LAGUNA VERDE NUCLEAR POWER PLANT: AN EXPERIENCE TO CONSIDER IN ADVANCED BWR DESIGN

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Abstract

Laguna Verde is a BWR 5 containment Mark II. Designed by GE, two external re-circulation loops, each of them having two speed re-circulation pump and a flow control valve to define the drive flow and consequently the total core flow an power control by total core flow. Laguna Verde Design and operational experience has shown some insights to be considering in design for advanced BRW reactors in order to improve the potential of nuclear power plants. NSSS and Balance of plant design, codes used to perform nuclear core design, margins derived from engineering judgment, at the time Laguna Verde designed and constructed had conducted to have a plant with an operational license, generating with a very good performance and availability. Nevertheless, some design characteristics and operational experience have shown that potential improvements or areas of opportunity shall be focused in the advanced BWR design. Computer codes used to design the nuclear core have been evolved relatively fast. The computers are faster and powerful than those used during the design process, also instrumentation and control are becoming part of this amazing technical evolution in the industry. The Laguna Verde experience is the subject to share in this paper.

1. INTRODUCTION

Laguna Verde Unit One began commercial operation in 1990 about fourteen years after the original design was developed.

During this period many changes happened in the nuclear industry that were incorporated in Laguna Verde design and operational philosophy. The line of production of the fuel design of the first core was out of production. The first reload was designed with new fuel design that was commercially available in the industry at that spot in time. New load strategies were developed in the industry that change the control rod pattern interchange, this means the control cell core (CCC), the spectral shift was also adopted to improve the fuel bum up efficiency, the total core flow window to operate at full power was introduced, the window includes a range from 87% to 107% rated core flow, this means an extension of the power flow map was adopted by using ELLLA and ICF. In order to satisfy the power demand the availability of each unit were increased and the fuel cycle length were extended from 12 to 18 months, including operational flexibilities such as cycle coast-down. Such changes require an increase in the design power density for the reloads, this implies a complication in satisfying thermal limits, hot excess reactivity and shutdown margin, even the fuel exposure limit was a restriction for reload design, considering the energy expectations, the reload design process required more advanced fuel design.

A power up-rate process was implemented for both units that were operating commercially at 1931 MW·th , to increase up to 2027 MW·th . This process was an opportunity to have, not only a higher capacity but to update the plant design using more advanced computer codes and methodologies than those used in the original design process.

The introduction of operational flexibilities and new design characteristics are demanding changes in the knowledge, skills and procedures that operator must have, including the operation in an extended power flow map related to the original design of the power flow map.

2. OPERATIONAL FLEXIBILITIES

2.1. ELLLA

Among the first set of operational flexibilities introduced in the Laguna Verde Nuclear Power station we found the extension of the power flow map by using ELLLA, this operational flexibility introduces a lower limit in the total core flow window, used to operate at full power. This mode of operations requires besides changes in the license including technical specifications changes, specific operators training. The lower limit of 87% rated core flow requires partial closure of the re-circulation flow control valve. This closure of the flow control valve has at least two consequences, the first one is related to the increase in the turbulences in the re-circulation pipes and fittings downstream of the control flow valves that shall face different conditions than those assumed in the original design process. The turbulent flow induced vibrations are generating an unexpected performance in the re-circulation system, drain pipes attached to the valves were broken and their design has to be modified, isolation valves downstream of the flow control valves were showing an unexpected performance with degradation in such way that the unit has to be dated during the final part of the fuel cycle, the design change in the isolation valves of the recirculation system was also introduced.

The second consequence is related to the status change in the operational alarms in the control room panels. The original design did not take into consideration during normal operation at full power the presence of alarms such as rod block alarm, that was originated in operation at the lower limit of the total core flow window and full power, this alarm is derived from the neutron noise originated from the boiling process in a high core average void content in the moderator system.

Operators are requiring measures to avoid operations in conditions such that alarms associated to or derived from normal operating conditions can appear, operating conditions that are having a potential decreasing in the operational margins must be avoided. Operators prefer to have a control room with panels free of alarms derived from the normal operation.

