RESULTS OF THE BASIC DESIGN OF THE EUROPEAN PRESSURIZED WATER REACTOR (EPR) AND FURTHER PROSPECTIVE

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INTRODUCTION

When NPI was founded in 1989, the development of an advanced nuclear power plant was initiated. Today, the EPR basic design has been successfully completed, taking into account the results of the preceding design phases performed within the framework of cooperation between Framatome, Siemens and Nuclear Power International. The EPR is an evolutionary design, with maximum consideration given to the experience accumulated by Framatome and Siemens with the existing designs of plants successfully operating. However, substantial improvements with regard to availability, safety and economy have been included. The main target of the basic design phase was a clear definition of technical features based on common technical codes that comply with economic targets and licensability requirements in France and Germany.

The EPR basic design represents a new design for a nuclear power plant that complies with the latest laws and regulations, both in France and in Germany as well as in most of the countries utilizing nuclear power. Cost estimates prove the design economically viable.

BACKGROUND

Both companies, Framatome and Siemens, have for many years successfully promoted the civil application of nuclear power. The belief in further development of nuclear power calls for the preservation and further improvement of their already extensive overall knowledge including scientific know-how, application of tools and methods, and technological and industrial experience. They decided to engage in long-term cooperation on the development, marketing and supply of the nuclear islands of pressurized light water reactors, including the overall concept for a complete nuclear power plant.

Within the framework of this cooperation, NPI, Framatome and Siemens started the development of a first common product. Before starting this work, it was necessary to decide on which approach the development should be based: development of completely new concepts or the enhancement of proven designs. Three main reasons finally resulted in the selection of the evolutionary approach:

1. The newly founded NPI could rely on the wealth of experience accumulated by its parent companies that had, up to this point in time, already built or under construction more than 100 nuclear power plants in various countries throughout the world. With an installed capacity exceeding 100,000 MW, this represents a figure larger than that of any other supplier worldwide. All these plants had recorded high availability and proved an outstanding level of safety. Altogether 1200 reactor operating years had formed the background for the ever-growing Franco-German experience for the design of the new generation of pressurized water reactors. Within the framework of this evolutionary approach, a number of innovative features have been investigated and some of them have been introduced into the design.
2. By adopting the evolutionary approach, unnecessary development risks can be avoided or minimized by maintaining a continuous development process based on proven design and therefore avoiding the necessity of a prototype.

3. Obviously, the evolutionary approach will minimize licensing risks that may arise in the case of a completely new design. It is generally believed that due consideration of the lessons learned from operating experience and probabilistic studies performed on existing plants ensure to the largest extent possible a real, credible enhancement of plant safety and thus minimize licensing risks.

In the context of these strategic orientations, NPI started with the development of a 1450-MW pressurized water reactor based on the latest designs, the N4 in France and the "KONVOI" in Germany.

TECHNICAL AND COMMERCIAL ASPECTS

During preceding preliminary project phases a number of important decisions were made and specified as main features that had to be confirmed during the basic design phase.

Technical Aspects:

With regard to component and system design it was generally agreed to implement proven technology as much as possible in order to derive maximum benefit from the experience accumulated in operating plants. It was one of the major targets during the basic design phase to confirm the choices that had been made and to check whether these choices provided a technical optimum. During the basic design, first detailed analysis work was started in order to check the interfaces and consistency of the technical concept. These analysis works confirmed that most of the main features chosen could be retained and contribute to the design optimum. Some of these main features, which determine the overall concept and which are now considered to be fixed, are as follows:

- confinement concept with a double-wall concrete containment,
- system configuration in a four-division/four-train structure,
- severe accident approach,
- general building arrangement,
- I & C architecture,
- man-machine interface,
- break preclusion concept,
- In-core instrumentation from the top of the reactor pressure vessel.

Of course there is still some room for further optimization work in some dedicated areas – for which the next project phase will be used – but it is anticipated that these studies will not have an impact on the general concept,

Commercial Aspects:

Due to the sound results of the basic design phase, a first cost estimate on the EPR was made. Based on the current technical concept, a price of 2,750 DM/kWe for a turnkey plant under German conditions was quoted to the German utilities. This cost evaluation included the so-called first-of-a-kind costs of a plant. Assuming the erection of an identical plant a cost reduction of approximately 15%, depending on site conditions, can be reached. Thus, considering investment costs of 2,400 DM/kW, specific annual generating costs can be expected that are about 10% lower than generating costs based on hard coal. These figures based on the current power level of 1525 MW reflect the German situation. We are confident, however, that this positive result will also urge the interest of utilities in Europe and around the world.

