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EPR Becomes Reality at Finland's Olkiluoto 3

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Abstract: The EPR is a third-generation pressurized water reactor (PWR). Its development was started in 1992 by Framatome and Siemens within a Franco-German partnership. Since 2001 this work has been continued by Framatome ANP, which was formed when the two companies merged their nuclear businesses. The French company AREVA, world market leader in nuclear technology, holds a 66% share in Framatome ANP, with Siemens owning 34%. From the very start, development of the EPR was focused on improving plant safety and economics even further. The new reactor development was jointly financed together with the leading power utilities of both countries. The first steps towards realization of an EPR nuclear power plant were taken at Olkiluoto, Finland in 2004 [1][2], consisting of initial preparation of the construction site. By mid-February 2005 the local municipality – Eurajoki – had issued a construction permit, and the Finnish Government a construction license pursuant to the Finnish Nuclear Energy Act. This had been preceded by a preliminary safety assessment prepared by the Finnish Radiation and Nuclear Safety Authority (STUK) for the Finnish Ministry of Trade and Industry in which STUK verified that it did not see any safety-related issues opposing issuance of the nuclear construction license. STUK emphasized that the evolutionary design of the EPR had been further improved by AREVA compared to the previous product lines. Concreting work began this spring and the unit will start commercial operation in 2009. Construction of an EPR has also been given the political go-ahead in France. According to the utility Electricité de France (EDF) the new reactor will be built as a forerunner of a later series at the site of Flamanville in Normandy. Construction is scheduled to begin in 2007. An EPR nuclear power plant has a rated electric capacity of around 1600 MW, depending on specific site conditions. Being the product of intense bilateral cooperation the EPR combines the technological accomplishments of the world's two leading PWR product lines – France's N4 and Germany's Konvoi. At the same time it incorporates a new class of safety: its highly advanced safety systems represent a further enhancement of the high safety level already provided by nuclear plants currently in operation in Germany and France. To attain the specified safety goals, measures have been taken to further reduce the probability of occurrence of core damage and to also ensure that all consequences of a (hypothetical) accident involving core melt remain restricted to the plant itself. The EPR has additionally made great progress in terms of low power generating costs, conservation of natural resources, and minimization of waste volumes. From the viewpoint of the European nuclear community, it therefore demonstrates nuclear energy's excellent prospects for the future as an economical option for carbon-dioxide-free base-load power generation in our liberalized power markets.

Keywords: Chemistry · Economics · EPR · Materials · Safety · Water

The EPR – A Third-Generation Reactor

It is now common practice to classify nuclear reactors into four so-called 'generations' (I to IV, Fig. 1). The nuclear power plants currently in operation belong to Generation II. The plants classified as Generation III, on the other hand, are those new reactor units that were developed from the Generation II plants and are primarily characterized by an even higher level of safety but much lower power generating costs. The EPR is a typical Generation III reactor.

A Generation IV reactor is also being developed for the distant future, these reactors being intended for special applications that go beyond power generation (*e.g.* production of hydrogen in high-temperature processes) as well as for conserving resources (*e.g.* in fast reactors).

Birth of the EPR and its Development Goals

Framatome of France and Germany's Siemens company began developing the EPR [3–6] in 1992 on behalf of and with significant support from the French national electric utility EDF and leading German electric utilities. The project was closely monitored and supported by licensing authorities and independent inspection agencies in both countries to ensure the EPR's license capability in France and Germany. Through the Olkiluoto 3 project, the EPR is now being ful-

