NUCLEAR ENERGY PRODUCTION STRATEGY OF EDF IN THE EARLY 21ST CENTURY: TECHNICAL AND ECONOMICAL CONSIDERATIONS

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ABSTRACT

With 56 Pressurized water reactors in operation EDF has accumulated 700 reactor-years of operating experience.

The success of the standardization policy decided in the mid seventies allows EDF to be a profitable company. But the efficiency of existing plants must continuously be improved from the safety and economical point of view: for example, fuel management (increased length of campaigns, MOX fuel utilization etc.) is a major topic.

EDF is also preparing the future and the renewal of existing plants:

- In 1997, EDF connected to the grid 2 N4 units (Chooz B1 and B2) and in the coming months two other units will be connected (CIVAUX 1 and 2). This design, 100% French, represents both an advanced and a proven reactor. The most important and innovative features of this evolutionary reactor are a revolutionary man-machine interface and a new turbine named ARABELLE.
- In collaboration with Germany and FRAMATOME, EDF has completed the basic design of the European Pressurized Reactor (EPR).

INTRODUCTION

In Europe the economic growth rate is low, so the growth of electricity consumption is low; as an example, in France the annual rate of increase of electricity demand is about 2%.

A dramatic expansion of nuclear energy happened in the seventies and the beginning of the eighties due to the high prices of fossil fuels: in 1980, the total output of western Europe nuclear power plants represented 40 GWe; by 1990 it was 120 GWe. With the dramatic decrease of fossil fuel prices that occurred since the mid eighties, the economical advantage of nuclear power has become very small.

As a consequence, the competition between nuclear and fossil will become fierce, all the more so since there has been a recent significant trend towards deregulation in the European Community electricity market.

In addition, the accident of Chernobyl in 1986, has had a bad influence on public acceptance vis-a-vis nuclear power.

For all these combined reasons, safety and economy are major concerns for nuclear energy.

EDF AND ITS EXISTING PLANT

At the beginning of 1998, EDF will operate 57 PWR units: 34 belonging to “900 Mw” series, 20 to “1300 Mw” series, 3 to “N4” (1450 Mw). With all these nuclear power plants, France is able to produce more than 75 % of electricity consumed in the country (77 % in 1996) and to export 15% of the total nuclear production. With the policy of standardization developed since 1976, the cost per kWh is low: this allows EDF to be a profitable company.

EDF nuclear units are relatively young: our “900 MW” units are less than 20 years old, our “1300 MW” units are less then 12 years old. If one combines the relatively low age of our units and the low growth rate of electrical consumption, it seems to be a paradox but, for EDF, “the future of nuclear power plants is our EXISTING plants”: it will be probably not necessary to connect to the grid new nuclear power plants during the first decade of the next century.

On the other hand, for existing plants, the importance of investment in the kWh cost breakdown is lower than for new nuclear power plants, so our existing units are very competitive against any other kinds of thermal power plants: this financial effect increases year after year.

HOW TO IMPROVE THE EFFICIENCY OF OUR EXISTING PLANTS

Several topics can be studied.

Fuel management

The utilization of available safety margins is a major topic for EDF. The problem is specially complicated because of the use of MOX fuel (a very “nervous” fissile material) and because our need to follow the grid with nuclear power plants (maneuverability eats margins).

Despite these difficulties, and after special safety studies, we were able to get the licence for increasing the length of campaigns of our 1300 MWe reactors (from 12 to 18 months); in some 900 MWe units we are also allowed to burn 30 % MOX fuel and, in the coming months, we hope to get the licence for increasing the length of campaign of our older reactors (FESSENHEIM and BUGEY).

These changes will potentially provide 2 billions French francs per year to EDF and improve safety and radiological protection of the labor force. This saving can be explained mainly by the gain in availability, off-setting the need to increase the enrichment of fissile materials.

In some cases, the safety demonstration needs the help of new methodologies, new computer codes (3D instead of 1D) and the coupling of thermohydraulics and neutronics codes.

Increased length of campaigns also means increased burn up (at this time the maximum licensed burn up is 47 000 MW-day/Te). In collaboration with IPSN (Institut de Protection et de Sûreté Nucléaire), EDF studies experiments about the resistance of fuel cladding in the case of a Reactivity Insertion Accident (RIA) with CABRI tests. For these RIA problems, France also organized some collaboration with USA and JAPAN.