The degradation of the performance of the isolation valves in the re-circulation loop conducted to anticipate the potential operation in a single loop, this is another flexibility that was not assumed in the original design. This mode of operation requires specific operator training and also changes in the license and in the technical specifications.

2.2. ICF

The other flexibility to extend the power flow map was the introduction of the named Increased core flow. This flexibility allows operation at full power with a window of total core flow beyond the 100% rated core flow and until 107% rated core flow. This flexibility required a specific evaluation of the flow induced vibrations in the reactor vessel internals and in the re-circulation loop. This flexibility introduces a change in the performance of the fuel allowing the extension of the fuel cycle. However transient scenarios are changing imposing more restrictions in the thermal limits. In order to evaluate the flow-induced vibrations, extended data must be collected during the startup test program, also specific instrumentation and very oriented testing must be used. This flexibility can have impact on the life span of reactor vessel internals, the upper limit for the total core flow window, in Laguna Verde this upper limit was selected such that it will not have impact on the life span.

2.3. Stability

As the core design considers higher power density, the operations maneuvers during the startup, mainly during shift speed of the re-circulation pump can conduct to a situation of potential instabilities, such as density power oscillations.

Laguna Verde unit one during a startup after a scram in cycle four, experienced such kind of instabilities, with peak to peak of the order of 10% of rated power, this unexpected performance, required an analysis of the core stability in the power flow map. Consequences such reduction of the operational area in the power flow map was established, changes to the procedures for shift speed of re-circulation pump were launched. Specific operator training was developed.

The new design concepts under feasibility studies are considering variable speed in the re-circulation pump. This concept requires evaluation of different transients scenarios that those analyzed in the original design, because of the consequences of re-circulation flow transient having different impact in the core performance during transients and also in LOCA analysis.

Such kind of changes also will impact the peak clad temperature, and consequently thermal limits will be modified, if such is the case.

Nuclear reactor stability has been an issue since the beginning of nuclear reactor design, however earlier stability evaluations made using computer codes based on the frequency domain with simplifications did not identify the potential instability associated wit specific scenarios. Nuclear industry made effort to have most accurate calculation tools, and also developed new systems to satisfy the criteria of detect and suppress. Utilities are evaluating the use of such systems that are requiring in some cases a complete change in systems like average power monitor, rod block monitor to include the oscillation power monitor.

Actually there is under feasibility study the introduction of stability monitoring system, based on identification and suppress concept.

Stability issue is an example of industry issues that are requiring more powerful, robust and best estimated computational codes, to make a permanent and a systematic evaluation program of the nuclear reactor performance.

2.4. Fuel design

As was earlier mentioned the increase in the capacity factors, and the extension of fuel cycles from 12 to 18 months, are demanding advanced fuel design. The fuel design must also consider that the main condenser material (Cu-Ni alloy) is imposing some restrictions in during startup following a reload period. The new design must have higher bum up limit, lower thermal limits, higher power density and seismic qualification required form the seismic criteria for Laguna Verde. Laguna Verde is located in a high seismic acceleration zone, and the combined loads form LOCA — Seismic, requires specific qualifications for fuel design.

Introduction of the new fuel design with different geometric characteristics also requires neutronic and thermal hydraulic compatibility with the fuel design remaining form the previous generation.

Evaluation of the power flow map lines were evaluated to avoid any of the earlier problems that operators were facing, such as stability, and other maneuvers in the control rod adjustment maneuvers

Laguna Verde had introduced the use of zinc and noble metals in the reactor water chemistry, this new environmental for the fuel are having impact on the water control chemistry, operational procedures and care operators must have during start up and others operational maneuvers. It is obvious that the new fuel design must be compatible with the water chemistry practices and capabilities. Main condenser system, condenser de-mineralizer beds are having impact on the reactor water chemistry and also on the control cooper contained in the reactor water. This design is under evaluation for future maintenance of the main condenser, feasibility studies are going to be developed in order to change the main condenser material, but other materials could have other restrictions in the fuel design, or operational restrictions during power adjustment.

