# DESIGN OF EPR

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**Abstract:**

At the origin was the common decision of Framatome and Siemens to cooperate to design a Nuclear Island which meets utilities and safety authority's requirements for a new generation of nuclear power plants. EDF and a group of main German Utilities joined this effort in 1991 and from that point were completely involved in the progress of the work. Compliance of the EPR with the European Utility Requirements (EUR) was verified to ensure a large acceptability of the design by other participating utilities. In addition, the entire process was backed up to the end of 1998 by the French and the German Safety Authorities which engaged into a long-lasting cooperation to define common requirements applicable to future Nuclear Power Plants. Upon signature of the Olkiluoto 3 contract, STUK, the Finnish safety and radiation authority, began reviewing the design of the EPR. Construction License for the Olkiluoto 3 NPP was obtained on February 17, 2005.

Following the positive conclusion of the political debate in France with regard to nuclear energy, EDF will also submit a request to start the construction of an EPR on the Flamanville site. In the US, the first steps in view of a Design Certification by the NRC have been taken. These three independent decisions make the EPR the leading first generation 3+ design under construction. It will ensure continuation of the French culture of NPPs series, the only one to allow utilities to fully benefit from reduced costs and shared experience feedback.

Main design features of EPR design are as follows:

Important safety functions are assured by separate systems in a straightforward operating mode. Four separate, redundant trains for all safety systems are installed in four separate layout division for which a strict separation is ensured so that common mode failure, for example due to internal hazards, can be ruled out. This four train-redundancy for the major safety systems provides flexibility in adapting the design to maintenance requirements, thus contributing to reduce the outage duration. Additional features are implemented to satisfy safety objectives required by the Safety Authorities for new generation plants in terms of

heightened protection against accidents, including core meltdown and their radiological consequences, robustness against external hazards, in particular airplane crash and earthquake.

The evolutionary approach chosen by EPR designers thus corresponds to the *optimal mix* between largely proven solutions derived from the largest experience and innovative features needed to meet new requirements, particularly in the field of safety.

EPR unique efficiency in the use of nuclear fuel fosters sustainable development.

Finally, EPR is a 1,600 MWe-class reactor with high efficiency, reduced construction time, extended service life, enhanced and more flexible fuel utilization and increased availability resulting in an outstanding competitiveness in terms of installed kW cost and kWh production cost.

## 1. EPR OBJECTIVES

Framatome and Siemens in cooperation with EDF and major German utilities have been active since 1992, in the development of the European Pressurized Water Reactor, also known as Evolutionary Pressurized Water Reactor (EPR).

Main objectives assigned to EPR were twofold:

- After a careful evaluation of specific passive safety features, it was decided to design the EPR following an evolutionary approach: the advantage of founding an advanced design on operational experience from approximately 100 nuclear power plants constructed by Framatome and Siemens was deemed by the designers to be quite important.
- As important as the evolutionary feature, was the objective to assure the competitiveness of nuclear power generation with any alternative energy sources. EPR was intended to provide a significant improvement in terms of power generation costs as compared to most modern nuclear power plants and to large gas power plants with combined cycles. To match this objective, a large unit power size was selected, i.e. in the 1,600 MWe range.

## 2. EVOLUTIONARY DESIGN

### 2.1. French and German Safety Authorities recommendations:

In compliance with the rules established by the French and German nuclear Safety Authorities for the next generation of PWR's, the EPR follows the following principles:

- An "evolutionary" design, to achieve maximum benefit from the accumulated experience in designing and operating the PWR units now in operation in France and Germany and in the countries where Framatome and Siemens exported their technologies (Belgium, Brazil, China, Korea, South Africa, Spain, Switzerland). EPR design is especially based on French N4 and German Konvoi experience.

