



# Refurbishment and Power uprating Costs of Spanish Nuclear Power Plants

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**ABSTRACT.** *Nuclear Power Plants have been in commercial operation in Spain since 1968 and provide at present almost one third of the electricity supply. The social and economic significance of the Spanish Nuclear Program has led the electric utility industry to design specific plans for the safe and reliable operation of the existing nuclear units in the coming years.*

*With due consideration to nuclear safety all units have been subject to refurbishment operations or plant modifications with the aim of ensuring not only the compliance with the requirements of the safety authorities, but also an environmentally friendly and more socially acceptable generating capacity based on solid economic grounds.*

*In this paper a brief description of the major refurbishment activities performed in the older units is given and a summary of the recent plant life management, plant life extension and power uprating programs is presented. Cost aspects and other economic considerations of the programs which are being implemented in the context of the current market liberalization policy are also shown.*

## 1. JOSÉ CABRERA NPP: THE SEP PROJECT

José Cabrera NPP was designed and built in the 60s. At that time the design of NPPs did not rely on a set of systematic and general acceptance criteria, as it happened later on after the introduction in 1971 of the general design criteria of Appendix A to 10CFR50.

During the first years of commercial operation, in the 70s, some improvements were introduced. These improvements were related to the new regulation, basically in the area of radwaste.

In this period also some modifications of greater scope were proposed in relation to the Emergency Core Cooling System and the Emergency Electricity Supply System.

In 1977 the U.S. Nuclear Regulatory Authority started a design review programme for the older NPPs. This programme was called S.E.P. (Systematic Evaluation Programme) and its objective was to identify the improvements that would need to be implemented in the first generation NPPs in order to adapt them to the new safety criteria.

1979 was the year of the Three Mile Island accident, which caused the enforcement of new safety criteria.

In this context the José Cabrera NPP Refurbishment Programme was initiated with the objective of updating its safety characteristics, incorporating new safety requirements resulting from the regulations and from the TMI accident. Other specific issues were also identified.

The Refurbishment Programme was oriented towards the fulfillment of criteria, guides and regulations in force at the time of its implementation, without trying to achieve the literal fulfillment of this regulation, but accepting derivations or alternatives which could be duly justified, because of the radiological cost of the regulation or because of the scarce safety improvements.

Deviations with respect to the regulations were considered to be justified in the following cases:

- When they did not mean a reduction in safety levels
- When there were systems unrelated to safety which could mean a support or enhancement of safety systems.
- When the surveillance programmes were amplified or intensified.
- When technical or administrative procedures which resulted in a greater reliability of the existing systems were implemented.

Those criteria, guides and regulations which had a greater impact from the point of view of safety were given priority.

The Refurbishment Programme was developed in three phases:

**Phase I** evaluated the safety status of the NPP. Its conclusions were presented to the Junta de Energía Nuclear (JEN) and to the Nuclear Safety Council (CSN).

**Phase II** was concerned with the design of modifications and improvements resulting from Phase I. It established a schedule for their implementation and for the introduction of those measures considered by the CSN as urgent.

Finally, **Phase III** was devoted to the implementation of modifications. It was done in two parts. The first one (Phase III A) took place between October 1982 and December 1983. The NPP operated then for a full cycle in order to shutdown in January 1985, when the second part was initiated (Phase III B). This second part lasted until October 1985.

Phase III A had a cost of 8.793 Million Pesetas and Phase III B of 6.551 Million Pesetas.

The main modifications were introduced in the following systems:

- Safety injection system (SIS)
- Component cooling water system (CCWS)
- Essential services water system (ESSWS)
- Component cooling water system (CCWS)
- Spent fuel pit cooling system (SFPCS)

- Overpressure protection system (OPS)
- Alternating current electrical system
- Instrumentation and control systems
- Fire protection system
- NPP documentation update

After completing the Refurbishment Programme, it is possible to say that José Cabrera NPP integrated the main design outlines and the safety philosophy of present-day NPPs, even when it did not fulfill literally the regulations.

The evaluation of the above modifications by the Safety Authorities (CSN) brought up some additional issues that had not been included in the established programme and which were required later. Among these issues were the following:

- Organizational improvements.
- New Organization Manual.
- Safe Shutdown study in case of fire.
- Follow-up of intergranular stress corrosion in the Steam Generators.

All these issues have been dealt with by the NPP and most of them have been considered closed by the CSN.

In this context, the CSN did not believe that there were any safety problems which required an immediate attention.

## **2. POWER UPGRADING OF THE SPANISH NPPs**

Increasing the electrical output of the nuclear power plants is of obvious economic interest for the Electricity Sector. The power increases currently contemplated amount to some 600 MWe for the period 1994-2003, over the 7,400 MWe installed, and further increases are foreseen as from that date.