Life extension

After several studies, EDF thinks that the maximum lifetime of its units is higher than 40 years ; this data has a very good influence for competitiveness even if some components must be replaced. Thus, if EDF’s generation mix has a lifetime of 40 years instead of 30 years, a calculation may be made showing that it leads to a possible investment saving of about 20 billion FFR per year, on average, during the period 2010 to 2030. Today, we already know how to replace many items of equipment faster and cheaper (for instance, EDF is able to change its steam generators in 35 days). Other components cannot be replaced so easily, the vessel for instance, but in fact we are lucky: the alloy of the vessel is not very sensitive to embrittlement and, as well, a cautious core management allows to give a low neutronic fluence on the vessel.

Safety reference state and periodic safety review

In order to improve safety and availability, EDF modifies periodically its reactors to take into account feedback of experience: our company spends more than 1 billion French francs each year to improve our existing units. But EDF desires to control modifications in order to maintain standardization of our plants and to avoid destabilization of our operators: French safety authorities accepted the safety review of our units on a ten yearly basis. Since 1993, EDF has devoted important efforts in that direction: the first phase has consisted in clarifying the reference state safety requirements (rules, criteria, specifications applicable), the second phase under completion consists in checking the compliance of the units against this reference state and the last phase will be the review itself of the reference state. Such a process gives a stable regulatory environment to the units, thus it is possible to reconcile safety and economy.

EDF PREPARES THE FUTURE

For the future, EDF has developed the N4 series and is developing the REP 2000 program.

N4: an advanced power reactor

In mid 1998, 3 N4 units will be connected to the grid (CHOOZ B1 and B2, CIVAUX 1).

The design of this new series, 100 % French, took into account all the feedback of experience from the French nuclear program supplemented by world-wide experience. Innovative features have been introduced to increase the output of the power plant by 40 to 50 MWe: new steam generators, primary pumps and main turbo generator for instance. But, most of all, prevention of accidents has been improved by a revolutionary man-machine interface: a computer aided I and C. The design has also been computer aided which represents a good contribution to safety.

EDF received the “AWARD POWER PLANT” from MacGraw Hill Publications during the ASME Annual Meeting in Denver (Colorado) of November 1997.

This reactor presents innovations about materials: composite pipes for some circuits, high efficiency concrete for the containment that allows an increased design pressure (plus 50%).

The new turbine “ARABELLE” has an optimized architecture which increases the yield by 1 % and lowers the costs (this turbine is 12 % lighter and 5 meters shorter than a turbine designed according to previous standards).

The most important and new feature of N4 is a revolutionary man-machine interface. The level of computerization of N4 series is not really higher than that of previous series, the decisions taken by the operator are not very different: this is the choice of EDF. With N4, there is something dramatically new: the computer gives to the operator summarized information and documents that can be accessed faster and easier. Digital control technology that had been chosen only for the relay level on 1300 MW units had to be extended to the rest of the plant, including the control room: it was a major challenge.

The general architecture of N4 I and C is the following: level 0 (actuators and sensors), level 1 with programmable controllers (protection and adjustment) and level 2 that provides the man-machine interface in the control room.

The MMI comprises the main system (KIC that is not safety classified) with four alphanumeric workstations (with graphic control and touch sensitive screens). In addition, there is a mimic display on which it is possible to see at each time the status of the unit; the information represented on this panel comes directly from level 1. As it was impossible to be sure to succeed in classifying KIC, a diversification of the systems has been chosen: below the mimic panel a conventional control panel, hardwired to the level 1 control system, may be used in case of total loss of KIC: it is classified 2E and it allows to the unit to be driven to a safe state. Finally, an emergency panel may be used in case of unavailability for the main control room (fire for instance)

With KIC, the operator can call up mainly detailed or general flow charts in order to supervise plant status, alarm pictures and alarm classification sheets, diagnostic aids, standard procedure pictures integrating decision trees, technical data sheets for different components or devices, list of maintenance operations or end of session handover instructions. The N4 I and C monitors 35,000 parameters, issues 19,000 digital instructions within less half a second and proposes 10,000 technical data sheets and 4,400 alarm data sheets.

REP 2000 Program

A) EUR: European Utility Requirement

This requirement is endorsed by 9 major electricity producers of Western Europe located in Germany, UK, Spain, Belgium, France, Italy, Netherlands, Finland and Sweden.

The objective of EUR is to define a common ground acceptable by the utilities, the public and the administrations. This would allow the designers to develop standard LWR designs acceptable everywhere in Western Europe. This would also allow the utilities to open their consultations to several vendors. The safety approaches, targets and criteria of the future plants, their design conditions, their performance targets, their systems and equipment specifications, are being harmonized under the leadership of the electricity producers. Benefits are expected in two fields: strengthening of nuclear energy competitiveness and improvement of public and authorities acceptance.

