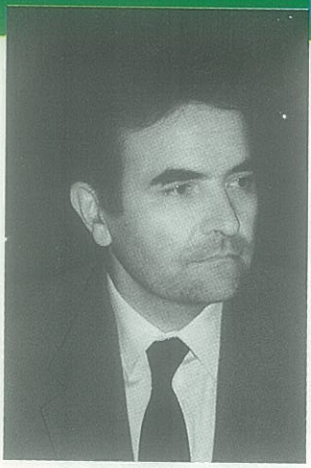

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A QUARTER OF A CENTURY OF NUCLEAR PROJECT ENGINEERING AND CONSTRUCTION: ACHIEVEMENTS, PROBLEMS AND SOLUTIONS

A. GARCIA-RODRIGUEZ

The year 1988 marks the 20th anniversary of the connection to the grid of the José Cabrera Nuclear Power Plant. The achievement of this important milestone in 1968 was the culmination of process initiated several years before that had to cover all the preliminary stages-training of the management group, feasibility studies, selection of the turnkey supplier and execution of the Project. It is on this last phase that we are going to focus; not so much on the actual starting point, but rather on what has been the complete process throughout almost a quarter of a century which, although essentially successful, might now require deep reflection within an international context.

It is as clear now as it was then that nuclear energy is a source that cannot be renounced by mankind. Evidently, the possibility of controlled conversion of matter into energy signifies a decisive step that should facilitate the gradual substitution of other energy sources that are more limited or that represent other problems which are difficult to solve. Fortunately, the period during which this substitution is going to be required is not limited to such an extent that it does not permit organized development of nuclear energy or even some hesitation in the process.

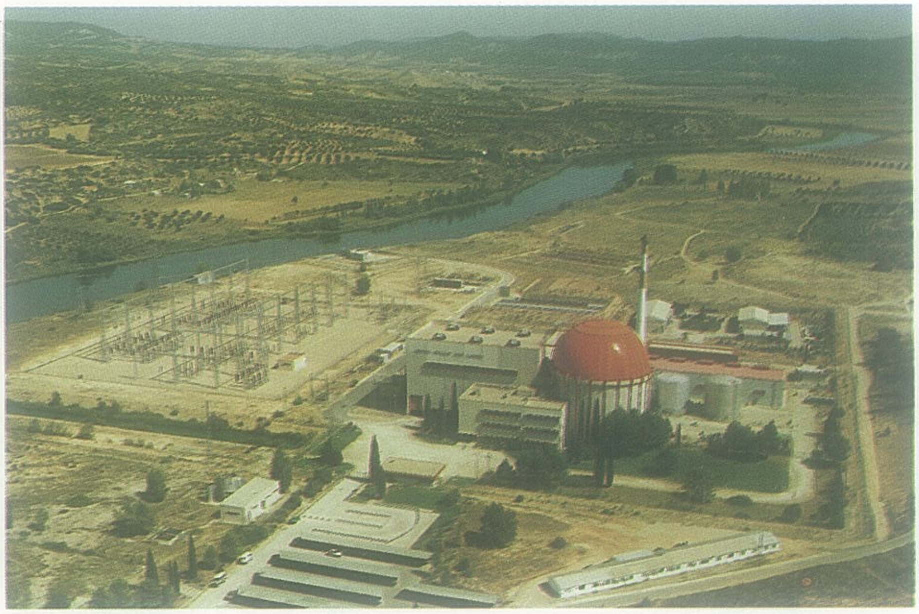
The difference between then and now is that, on the one hand, we have consumed a quarter of a century of the time available while, on the other, we have performed a great feat in this space of time. This is an objective fact, although the initial optimism of nearly everyone, the impatience of many, the ingenuousness of quite a number and the personal interest of few condition an erroneous impression about what the role of nuclear energy has been and, without doubt, will be, regardless of what the situation might be at this particular moment.

It is the opinion of some that the present problem with nuclear energy stems from the fact that too much has been expected of it in too short a time. In just over 40 years since the first experiments were carried out and 30 since the first applications were made, its technological development and complete commercial implementation have been achieved. The fact that several industrialized countries are supplied with electrical energy of nuclear origin in percentages that reach up to 70 % in France is irrefutable proof of the foregoing.