- An enhanced safety level. On the one hand, a decreased core melt probability has been achieved by improving the availability of the safety systems. On the other, design features have been incorporated to limit radiological consequences in case of a severe accident. For accidents without core melt, the architecture of the peripheral buildings as well as the associated ventilation systems eliminate the necessity of protective measures for people living near the damaged NPP unit. In the highly improbable, but nevertheless envisaged situation of a core melt accident at low pressure, the reinforced reactor building and specific palliative devices will limit radioactive releases. Only a few limited protective measures would be required. Lastly, the reactor design and the confinement concept eliminate situations that could lead to large early releases.

With the EPR, the probability of an accident leading to core melt, already extremely small with the previous-generation reactors, becomes infinitesimal.

- Taking potential operating problems into account very early in the design effort. In-depth work has been done during the Basic Design phase to reduce to a minimum collective personnel radiation exposure. Equipment maintenance has been enhanced by good accessibility. Finally, the human factor was integrated into the design to minimize the potential for human error in the operation of EPR units.

## 2.2. Main design and operating data

Rated thermal NSSS power from 4300 to 4600 MWth

Rated net electrical power ~1 650 MW (depending on site conditions)

*Reactor coolant system*

Number of loops 4

Operating pressure 155 bars

Total flow/loop 28 000 m3/h

Main steam pressure 78 bars

*Core*

Number of fuel assemblies 241

Number of RCCA 89

Fuel assembly array 17x17

Active height 420 cm

### 2.3. Systems architecture

The fluid systems architecture was the result of an intensive exchange of information regarding design and operating experience between the EPR designers and the participating French and German electric utilities. Using probabilistic evaluations from the outset of the project was useful for defining the following principles.

*- Design based on simple principles*

The most important safety functions are ensured by diversified systems. Combinations of functions that would increase the complexity of systems operation have been avoided. The teams responsible for operations and maintenance will therefore have an improved view of EPR unit status, even in perturbed plant situations.

*- Physical separation*

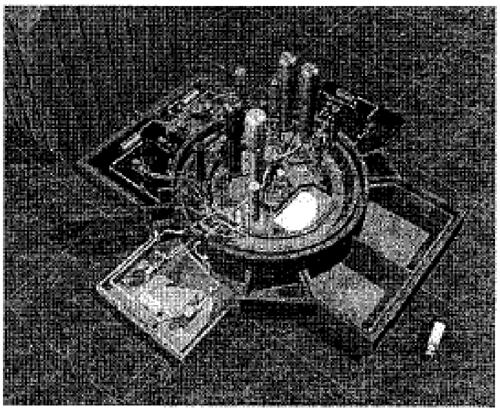

**Figure 1: Layout of the four redundancies**

The different trains of the safeguard systems are installed in four physically separated divisions of the plant.

*- Functional diversity*

The risk of common mode failures that could affect redundant systems has been reduced by systematically seeking functional diversity. If a redundant system is completely lost, there will always be a diversified system that can perform this function and bring the EPR unit to safe shutdown (complete loss of the residual heat removal system, loss of steam generator feed water supply or complete loss of the medium-pressure safety injection system).

*-Redundancy*

Four-fold redundancy is used for the main safeguard systems (safety injection, emergency steam generator feed water supply) and the associated support systems (electrical power supplies and cooling systems). The four-train architecture, along with a four-loop primary system design, contributes to the simplicity of operation. It provides flexibility to adapt the design to maintenance requirements during operation as well as during outages, when the redundancy level is increased due to lower residual power, and a lower load on the systems that may be needed. Although a four-train architecture may at first appear to be costly, the avoidance of headers favorably influences the sizing of the pumps which are not affected by a loss of useful flow. The overall cost comparison is much more balanced and the four-train architecture provides definite advantages for the operation of the plant.

## 2.4. I&C Design

The I&C architecture has been developed to satisfy diversity and reliability requirements.

The different automation systems are either realized in the safety-oriented TELEPERM-XS™ technology or in the standard TELEPERM-XP™ technology (for Olkiluoto). The TELEPERM technology has been successfully implemented in operating nuclear unit upgrades (in Germany and in Eastern Europe) as well as in a new project (Tianwan project in China).

