	EMO	SKODA	440	Oct/83	Apr/00	198
KHMELNITSKI-2	Ukraine	NNEGC	PAIP	1000	Feb/85	Dec/05	250
ROVNO-4*	Ukraine	NNEGC	PAA	1000	Aug/86	Apr/06	236
COMANCHE PEAK-2	EUA	TXU	WH	1215	Oct/74	Aug/93	226
WATTS BAR-1	EUA	TVA	WH	1270	Dec/72	May/96	281

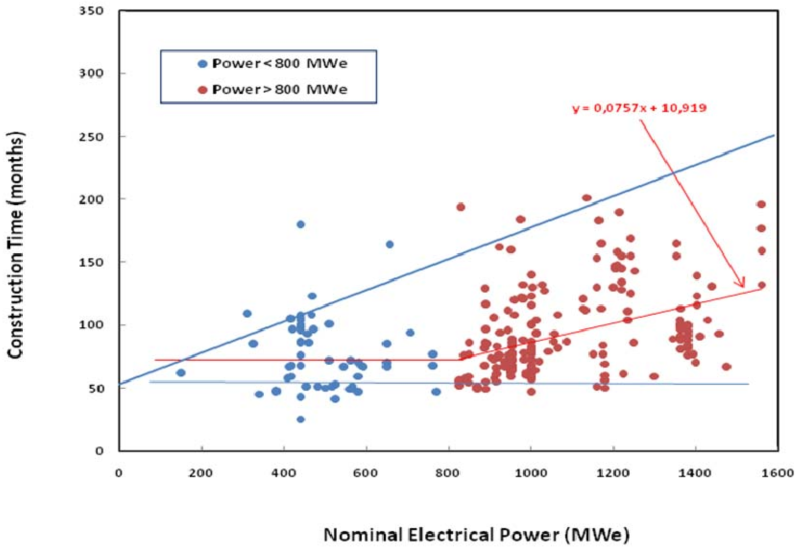

Figure 3. Construction time of PWRs, without the extreme cases

In order to understand how different determinants affect the construction time we look on the construction experience of different countries, in the hope that this perspective may present specific technical, regulatory, market or institutional characteristics. From the 26 countries that have PWR reactors, some of them hold nuclear technology and have their own constructors, which built the majority of the plants. Among them are the USA, France, Germany, Japan and Russia. Figures 4 to 9 show the construction time in those countries and in the countries that do not hold indigenous constructors. The straight lines in the figures are the world average construction time as a function of power level.

From these figures, it can be observed that the countries with nuclear technology built nuclear power plants in their territory in less time than the world average, regardless of the rated power of the plants, with the exception of USA. In many cases, high-power reactors could be built in about 4 years. Japan, for example, had systematically built reactors in less than 4 years.

In US the first plants with low power took less time than the world average. Those plants had their construction between June of 1967 and April of 1969. After mid-1970s, the construction time had a significant increase, compared to the world average and to the previous American plants, already in operation.

Figure 9 shows the construction time compared to the world average for countries that could not build their own PWR plants. It is not possible to establish a trend in construction time as function of the power level. In general, the construction time is in the range between 50 and 200 months, regardless of its power, with average around 80 months (horizontal line), above the world average of 75 months for low and medium power plants.

The number of reactor constructors and operators vary among the countries. Table 3 shows the number of PWR constructors and operators in several countries obtained from the IAEA report [1].

