COFRENTES NPP POWER UPRATE TO 110%

IBERINCO ENGINEERING EQUIPMENT

The continuous search for improved profitability of nuclear power plants has led a large number of plants to undertake Power Uprate (PU) projects, either in the modality of increases based on fewer measurement uncertainties (increases of around 1.4% to 1.7%) or of increases of expanded power (of up to 5%) and/or extended power (of more than 5%).

At present, more than one hundred American and European plants have completed power uprates ranging from 1% of Original Thermal Power (OTP) to values of 20% OTP. Another fifty plants around the world are in the process of executing or plan to execute uprates in the next four years.

Cofrentes NPP has been one of the plants that has most decisively undertaken Power Uprates projects, as in the last fifteen years it has completed three successive uprates; it licensed 102% in 1988, 104.2% in 1998 and 110% OTP (1081 MWe) in 2002. The CSN is currently evaluating the license proposal for the Flow Adjustment Power Uprate – "APAC" (1096 MWe) – based on reduced uncertainty in the feedwater flow measurement for calculating the generated thermal power.

This article describes the process followed in Cofrentes NPP for the Extended Power Uprate to 110% OTP. It describes everything from the methodology used, analyses performed, required modifications, resources employed and licensing process, to the most significant results obtained during the project.

PROCESS

The purpose of thermal power uprates in nuclear power plants is to take utmost advantage of the capacities inherent in their original design, making use of the wide margins of conservatism with which the systems, equipment and components (SEC) are designed.

Progressive power uprates can be achieved with investments ranging from one million euros to more than 60 million euros, and their profitability can be fully justified.

Implementation of a PU first requires a permit from the Regulatory Body and, depending on the power level pursued, the process may require modification and/or replacement of certain systems or equipment whose original design does not cover the new requested level of power.

From the standpoint of execution, a general PU process involves four sequential phases, the results of which are reflected in the following products (see figure 1):

- Technical and Economic Viability Studies: for determining if the PU is technically viable and at what cost/benefit it can be achieved.
- Detailed evaluation and project modifications: this includes a detailed study of the system, equipment and component capacity needed to operate under PU conditions, as well as specification of required equipment and system modifications.
- Licensing Report: a report is drawn up that discusses and describes the conclusions that, together with the proposed modifications of the Technical Operation Specifications and of the Final Safety Assessment, justify and support the License Application for the new power.
- Implementation of modifications, actual in-plant tests and final approval: after a favorable judgment of the license application by the Regulatory Body, i.e. the Consejo de Seguridad Nuclear (CSN), and implementation of the required modifications, the plant is subjected to specific startup tests to verify correct operation and response of the plant under PU conditions. Once it is demonstrated that these tests are satisfactory and after the obligatory final approval of the CSN, the plant begins to operate at the new licensed power.

The following sections provide a detailed description of the scope of each of these phases.

VIABILITY ANALYSIS

Viability studies are developed from two different though complementary perspectives: technical and economic.

The purpose of technical viability studies is to identify the more important SEC limitations, as well as any SEC modifications that would have to be made in connection with two power uprate alternatives – PU 110% and PU

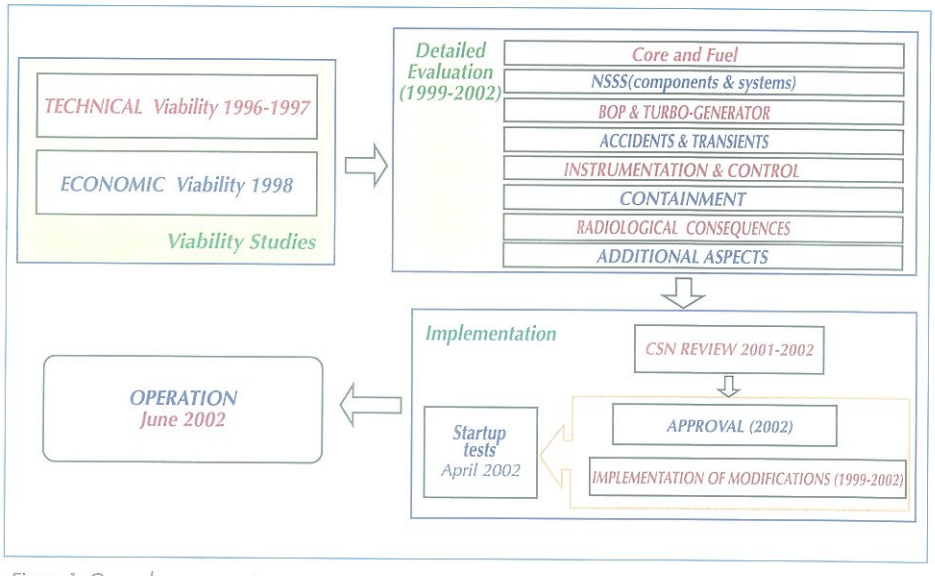


Figure 1. General power uprate process.

