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The European Pressurized Water Reactor: A Safe and Competitive Solution for Future Energy Needs

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1 INTRODUCTION

The European Pressurized Water Reactor – the EPR – is a PWR in the 1600 MW class. Its design is based on experience feedback from several thousand reactors x years of light water reactor operation worldwide, primarily those incorporating the most recent technologies: the French N4 and the German KONVOI reactors. It is an evolutionary design that ensures continuity in the mastery of PWR technology, minimizing the risk for the customer.

2 DEVELOPMENT OF THE EPR

From the start of the project in 1991, a Franco-German cooperation was set up to develop the EPR:

- On vendors' side, the two most experienced European nuclear suppliers, Framatome and Siemens acted together first through their equally-shared subsidiary Nuclear Power International, then by merging their nuclear activities in January 2001 to form Framatome ANP, now in the AREVA group.
- On operators' side, Electricité de France and the major German Utilities formed a strong group to represent the interests of future owners of the EPR. They support the project by assigning their most experienced staff to review and approve the development results.
- Moreover, the French and German Safety Authorities and safety experts worked closely together in order to ensure that state-of-the-art safety standards in France and Germany be met on the EPR. Their major objective was the establishment of a set of common rules and regulations in order to harmonize the French and German licensing requirements. During the Basic Design, they actively and intensively reviewed the EPR safety concept on the basis of their jointly issued "Proposal for a common safety approach for future pressurized water reactors". This work was concluded in October 2000 by the validation of the Technical Guidelines for the design and construction of future Nuclear Power Plants with PWRs by the French "*Groupe Permanent Réacteurs*". German experts participated in this work.

The structure of the EPR Design Project involving all organizations of the nuclear industry from the very beginning ensures a comprehensive industrial approach for the development of the nuclear power plant technology of the future.

Also, the compliance of the EPR with the European Utility Requirements - EUR - provides a wide acceptability without need for significant adaptations to meet other authorities´ or customers´ requirements.

3 EPR DESIGN PHILOSOPHY

The EPR design philosophy is governed by three essential targets:

- Improved safety level as compared to existing plants by deterministic and probabilistic considerations
- Mitigation of hypothetical severe accidents by restricting their consequences to the plant itself
- Competitive power generation costs.

3.1 Safety Approach

A twofold strategy is pursued for the EPR safety requirements: First, to improve the preventive measures against accidents, and second, - although the severe accident frequency has been further reduced by deterministic design criteria and verified by probabilistic assessments of the design choices – to mitigate severe accidents consequences.

These safety requirements are implemented by designing the plant on a strong deterministic basis and, beyond this basis, by consideration of risk reduction measures (Figure 1)