EUR comprises 4 volumes:

- volume 1 and 2 are relative to nuclear island. Their version B is under review by safety authorities of the nine European countries and the European Union administration.
- volume 3 is relative to specific designs: vendors are developing projects for the European market in consistency with the EUR document. The EUR utilities are writing specific set of requirements that would address these designs, with contribution of the corresponding vendors.
- volume 4 has been produced. It addresses the conventional island. It is now being reviewed by vendors and utilities outside the EUR Group.

EUR utilities don’t work singly: at some stages of EUR process, some meetings have been organized with EPRI in order to review and explain the differences between US URD and EUR.

More recently an International Utility Advisory Committee has bee settled in order to exchange information and opinions about EUR: some utilities of Pacific basic attended to meetings of this committee: Japan, China for instance.

B) EPR (European Pressurized Reactor)

EDF, jointly with German utilities, Siemens, Framatome and NPI (a joint subsidiary of Siemens and Framatome) is studying a new advanced reactor called EPR (European Pressurized Reactor).

EPR will be an evolutionary design that will take into account the experience of existing reactors, especially the French N4 and the German KONVOI. A special attention has been paid to the operation and maintenance concerns: the project is driven to minimize especially the generation cost (and to control the investment cost): the choice of a four-train architecture for safety systems will allow maintenance during operations and thus reduction of outage duration. The choice of high margins for the core will allow a good economical efficiency of fuel management.

Concerning the performances, EPR is designed for an average availability of more then 87% (90% expected with a planned outage period less than 25 days and the possibility of a refuelling outage of 19 days), for a high maneuverability (such as it can be operated in continuous operation between 20% and 100% of rated power).

The safety strategy of EPR is first, to improve the preventive measures against accidents and second, even if the probability of severe accidents, up to core melt, has been further reduced, to implement features, mainly concerning containment integrity, to mitigate their consequences, so that stringent countermeasures are restricted to the immediate vicinity of the plant.

These safety requirements are implemented by designing the plant on **a strong deterministic basis.**

Accident prevention measures are enforced by:

- Simplification of safety systems
- Elimination of common mode failures by physical separation.
- Increase of grace periods for operator actions by designing components (e.g. pressurized and steam generators) with larger water inventories to smoothen transients.
- Less sensitivity to human errors by computer aided man-machine interface taking into account the feed back of experience of N4.

In addition to deterministic approach, we consider events with multiple failures and coincident occurrences up to the total loss of safety-grade systems on a **probabilistic basis** in order to limit the residual risk. A probabilistic design target for the integral core melt frequency for internal events and reactor in power states of 10^{-6}/a is used while the shutdown states shall contribute to the core melt frequency less than the power states.

The basic design phase ended mid 1997: the economical assessment showed that the competitiveness of EPR compared to fossil fired plants is good. Despite this good result, EDF and its partners are studying the possibilities for further cost reductions: as an example, an increased output would be surely possible with all the margins available on the large core. We expect that this optimization phase will be finished by the end of 1998,

C) Technological survey of new foreign design

A large nuclear company like EDF must absolutely be aware of all kinds of designs available on the market in the future in order to make the best choices. It is the reason why, beyond N4 and EPR, we study other designs generally in collaboration with other utilities. We look at passive and evolutionary designs for both pressurized and boiling water reactors.

As examples, EDF:

- is involved in ALWR program with Pacific Basin utilities (USA, Japan, Korea etc...)
- participates with other European utilities to EPP Project (EPP: European passive plant, an adaptation of AP600 of Westinghouse to European context with a minimum power of 1000 MWe).
- participates with JAPCO to SPWR program (SPWR: Simplified Pressurized Water Reactor, adaptation of AP600 to Japanese context with a power of 1000-1200 MWe).
- made an economical and technical assessment of ABWR (GE) adapted to European context. This job will probably be deepened with other European utilities.
- is a member of CE 80^{+} executive advisory committee,
- will get information about SWR 1000 program (Siemens),
- plans to participate with other European utilities to ESBWR studies (ESBWR of GE: European simplified boiling water reactor),

- will study, in the frame of EUR steering committee, the compliance of BWR 90 (ABB) to EUR,
- studied the general compliance of VVER AES 92 to EUR

Some of these designs are interesting and represent true technological breakthroughs.

CONCLUSION

Safety and competitiveness are major topics for EDF. This is valuable for existing plants and for the renewal of our existing units on the future. EDF is open to international cooperation: some example in this paper demonstrate this reality, especially with European and Pacific Basin countries.