It is estimated that somewhat more than half the 600 MWe foreseen may be obtained through moderate investments, as a result of which they will be highly competitive, while the remainder will require heavier investment, fundamentally in BOP equipment.

Furthermore, the electricity produced by such upgrading of the plants will have a relatively low cost in comparison with production by other energy sources. The investment associated with the foreseen upratings are, in terms of pesetas/kW, lower than or comparable to those corresponding to alternative means of generation. In addition, the variable production costs would be lower than those of such alternative means since, on the one hand, they would arise as a result of improved plant energy efficiency (there would be no appreciable increase in fuel, operation or maintenance costs) and, on the other, there would be higher burnup of a fuel whose cost is relatively low in comparison to the alternatives. As a result, upgrading the electrical output of the country's nuclear power plants would contribute to reducing the overall cost of the electricity generated.

As has been indicated above, two main paths are foreseen for plant uprating: increasing the thermal power of the nuclear reactor and replacing equipment in order to improve the performance of the non-nuclear part of the plant. The two are related, since no increase in reactor power will provide positive results unless the other plant equipment, for example the turbine or the alternator, is capable of handling it.

### **Power uprating through improved energy efficiency**

Increases in electrical output may be achieved by modifying or replacing equipment, thus improving the thermal output of the plant. The replacement of defective steam generators with others of a more modern design serving to improve the quality of the steam, along with that of turbines, feedwater heaters and reheater/moisture separator tube bundles for more efficient equipment, allows higher levels of output to be achieved from the alternator for the same nuclear power and fuel consumption.

Such upratings in electrical power require approval by the Ministry of Industry and Energy (MIE). They may be complemented by a plan for the optimization of on-site electricity consumption.

Other possible increases over and above those currently planned require more significant investments, and should be scheduled depending on the opportunities existing for such replacements (due to faults, loss of component efficiency or for other reasons).

It should be remembered that increasing rated electrical power has a special impact on the plant cooling system, and that in some plants this will mean the need to increase their capacity.

In designing the components (steam generators, turbines, heaters, etc.) for the modifications and replacements that are currently being performed at different plants, or to be performed in the near future, consideration is given to potential power upratings, the new equipment being specified for an additional capacity of between 5 and 15% of the original design.

### **Uprated reactor thermal power**

Increasing power output by uprating the reactor thermal power, following evaluation of the suitability and results of the corresponding feasibility studies, requires that a specific plan be developed for each plant. Generally speaking, this includes the performance of engineering and safety studies in relation to accident and transient analysis and to the analysis of fuel behavior, as well as the performance of certain specific analyses relating to the specification of new equipment (where applicable) and the modification of existing equipments.

All the above is subject to an authorization and licensing process which includes the drawing up of the report required for authorization of the corresponding modifications and revision of the Final Safety Analysis Report and Operating Technical Specifications. The reports must be submitted to the regulatory body responsible for nuclear matters (Nuclear Safety Council, CSN) and the MIE for approval and, where applicable, the recognition on the new electrical power level.

It should be pointed out that uprating the thermal power of existing reactors does not reduce the plant safety margins established in the original license, but rather that it is possible because of the better knowledge of nuclear reactor dynamics as a result of the continued R&D effort. Now more precise thermal-hydraulic, neutronic and mechanical parameters are incorporated into current calculation codes, which make more realistic (best estimate) predictions and verify the suitability of the available margins.

Consideration should also be given, when undertaking an uprating exercise, to possible synergies with other projects mapped out for the future or already under way at the plants. This analysis is important since there may be complex interfaces, new analyses or tasks common to the different projects, and their adequate scheduling may serve to avoid subsequent problems and extra costs. Among the examples of such other projects worthy of special mention are the reduction or elimination of plant scrams, the stretching out of operating cycles and the review of setpoints or analytical hypotheses.

### **Current situation and foreseen activities**

The interest of the Spanish NPPs in uprating is a fact that has been manifested for some time and which has already led to the performance of different feasibility studies and/or to the implementation of different progressive power increases at certain plants.

In 1988 a 2% nuclear boiling ratio (NBR) increase was licensed and implemented at Cofrentes NPP, a BWR originally rated at 975 MWe, which has since then been operating satisfactorily at the new power level (990 MWe). Gradual increases in electrical output have been obtained at the Vandellós II and Trillo plants as a result of improved thermal output of the installations and, in the latter case, also due to a redesign of the turbine. More specifically, Vandellós II NPP uprated from 992 MWe to 996 MWe in 1991, and subsequently to 1,004 MWe in 1992, and Trillo increased in 1992 from 1,041 MWe to its current level of 1,066 MWe.

Table 1 shows the uprating schedule that the Spanish NPPs have recently initiated or intend to implement in the near future.