2.5. Power up-rate

Laguna Verde nuclear power plant performed the design evaluation to re-dimension the reactor power generation capability, raising from 1931 MW·th to 2027 MW·th . This was an opportunity to reevaluate the design, update the methodologies and the calculation tools used in the process. The challenge was to increase the power capability without decreasing any safety margin and avoiding any plant backfiting or modification. The following identifies, not all but some of the systems and the areas of opportunity that Laguna Verde would like to share.

First of all the fuel design was identified as a potential area of change to avoid the restrictions imposed by the new power capability and plant capacity factors required by operational programs developed to satisfy the power demand.

The main turbine and turbine control valves, were analyzed to identify capability to mange the new steam generation rate from the nuclear reactor, control capability of the turbine control valves, considering that the pressure in the reactor vessel was unchanged related to the original design pressure. For such purposes tests were successfully performed to show the capability of the control system.

Reliability of the safety relief valves were developed to show that the new steam generation capability has not impact in the relief system. Re-circulation system and the performance and capability of the pumps and control system were evaluated, changes in the pump performance were identified, it also has impact in the heat balance.

New computer codes related to those used in the original design were used to evaluate ATWS and LOCA analysis. The new computer codes required new methodology, however the process show that the tools used in the design process and the criteria used for the original design were having relatively large margins derived from uncertainties, this large margin allows us to up-rate the power capability without changing safety margins. The use of best estimated computer codes in constant development in the industry, combined with a continuous evaluation of the design will give us additional power capabilities, nevertheless some additional restrictions would also appear.

Main condenser has two boxes in serial arrangement, cooled by sea water, and it is having some restrictions mainly during hot sea water season. From my personal point of view this is one of the main challenges not only in the nuclear industry, the availability and the performance of the heat sink shall include advanced features in design. Thermal efficiency and economic performance are highly dependent on the heat sink. Parallel or serial arrangements, tube pitch and arrangement, heat transfer area and pipe availability, auxiliary systems such as cold condensed water aspersion, materials research are area of opportunity to have more efficient systems.

2.6. Spent fuel pool

As the energy requirements are satisfied there are other problems emerging, the original design of the spent fuel pool was a standard one, however the national program of the spent fuel management is waiting for more advanced technologies in the industry, the potential accumulation of the spent fuel discharged from the reactors are demanding temporal storage, Laguna Verde modified the spent fuel pool design, using the high density racks.

The actual capacity of each spent fuel pool is 3177 spent fuel assemblies — about 28 equilibrium cycle reloads. The new capability of the spent fuel pool required at least evaluation to assure sub-criticality, and heat load mainly when the full core is discharged from the core. Also every new fuel design is requiring an evaluation of the impact on the spent fuel capability and safety. Both spent fuel pools are completely independent, and this design concept has advantages, form the safety point of view. However there are some restrictions from the fuel management point of view. Since both units started up in different time and the independence of spent fuel pools make difficult to use some of the low burned fuel assemblies available of unit one to load in the first cycle of unit two, the need for neutron sources can not be avoided during start-up of unit two. Additionally fuel management became more restricted due to the fact that not all the highest reactivity fuel assemblies available at the site can be used in the reload. This means that the interchange of fuel assemblies between the spent fuel pool of both units must be evaluated in the new advanced reactor multiple units sites.

Spent fuel pool capacity and interchange in multiple units sites constitutes an area of opportunity in the advanced reactors design for countries developing slowly their final spent fuel management program, in order to give enough time to analyze and evaluate the feasibility of potential technologically and economically solutions to this issue.

2.7. Instrumentation and control

Laguna Verde Unit two started three fuel cycles after the unit one, during the construction process and start-up program of unit one some of the components of unit two were used as spare parts of unit one, for that reason during construction program of unit two such components were required but such components were out of the market, companies closed, or new advanced systems were developed for such purposes. That was the case of the Transverse In core Probe (TIP), Source (SRNM) and Intermediate range (IRNM) neutron monitoring systems.