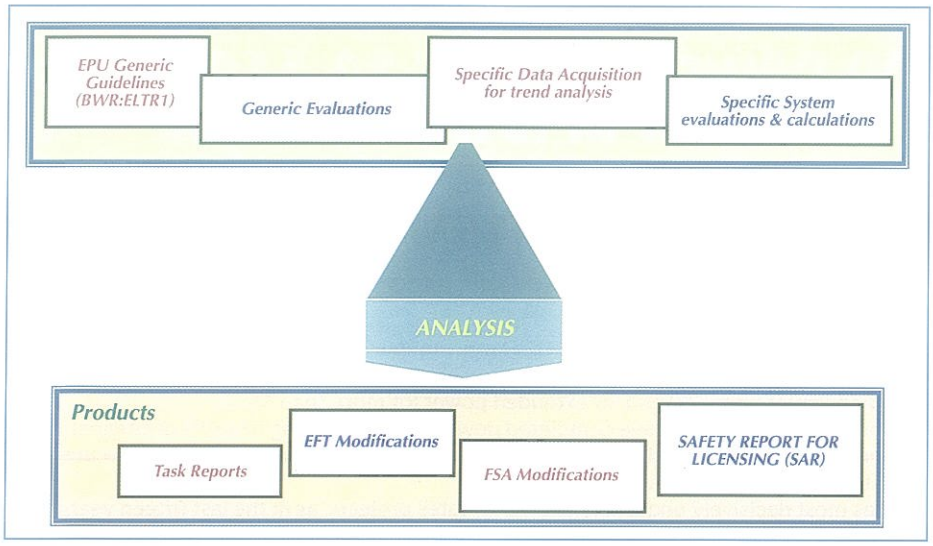


Figure 2. Detailed assessment process.

115% – so that an economic study for each of these alternatives can subsequently be performed.

After the technical viability study is completed and once the required modifications are determined, the required investments are assessed, the operating costs associated with the resulting kW-h are calculated and, based on these data, the economic parameters – VAN (Current Net Value) and TIR (Internal Return Rate) – are determined for each potential alternative.

As a result of the technical-economic study performed by Cofrentes NPP, it was concluded that the 110% Power Uprate option was the one that best satisfied the profitability and technical viability criteria required by IBERDROLA. The resulting economic parameters were: VAN, 40 M€; TIR, 21%; Cost per kW installed, 390 M€; Electric Power Uprate, 52 MWe.

DETAILED ANALYSIS

After the technical-economic viability studies were completed and EPU profitability was assessed, the detailed analysis phase was begun.

The purpose of this analysis is to try to confirm the results predicted in the viability study phase. This involves a detailed study of the capacity of NSSS, BOP and Turbo-Generator systems, equipment and components affected by the EPU.

Studies were carried out for a power of 3,250 MWt (112.2% OTP), always maintaining margins greater than those required for the target licensed power (110% OTP). In addition, for those studies that require a specific evaluation of the licensed power, the calculations are made for 110% power (3,184 MWt).

From the standpoint of methodology, the Cofrentes NPP EPU project has been based on the methodology established in General Electric's (GE's) generic guidelines for BWR reactors approved by the U.S. Regulatory Body (NRC). The study scopes of this project, the methodology of which was subject to approval by the Regulatory Body, were structured so that development times could be established in a way that would ensure that the information that was eventually provided to the CSN with the license application would coincide with the information required by this body to pass judgment on the PU.

As for the organizations involved in this detailed analysis phase, the project has been directed and coordinated by Iberdrola Ingeniería y Consultoría (IBERINCO), with the participation of both national (IBERINCO, EEAA, TSI, SERLED, etc.) and foreign (General Electric, ABB, EPPG, ESG, etc.) engineering firms.