THE BEGINNING

As is well known, the nuclear technology of light water was initially developed through the extensive Nuclear Naval Propulsion Program in the United States of America. For those of us who work in this field, the director of this Program, Admiral Rickover, is a familiar, already legendary figure, and author, too, of the excellent report to the members of the Commission on the TMI Accident, written upon request by the President of the United States of America.

For the design of the José Cabrera Nuclear Power Plant, direct reference was made to Unit I of the San Onofre Nuclear Power Plant in the USA. It was conceived to have an electric power of 60 MW, but during the negotations of the initial proposal it was changed to



José Cabrera Nuclear Power Plant

the 160 MW that were finally installed. The first generation of nuclear power plants, to which José Cabrera doubtlessly pertains, saw the confluence of two technologies which were then considered to be proven –electrical generation by fossil fuels and the production of heat in nuclear reactors for naval propulsion. They were conventional power plants in which the boiler was substituted by a nuclear reactor –hence its initial denomination of nuclear boiler– and a whole series of auxiliary systems. The concept was so clear that, from the point of view of basic technology, it has evolved very little to the present time. The reactor and fundamental auxiliary systems of the José Cabrera Nuclear Power Plant, including the fuel itself, differ very little conceptually from the latest PWR reactors in construction. The matter was so obvious that plants of this generation could be offered, as they were, on a "turnkey" basis. The results were not judged in that era to be completely satisfactory. In the case of José Cabrera, it was necessary to employ about 500,000 engineering man-hours (m-h) –2-1/2 times the number necessary at the time for a thermal power plant of the same size– 150,000 construction management m-h, and more than 4 million construction m-h. The effort necessary to fulfil the documentary and physical aspects inherent to a nuclear facility had not been adequately assessed, which meant that the suppliers of these first "turnkey" plants lost money and decided to relinquish a contracting system that involved such a high economic risk. The deviations were not significant, but aspects were identified that, because they were out of reasonable control, could not be adequately assessed in a competitive context.

It is as well to point out that the basic criteria applicable to nuclear power plant safety –in-depth defense and postulated accidents of low probability– have not in the main had to be revised, and the safety functions and single failure criterion have also been maintained. What has suffered a big change, and which is not completely justified, is the way in which these criteria are fulfilled. Requirements have emerged derived from a better technological knowledge of physical phenomena, wider margins of safety have been imposed, accidents of less probability have been considered and, above all, there has been an extensive regulatory activity relentlessly reinterpreting basic criteria.

DEVELOPMENT

The end of the '60s saw the commencement of the second generation of light water nuclear power plants in the United States. The increase in costs over those estimated in previous plants, led to the decision to counteract it using the scale factor. In this way, the former 300-600 MW rapidly passed to 800, 1000 and 1200 MW.

Completely in parallel with this new generation of nuclear plants, a rigorous regulatory process was developed, of which it is worth recalling some of the most important milestones:

- In 1969, the Atomic Energy Commission (AEC) published 10CFR50 Appendix B, "Quality Assurance Criteria for Nuclear Power Plants", introducing the new concept of Quality Assurance. The publication in 1972 of Safety Guide 1.28, establishing an acceptable method to implement this concept in engineering and construction, had a considerable impact on requierements, documentation and, in short, on the effort to be made in these areas of activity.
- In 1970, the AEC started publishing the Safety Guides, which were transformed into Regulatory Guides from 1975 when the Nuclear Regulatory Commission (NRC) was constituted.
- During these initial years of regulatory activity, a series of new requirements and criteria was introduced which had a big impact on projects, among which it is worth highlighting 10CFR50, App. k (ECCS), WASH-1270 (ATWS), Reg. Guide 1.75 (Physical Segregation of Electrical Systems), BTP 9.5-1 (Fire Protection), Reg. Guide 8.8 (ALARA), NUREG 588 (Environmental Qualification), and Reg. Guide 1.100 (Seismic Qualification of Electrical Equipment).
- In 1978, revision 3 of Regulatory Guide 1.70 was published, which susbstantially affected the structure and content of Safety Reports.
- The TMI accident in March 1979 had a considerable impact on different aspects of the standards applicable to nuclear power plants, originating new requirements that have been progressively appearing since 1980.

Plants contracted in the United States at the end of the '60s and throughout the '70s had to coexist with the process of development and revision of regulatory requirements. Other countries which, like Spain, designed and constructed nuclear power plants using USA basic technology were affected in a similar fashion.