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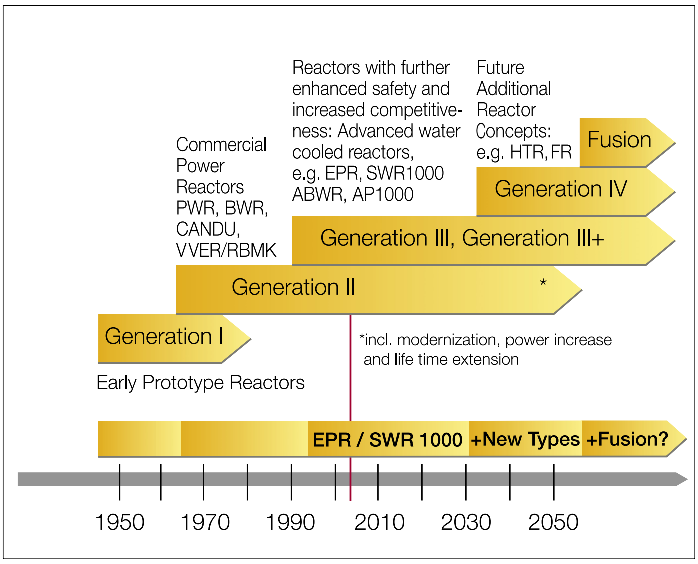
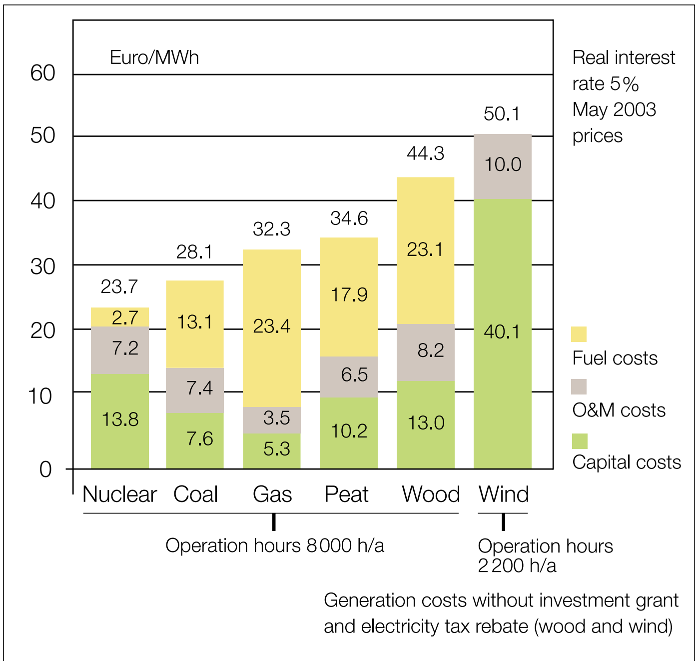


Fig. 1. Chronology of generations of nuclear reactors



Source: R. Tarjanne & K. Luostarinen 15.05.2003; Lappeenranta University of Technology

Fig. 3. Power generating costs of new nuclear power plants according to Professor Risto Tarjanne, Lappeenranta University of Technology.

ly licensed for the first time by the Finnish authorities.

The EPR builds on proven technologies deployed in the two countries' most recently built nuclear power plants – the French N4-series units and the German Konvoi-series plants – and constitutes an evolutionary concept based on these designs (Fig. 2). An evolutionary design was chosen in order to be able to make full use of all of the reactor construction and operating experience that has been gained not only in France and Germany – with their total of 2070 reactor operating years – but also worldwide. Guiding principles in the design process included the requirements elaborated by European and US electric utilities for future nuclear power plants, as well as joint recommendations of the French and German licensing authorities.

The key development goals were:

- To further increase safety and, at the same time,
- To further improve economic performance.

Enhanced Competitiveness

Professor Risto Tarjanne of Lappeenranta University of Technology has shown in detailed studies [7] that – for the specific operating requirements of a Finnish power utility – nuclear power plants are competitive with other power generating technologies (Fig. 3). Nuclear energy yields the lowest and most stable power generating costs of all, even when one ignores the 'carbon dioxide taxes' levied on fossil energy sources.

The following factors contribute towards making the EPR's power generating costs even lower than those of the most recently built nuclear power plants currently in operation:

- Larger net electric output of around 1600 MW: this leads to lower specific construction costs;
- Higher secondary-side pressure of 78 bar: this in conjunction with an opti-

Technical Data:

Reactor thermal output:	4300 MW
Net electric output:	approx. 1600 MW
Main steam pressure:	78 bar
Main steam temperature:	293°C
Reactor pressure vessel height:	13 m
Reactor core height:	4.2 m
Number of fuel assemblies:	241
Uranium inventory in reactor:	128 t UO_2
Number of control rods:	89
Containment height:	63 m
Containment inside width:	49 m
Outer Containment wall thickness:	2 m

Fig. 2. Affordable climate protection: the EPR (foreground) will become a reality at Olkiluoto in Finland in 2009

mized turbine design results in an efficiency of more than 37% under Finnish conditions – the highest efficiency of any light water reactor plant in the world;

- Shorter construction period of 48 months;
- Extended design plant service life of 60 years;
- Higher fuel utilization with a discharge burnup of more than 60 GWd/t: this means reduced uranium consumption and lower spent fuel management costs;
- Greater ease of maintenance thanks to improved accessibility and standardization, with preventive maintenance being possible while the plant is on line;
- Shorter refueling outages leading to higher plant availability.