In particular, the most significant participants have been General Electric (GE), which focused on the NSSS- and containment-related studies, and IBERINCO, which performed all BOP-related studies and reviewed and approved the NSSS, containment and other project studies.

Following is a description, by areas of development, of the scopes and results obtained from the detailed systems analysis, the general process of which is shown in figure 2.

FUEL, ACCIDENTS AND TRANSIENTS

The fuel safety design and assessment for the 110% EPU was performed by using the methods and procedures included in the GIRALDA methodology approved by the Consejo de Seguridad Nuclear.

Based on a definition of the power-flow operating map and the heat balance under rated conditions, the following evaluations were performed:

- Reactor heat balances under non-rated conditions.
- Fuel and core performance.
- Thermohydraulic stability.
- Emergency Core Cooling Systems Capacity.
- Transient analysis.
- ATWS analysis.

A generic evaluation of Cofrentes NPP core performance under extended power conditions was done for a representative core under conditions of equilibrium cycle of GE-14 type fuel assemblies, at a power of 3,250 MWt and a pressure of 1,070 psia at the pressure vessel dome. It should be noted that the analysis pressure used is the same as under conditions prior to the 110% EPU, which reduce the number of analyses.

Fuel and Core Design

For the 110% EPU core performance evaluation, very demanding core design conditions have been established so that the core analyzed under the new operating conditions covers the possible range of operations that may be present during the actual cycles.

To be able to satisfy the requirements imposed on the core, it was necessary to revise the load maps that are traditionally used in Cofrentes NPP cores and also use new fuel assembly designs, with enrichments and Gadolinium content that make it possible to achieve the necessary cycle length on one hand and on the other provide the desired operating flexibility.

Stability

Cofrentes NPP has adopted a long-term solution called "E1A" for controlling reactor stability. This solution consists of a definition of the exclusion regions (ER), restriction regions (RR) and monitoring regions (MR) associated with a instability detection system.

The regions are affected by changes in operating conditions and by changes in the plant or fuel resulting from the power uprate. The generic regions have been recalculated for the power uprate conditions of the 110% EPU,

with the conclusion that the instability detection system is not affected by this EPU.

Emergency Core Cooling Systems Capacity (ECCS-LOCA)

The analyses performed to confirm ECCS capacity calculate the maximum cladding temperature of the fuel assembly rods during a LOCA caused by a break of any of the pipes connected to the reactor vessel, considering the locations and sizes of the most unfavorable breaks.

The temperatures reached allow for a considerable margin up to 2,200 °F (1,478 K), which is the limit established in 10CFR 50.46. The results obtained from the thermo-mechanical analysis show that the established limits for cladding oxidation, hydrogen generation, coolable geometry and long-term cooling are met.

Thus it is concluded that ECCS capacity with the current Cofrentes NPP design is justified under 110% EPU operating conditions.

Reactor Transients

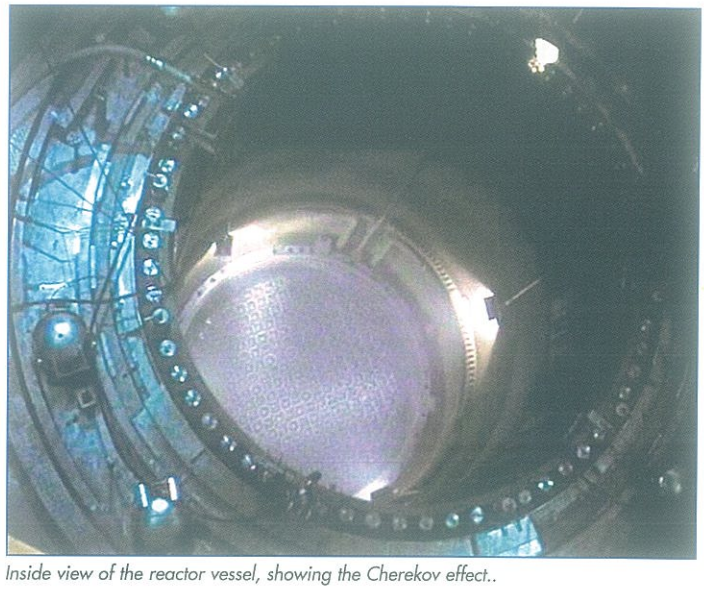
The operating limits ensure that the safety limits are not exceeded in a postulated range of events. The generic studies of thermal limits have been performed with the core of a equilibrium cycle composed of GE-14 fuel, and some conservative requirements have been imposed on this core to cover the conditions that could arise during the actual cycles in the new extended power situation of the 110% EPU. The most limiting transients have been analyzed for each category of transients.

