IN SEARCH OF THE IDEAL BURN

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This paper shows a two steps method able to establish optimum operating cycle length and associated fuel batchs discharge burnup. Application results (performed for Cofrentes NPP) indicate a potential improvement linked to burnup increases. An international research effort called "Robust Fuel Program" has been launched to facilitate, among other issues, high burnup licensing. This paper summarizes bases, objectives and expectations for such a program.

IBERDROLA has developed a method to analyse economical cycle performance by using relevant concepts within a fix and variable cost model. Relevant concepts means power operation, refueling and fuel. In the other hand, fix costs are independent of production while variable costs are proportional to it. Taking into account model uncertainties, it can be established that reference case (Cofrentes NPP) optimum is obtained for equilibrium cycle lengths between 21 and 22 months.

Once cycle energy and reload batch fraction are established, average enrichment can also be known by using a 3D nodal simulator. For such applications, IBERDROLA has already developed a system called "EVACOM" able to perform very detailed fuel cycle scoping calculations covering from current conditions to equilibrium. By means of neutronic, thermohydraulic and economic coupling models some advantages of burnup increases have been analised in a three steps schedule: available pin burnup margin, available enrichment limit and mechanical performance limit.

"Robust Fuel Program" (RFP) was launched to facilitate technical resolution of any issue linked to design and licensing of advanced fuel, particularly high burnup fuel. Initiative for such development was taken by US electrical utilities (with the participation of UNESA) looking to a target of increasing fuel reliability and operating margins to obtain power operation enhanced economical results.

INTRODUCTION

In a deregulated market system, nuclear power producers should seek long-term continuity and positioning by achieving the best possible technical and economic performance from their facilities, which should also operate reliably and safely on a sustained basis, within the limits imposed by licensing bases and requirements.

In this new framework, the operating margin is optimized from the areas of operation, maintenance, fuel management and design enhancements, combining technology and performance.

Therefore, the issue in question is not to achieve high burns by following an international model, but rather to design a reactor operating environment in terms of cycle length, refueling fraction, power and availability that will result in optimum returns that are compatible with the technological state of the art.

In this article, we will develop these concepts on a generic basis, but we will also provide specific, realistic data on the processes followed to date by IBERDROLA in search of the ideal burn.

OPTIMUM CYCLE LENGTH

Most Spanish reactors began operating in annual cycles. During the decade of the 90s there was a general transition to longer cycles, and at present they are operating in cycles with rated energy contents of around 500 Effective Days at Full Power, representative of 18-month cycles. Nevertheless, there are some exceptions, i.e. reactors that, owing to technical limitations or for purely economic reasons, are still operating on an annual cycle or that have even switched to 24-month cycles.

Cofrentes NPP.

The factors that made it advisable to switch to longer cycles included the increase in energy generation due to the lower number of refueling outages and reduced refueling costs; this was offset by higher fuel costs resulting from the higher purchase price due to increased enrichment and lower efficiency of fuel burn. In most cases, the improvements in production and expenses more than compensated for the higher fuel cost.

In view of the new electrical regulations and based on the experience gained in operating with 18-month cycles, IBERDROLA has developed an analytical model for determining what today would be the optimum duration of the fuel cycle. In the new scenario, there is no direct payback on fuel costs, and the operating optimum will involve obtaining the maximum operating margin, which will depend on market returns; from here the operating and fuel costs are inferred.

The model establishes all the boundaries that involve minimum and maximum limitations on cycle duration from a purely technical point of view, and then it defines, within a technically viable space that has been determined, the economic function to be maximized and, consequently, the optimum point of operation. In the event that the optimum cycle does not coincide with the current one, the model allows for designing a transition strategy from one to the other, and also for assessing the economic impact.

The economic operating model for the production system has been developed by separating costs into major items, and within each item into fixed and variable costs. The major items include the operating, refueling and fuel costs. Fixed costs are those costs independent of production, whereas variable costs are proportional to it.