It should also be taken into account that at present certain plants have not yet completed the feasibility studies corresponding to their intention to uprate nuclear power, or having already implemented equipment replacements or modifications, have either yet to carry out the tests required for establishment of their new definitive power level or are awaiting recognition of such tests by the MIE. In this respect, the forecast included in the aforementioned table may undergo deviations, in magnitude or date, due both to the final results of the studies and tests and to whatever effects might arise as a result of the future regulatory framework established for the Spanish electricity system.

### **3. NPP LIFE MANAGEMENT IN SPAIN**

The service life of Spanish NPPs has not been fixed and their remaining life will depend on their totally safe operation. The license to operate the plant granted by the Regulatory Body is open as far as its duration is concerned and can be renewed periodically.

Even when the main components of Spanish NPPs were designed for a life cycle of 40 years, studies on aging of critical components and experience, both national and international, show that the frequency and the severity of transients is less than those considered in the design. On the other hand, international experience, and the Spanish pilot projects, prove the technical feasibility of extending service life beyond 40 years.

In Spain the amortization period for NPPs has been 25 years until 1996. Starting in January 1997 the Protocol signed in December 1996 by the Electric utilities and the Ministry of Industry and Energy extended the amortization period for NPPs to 30 years.

After the signature of this Protocol a completely new scenario for electricity generation activities has been created. The Protocol established a 10 year transient period (1998-2008) before the electric utility industry is totally liberalized.

Figure 1 shows the end of the 30 year amortization period and its relation with the 10 year transient period established in the Electricity Protocol.

During this transient period, for those NPP which are not totally amortized, the Protocol admits 67.5% of sunk costs. With respect to the previous regulatory framework this means an important reduction in revenue. On the other hand, it guarantees the recovery of the initial investment, even when the return on that investment decreases.

The economic viability of NPPs is guaranteed during the transient period, but the pressure to reduce generation costs is going to be strong and that will affect the investments to be made during this period.

With a 25 year amortization period, at the end of the transient period established in the Protocol (year 2008) many of the Spanish units will be totally amortized (José Cabrera, Garoña; Almaraz I and II, and Ascó I) and two more (Cofrentes and Ascó II) will be almost amortized. This means that approximately one half of the nuclear generating capacity will be amortized and the investment costs of these units will only be corresponding to the new investments required to extend their service life.

In the period 2008-2013 the competitiveness will vary substantially from some units to others. Those which are totally amortized will be very competitive and those which are not will have some difficulties. Beyond 2013, all units will be in an excellent competitive position. If the amortization period is extended to 30 years this advantageous position will be postponed for the more modern units.

In spite of all the uncertainties around the future market for electricity it can be said that at the end of the transient period NPPs will be in an advantageous position with respect to other energy sources and very advantageous 5 years thereafter. There is an important economic incentive to extend the service life of Spanish NPPs.

### **Position of the Regulatory Authority**

Contrary to the United States practice, in Spain the license to operate a nuclear unit is open as far as its duration is concerned. Therefore, there are no legal restrictions to extend service life beyond 40 years by means of granting successive operation permits.

The Spanish Safety Authority (CSN) has required from all NPPs an Aging Management Plan for main components.

The current processes of continuous evaluation and periodic safety review will allow the Operation Permit to be renewed for a given period until the 40 years of service are reached.

The periodic safety review which requests the extension of the service life beyond 40 years should include an evaluation of those components whose life is limited to 40 years, justifying its qualification for a longer period.

The methods of analysis to justify this life extension have not been established yet.