In accordance with the results, it is concluded that the extended power condition of the 110% EPU does not result in any change in the basic characteristics of any of the limiting events; the initial conditions and transients that determine the most conservative operating conditions are not modified.

Anticipated Transients Without Scram (ATWS)

The acceptability of ATWS sequences in Cofrentes NPP under 110% EPU conditions has been verified by analyzing the most limiting ATWS sequences. System performance and operator actions considered in the analyses are based on the indications contained in the Cofrentes NPP Emergency Operation Procedures.

The results show that the most limiting values, for both the vessel overpressure criterion and the fuel and containment conditions, do not exceed any of the acceptance limits of these sequences.



Inside view of the reactor vessel, showing the Cherekov effect..

MECHANICAL SYSTEMS

Safety-related and non-safety related aspects of Cofrentes NPP equipment and systems have been assessed to determine which of them were affected by the power uprate and, in both cases, determine if they were acceptable for the new operating conditions or if they required modification or replacement.

The data acquisition campaigns at different power levels have been fundamental elements for these analyses. These, together with the plant simulation and calculation programs, have been used to confirm the capacity of systems and equipment with their adequate margins or, if necessary, to specify the requirements of equipment to be modified for safely operating at the new power level in accordance with existing design bases.

As a general criterion of project development for the different areas, the evaluations have been performed for a power of 112.3% OTP and, when any modification was needed, this has been specified at least for conditions at 115% OTP.

The main evaluations performed in the mechanical area are as follows:

- Reactor and connected systems (overpressure protection, reactor vessel and internals, primary circuit systems and materials).
- Engineered safety feature systems (primary Containment response to accidents, emergency systems).
- Auxiliary systems (spent fuel storage, component cooling, final heat sump, HVAC, PCI).
- Energy conversions systems (condensate and feedwater, main steam, turbine exhausts and bypass, heater drainage).

The main modifications made in the mechanical area are as follows:

- Main high-pressure turbine: machining of the diaphragms of the first three stages, in order to extend the steam feedthrough capacity.
- Essential service water system pump and motor replacement: increase flow by 11%.
- Replacement of final heat sump sprinklers with newly designed sprinklers, which increase the heat exchange capacity and ensure more than 1 °C margin with respect to the design maximum of 35°C under LOCA conditions.
- Replacement of the three heater drain pumps with new higher-capacity pumps, and replacement of eight level control valves in this system.
- Replacement of the plant's service water pumps (increasing their capacity), and replacement of the cooling tower fans and tower filler, which has decreased the maximum system temperature to 26 °C.
- Increased Boron concentration in the standby liquid control system storage tank.

Prior to the power uprate to 110% OTP, a series of modifications had already been made that, as they had been specified for values of around 115% OTP, have helped considerably to achieve the new power level. These modifications include optimization of the cold focus, replacement of the four condenser tube bundles with new ones made of titanium tubes, upgraded filler of the natural draft towers, replacement of the circulation water pump drivers, replacement of the MSR tube bundles and moisture separators and, finally, replacement of the feedwater pump turbine rotors.

TURBO-GENERATOR

On occasion of the thermal power uprate in Cofrentes NPP to 110% OTP, the turbo-generator equipment supplier

advised that the high-pressure turbine rotor would have to be replaced or modified in order to make way for the increased steam flow produced under 110% EPU conditions, at a pressure of 1070 psia in the vessel dome and with the same dynamic control margin.

For the option of modifying the high-pressure rotor, the supplier indicated that the moving blades of the first three stages would have to be modified. Although the cost of this modification was approximately 60% of the cost involved in completely replacing the rotor, it was not considered as an economically attractive option because the increased efficiency it would provide was insignificant.

To confirm the validity of the recommendations and assess the most profitable option, Cofrentes NPP decided to check the real maximum capacity of the high-pressure turbine. To do so, it carried out a test that involved reducing the main steam heating flow at the 2nd reheater stage and then increasing the main steam flow at the intake of the high-pressure turbine. During the test, choking was continued until the moment when the turbine bypass to the condenser began to open, which is the moment that marks the maximum intake capacity of the high-pressure turbine (for the pressure existing at that moment at the turbine inlet).