Factors aimed at ensuring the longest possible periods of uninterrupted power operation with minimal downtime comprise:

- Fuel operating cycles of up to 24 months;
- Short refueling outages, even when extensive maintenance work is necessary;
- Plant availability ratings of more than 90%.

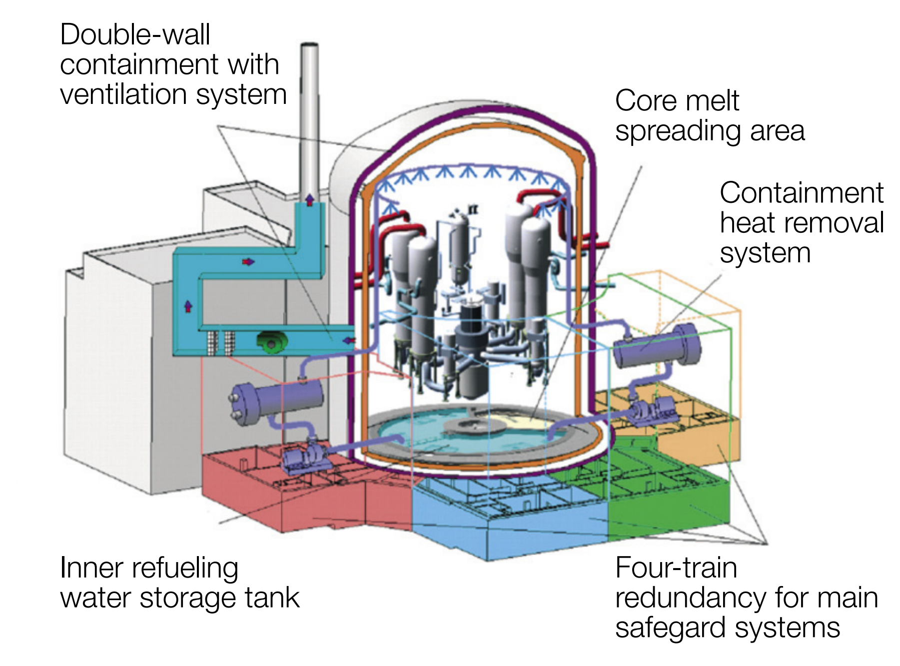


Fig. 4. Major safety features of the EPR

Greater Safety

Safety levels at nuclear power plants have been constantly improved in the past. The EPR, as a nuclear reactor of the third generation, represents yet another step forward in terms of safety technology by offering in particular the following features (Fig. 4):

- Improved accident prevention, to reduce the probability of core damage even further: this is achieved by a larger water inventory in the reactor coolant system, a lower core power density, high safety-system reliability thanks to quadruple redundancy and strict physical separation of all four safety system trains, as well as digital instrumentation & control systems and optimized man-machine interfaces.
- Improved accident control, to ensure that – in the extremely unlikely event of a core melt accident – the consequences of such an accident would remain restricted to the plant itself: this is done by confining the radioactivity inside a robust double-walled containment, by allowing the molten core material (corium) to stabilize and spread out underneath the reactor pressure vessel and by protecting the concrete.
- Improved protection against external hazards (such as aircraft crash, including large commercial jetliners) and internal risks (such as fire and flooding).

Full quadruple redundancy is provided in all safety systems and all of their auxiliary systems. The individual trains of the safety-related systems are installed with strict physical separation in four different buildings. The risks associated with common mode failures – which can also affect redundant systems of technically identical design – have been reduced by systematically applying the principle of functional diversity. If all redundant trains of a safety system should completely fail, there are always diverse safety features available that can take over its tasks, thus enabling the EPR to be safely shut down and cooled.

Not only has the probability of occurrence of core damage states been reduced, but the radiological consequences of severe accidents have additionally been limited by means of a new containment design. This new design ensures that the containment will retain its structural integrity under accident conditions, including those caused by external man-made hazards. The events of September 11, 2001 have likewise been taken into consideration.

Subatmospheric pressure conditions are continuously maintained in the annulus of the double shell containment in order to ensure leakage control. Any radioactive leakages from the primary containment can be collected in the space between the two containment shells and directed through a filter system before being discharged to the outside atmosphere. Negative pressure conditions are continuously maintained in this containment annulus to ensure leakage control in the event of filter system failure.