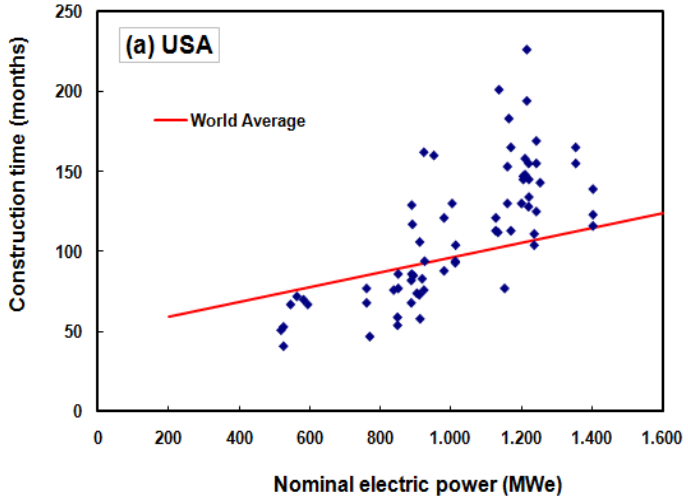

Figure 4. PWR construction time in the USA

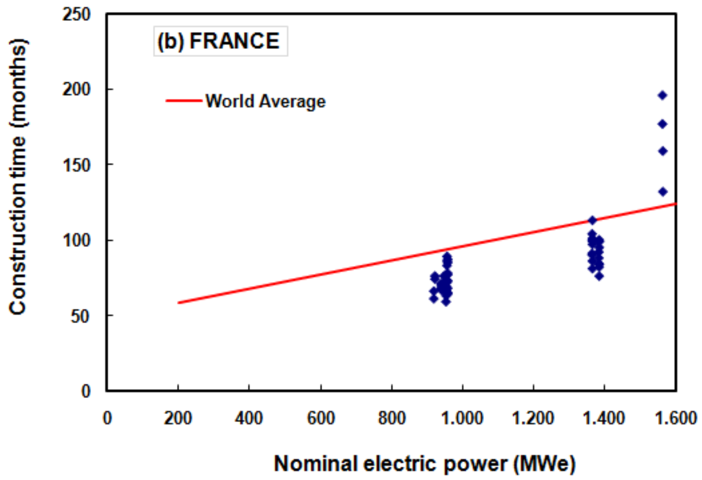

Figure 5. PWR construction time in France

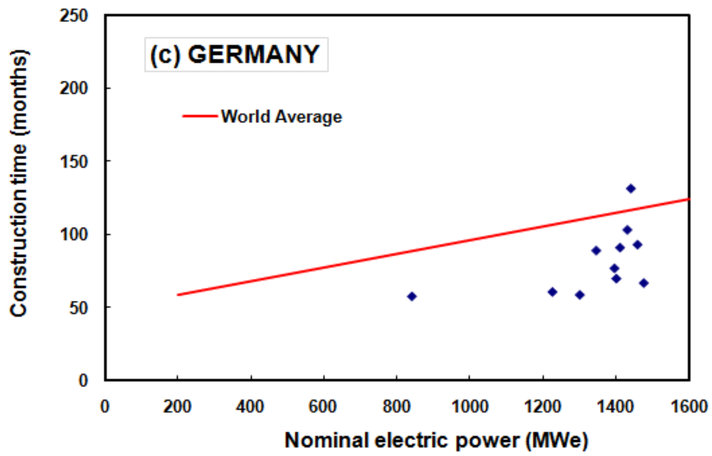

Figure 6. PWR construction time in Germany

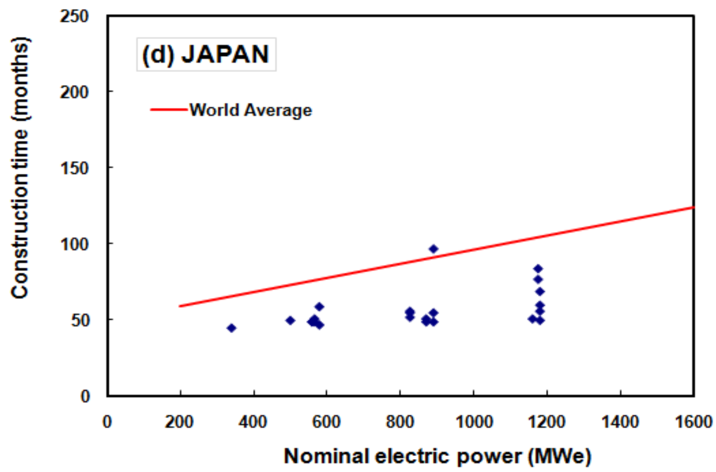

Figure 7. PWR construction time in Japan

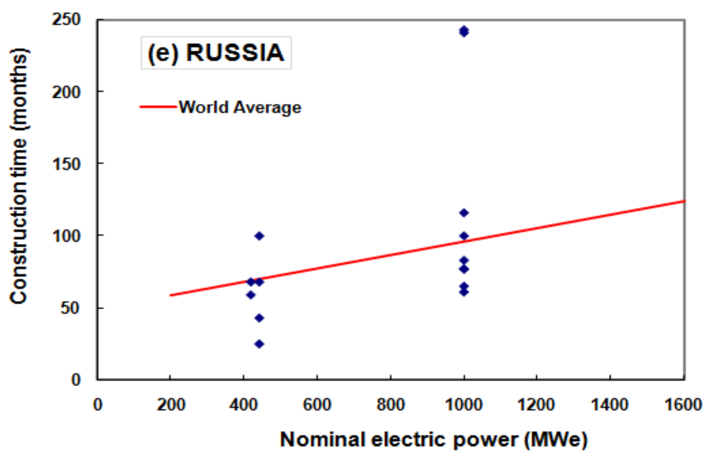

Figure 8. PWR construction time in Russia

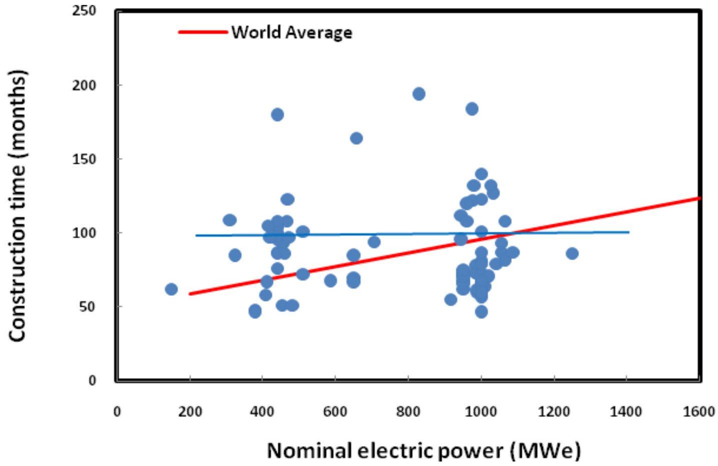

Figure 9. Construction time of PWR in non constructor countries

Table 3. Number of constructors and operators of PWRs in several countries

Country	**Number of PWR constructors**	**Number of operators**	**Number of PWR**
USA	3	20	69
France	1*	1	58
Japan	1	5	23
Germany	1*	3	11
Russia	1	1	15
Countries without a nuclear industry (20 countries)	0	27	91

(*) One of the constructors stands practically alone in the local market.

4. DISCUSSION ABOUT CONSTRUCTION TIME OF PWRs

The results presented in the previous section allow general and specific observations regarding construction time of PWRs. Below we discuss the data presented in Sect. 3 and highlight important actions that can be taken to reduce construction time in the future.

4.1. Technical determinants

Considering the power level as a measure of plant size, plant complexity and standardization, it is possible to say that the first two variables contribute to increase the construction time and the third to decrease it. The curve fittings shown in Figures 2 and 3 indicate that the construction time increased with the nominal power level of the plants. The results appear to show that larger plants require more capital, complex systems, and effort to be built and thus present longer construction times. Similar behavior has been observed with regard to cost [2,5]. Thus it seems that the nuclear power technology is such that possible gains due to economies of scale through size increase are reduced by losses due to additions of plant complexity. This result seems to indicate that smaller PWRs can be built in shorter times and perhaps be less expensive than it is usually expected. This surely is an issue that deserves more research.