The test results demonstrated that the high-pressure turbine had a greater capacity than the one initially deduced from GE's theoretical studies. This meant that the high-pressure turbine could accommodate the flow at 110% OTP (if, at the same time, an adequate control margin was maintained) by making some modifications of a much lesser scope than the rotor replacement and costing approximately 8% of the cost of a new rotor.

The high-pressure turbine steam path modifications that were finally made consisted of an approximately 10% increase in the feedthrough section of the first three diaphragm stages, which were completed by GE during the refueling in March 2002.

On the other hand, as part of the 110% EPU project, an exhaustive study of the main generator and its auxiliary cooling systems has been carried out. The study concludes that the generator has the capacity to operate under the new power conditions at 110% OTP. A new power map was prepared as part of the project that will permit operation up to an apparent power of 1,117 MVA.

Although not strictly motivated by the 110% EPU, the generator coil water control was upgraded to improve signaling and include it in the distributed control system.

Installation maneuver of one of the new Essential Service Water pumps.

ELECTRICAL SYSTEMS

All electrical systems affected either by increased production of electric power, or else by an increase in required internal consumption, under the new 110% EPU conditions have been evaluated.

It was concluded from the evaluation of the plant's energy systems that the Isolated Phase bars, Generation Switch, Main Transformers and all associated equipment are adequate for correct operation under the new 110% EPU conditions.

As regards evaluation of the internal energy systems and owing to the mechanical system changes described above, it was necessary to change the plant's essential service water system and service water pumps. The plant's internal electric systems, including the energy distribution systems, batteries and emergency diesel generators, were evaluated by accounting for all new consumptions, and it was concluded that the existing equipment ensures correct plant operation.

The Generator and auxiliary system evaluation determined that this equipment meets all requirements necessary for operation under 110% EPU conditions, provided that the power factor is not lower than 0.97.

In addition, it has been confirmed that the 110% EPU will not have any significant impact on grid stability.

INSTRUMENTATION & CONTROL SYSTEMS

All changes in process variables owing to the new 110% EPU conditions have been evaluated in order to identify any changes required in the control parameters, calibration ranges or setpoints of NSSS and BOP system instrumentation.

The plant instrumentation and control system analysis concluded that the reactor thermal power uprate only affects the following setpoints:

- Neutronic Monitoring System APRM measurement range.
- Isolation of main steam lines due to high steam flow.
- Actuation of the Reactor Protection System due to high neutronic flux, high neutronic flux simulated as a function of flow ,and high neutronic flux during startup.
- Blocking of control rod extraction due to high neutronic flux simulated as a function of flow, low scale, and high neutronic flux during startup.

As for setpoints, they were calculated using GE's own NRC-approved methodology and, at the same time, they were adjusted to maintain operating margins similar to the existing ones and also to ensure they would correctly fulfill their safety function under 110% EPU conditions.

On the other hand, the measurement range of the Neutronic Monitoring System APRMs also had to be modified, extending the existing 125% range up to the 150% required for 110% EPU conditions.

RADIOLOGICAL PROTECTION

The following evaluations have been performed in the Radiological Protection area:

- Analysis of radioactive effluent emissions through the liquid waste treatment system and gaseous effluent treatment system.
- Analysis of the radiological consequences to the population's Critical Individual, IC, due to radioactive liquid and gaseous effluents released to the exterior during normal operation, and calculation of analytical limits (and setpoints) of radiation monitors included in the MCDE, which form the monitoring

system for these effluents during normal operation.

- Evaluation of radiation sources present in the reactor core and coolant, as well as in-plant radiation levels during normal operation, refueling and post-accident.
- Analysis of the radiological consequences of Design Base Accidents, DBA.

The radiological analysis of radioactive effluent emissions (using the methodology and guidelines described in NUREG-0016) has concluded that the radioactivity released to the atmosphere due to effluent emission under 110% EPU conditions does not undergo any significant variations. In the case of liquid effluents, the variation is always less than 10% of the values corresponding to rated power, and the variation for gaseous effluents is insignificant.