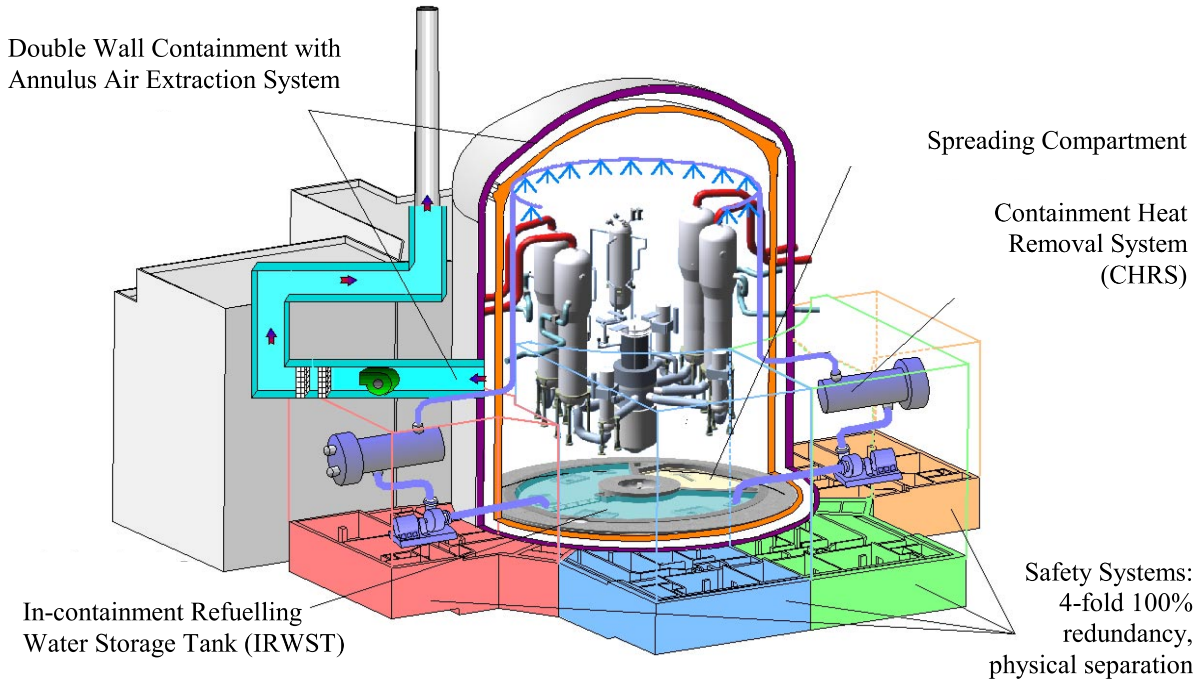

Figure 1: Main Safety Features

Accident Prevention measures are enforced by:

- Simplification of the safety systems with increased reliability through a 4-fold 100% redundancy (4-train concept).
- Elimination of common mode failures by physical separation and diverse back-up functions for safety functions.
- Extended grace periods for operator actions by designing components (e.g. pressurizer and steam generators) with larger water inventories to smoothen transients.
- Reduced sensitivity to human errors due to an optimized man-machine interface based on fully digitalized instrumentation and control systems and status-oriented information supplied by modern operator information systems.

Low probability events with multiple failures and coincident occurrences up to the total loss of safety-grade systems are considered, in addition to the deterministic design basis. Representative scenarios are defined for both mitigation of core melt and prevention of large releases, in order to provide a design basis for risk reduction features.

Consequently, the EPR design incorporates the following design provisions:

- Prevention of high pressure core melt by high reliability of decay heat removal systems, complemented by dedicated severe accident depressurization valves.
- Prevention of hydrogen combustion by reducing the hydrogen-concentration in the containment at an early stage by catalytic hydrogen recombiners.
- Limitation of molten core-concrete interaction by spreading the corium in a dedicated spreading compartment (Figure 2).
- Control of the containment pressure increase by a dedicated containment heat removal system (CHRS), which consists of a spray system and which allows recirculation through the cooling structure of the melt retention device.
- Collection of all leaks and prevention of any bypass of the confinement is achieved by double wall containment.

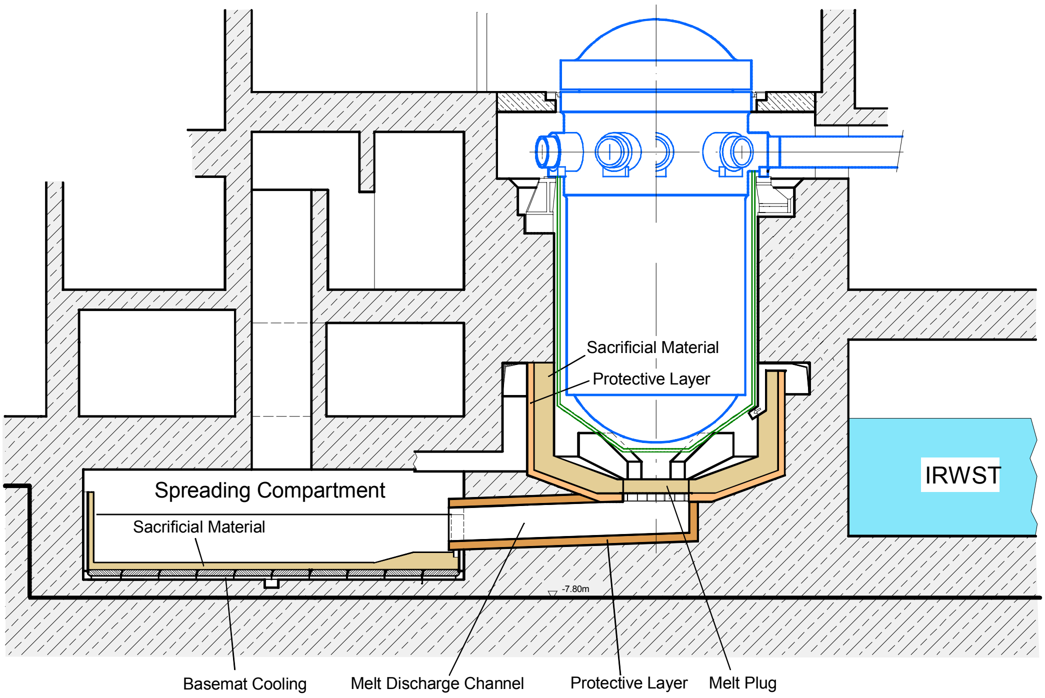

Figure 2: Severe Accident Mitigation (vertical cut)

By these measures, the external source terms are limited in a way that stringent countermeasures, such as relocation or evacuation of the population is restricted to the immediate vicinity of the plant and the restrictions of the use of cereals and other crops are limited to the first year harvest.