The control room is fully computerized with an operator-friendly Man-Machine Interface fully benefiting from the unique N4 experience feedback.

## 2.5. Mitigation of severe accidents

Compliance with safety objectives related to severe accidents led to the incorporation of particular design measures; the main design measures are:

- High-pressure core melt situations can endanger the integrity of the containment. In existing NPP units, the high reliability of the depressurization and residual heat removal systems make it possible to practically exclude this risk. In the EPR, a supplementary line of defense is provided: a set of motor-driven valves activated by the reactor operators palliates the potential failure of the other lines of defense.
- Exclusion of violent phenomena that can result from the production of hydrogen is provided by catalytic recombiners (about 40 of them) to consume the hydrogen. The pressure increase that would result from the combustion of hydrogen is taken into account in the containment design.
- Corium spreading and cooling can take place in a dedicated room next to the bottom of the reactor pit, whose walls and floor are covered with sacrificial concrete. A cooling structure under the spreading area allows for extraction of the residual heat, cooling and quick solidification of the corium. Erosion of the structural concrete of the base mat is thus prevented. An entirely passive valve arrangement allows for covering the layer of hot material and for feeding the cooling structure with water from the In-Containment Refueling Water Storage Tank (IRWST), located next to the corium spreading chamber. In a second phase, after twelve hours, the Containment Heat Removal system is started which cools the spreading area.

- The design and general arrangement of the NPP buildings enable collecting possible leaks through the penetrations and filtering them before their release. This design meets the strict radioactive release objective imposed for next-generation reactors.

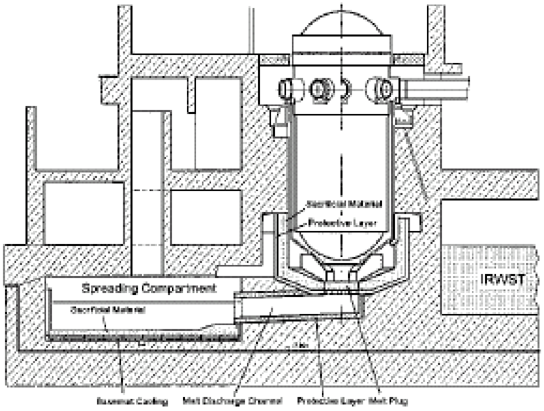


Figure 2: Reactor Cavity section

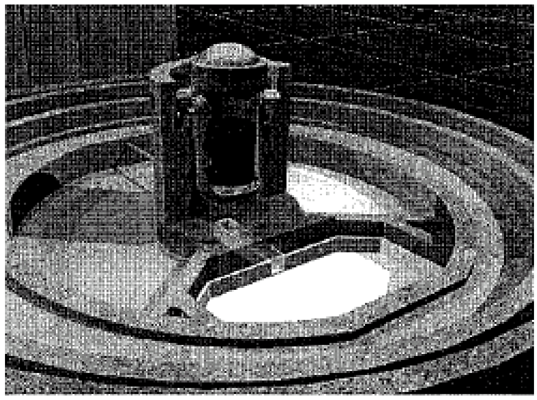

Figure 3: View of the corium spreading area

## 2.6. Plant Layout and Building Technology

The reactor building is located in the centre of the plot plan .Containment is surrounded by safeguard and fuel buildings that contain the safety systems. All safety-related systems are designed with a four-fold redundancy and located in physically separated divisions.

Each division comprises a low-head safety injection/residual heat removal system with a related intermediate cooling system, a medium-head injection system and an emergency feed-water system. The related electrical systems as well as the instrumentation and control systems are also allocated to these divisions but located on a higher building level.

The inner containment is a pre-stressed concrete cylindrical wall with an elliptical head and a reinforced concrete base mat. A metallic liner fitted on the inner surface ensures the leak tightness of the containment. The outer containment is formed by a reinforced cylindrical wall, resting on the same base mat as well as the central part of the reinforced concrete dome which serves as protection against external hazards.