The evaluation of Critical Individual doses, performed with the methodology of Regulatory Guide 1.109 and the new standards of the 2001 RPSRI, shows that the extended power uprate to 110% represents a 1.7% effective dose increase for the "adult" and "child" groups, whereas for the "infant" group it involves a 2.2% increase. In either case, the doses obtained for the 110% EPU continue to be well below the established limits.

The setpoints of the effluent monitors stay practically constant, although they have been adjusted to ensure that alarm/trip occurs before the radiological criteria specified for Cofrentes NPP are exceeded.

The reactor core inventory evaluation (using code ORIGEN2.1) has confirmed that the radioactivity of core fission products increases by approximately 5% with respect to the activity corresponding to power at 104.2% OTP. With this inventory, the radiological consequences of a DBA accident resulting in fuel damage (LOCA, FUHA, CRDA) have been analyzed, and the results show that the doses for these accidents represent an increase of around 5% with respect to the values corresponding to 104.2% OTP. The dose values obtained in the exclusion zone, low population zone and control room continue to be below the values indicated in applicable standards (10CFR100 and 10CFR50).

TESTS

The acceptance tests for the Extended Power Uprate to 110% have been specifically established for Cofrentes NPP. Most of the 110% EPU acceptance tests are included in the EFS, section 14.2.12.3, and other tests and additional data that have emerged either as an explicit requirement of the Consejo de Seguridad Nuclear or else at Cofrentes NPP's own initiative have been performed and acquired.

The acceptance tests can be classified in two groups:

- Tests to verify that control systems behave in a stable manner in the face of transients established in the testing procedures for the power uprate conditions (variations in reactor vessel level and pressure, and variations in feedwater flow).
- Tests to confirm operation and acceptability of certain safety-related systems (essential service water system (P40) test, full closure of all MSIV, emergency diesel generator test, etc.).

In addition, certain specific operating data were compiled in order to compare them with previous plant conditions (vibrations in main steam and feedwater piping, electrical equipment operation, radiation measurements, cooling water chemistry, etc.).

The 110% EPU tests were developed, in some cases, by using already existent testing procedures, and in others cases with procedures specifically issued and approved for the 110% EPU startup tests.

For execution, the test program for the power uprate to 110% was implemented in five (5) power stages (test conditions), where the last test condition corresponded to the value of the new thermal power (3,184 MWt) to be licensed.

The following is concluded from the results of tests performed between March and April, 2001:

- All plant systems behave in a stable manner during plant startup and subsequent testing.
- The tests of vessel level and pressure control system transients were successfully completed.
- The safety-related system tests were successfully completed, and the acceptance criteria of these tests were satisfactorily met.
- After reaching the thermal power corresponding to 110% OTP (3184 MWt), Cofrentes NPP operated satisfactorily and without interruption for approximately three consecutive days.

General view of the rotor of one of the Low-Pressure Turbines.

The specific operating data at 110% were acquired during this period.

The satisfactory test results and correct system and equipment operation, as deduced from the values recorded during data acquisition, confirm and justify the safe and stable operation of Cofrentes NPP at the new thermal power of 110%.

SAFETY

The main task of the Safety and Licensing Area in the 110% EPU project was to prepare technical support documents for the license application submitted to the Ministry of the Economy's General Directorship for Energy Policy and Mines. This documentation included the following:

- Safety Assessment (SA) Report containing the main evaluations made and their conclusions. The structure and contents of this assessment follow the model of General Electric's generic document approved by the NRC for extended power uprate licensing reports.
- Proposed modification of the Technical Operation Specifications (ETF). The most relevant changes in the ETF are as follows:
- Modification of the pressure-temperature limit curves for the vessel, which have been developed on the basis of ASME Code Cases N588 and N640.
- Modifications stemming from the results of the Primary Containment response evaluation and hypotheses used in this evaluation (leak test pressure, etc.).
- Modification of admissible values and setpoints of affected instrumentation (averaged power range monitors, radioactive effluent radiation monitors, and isolation of MSIVs due to high steam flow).

• Modifications stemming from the new boron concentration required in the core for reaching and maintaining safe shutdown.

• Modification of the maximum mean temperature allowed for Final Heat Sump water (UHS).

• Proposed modification of the Final Safety Assessment (FSA). The above mentioned Final Safety Report has been included in the FSA as Appendix 15H, in order to provide an historical record of the safety assessment made in relation to the 110% EPU.