SIGNIFICANT CHARACTERISTICS OF THE BASIC DESIGN

As already stated, one of the reasons for the success of the basic design phase was the fruitful cooperation between the partners that started on the vendors' side and which was later on shared by the utilities and authorities. The main goal of the basic design phase was to establish a clearly defined set of technical features based on a common set of EPR technical codes (ETC). In particular, the objective was to ensure the licensability of the overall concept in France and Germany. It must be noted that the good results of the basic design phase were attained in close cooperation between the vendors and the utilities, bearing in mind that both the licensing requirements and the operating experience and practice are different. The technical advisors of the safety authorities in France and Germany, i. e. the Groupe Permanent chargé des Réacteurs nucléaires (GPR) and the Reactor Safety Commission (RSK), received the relevant information during the whole design process. Most of the technical features of the EPR and a first issue of the most important ETCs have been commented on and accepted, and most of these comments were already considered in the basic design. The process will continue and is scheduled to be completed with a set of common Franco-German guidelines at the end of 1998, just in time before starting the detailed design work. From the vendors' point of view the harmonized requirements from the utilities contained in the EUR (European Utility Requirements) as well as from the regulatory bodies (GPR/RSK) will lead to a situation previously considered improbable to be achieved. This will allow the same design to be offered in both countries and thus simplify the design work and licensing procedure, and reduce overall costs.

STATUS OF THE BASIC DESIGN

According to the contractual definition, the basic design shall be the basis for further nuclear plants in France and Germany as well as in third countries. For meeting that general purpose, it had the following objectives:

- to enable the French and German safety authorities to assess the safety level of the EPR nuclear island and its licensability in France and Germany,
- to enable the utilities and the vendors to perform a cost estimate, and
- to serve as the basis for the performance of subsequent phases.

With the submittal of the Basic Design Report, the reports for safety analysis and the first set of EPR technical codes (ETC) in June 1997, the contractual work was completed right on schedule and took into account the comments of our utilities in a satisfying manner. The results of the basic design phase documented in more than 1000 reports and drawings show that the EPR is in a considerable number of its features establishing a new state of the art, mainly in the fields of:

Economy

- Reduced investment and generating costs due to:
    - Optimized fuel management,
    - Innovative steam generator with economizer,
    - Reduced outage time,
    - Lifetime extension to 60 years

Safety/system design

- Improvement in the preventive area due to:
    - Combination of multiple redundancy and diversity,
    - Systematic evaluation by means of probabilistic studies during design,
    - Systematic consideration of shutdown states
- Mitigation of severe core damage scenarios by dedicated design means.

Instrumentation & Control

- Use of digital technology for safety I&C
- Improved man-machine interface

Layout

- Improved separation concept covering safety and operating aspects
- Enlarged service area
- Dedicated containment annulus for leakage control
- Large spent fuel capacity for approx. 950 fuel assemblies or for more than 20 operating years.

TECHNICAL FEATURES

The layout and the buildings of the Nuclear Island including the containment are mainly based on the French technology of N4.

For the containment the French technology was chosen because:

- It is cheaper than the steel sphere, and
- We decided to have a permanently closed containment during operation so that the fuel storage pool has to be situated outside the containment.

The layout differs from the French N4-layout insofar as four consequently separated safety buildings are provided which contain all safety systems. Two of them are protected against aircraft crashes whereas the central building separates the two others, so that in case of aircraft crash only one of these safety buildings is affected.

The consequent separation of the four safety divisions has an advantage regarding the protection against common cause failures due to e.g. steam release or flooding. Additionally, it creates the possibility for preventive maintenance during full power operation enabling a short refueling outage of 19 days.

Besides the duration of the refueling outages, the number of forced shutdowns strongly affects the plant availability. EPR features therefore a number of I&C functions that lead to transient limitation and partial trip in order to reduce the number of automatic reactor trips. Instead of leading to reactor trip with long lasting shutdown times, those transients cause only a power reduction to in the range of 40 to 60%. Afterwards, recovery to full power operation can be realized in a short period.

Another important contributor to economic power generation cost is the fuel cost. The main precondition to permit advanced core strategies requires that the operator has sufficient information about the power distribution in the core. This information is provided by the core instrumentation system that consists of two different measurement principles. The first is an aeroball system that contains a number of small spheres that are brought into the core by compressed nitrogen. There they are activated for 3 minutes and brought back to a measurement room where the activation is measured. From these values, the power inside the core can be calculated.

The second measurement principle of the in-core instrumentation is the self-powered neutron detector system. The clear picture of the power distribution provided by these systems permits the plant to be operated with full low leakage core patterns leading to burn-ups of up to 50 MWd/kg with an enrichment of 4%. Extrapolating these values into the future and assuming even slightly higher enrichments, a possible burn-up up to 70 MWd/kg in one year cycles and well over 60 MWd/kg in cycles of 1.5 years are realistic, thus contributing significantly to the economic competitiveness of the EPR.