To avoid the subjectivity inherent in this type of model, an attempt has been made to avoid as much as possible any theoretical data or data based on the experience of others and to trust more in the plant's own data resulting from its operating history.

There are some operating and maintenance costs that are practically independent of production. A linear correlation can be established that has a constant term and a part that is linearly dependent on the cycle duration in days. There are some refueling costs that follow a similar correlation, i.e. a constant term independent of the refueling duration and another term that is linearly dependent on the refueling duration in days.

The fuel cost model follows the same approach as the rest of the costs, i.e. it is broken down into a fixed and a variable part. The core is visualized as a fund of energy to which a refueling is added every year, which increases reactivity and is integrally consumed during the cycle. The situation at the end of the cycle is such that the reactivity returns to the value of the initial fund.

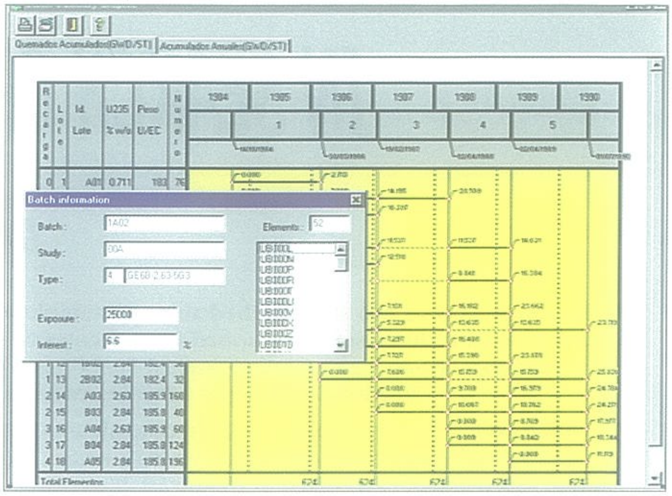
This model is the one normally used for balanced cycles in which all the cycle energy can be considered as being produced by the last refueling, whereas the rest of the core is a reactivity fund that is transferred from one cycle to another under identical conditions.

Our economic cost model for the first part of the nuclear fuel cycle assumes that the value of the last refueling should be amortized with the cycle's production and that it is the variable part of the cost. In addition, the value of the rest of the core (which is not burned up in the model, but rather transferred intact from one cycle to another) is a permanent fixed asset whose financial cost, along with the provision for the final amortization, make up the fixed part of the fuel cost.

Since the refueling is paid in accordance with a payment schedule whose center of gravity is six months prior to the beginning of the cycle (BOC), the total value from refueling to BOC will be obtained by adding a 6-month financial cost to its actual value at a set interest rate. The residual core value is obtained by subtracting the refueling value from the total core value.

The results obtained for the first reference case, which consists of the best estimation of the actual situation in Cofrentes NPP, indicate that the maximum daily margin is associated with a 21.5-month balanced cycle, with a very slight gradient in the immediate vicinity. Based on the uncertainties inherent in the model, it can be said that the mathematical optimum of the reference case places the optimum length of the Cofrentes NPP balanced cycle between 21 and 22 months, but because of the transition cost and unavailability of sufficiently advanced fuels, extending the current 18-month cycle is not feasible.

Numerous sensitivity analyses performed on the parameters that characterize the model indicate that the conclusions will only be affected, insofar as optimum length is concerned, by the relative duration of the refueling outages versus the days of operation during the cycle.



EVACOM: Batch Summary Graphic.