The original design for TIP includes neutron detector and collecting information, however in the market were available an automatic TIP with Gamma detector, using computerized automatic data collecting system, that makes faster the total core power range monitor calibration, and faster startups. This concept improves the capacity factor of the plant.

The original concept for neutron monitoring includes three systems, Source range, Intermediate range and Power range. During start-up the operator has to select and operate each system in the adequate range manually. That set of systems evolved to a new concept considering only the Wide range and the Power range. Wide range substitutes Source and intermediate and became computerized, this also makes faster start-ups and improve capacity factors.

The set of new systems were installed in unit two and are actually operating showing the operational and unit availability advantage.

The non-programmed SCRAMS during the start-up program of unit two became significantly reduced in comparison to unit one.

As the neutron monitoring components in unit one approach to their end of life, substitution for spare parts are almost impossible, new concept design and computerized must be considered.

The use of computerized systems are imposing different failure modes and consequences of the failures must be analyzed to assure that they are not endangered the safety margins of the design. Quality Control of software design, are evolving as the potential of errors are identified. Computer platforms and software and firmware are evolving really fast, component and system substitution must be taken into account in the advanced design in order to have an amicable management program to update such kind of systems.

2.8. Core monitoring system

The core monitoring system originally was based on a Honeywell computer, the program for core monitoring system was based on the TIP readings and Local Power reading detectors, interpolation of the corrected reading were used to evaluate neutron flux and power distributions and from that thermal limits were derived. This first concept has not had prediction capability to evaluate some adjustment power manoeuvres.

Simulators based on the diffusion theory were evolving and the computer platforms made reality the use of such programs with restrictions, however they include the prediction capability.

Nowadays faster computers and more robust and powerful programs considered as best estimated are available to monitoring and predicting the core performance. Substitution of one monitoring system for an advanced system is becoming a challenge not only for management of life components but also for engineering and replacement, this is due to the interfaces among different systems. This evolution and retirement of the market of components or systems must be addressed in the advanced nuclear reactors design.

2.9. Components out of service

Nuclear power plants are often facing situations in which a component or a system is not available or is out of service, and the original design requires de-rating the unit or shutdown within a certain period of time. There is the possibility to evaluate the performance of the unit in a scenario that is not having the component or the affected system out of service, to show that there is not safety impact or to identify the restrictions to be applied in such operational scenario, and by this analysis to apply for a license exception in order to continue in line until the programmed shutdown or when spare parts are available.

This temporal permit to operate with equipment out of service is becoming a standard practice to perform the core analysis and reload design and licensing. We found among others SRV OOS, MSIV OOS, SLO, EOC RPTOOS.

It is very important that such potential operational scenarios must be taken into account from the beginning of the advanced nuclear reactor design process.

3. CONCLUSIONS

The experiences of the operating units are giving insights that must be taken into account in advanced nuclear power reactor design process.

Operating units experience is also showing that every concept in design must be considered in at least two perspectives, one is the local system benefits and problems associated, the second is related to the integral unit and plant related systems and components that will experience impact derived from the specific local system.

Evolution of the operational flexibilities must be evaluated and considered from the beginning of the design process to take into consideration the integral impact on the systems associated in the unit.

Developing new computer tools and best-estimate computer programs and the methodologies associated with them must be used systematically to identify safety margins, or potential restrictions derived from the use of old ones that did not identify restrictions at the moment of the original evaluation.

Experience shows that out of market components requires a new approach for process such as: design, built, maintenance, engineering and life component management for the new and advanced nuclear reactor design.

Nuclear industry in some countries are requiring support and time to evaluate technically and economically different options to launch their spent fuel management program. Adequate design criteria for the temporal storage capability in the spent fuel pools must be developed for advanced reactors.

Finally, it is very important to emphasize that nuclear industry and specially nuclear reactor must be under permanent and systematic evaluation, using not only the standard methods and computer codes, the nuclear community must support development of new computing tools, integration of qualified evaluation teams to assure that all aspects and specially all safety concern of the nuclear industry are permanently.

REFERENCE

[1] Safety Analysis Report of Laguna Verde Nuclear Power Station.