The clear picture of the power distribution that is provided by the in-core detectors can also be used to judge the margins of the core during transients without risking a scram. This is performed by limitation functions that use the measurements of the In-core instrumentation to build up signals for the local core protection. These functions bring back the local power density to safe conditions by soft measures like dropping only four control rods instead of tripping the reactor completely.

In order to achieve a high load following capability without posing undue stresses to the components – a prerequisite for a plant operational lifetime of up to 60 years – requires a careful design of the part-load diagram. For EPR, the pressure rises from 72.5 bars at full power to about 84.6 bars at 50 % power output. This feature leads to the comfortable situation that on the primary side the mean temperature is held constant, whereas the core outlet temperature slightly falls and the core inlet temperature rises. With this operation diagram there is no need for reactivity compensation during load variations between 50 and 100 % power. In addition, the volume of the primary system water content is nearly constant so that no additional feeding from the volume control system and no additional letdown is necessary. Consequently no stresses occur on the nozzles of the volume control system.

Besides the important consideration of economic competitiveness and ease of operation, the enhancement of the safety level was addressed. In addition to strengthen the accident prevention features, the EPR design comprises measures to reduce radiological releases as consequence of severe core damage sequences.

As one of the first reactor designs, EPR does not any more shift the consequences of severe core damages to the residual risk, but provides features to mitigate them. Lowering the consequences of severe accidents means that the external source term is limited in a way that stringent countermeasures such as relocation or evacuation of the population is restricted to the immediate vicinity of the plant.

The main requirements to limit the external source terms are:

- Short- and long-term confinement function of the containment must be assured.
- The corium must be stabilized within the containment.
- Direct leakage from the containment to the environment must be prevented.

For the fulfillment of these requirements, maintaining the containment integrity is the most important challenge. It shall be achieved by:

- Avoidance of containment failure or bypass,
- cooling of the corium in the containment and retention of fission products by water covering,
- preservation of containment functions, such as low leak rates, reliable containment isolation function, prevention of basemat melt through and ultimate pressure resistance to cope with energetic events,
- pressure reduction inside containment by dedicated heat removal, and
- collection of unavoidable containment leakage in the annulus atmosphere and release via the stack after filtration.

Consequently, the EPR design includes the following design features:

- Prevention of high-pressure core melt situations, first by a highly reliable of the decay heat removal system, complemented by depressurization means (pressurizer relief valves). This depressurization at the same time eliminates the danger of direct containment heating.

- The prevention of hydrogen combustion with high loads (high turbulent global deflagration, DDT, detonation) by reducing the hydrogen-concentration in the containment at an early stage by catalytic H_2-recombiners and, if necessary, by selectively arranged igniters. The potential effects resulting from the deflagration phenomena are considered in the design of the containment and of the internal structures.

- The prevention of ex-vessel steam explosion endangering the containment integrity by minimizing the amount of water where the corium is spread.
- The prevention of the molten core-concrete interaction by spreading the corium in a dedicated spreading compartment that is equipped with a protective layer. This original EPR feature consists in a large spreading area located outside the reactor pit.
- The reactor pit and the spreading compartment are connected via a melt discharge channel that has a slope and that is closed by a steel plate. This steel plate (possibly covered with refractory material) resists melt through for a certain time in order to accumulate the melt in the pit.
- The spreading compartment is connected with the In-Containment Refueling Water Storage Tank (IRWST) with pipes for water flooding after spreading. These pipes are closed during normal operation and accident conditions by plugs that will be melted by the corium.

At the end of the Basic Design Phase, it has been demonstrated that the EPR meets its design objectives. In particular, the mitigation of Severe Accident sequences, as described above and which is one of the most distinctive features has thoroughly and successfully been covered.

Furthermore, first analyses that were performed at the end of the Basic Design show that the EPR can be adapted to reduce further the production cost without putting into question its main objectives in terms of safety and performance.

OUTLOOK

At the end of 1998 or the beginning of 1999, all information necessary for the optimized design for a national licensing application and for start of detailed design will be available. In this respect, it is anticipated that a set of guidelines will be received from the licensing authorities that regulate major deviations from the current national codes and standards in use. We expect the cooperation to continue, either with licensing procedures in parallel or with different licensing procedures in the two countries. With the fulfillment of the above-mentioned conditions, a big step toward the main objective – order placement for the first EPR – will be taken.

As power demand may increase or replacement of older units is required, we anticipate that a plant will be erected in Europe, combining the strengths of the cooperation by forming a reference for a new generation of nuclear power plants.

The EPR is already confirmed to be a product which fulfills all the most demanding safety requirements defined by the Franco-German safety authorities, while meeting the economic goal of competitive power generation.