Since some countries strove for efficient methods of construction such as standardization, modularization and serialization, Figures 4 to 9 help one to verify the impact of those efforts on construction times. Countries that built standardized power plants were able to present shorter construction times (France, Japan and Russia). The serial construction of several plants, modularization and other methods of construction adopted by these countries seem to have substantially reduced construction times. Below we present the current trend in the nuclear industry for improving the construction methods that goes in this direction [10]:

- Open top installation – major components, such as the reactor vessel and steam generators, are put in position by heavy duty cranes through the open roof;
- Modularization with pre-fabrication and pre-assembly – this technique is used in many different industries. Modules can include several components and they can be built considering the construction of several nuclear plants. The assembly of the module can be performed away from the site and they can be installed in a simple way with the open top installation;
- New techniques for piping welding and rebar installation for reinforced concrete;
- Information management and control using computer systems, including 3-D simulation models.

The comparison of Figures 4 to 8 with Figure 9 shows that the existence of an indigenous nuclear technology industry tends to allow a country to build power plants quicker than those countries that do not dominate the technology. This aspect is clear as we observe countries such as France, Germany, Japan and Russia. One possible explanation is that the constructors were responsible to provide the nuclear island and layout of the plant, which represented approximately 20 % of the total project cost. The remaining parts of the project were contracted in other engineering and architecture companies or components and systems suppliers. The absence of local design capacity induces the need for foreign services, resulting in time consuming negotiations, extensions of delivery times, quality assurance, equipment transportation and other similar problems. Today many constructors are planning to extend their responsibility to approximately 60 % of the total project cost, between 2010 and 2030, in order to decrease cost and construction times [11]. But with the current globalization level of engineering services and technical supplies, which is much larger than 20 or 30 years ago, it is expected that this issue becomes less important.

It should be mentioned that the recent accident of the Daichii plants, in Fukushima, will certainly represent some increase in design revisions, and additions of complexity to some safety systems for the new plants under construction. Those revisions will certainly add some additional time to the construction of the new plants, which will have to be compensated by other means to maintain cost and construction time under control.

4.2. Regulatory determinants

It is known that the regulation in the nuclear industry affected the construction time, as is shown in Figure 1 during the 1970s and 1980s. Part of the construction time increase that occurred during that period can be associated to licensing instabilities in some countries. Any industrial facility that can potentially cause damage to the environment or to the population is required to undertake a licensing process that is in general principles similar across countries. The International Atomic Energy Agency (IAEA) suggests that the licensing process of a nuclear power plant be divided into four stages, each one with specific permits: approval of the site, approval of the plant executive engineering project to allow the construction beginning, approval for the initial testing, and approval for permanent operation. The core of the licensing process is the public acceptance of the project. The number of permits, the way to obtain them, and the time involved in each stage may vary greatly among the countries [9,12].

Table 4 presents the necessary permits in some countries [9,14-16] and shows that countries with simpler regulatory procedures were able to build power plants in shorter times. This is the case of France, Japan and Germany. US also have a simple regulatory system but contradict this observation, indicating that their poorer performance regarding construction time of PWRs is more complex. The time involved to obtain the several permits varies substantially among the countries since it depends on their institutions and their respective cultural, political and market characteristics. In the next section this issue is discussed.

Table 4. Permits associated to the licensing process in some countries.

Country	Number of Permits	Permits
France	2	• Permit for the social and economic aspects of the project • Permit for the site, technical design, environmental impacts and construction
USA*	2	• Permit for construction • Permit for operation
Japan	3	• Permit for the site, basic design, and environmental impacts • Permit for construction • Permit for operation
Germany	5	• Permit for the site and construction of the civil engineering systems • Permit for construction and approval for important safety systems • Permit for using nuclear materials • Permit for initial tests • Permit for permanent operation
Brazil	8	• Permit for the site (CNEN) • Approval for the project (IBAMA) • Permit for construction (CNEN) • Permit for construction (IBAMA) • Permit for utilizing nuclear material (CNEN) • Permit for initial operation (CNEN) • Permit for permanent operation (CNEN) • Permit for operation (IBAMA)

(*) A new procedure has been established since 2005 with two optional licenses and one obligatory final license: (1) Certification of design; (2) License previous approval of the site; and (3) Combined license for construction and operation.