The situation described could be considered as having a two-fold effect on facilities, one permanent and the other transient. The first refers to the physical and engineering aspects, while the latter is derived from the need to introduce changes into work already performed applying different criteria. As it is difficult to quantify both effects individually, an overall assessment seems preferable.

From the physical point of view, the evolution of safety regulations has affected new requirements for materials, structures, equipment and systems. The result is a considerable increase in the amount of work units –m^3 of concrete, reinforcement steel, structural steel, power cables, piping, etc.– as well as in the majority of the equipment-pumps, heat exchangers, valves, electric cabinets, control systems, etc. It is estimated that the units indicated have increased between 50 % and 100 %

since 1970. On the other hand, the unit price of equipment and materials and that of their installation have also suffered a substantial increase, derived from the greater difficulty experienced in fulfilling more rigorous conditions.

The influence on plant engineering is even more important. But it is worth pointing out that it basically refers to the engineering associated with the Balance of Plant (BOP). The basic engineering, included in the Nuclear Steam Supply System (NSSS), does not represent a significant volume and has not been affected to the same extent. The impact, therefore, has surprisingly been on the "outskirts", giving it considerable weight and importance in the development of the Project. Plant engineering –engineering and design, equipment procurement, field design, and plant startup support engineering– has risen, in the United States, from 1.7×10^6 m-h estimated in 1971 to 10.9×10^6 m-h during 1982-1983, according to the data bank of Ramesh N. Budwani, Burns and Roe, Inc., published periodically in the Power Engineering magazine. From our own experience in Spain, we have seen project engineering –engineering and design– grow from 800,000 m-h estimated in 1971, to around 5,000,000 recorded in recent projects. Moreover, it has been necessary to undertake with great detail the field design of very many structures and systems which was not formally required previously.

With respect to construction, the increased effort amply exceeds the percentages of increase in work units. According to R. N. Budwani, in the USA in 1970-1972, 5.3×10^6 m-h were estimated for direct work –craft– to construct a nuclear unit, a quantity that rose to $31{,}5 \times 10^6$ m-h in estimates for 1982-1983. Although the number of plants in Spain is not sufficient to be able to compare trends on a long-term basis, it may be concluded that we are progressing in the order of abolute magnitude recorded in the United States, though generally in the lower part of the range. It seems clear, therefore, that only a part of the increase in construction effort is due to a larger volume of work, while the rest is derived from considerably stricter performance requirements, and from modifications to work already performed as a consequence of the lack of stability in safety regulations.

Although, as indicated previously, there have been significant increases in practically all the activities necessary to develop a Nuclear Project, it is engineering and construction that have been largely affected. These two activities today have considerable weight within the Project. Moreover, it is from these that a proportionally greater induced effect is derived, since it is they that largely determine the schedule and, therefore, the total cost of the Project, through the great interest during construction amounts that have been registered in recent years.

CURRENT SITUATION

We therefore find ourselves faced with a situation that could be expressed as follows:

- We avail of light water reactor technology which is completely proven.
- A sustained increase has been recorded in the cost of these facilities from the time of the initial commercial applications to the present.
- The technology and its application has matured considerably. Nevertheless, there is no guarantee of stability in the safety regulatory process and even less in the rising trend in the cost of initial installation.
- Public opinion on the nuclear option nowadays is not generally favourable, giving rise to significant political and practical consequences.
- A certain temporary overcapacity is registered in the installed power and the price of hydrocarbons seem to have stabilized.

There are some factors inherent to nuclear energy, in its present state, with respect to which certain measures can be taken. On the other hand, there are others, related with the state of opinion and its effects, whose handling (if this exists), remains beyond the scope of any thecnical consideration.

One must necessarily start from what has already been done, both on an international level and in Spain, to fully apply the lessons learned while conserving all that has been positively achieved. Existing nuclear power plants should extend their operation as far as possible, and the next generation of plants should respond to identical technology, incorporating improvements derived from operating experience.

On the basis of the foregoing, we have acquired wide experience and are continuously gaining more to be able to improve the situation and reduce costs.

In the first place, a considerable effort should be made to stabilize regulatory requirements, establishing uniform safety criteria on an international level. It would be folly to say that the present situation should be handled with a totally different approach, but an overall review would be advisable to eliminate the consequences of a somewhat disorderly development.

