The EPR -
A Safe and Competitive Solution for Future Energy Needs

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Introduction

In 2002, the Finnish Government gave the go-ahead for construction of the country's fifth nuclear power plant unit. In December of 2003, the AREVA NP/Siemens Consortium was awarded a turnkey contract by the Finnish utility Teollisuuden Voima Oy (TVO) to build a new nuclear power plant at the Olkiluoto site where two boiling water reactor units are already in operation. "Olkiluoto 3" [1][2] is an EPR, and thus the world's very first third-generation nuclear power plant under construction. The reactor is being supplied by AREVA NP, the turbine and generator by Siemens. AREVA NP, which is head of the consortium, is responsible for overall project management as well as technical and functional integration.

Figure 1: Affordable climate protection: the EPR (foreground) at Olkiluoto in Finland is to start producing electricity in 2009.

AREVA: Power is Our Core Business

With manufacturing facilities in 40 countries and a sales network in more than 100, AREVA offers customers reliable technological solutions for CO₂-free power generation and electricity transmission and distribution. AREVA is the world leader in nuclear power and the only company to cover all industrial activities in this field (from uranium mining, processing
and enrichment as well as fuel manufacture, through reactor construction and services to reprocessing of used fuel). 

**AREVA NP: Leader in the Development and Advancement of Nuclear Power**

In January 2001 the nuclear activities of Framatome and Siemens were combined within a new company, Framatome ANP, which was renamed AREVA NP in April 2006.

AREVA has a 66 percent stake in the company and Siemens 34 percent. The joint venture, which is headquartered in Paris, has a total workforce of over 14,000 employees and regional subsidiaries in the U.S. and Germany. AREVA NP's focus includes the development and turnkey erection of nuclear power plants and research reactors as well as their modernization, maintenance and repair, the design and supply of electrical equipment and instrumentation and control (I&C) systems, heavy component manufacture, and the design and supply of fuel assemblies for many reactor designs, including those supplied by other vendors.

Construction of the new nuclear plant in Finland is helping to safeguard not only the invaluable know-how and expertise of AREVA's engineers in the nuclear field, but also the outstanding reputation of the European nuclear technology on the international market. Thanks to this contract and the worldwide renaissance of nuclear energy, the German part of the company – AREVA NP GmbH – has been able to take on around 550 new employees in the last two and a half years, most of them young people. The total workforce at AREVA NP GmbH presently numbers around 2750.

**Birth of the EPR and its Development Goals**

In 1992, Framatome and Siemens began developing the EPR [3-6] on behalf of and with significant support from the French national electric utility Electricité de France (EDF) as well as 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 licensability in France and Germany. For the Finnish Olkiluoto 3 project, the EPR then underwent a complete design review for the first time. Following a positive overall assessment by the Finnish authorities the Government granted the construction license in February 2005. Before the customer takes over the power plant, he must first apply for an operating license as part of the second stage in licensing.

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. 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 more than 2100 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.
Key development goals were to further increase safety and at the same time to further improve economic performance in order to strengthen nuclear energy's competitiveness with other energy sources, both fossil and renewable.

The EPR Design

The EPR has a slightly higher reactor thermal output than other pressurized water reactors currently in operation. The deployment of steam generators with economizer sections along with an advanced steam turbine design lead to a higher efficiency.

Safety systems directly connected to the reactor coolant system that serve to inject coolant into the system and to remove residual heat in the event of a loss-of-coolant accident (LOCA) are designed with quadruple redundancy.

The emergency core cooling systems comprise four passive accumulators as well as four low- and intermediate-pressure safety injection systems. The in-containment refueling water storage tank serves to store water for emergency core cooling and accommodates any leakage water discharged via a pipe break in the reactor coolant system.

In addition to the systems for residual heat removal that are connected directly to the reactor coolant system, a further system designed to assure heat removal in the event of loss of normal feedwater supply is connected to the secondary system. This consists of a four-train emergency feedwater system that supplies water to each steam generator. In the steam generators, the heat generated in the reactor is used to produce steam for driving the turbine. This steam is then condensed in the turbine condenser. If the condenser should be unavailable due to loss of the main heat sink, the excess steam can be directly discharged to the atmosphere from the steam generators. The emergency feedwater system on the secondary side is equipped with electric-motor-driven pumps that can be powered, if necessary, by the unit's four large emergency diesel generators. In addition, the plant is also equipped with two small, separate diesel generators to ensure that feedwater supply to the steam generators is...
guaranteed even in the event of simultaneous failure of all four of the large emergency diesels.