In Brazil, nuclear power projects are required to obtain permits from two independent agencies: National Commission for Nuclear Energy (CNEN) responsible for the nuclear licensing process, and the Brazilian Environmental Institute (IBAMA) responsible for the environmental licensing process. The documentation for the nuclear licensing process is reasonably normalized by CNEN, while that for the environmental licensing is not. This fact creates major discussions between the project team and the licensing body which tend to extend the time required to complete the project and start commercial operation.

4.3. Economic and institutional determinants

In this section we discuss the economic and institutional determinants that may have affected the PWR construction times in the world. It has been observed that political decisions, electricity demand changes, and economic situation of a country or operator may interrupt or delay the construction of nuclear power plants. In US some of these determinants have played together during the 1970s and 1980s and affected the construction time of their PWRs. The complexity introduced to plant designs by safety regulations during the construction of many plants contributed to increase construction time and costs in US. The costs overruns, besides affecting the construction itself, also affected the economic position of several projects in the American electricity market, which did not grow as was previously expected. The improvements regarding efficient use of electricity during that period decreased the growth rate of electricity demand in that country. All these facts together imposed interruptions and contributed to delays and longer construction times of PWRs. Similar external market or economy impacts imposed delays to the Brazilian power plants, Angra-2 and Angra-3. The first started operation in 1999, after an interruption of almost 20 years and the second restarted construction recently.

In that same period France, Japan and Germany succeed in building their reactors in much less time. When we exam the overall nuclear business environment in that period we notice that the main actors in these countries were more collaborative and managed to construct more effective partnerships. The licensing procedures and the plans for capacity expansion were more predictable in these countries and that, as shown in Figures 5 to 8, appears to have allowed them to build PWRs in shorter times.

The construction time also seems to be affected by the number of constructors and operators in a given country. From Table 3 it is observed that France and Russia have only one constructor and one government controlled operator. The presence of just one constructor seems to have allowed these countries, to a certain extent, to standardize and serialize the construction of their plants, reducing the design time, the components and systems production, and to hold more control over the support industries.

A final remark is that cost overruns seem to have lower impact on countries with more centralized operation and construction processes. For instance, the construction of four French large nuclear power plants of 1560 MWe (Figure 5) were carried out and finished although their construction times were well above those of previous plants with power level around 900 and 1300 MWe.

5. CONCLUSIONS

The time to build a nuclear power plant up to its entry into commercial operation is critical for the competitiveness of this system in the electric power market. According to the IAEA data, the average construction time for plants with nominal power below 800 MWe is about 71 months, while for higher power reactors, the construction time increases about 8 months for each increase of 100 MWe in power.

Countries which succeeded to establish a more collaborative environment among utilities, constructors, regulators, and energy planners through effective partnerships were able to build PWRs in shorter times. The construction time in Germany, France and Russia was around 80 months and in Japan, about 60 months. The envelope of 95% of all plants includes a range between 50 and 250 months of construction time.

The analysis considered the nominal power level as a measure of PWR size, technology complexity and standardization. The evaluations indicate that construction time increased with reactor size and seems to indicate that part of the cost gains due to economies of scale may be offset by additions of technology complexity.

The evaluations show that construction time of PWRs has been longer for countries that did not hold the technology to build their own reactors, and depended on contracts with foreign suppliers. Countries with standardized reactor designs (France, Japan and Russia) were able to build plants in shorter times. The presence of a large number of designs and constructors in some countries appears to have led to a great diversity of plants, precluded standardization, and contributed to longer construction times.

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