The method of management for nuclear projects has been based on the system used for conventional power plants. This formula, which was justified at the outset, can no longer be maintained. The need to study, define, document, construct, test and licence, makes one reflect on the advisability of adopting very clear licensing schemes and highly elaborate procedures that are more fitting to industry than to construction and, in particular, similar –while respecting obvious differences– to those habitually applied in civil aviation. It is not possible to continue constructing nuclear power plants to measure; they have to be based on CERTIFIED DESIGNS that are easily adaptable to each case. The engineering cannot be performed completely in parallel with the construction, and construction procedures cannot be improvised. What is needed, therefore, is an efficient standardization process prometed by the electric utilities. Very professional, stable organizations are also essential, which are capable of maintaining and adapting the standard designs, and of studying, optimizing and directing the construction processes.

THE FUTURE

It seems clear that the only reasonable response to solving the problems that affect the nuclear industry is standardization. The maturity reached by light water technology permits us to consider that it is now possible to approach standardization in the design and construction of nuclear power plants with greater success than in the past.

The maturity of the technology permits us to think of greater stability in criteria and designs, without making its total immobilization either necessary or advisable. This signifies that standardization should be compatible with technologic evolution. Standard designs should therefore have limited validity, for periods of about 10 years. All nuclear power plants pertaining to a particular series, initiated during this period, would be completely adjusted to the standard design. After that period, a new, revised standard design would incorporate the improvements derived from previous experiences and technologic development, with validity for a new period of time.

The reduction in the number of plants to be constructed in the short –and medium– term prevents consideration of standardization at a national level by the majority of countries, even by those that are more industrialized. The example of standardization plans in France, Germany, Italy and the United Kingdom is most revealing. The little or non-existant rythm, with respect to the number of units to be constructed, hinders the complete application of the standardization concept. Only Japan, with its series of advanced light water plants –ABWR and APWR– seems to be able to benefit sufficiently from such standardization.

On the other hand, it should be noted that the United Kingdom, Italy and Japan use USA technology, although the safety criteria have undergone different modifications in each country. Consequently, none of the three designs would be licensable in the USA, or in any of the other two countries, without first undergoing an extensive process of revision which would largely invalidate the concept of standardization. In the case of Germany, reconciliation of the criteria would be even more difficult.

The ideal solution for this problem consists, logically, in the adoption of uniform safety criteria by all countries. In this respect, the IAEA's NUSS program makes an attempt in that direction, although the degree of development achieved is not sufficient. This ideal solution, therefore, is presently out of reach. Nevertheless, the establishment of collaboration agreements between groups of two, three or four countries exists for developing standardized designs that can be used by them all. In this way, one can reap the benefits of standardization without necessarily renouncing free competition, since it would be possible to participate in more than one project of this nature.

Although the advantages of standardization are well known, it might be worth while to briefly review those that are of more interest:

- *Optimization of Plant Design:* Derived from an in-depth study of alternative solutions, developed more in advance than usual in an ordinary project.
- *Improvement of Construction Process:* Study of the construction process and preparation of procedures, simultaneously with the plant design, permits rationalization of construction from the conceptual stage.
- *Standardization of Equipment and Components:* The process permits a certain amount of optimization and uniformity of equipment, within the need to be able to use supplies from alternative manufacturers.
- *Improvement in Quality:* Derived from the learning process and improvement in procedures through experience gained in successive projects in the series.
- *Reduction in the Project Execution Period:* As a consequence of using engineering information practically shelved since the beginning, as well as construction procedures optimized in other projects.
- *Reduction in Investment:* Practically all Project activities may be affected by a decrease in material investment. Moreover, considerable savings may be made in interests during construction as a result of the reduction in the project execution period.
- *Improvement in Plant Operation:* A collaboration agreement among several plants that pertain to standardized series may be mutually beneficial from the points of view of operating, maintenance and availability experience.

Standardization could give rise to some difficulties in formalizing the proposed international collaboration. Possible problems refer to the way effective agreements are established among the regulatory bodies and also among the electric utilities. However, when these obstacles are overcome, it could be an effective formula in getting nuclear energy to be a real option again in the near future, both in Spain and in many other countries.

So that this becomes a reality in Spain, thought should be given to the approach towards the first stages of a process that would necessarily be subject to some kind of active collaboration in one or more of the current experiences outside the country.