In the hypothetical event of an accident causing nuclear fuel degradation further provisions are taken to retain the radioactivity inside the containment so that there would no longer be any need to evacuate the population living in the immediate vicinity of the plant or place long-term restrictions on food consumption – in other words, relocation of the population would not be necessary.

Safe Plant Operation through Customized Water Chemistry

In the EPR, as at any nuclear power plants, water chemistry serves to keep the plant operating safely and to protect both system components and plant personnel. Water chemistry tasks can be divided into several main categories:

- To minimize the rates of metal loss of structural materials;
- To prevent corrosion product deposition on heat-exchange surfaces as far as possible.

These first two tasks are achieved by establishing optimum physical and chemical conditions such as pH level and OR (oxidation-reduction) potential.

- To prevent the occurrence of selective corrosion;
- To stop a corrosion-assisting environment from arising.

These tasks require that system fluids have as high a degree of purity as possible and that mechanisms be prevented that could cause corrosive species to concentrate in corrosion product deposits (*i.e.* to minimize corrosion product deposition).

And the following applies to the reactor coolant system in particular:

- Corrosion product transport and deposition must be controlled in such a way that contamination with radionuclides is minimized (to protect personnel).
- Radiochemical formation of oxygen must be suppressed.

In selecting water chemistry regimes for the primary and secondary sides of the plant, use can be made of the many years of experience gained in both France and Germany [8]. The most recent advances in this field have been considered for the EPR.

Primary water chemistry takes aspects related to safety, plant life extension and man-rem reduction into account. The reactor coolant serves to transport the heat from the reactor core to the steam generators, to moderate ('slow down') fast neutrons and to capture neutrons for purposes of reactivity control. In order that the coolant can perform its task of capturing neutrons, boric acid is added to the water. The boron-10 isotope contained in the boric acid captures the neutrons. The EPR will be operated on a new chemistry regime using enriched boric acid (EBA) in which the reactive B-10 content has been increased above the natural level. The resulting improvement in pH adjustment (achieved by adding lithium hydroxide – LiOH – as an alkalizing agent) protects materials against corrosion and reduces anticipated radionuclide contamination. In other words, this approach protects both materials and personnel.

Secondary water chemistry for the EPR will comprise the so-called high AVT method (AVT = all volatile treatment). In the plant's secondary circuit, heat is transported from the steam generators to the turbine where it is used to generate electricity. To do this, steam is produced in the steam generators by evaporating feedwater, causing the steam generators to become a collecting point for corrosion products carried into them with the feedwater. High levels of corrosion product ingress into the steam generators damage their tubes, and directly or indirectly reduce plant output. Implementation of high AVT water chemistry prevents this mechanism by significantly reducing the amount of corrosion products entering the steam generators. This water chemistry regime with its elevated pH counteracts corrosion and erosion-corrosion of carbon steels and thus minimizes the corrosion product inventory of the secondary cycle. This secondary water chemistry is both economical and protects materials.

Materials Contribute to Plant Service Life of 60 Years

The joint development of the EPR by Framatome and Siemens also provided a unique opportunity for the successful features of the two companies' previous material selection concepts to be combined and developed further in order to meet the requirements for a plant service life of 60 years. The EPR's reactor pressure vessel, steam generators and pressurizer will be fabricated from the French grade equivalent to the 20 Mn Mo Ni 55 steel. As in all 58 of France's nuclear power plant units currently in operation, the reactor coolant piping will be made from an austenitic chromium-nickel steel. Depending on specific customer requirements, the steam generators will be equipped with tubes made of the nickel-base alloy Inconel 690 that was developed in the 1980s and has proven itself in extensive laboratory tests as well as during past operation to be fully equivalent to Incoloy 800.

Future Prospects

Against the backdrop of climate change, reducing the world's carbon dioxide emissions represents the greatest challenge of the 21st century. In addition, the world's demand for energy is growing rapidly and electricity consumption can be expected to increase out of all proportion. What this means today is that we have to make the most efficient use possible of every single energy source currently available, while at the same time placing top priority on research into new energy sources that produce less CO_2 or none at all. For this reason, more and more importance will be attached in the future to nuclear energy as a CO_2-free energy source.

Construction of a new, state-of-the-art nuclear power plant makes economic sense, even in liberalized power markets, and helps achieve climate protection targets. Moreover, giving nuclear energy a reasonable share in the energy mix reduces our dependence on fossil fuel imports. This meets both economic and environmental goals in equal measure. An impressive example for this is the construction of Olkiluoto 3 – an EPR – in Finland.

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