OPTIMUM BURN FOR FUEL DISCHARGE

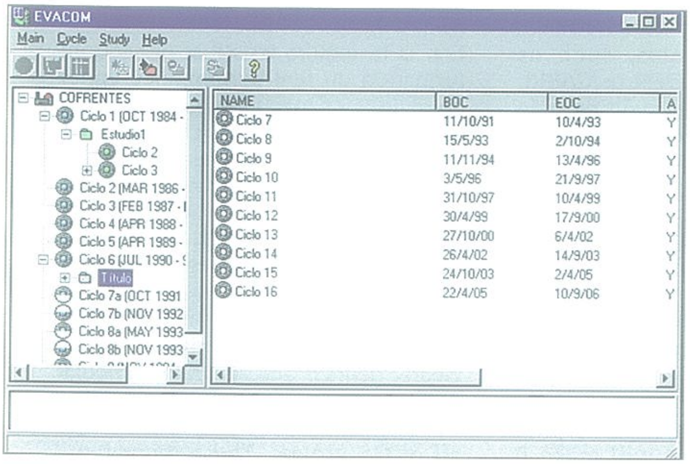
Once the cycle length is defined, the next stage of the optimization process must be addressed. This involves determining the refueling fraction and average enrichment, which will provide an objective discharge burn.

Operationally speaking, it is not feasible to frequently refuel only a few assemblies, because this would unacceptably reduce reactor availability. At the other extreme, it also would not be acceptable to refuel the core almost completely, because we would be unloading medium reactivity assemblies or else they would have to be used in very prolonged "Coastdown" operations, which again would be very detrimental to availability. The refueling fraction admits a range of acceptable values between / of the core for short cycles and almost fi for very long cycles. In the case of 18-month cycles, we will define the acceptable refueling fraction range as around 1/3 .

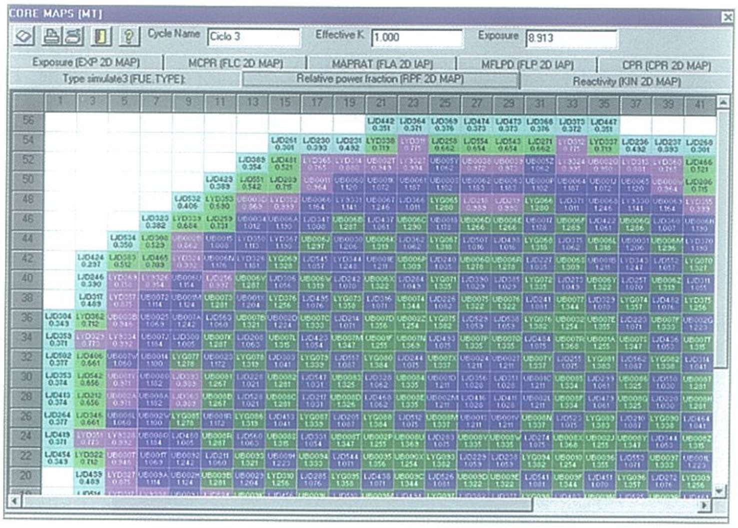
Once the energy that can be produced in the cycle and the size of the refueling batch are known, the required average enrichment can be determined by using a three-dimensional nodal simulator. There are simpler methods for estimating enrichment, but direct use of a simulator simultaneously provides valuable information on the viability of the proposed cycle. For this purpose, IBERDROLA has developed a system called EVACOM that is capable of performing very detailed analyses of a multi-cycle scheme from a real situation to equilibrium, with connected neutronic, thermo-hydraulic and economic models. Some of its user communication "screens" have been used to illustrate this article.

Recently the EPRI distributed a survey to nuclear reactor owner utilities to determine their interest in a high burn. It divided the survey into three stages by increasing order of difficulty of accomplishment, i.e., exhaustion of existing margins, increase of licensed burn without exceeding the enrichment limits, and finally increased enrichment up to a certain high burn target. The parametric analyses performed with EVACOM have determined, again for the specific case of Cofrentes NPP, the advantages associated with each of these stages:

a) Exhaustion of the existing margin versus the currently licensed rod burn values: This involves increasing the enrichment until an average peak rod burn of 62 MWd/KgU is obtained. This hypothesis results in an average batch



EVACOM: Main Screen.