The reactor building, the fuel building and the four safeguard buildings are protected against external hazards, such as earthquake and explosion pressure waves. All these buildings are situated on a common raft. This construction provides a very good resistance to the external hazard loads.

Protection against aircraft crash is achieved by bunkerization of the safeguard buildings 2 and 3, the reactor building and the fuel building. The main control room is located in the bunkered safeguard buildings.

Safeguard buildings 1 and 4 are not bunkered but are geographically separated, so that should one division be affected, the other would remain operable.

## 3. COMPETITIVENESS

### 3.1. Efficiency

EPR has been designed for maximum reactor efficiency combined with the most efficient and flexible use of fissile material. The nuclear steam supply system (NSSS) design is compatible with a high discharge burn up in excess of 60 Gwd/t. Intrinsically, high discharge burn up fuel reduces the volume of the high activity radwaste per unit of energy produced, typically 15% reduction on long-lived actinides generation per MWh compared to reactors in operation today. In addition the EPR design enables flexible fuel management thanks to the core low power density.

The secondary pressure (78 bars), which conditions the efficiency of the thermodynamic cycle in the secondary system, is the highest of its category. A net efficiency of 37 % can be obtained by current steam turbines depending upon site conditions. This is the highest value reached for a Light Water Reactor so far.

### 3.2. Reduced duration of scheduled refueling and maintenance outages

Reducing scheduled outage duration to improve overall unit availability was, from the very beginning of this project, one of the key objectives. The general layout of the equipment has been planned to facilitate maintenance operations. System designs allow performance of certain maintenance operations while the EPR unit is in operation thus reducing the amount of servicing during outages. A standard refueling outage of less than 16 days is possible for performing all necessary operations: reactor cool down, fuel unloading, inspection, maintenance, refueling, and then bringing the reactor back to normal operating temperature.

Duration of an outage for refueling only does not exceed 12 days.

The short scheduled outages and a reduced number of unscheduled outages produce an overall availability of 92 % over the EPR unit's service life.

### 3.3. Service life

The EPR's technical service life is 60 years, maximizing the plant's economic performance. All non-replaceable equipment, such as the reactor vessel or civil works structures, has been designed to attain this limit. All other equipment is designed to ensure a long service life, as well as ease of replacement should that be necessary.

### 3.4. Flexibility for fuel management and operation

Due to its considerable margins for fuel management optimization, EPR core is designed for outstanding flexibility with respect to fuel cycle length and fuel management strategy: reference cycle length is 18 months, but fuel cycle lengths up to 24 months, IN-OUT and OUT-IN fuel management capabilities are offered. A great flexibility for using MOX (mixed UO2-PUO2) fuel assemblies in the core, i.e. of recycling plutonium extracted from spent fuel assemblies is also provided.

In terms of operation, EPR is designed to offer the Utilities a high level of maneuverability. It has the capacity to be permanently operated at any power level between 20 and 100% of its nominal power in a fully automatic way, with primary and secondary frequency controls in operation.

The EPR capability regarding maneuverability is a particularly well adapted response to scheduled and unscheduled power grid demands for load variations, managing of grid perturbations or mitigation of grid failures.

## 4. EPR PROGRESS

### 4.1. The Olkiluoto project

The Contract for Olkiluoto 3 implementation was signed on December 18, 2003 between TVO and the consortium made up of Framatome ANP and Siemens Power Generation, respectively to be in charge of the Nuclear and Turbine Islands including civil works. The Framatome ANP – Siemens consortium will supply the Nuclear Power Plant unit as a turnkey delivery. Main project licensing milestones are as follows :

- The PSAR was submitted to STUK in early January 2004,
- The Construction license was awarded on the 17 February 2005,
- FSAR will be issued and commissioning will start in mid 2007,
- Operation license is expected mid 2008.

### 4.2. The Flamanville 3 Project:

In September 2004 the DGSNR issued a letter which officially set the safety objectives to be satisfied by the next generation PWRs to be licensed in France. Assessment work which is taking place now has to be understood as a preparation of the formal licensing process which will start when EDF will submit the official application for the construction license.