On the other hand, the evaluation of licensing requirements applicable to Cofrentes NPP has concluded that all analyzed rules and regulations (national, NRC and industry regulations) are generically met, or otherwise it has been determined that they are either met in the different specific evaluations performed in each area or else they are not affected by the 110% EPU.

In addition, other evaluations have been performed to analyze the impact of the 110% EPU on the following areas: Probabilistic Safety Assessment (PSA), Emergency Operation Procedures and Severe Accident Guidelines (EOP/SAG), human factors and operator training, safe shutdown capacity in the event of fire, and conformance with Appendix R of 10 CFR 50, total Alternating Current Loss (SBO), and environmental impact.

SOME SIGNIFICANT DATA

Throughout the four phases of development described above, numerous human and material resources were used. The appraisal, tracking and control of these resources are critical aspects for successful completion of a project such as this one. Following is a description of the most important organizational aspects.

• Referring first to logistics, it should be remembered that this kind of project generates an enormous amount of documentation. To give some examples, more than 15,000 computer files (3.5 Gigabytes) were generated, more than 3,200 e-mails were exchanged, more than 5,000 inputs/outputs were recorded, and more than 1,500 project documents were produced.

• As for engineering firms, both national (IBERINCO, EEAA, TSI, SERLED, etc.) and foreign (GE, ABB, ESG, EPPG, etc.) firms took part and accounted for a major portion of the project's economic budget, since this was an engineering-intensive project in terms of investment in new equipment. It should be noted that the intervention of different engineering firms requires careful coordination and control of project activities. In addition, a large number of resources were consumed in reviewing and controlling work done by the foreign engineering firms.

• As regards the Licensing process, the clarification and resolution of comments resulting from the Regulatory Body's review process took nearly 16 months. During this period, 32 official requests for additional and/or complementary information were generated and 11 inspections/audits performed.

Throughout the whole process, there was a climate of utmost transparency and collaboration both by the CSN and by people from Cofrentes NPP and Iberinco involved in the licensing process, which is highly appreciated.

• As for activity programming, the project as a whole (4 phases) was carried out during the period between 1996 and June 2002. After completing the viability studies in 1998, the detailed analysis was performed during the following two years. Design modifications (OCPS) were implemented on a continuous basis, but especially during the outages for refuelings 12 (October 2000) and 13 (March 2002). The required licensing application reports were submitted to the CSN in late 2000, the preliminary permit was obtained in March 2002 and, after the mandatory tests were completed in April 2002, the final permit for operation at 110% OTP was obtained in June 2002.

OTHER ADVANTAGES OF THE 110% EPU

Additional advantages of the Cofrentes NPP power uprate to 110% include the following:

• The project has included the upgrading of a good number of plant equipment, which serves to support life management and value maintenance of the plant's assets.

• It has involved a complete design review with the new codes, methodologies and tests performed, which have confirmed that suitable design margins are being maintained in conformance with license requirements.

• The project has helped to acquire a more thorough knowledge of the plant by identifying its critical systems, equipment and components.

• A project of this nature greatly motivates all taskforces involved in it, from Engineering to Operation and Maintenance and up to the very plant management, as interaction on a large scale is required to resolve the multiple interfaces, address issues that arise during development, successfully meet scheduled deadlines and achieve the expected results.

CONCLUSIONS

The most significant conclusion of the Cofrentes 110% EPU project is that its execution has succeeded in increasing the plant's productive capacity by some 52 MWe, with a very competitive cost of some 390€ per installed kW and a 21% return on investment.

To execute this project, activities have been developed during the last seven years that have required the participation of both national and foreign engineering firms.

Design modifications have been implemented in order to meet 110% operating conditions. The most significant modifications are the ones that affect the BOP and, in particular, extension of the high-pressure turbine capacity. In addition, the mandatory operating tests have been performed, including consideration of major transients, and the results of these have led to a favorable judgment by the CSN.

The licensing process was developed over 16 months, culminating in final approval on June 12, 2002.

Since June 13, 2002, Cofrentes NPP is operating at 110% with fully satisfactory results, in keeping with predictions considered in the 110% EPU project.

Finally, it should be noted that the Cofrentes NPP 2003-2007 strategic plan addresses an evaluation and, if appropriate, development of a subsequent power uprate to 120% OTP.

Members of IBERINCO engineering equipment.