EVACOM: Core Map Graphic

enrichment slightly greater than 4 w/o and a discharge burn of 52 MWd/KgU. Under current conditions of concentrate price, conversion, enrichment and manufacture, the cost of the first part of the fuel cycle would be reduced by 4%.

b) Exhaustion of the current margin versus the currently licensed enrichment values: This involves increasing the enrichment of all possible rods up to 5 w/o. Due to reasons of local peak limitations (as the reactor in question is a BWR), this hypothesis results in an average batch enrichment of around 4.20 w/o and a batch discharge burn of 55 MWd/KgU. An extension of the current license would be required for the rod burns, as the value would exceed 62 MWd/KgU and reach 65 MWd / KgU. Under current market conditions, the cost of the first part of the fuel cycle would be reduced by 1% compared to the preceding stage.

c) Achievement of a high burn target of 70 MWd/KgU for the average peak rod value: This case would require increasing not only the rod burn license, but also the enrichment limits above 5 w/o (specifically up to 5.3-5.4 w/o) for all facilities involved (manufacturer, transportation, etc.). Therefore there are many difficulties involved. The advantage is that cost of the first part of the fuel cycle would be reduced by another 2 % compared to the preceding stage.

Based on the above, the obvious conclusion is that the discharge burn should be increased by stages and that each target should be analyzed in terms of cost-benefit (technical and economic), the same as any other major investment.

Up to this point, no mention has been made of the associated technical limitations, which are determined by cladding material features, fuel and core reactivity, thermal performance of the fuel bars, operating performance of the rods, limitations associated with reactivity insertion accidents, bar-cladding interaction, shutdown margin, and numerous aspects (construed as restrictive criteria) concerning criticality, transport, analytical methods, mechanical design, fuel reliability, activity inventory, etc. These aspects are considered as part of the international efforts that we will describe in the last section in this article.

An effect that we have not adequately developed and that always results in a net positive balance in favor of an increased burn is the cost of the second part of the nuclear fuel cycle. In fact, the higher the cost of spent fuel assembly management, the greater will the incentive be to reduce the number of assemblies, and consequently there will be a greater tendency to increase discharge burns. For this reason it is not unusual to observe national trends in discharge burns that go beyond individual reactor or corporate strategies and that are primarily targeted at minimizing the costs of the second part of the cycle.

The rate at which these stages are covered can therefore be accelerated or deferred over time depending on how the costs of the second part of the cycle are treated, how market prices evolve, and the features that new, commercially proven materials or designs can reliably offer.

The most ambitious high burn targets assume that advanced operating strategies are adopted, i.e., cores designed according to the criterion of low radial leaks, higher relative powers, increased discharge burns and cycle lengths, as well as an increasingly complex chemical environment. All this involves a series of challenges that, if not properly addressed, could thwart the intended economic optimization, at least in the current technological and regulatory framework.

ROBUST FUEL PROGRAM

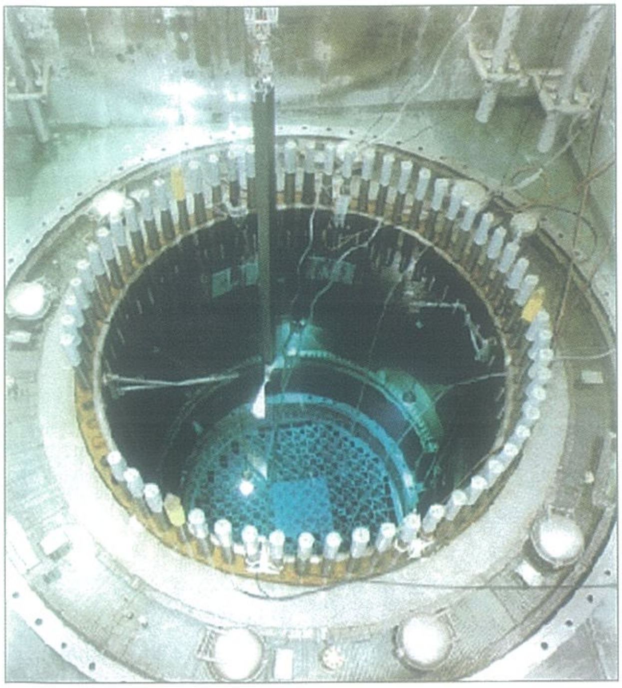
The Robust Fuel Program (RFP) grew out of an initiative of the North American utilities to increase fuel reliability, increase operating margins and thus obtain a better economic return on operation of their plants. Having set these goals, which were fully shared by the U.S. Regulatory Body insofar as safety is concerned, the EPRI was commissioned to define and manage a comprehensive program aimed at achieving these objectives.