EDF officially announced the selection of the Flamanville site in October 2004. As required by the French law, a public debate is presently being held to gather all comments from all stakeholders with regard to the contemplated construction of an EPR unit on the Flamanville site next to the already two 1300 MWe units in operation. This debate will be concluded in early 2006. The Commission in charge has considered that the debate should not only be local but also organized on a national scale and has enlarged the scope to some general issues which were already discussed during the national debate on the energy policy which took place in 2003 (more information are available on the web site: www.debatpublic-epr.org/).

Only after this step and after consideration of the results of the public debate, EDF will proceed with the formal application and submittal of the PSAR to DGSNR in accordance with the French Law.

## 4.3. EPR Design Certification in the USA

Early 2005, Framatome ANP, Inc. officially informed the NRC of its intent to launch design certification for the evolutionary EPR design in accordance with 10CFR52.

As it is usual in this situation the project started with a pre-application review which is presently ongoing.

September 15, 2005, AREVA Inc. announced the creation of UniStar Nuclear with the Constellation Energy Group to provide a framework through which the first fleet of advanced nuclear power plants in America in nearly three decades could be developed and deployed.

The UniStar Nuclear model brings together in one complete package, a pre-eminent nuclear reactor vendor and an experienced nuclear fleet licensee, operator and owner relying on a major A/E (Bechtel) as a sub-supplier. Specifically, UniStar Nuclear will offer the business framework that could enable the development of joint ventures with Constellation Energy, other energy companies, and interested parties. Those joint ventures, in turn, would license, construct, own and operate nuclear power plants as part of a standardized fleet (more information is available on www.unistarnuclear.com.)

## CONCLUSION

The EPR design is a culminating step in PWR technology. EPR evolutionary design protects against licensing, construction and technical risks and their financial consequences. EPR design advanced features also ensures its competitiveness in terms of installed kW cost and kWh production cost.

At the end of the Basic Design phase, a Standard Preliminary Safety Analysis Report and a complete bill of quantities were generated. Exhaustive cost analyses demonstrated particularly

low power generation costs, thus ensuring EPR competitiveness against alternative means for electric power generation.
The Basic Design of the EPR has been extensively reviewed by the Safety Authorities and their support organizations IRSN (French Institute for Radiological Protection and Nuclear Safety) and GRS (Germany's central expert institution for nuclear safety). This review led to a set of Technical Guidelines drawn up by the "Groupe Permanent Réacteur" (French Advisory Group to the Safety Authorities – GPR) together with German Experts which were submitted to the French Safety Authorities in November 2000. On September 28, 2004, this document was officially endorsed by DGSNR through a letter signed by Mr. Lacoste, on behalf of both Ministers who oversees the Nuclear Safety (the Minister of Industry and the Minister of Environment).

Construction of a first unit in Finland on the Olkiluoto site is a major milestone in the development of the EPR project: the key options and economic merits have been proven in a highly competitive arena. EPR detailed design is now being achieved within the framework of the Olkiluoto 3 contract with the procurement process close to the end for the main components. The Construction license has been awarded allowing construction to start on site.

The next milestone is the decision to build a demonstration unit in France to prepare for the replacement of the EDF fleet. Following selection by EDF of the Flamanville site, the administrative process is on-going. The next milestone is the award of the construction license for Flamanville 3 which is expected approximately two years after the Olkiluoto 3 license.

To answer the request for proposals of the Chinese Industry for construction of third generation design NPPs, AREVA has proposed the EPR. The evolutionary design of the EPR would allow China to fully capitalize in the most efficient way on its already acquired experience gained from the successful achievements of the previous nuclear projects.

The EPR Design Certification project by the NRC is the most recent initiative which will ensure compliance of the EPR design with respect to safety requirements which are required by the US NRC. Considering the future need of replacement of aging NPPs which will become acute in the US in the next decade, the EPR should be a strong contender in this competition.