3.2 Protection against external hazards

The EPR provides particularly effective physical protection against external hazards.

- To withstand an airplane crash (APC), the Reactor Building, control room, Spent Fuel Building and two of the four Safeguard Buildings (2 and 3) are protected by an outer shell made of reinforced concrete, thick enough to withstand the high-speed impact of a military aircraft and also a commercial aircraft. The other two Safeguard Buildings are located at opposite sides of the Reactor Building so that only one would be destroyed by an aircraft crash, therefore without any safety consequences. Similarly, the Diesel generators for emergency electricity supply are located in two different buildings, also protected by geographical separation (Figure 3).
- To withstand severe earthquakes, the EPR is designed with large safety margins. The entire nuclear island stands on a single reinforced concrete basemat. The height of the buildings has been minimized. The heaviest components, in particular the water tanks, are located at the lowest possible level.

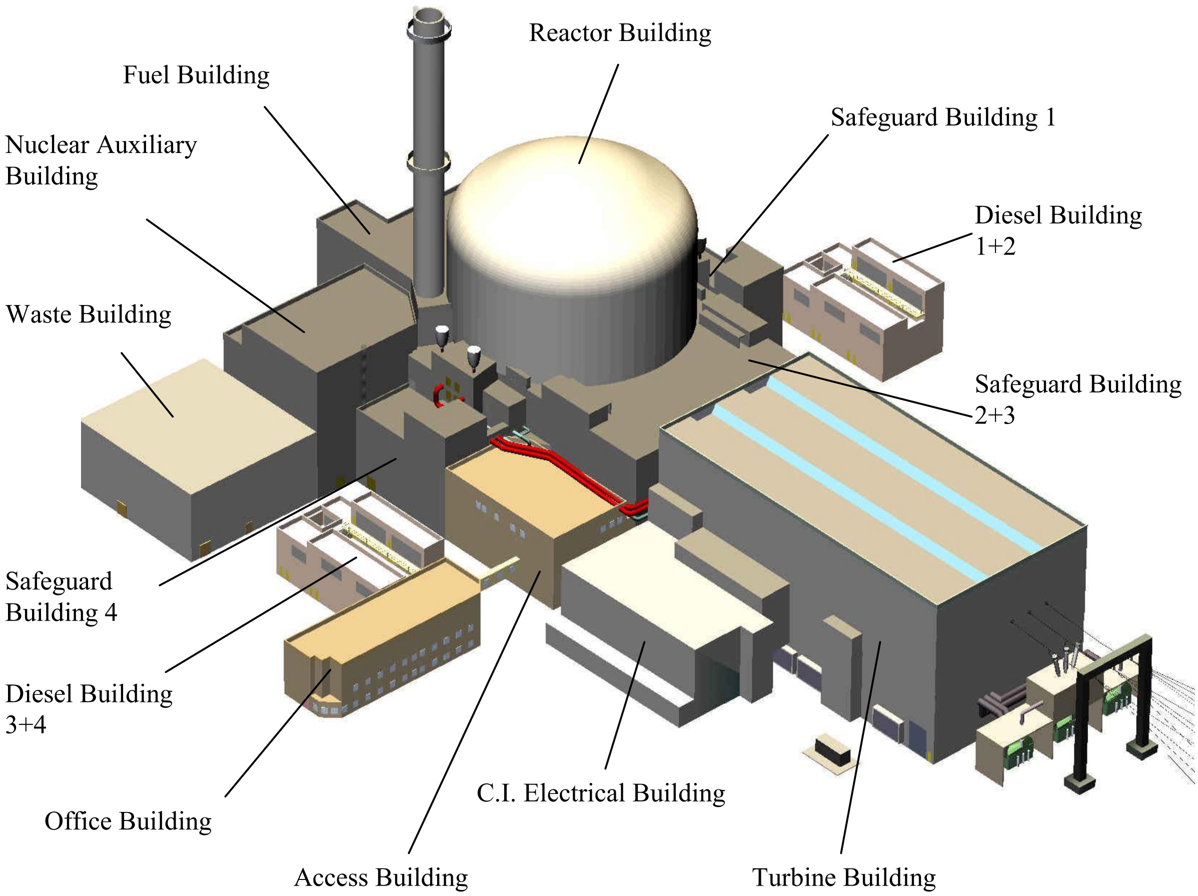

Figure 3: Plot Plan

3.3 Main data and technological innovations

The main data are shown in the following table:

Core thermal power	4300	MW_{th}
Net power output	~ 1600	MW_{el}
Reactor coolant system		
– Number of loops	4	
– Operating pressure	155	bar abs
– RPV inlet/outlet temperature	295,9 / 327,2	°C
– Total coolant flow per loop	28330	m^3/h
Steam pressure	78	bar abs
Core		
– Number of fuel assemblies	241	
– Number of control rod cluster assemblies	89	
– Fuel assembly array	17 x 17 - 24	
– Active height	420	cm
– Average linear heat rate	156,1	W/cm

In addition to the innovative features associated with its reinforced level of safety, the EPR benefits from many technological innovations:

- The reactor core is surrounded by a neutron reflector that improves fuel utilization and protects the pressure vessel against irradiation-related aging phenomenon.
- The pressure vessel is made of optimized steel resistant to aging and designed with a reduced number of welds.
- The steam generators, equipped with an axial economizer, allow production of high-quality steam (78 bar) and therefore high plant efficiency (36-37 %).
- The reactor protection system uses proven digital technology.
- The plant control room is fully computerized with an operator-friendly Man-Machine Interface.

4 COMPETITIVENESS

Future nuclear power plants will have to be even more competitive to cope with the newly liberalized electricity market.

Due to an early focus on economic competitiveness during the design process, the EPR offers significantly reduced power generation costs, estimated as being 10 % lower than those of the most modern nuclear units currently in operation, and about 20 % less than those of large combined-cycle gas plants.

This competitiveness is achieved through:

- Unit power in the 1600 MW range, i.e. the highest unit power to date (a further power increase is possible without major changes, as the reactor equipment is already designed for a core thermal power of 4500 MW_{th}).
- 36-37 % efficiency depending on site conditions, the highest value ever for light water reactors.

- Construction time from pouring of the first concrete not exceeding 48-months.
- Service life increased to 60 years.
- Enhanced fuel utilization.
- Up to 92 % availability factor, on average, during the entire service life of the plant, obtained through long irradiation cycles, shorter refueling outages and in-service maintenance.

Large operating margins are available due to the core design, giving the EPR outstanding flexibility to accommodate – in accordance with the various need of the utilities – different types of fuel (UO_2, UO_2-Gd_2O_3, MOX), different fuel management strategies and irradiation cycle lengths (up to 24 months), coast down and stretch out operation.

5 SUMMARY OF THE ADVANTAGES OF THE EPR

- Evolutionary design minimizing risks.
- Continuity in the mastery of PWR technology.
- Competitiveness: a 1600 MW_{el}-class reactor, with high efficiency, reduced construction time, extended service life, enhanced fuel utilization and increased availability.
- Safety:
  - Heightened protection against core meltdown and its radiological consequences;
  - Robustness against external hazards, in particular airplane crashes and earthquakes.
- Flexible and optimized operability.
- Enhanced radiological protection of operating and maintenance personnel.

6 PROJECTS

6.1 Finland

In January of 2002, the Finnish government made a positive decision-in-principle regarding the construction of a fifth reactor; the Parliament ratified the government's decision-in-principle in May 2002.

Four months after the project received parliamentary approval, TVO issued invitations to tender a bid for building the nuclear plant. The company asked for bids for either a PWR or BWR with a capacity of between 1000 and 1600 MW. The aim was to bring the new unit on line "by the end of this decade".

TVO received bids on March 31st, 2003 from several supplier candidates including a Consortium of Framatome ANP and Siemens. On October 15th, 2003 TVO announced that the company had chosen a preferred bidder – the Framatome ANP/Siemens Consortium. It was explained that the European Pressurized Water Reactor – the EPR – was the most competitive with respect to power generation cost. At the same time it was told the new nuclear plant would be built at the Olkiluoto site on the West coast of Finland.

Contract negotiations were concluded in a very short time, and the contract was signed in Helsinki on December 18th, 2003. According to the contract, the Consortium will supply the plant on a turnkey basis.

The site preparation works are currently going on as well as the elaboration of the detailed design. First concrete for the foundation plate shall be poured in May 2005 leading to commercial operation in spring 2009.

6.2 France

On May 5, 2004, the French Government formally gave to EDF its approval for the construction of an EPR unit in France. Discussions are now on-going with the French utility to prepare launching of a first-of-a-series in the near future.

6.3 Other perspectives

Interest is currently rising for the EPR design in different countries in Europe, Asia and America. EPR could in particular be selected in China in the years to come, to help this country meet its rapidly growing electricity needs. In France, the EPR design is obviously meant to replace the current fleet in the 10 years to come.

With these promising perspectives, owners of EPR units would greatly benefit from sharing a wide experience feedback.