Because of the similarities between the situation of Spanish reactors and that of the American plants, the former decided in late 1998 to also take part in the Program.

The justification for implementing RFP was to achieve the following goals:

- Resolve those aspects that, with the designs currently in use, could cast doubts on fully satisfactory fuel operation.

- Thoroughly understand all phenomena related to fuel operation under conditions of high demand, so that the actual margins available can be established, thus avoiding the imposition of unnecessary operating restrictions.



Cofrentes NPP Core.

• Acquire the technological know-how required to justify acceptance of innovations that introduce new kinds of fuel assemblies into the design and to provide documentary proof that, by satisfying certain requirements, the discharge burn can be extended beyond those values currently accepted by the Regulatory Authority. Definition of these requirements is, to a certain extent, the objective that synthesizes what this program is pursuing.

The RFP program considers that the overall enhancement of nuclear fuel performance is a strategic goal of nuclear power plant owner utilities. This goal will, when the time comes, be passed on to the fuel supplier as a design and manufacturing criterion. For this reason, this type of project should be led by reactor owners, who should articulate the proper mechanisms for integrating suppliers and establish the connections needed to guarantee the licensing process by the Regulatory Body.

Even though the members of the RFP program are electric utilities (mostly American) and it is precisely these companies that have the greatest stake in its eventual success, the program is set up as a joint effort of manufacturers and plant operation managers, with the added support of research centers that carry out the required tests. Organizations external to the Program, such as INPO and NEI, also actively participate in it, the latter serving as link to the NRC. EPRI's involvement as an adviser in other current international programs, such as NFIR, HALDEN or CABRI, means that it will be able to compare data or have access to external feedback that can be analyzed by RFP.

The Spanish electric utilities have committed themselves to all the objectives of RFP. Moreover, by participating in the program, they will be able to simultaneously generate and obtain comprehensive information that will make it possible to implement a network of interrelations within the Spanish nuclear industry, similar in all respects to the American model, as the most ideal formula for using and benefiting from their involvement in the program.

From a technical standpoint, different theories can be advanced regarding the emergence of new problems related to fuel performance precisely at the time when new improvements implemented in current fuels have already resolved aspects such as the following: failures due to metallic particles carried by the coolant, formation of hydrides that embrittle the cladding, hydrodynamic problems between the vessel and the cask, or cladding-bar interaction, to mention only the better known ones.

The most plausible explanation indicates that the new operating conditions, which are more demanding than before, shape a scenario that is still not sufficiently understood. In fact, the most exhaustive inspection programs seem to prove that most conflicts emerge because current predictive models of thermo-mechanical and structural fuel performance are not completely applicable.

Some improvable elements have already been fully identified: the mechanical design, including the materials used and the coolant chemistry, as an environmental condition likely to cause certain problems. Manufacturers continue to search for solutions, but they still lack sufficient theoretical and experimental comparisons to verify whether or not their lines of research are headed in the right direction.

There is also a good deal of concern, especially among the Regulatory Bodies, regarding the validity of the limits addressed in Accident Analyses for the range of discharge burns that today has become standard. Their position is to require tests that provide information on fuel performance under conditions of reactivity insertion accidents (RIA) and loss of coolant accidents (LOCA). In the face of this position, the industry's position should be to ensure that these tests adhere to realistic operating conditions.