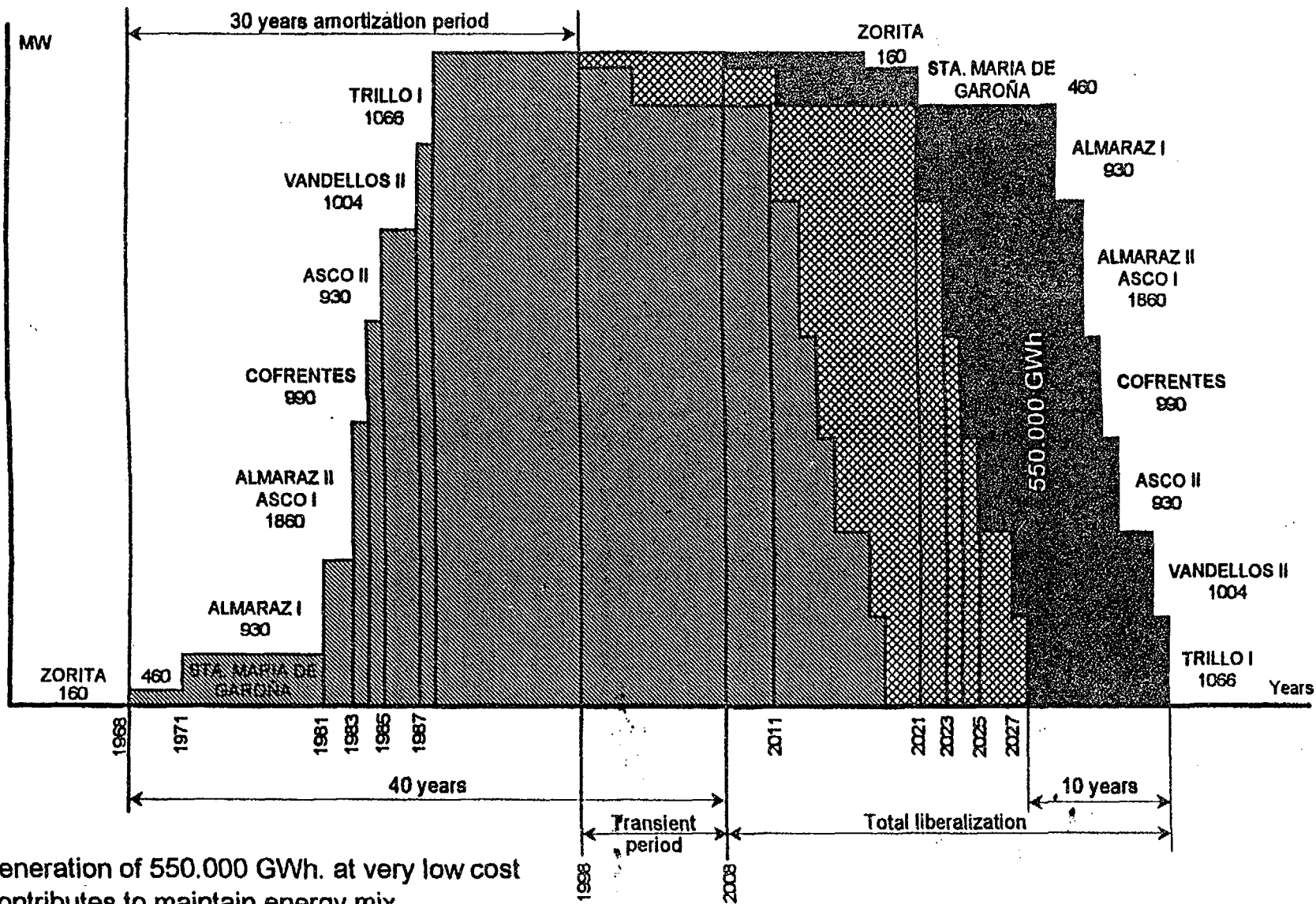
**TABLE 1**

**POWER UPRATING PLANS FOR SPANISH NUCLEAR POWER PLANTS**

Year	Date	NPP (-unit)	Initial power (MWe)	Foreseen power increase (MWe)	Reason
1994					
1995	Oct-95	Ascó-1	930	17	LP turbine change and improved steam quality due to new SGs.
1996	Apr-96	Vandellós II	1,004	5	Feedwater control valve replacement and reduction in secondary side losses.
	Sep-96	Almaraz-1	930	53	HP and LP turbine replacement and improvement steam quality due to new SGs.
	Oct-96	Ascó-2	930	38	HP and LP turbine replacement and improvement steam quality due to new SGs.
1997	Apr-97	Ascó-1	947	21	LP turbine replacement
	Jun-97	Almaraz-2	930	53	HP and LP turbine replacement and improvement steam quality due to new SGs.
	3 <sup>rd</sup> Q-97	Cofrentes	990	35	Reactor power increase to 105% and MSR improvements
1998					
1999	Apr-99	Vandellós II	1,009	35	HP and LP turbine replacement
	Sep-99	Ascó-2	968	52	Increase in reactor power to 104,5%
2000	Mar-00	Ascó-1	968	52	Increase in reactor power to 108%
	Apr-00	Almaraz-2	983	57	Increase in reactor power to 108%
	3 <sup>rd</sup> Q -00	Cofrentes	1,025	15	Increase in reactor power to 115%
2001	Mar-01	Almaraz-1	983	57	Increase in reactor power to 108%
	2001	Cofrentes	1,040	27	Increase in reactor power 3%/year up to 1120 MWe.
2002	2002	Cofrentes	1,067	27	(See previous reason)
2003	2003	Cofrentes	1,094	26	(See previous reason)
2010	2010	Cofrentes	1,120	50	TG set change (LP turbines and alternator)

FIGURE 1

**LIFE EXTENSION**



- Generation of 550.000 GWh. at very low cost
- Contributes to maintain energy mix