To address all these requirements, RFP has implemented a task force consisting of four independent but coordinated groups whose competences are clearly defined and separate, although there will be some matters that will have to be analyzed by several or even all of the groups. These groups and their responsibilities are as follows:

• Chemistry Group, to study the chemical environment in which operation is developed, with special attention to problems associated with it, such as AOA, deposit of sludge in claddings, or effects of injecting additives in the coolant.

• Transient Group, in charge of obtaining acceptance of the Design Bases for transients, considering new designs and burn extension. It will take part in managing the CABRI RIA tests, with the scope deemed advisable, and it will verify the NRC's LOCA tests in the Argonne National Laboratory.

• High Burn Group, which focuses on characterizing fuel performance under these conditions, developing first the requirements that should be fulfilled in this environment and demonstrating that appropriate margins are available for problem-free operation.

• Failure Group, whose mission is to investigate failure mechanisms and causes in fuel, in order to determine what conditions the design must fulfill to prevent or mitigate the effect of failures.

In short, it can be concluded that active participation in RFP, under the leadership of nuclear reactor owner utilities, is fully justified in the context of solving current problems and licensing new design margins for burn. The results of RFP will be used to enhance the levels of quality, reliability, safety and economy of nuclear fuel operation in Spanish nuclear power plants, with benefits for the refueling supplier and participating research teams.

In conclusion, we should add that this very comprehensive Program should be seen not as a panacea that will help solve current problems, though that is undoubtedly one of its objectives, but rather it should be considered as the most appropriate way to drive a decisive, quantum leap towards fuel design optimization that, in the years to come, will make it possible to continue including nuclear generation as one of the safest, most economic sources of electric energy production.

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NEWS

WANO organized the "Team Leader Seminar" course in Trillo NPP, and Ontario Power included Almaraz-Trillo NPPs in its Management Training Program visits.

During the month of November 2000, Almaraz-Trillo nuclear power plants hosted two activities organized jointly with the WANO Paris center, which were developed in both facilities.

The first activity, held on November 6 and 9 in the Trillo plant residence, was the "Team Leader Seminar" course for training team leaders who are going to be responsible for Peer Reviews.

This seminar was attended by two representatives from two French plants, four from English plants, two from Belgian plants, one from the Brazilian Angra 2 plant, one from the Hungarian Packs plant, and one from the Japanese utility Tokyo Electric Co, as well as the director of Trillo NPP, Víctor Sola.

The purpose of Peer Reviews is to exchange operating experiences between the different nuclear power plants, and the reviews are performed by teams of up to 20 people with extensive experience in all areas of plant operation who assess the plant during a three-week visit.

To assure the success of these missions, the team leader must be a highly experienced professional, which was the issue addressed in the seminar held in Trillo.

The second activity, which took place on November 6-10, was a visit by a group of participants in the training program for management personnel from the nuclear power plants owned by the Canadian electric utility Ontario Power – 19 reactors and 11,000 MW – for the purpose of observing and determining "good management practices" to be implemented in this company and to share different opinions in this respect.

Meetings were held in the Madrid offices, the Almaraz plant and the Trillo plant, and many interviews were held with the Management and most of the department, unit and section directors. In addition, the participants took part in different routine plant activities: daily meetings, shift changes, maintenance activities, etc., to observe first-hand how jobs are developed.

Obituaries

Angel Juan Simón

In January, the Spanish nuclear industry lost two of its most prominent members: Angel Juan Simón (1928), President of Equipos Nucleares, S.A. (ENSA), and Enrique Valero (1948), Project Director of C.N. Valdecaballeros, Manager of SEPI Nuclear Group and President of the SNE from 1993-1994.

Enrique Valero

The nuclear community sends its sincerest condolences to the families of these two eminent professionals and colleagues.