Even Greater Safety

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

- **Improved accident prevention**, to reduce the probability of core damage even further: this is provided 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 an optimized man-machine interface.

- **Improved accident control**, to ensure that – in the extremely unlikely event of a core melt accident – the consequences of such an accident remain restricted to the plant itself: this is done by confining the radioactivity inside a robust double-walled containment, by allowing the postulated molten core material (corium) to stabilize and spread out underneath the reactor pressure vessel and by protecting the concrete against meltthrough.

- **Improved protection against external hazards** (such as aircraft crash, including large commercial jetliners) and internal risks (such as fire and flooding).

Figure 3: The main safety systems of the EPR at a glance.

Full quadruple redundancy is provided in all safety systems and all of their auxiliary systems. 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 one redundant system train should completely fail, there is always another train of diverse design that can take over its tasks, thus enabling the EPR to be
safely shut down and cooled. These comprise, in particular, backup functions deployed on a systematic basis to further enhance safeguards for accident prevention. If an entire accident control function should fail, diverse actions will be implemented to achieve the same safety objective. What does this mean in concrete terms? For example, if all four redundant intermediate-pressure safety injection trains should be lost after a small-break LOCA, the residual heat from the reactor core can alternatively be removed via the secondary system, and the pressure reduced to a level at which the passive accumulators and low-pressure safety injection pumps can feed emergency coolant into the reactor. Hence, even in the extremely unlikely event of complete loss of all four redundant subsystems, the accident can still be controlled in such a way that destruction of the core is ruled out. The individual trains of the safety-related systems are installed with strict physical separation in four different buildings.

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. Any radioactive leakages from the primary containment are collected in the space between the two containment shells and can be 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. This means that in the hypothetical event of an accident causing melting of the core 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.

Probabilistic safety analyses were incorporated from the outset into the design process in order to determine and evaluate the probability of accident sequences capable of leading to severe core damage or significant releases of radioactivity.

Innovative Design Features

The safety authorities require that, despite all enhancements incorporated into the EPR design for accident prevention, provisions nevertheless be made to control all events that could possibly lead to melting of the core following a postulated loss of all safety systems, the aim of this being to prevent catastrophic impacts on the environment. In the case of the EPR this primarily meant providing engineered safeguards that would prevent destruction of the containment in the event of a postulated core melt accident. These safeguards comprise, in particular, reactor coolant system depressurization, a special reactor pit design, core melt stabilization, the design of the containment, containment heat removal and hydrogen reduction.

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. 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.

Figure 4: Power generating costs of new nuclear power plants according to Professor Risto Tarjanne, Lappeenranta University of Technology.

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 optimized 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
- 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%.
The Future of Nuclear Power in Europe and the Rest of the World

In April 2006, 443 nuclear reactors having a total electric output of around 379 gigawatts (GW) were in operation in 31 countries [8]. They met approximately 16 percent of the world's demand for electric power. Another 26 reactors designed for a total output of around 21 GW were under construction in 11 countries.

In the European Union (EU), 13 of the 25 member states operate a total of 149 nuclear power plant units meeting approximately 32 percent of the EU's demand for electricity.

In view of the clear benefits of nuclear power – such as security of supply, economic efficiency and environmental friendliness – as well as our growing energy and climate problems, it is no surprise that nuclear energy is experiencing an upswing all over the world. The U.S. Government's Energy Information Administration [9] estimates that, assuming moderate construction of new power plants, the total installed generating capacity will increase by 60 GW by the year 2025, or by around 200 GW if new nuclear power plants are built in parallel with the increase in global power demand. This translates into an anticipated need for between 46 and 160 new reactors of the 1300-MWe class, not counting those required to replace generating capacity lost through nuclear power plant decommissioning.

Which of these scenarios will actually materialize will likely depend to a considerable extent on how world market prices for fossil fuels develop. The fact that things are looking up again for nuclear power can be seen in some examples of worldwide developments:

- Following the passing of the Energy Policy Act in mid-2005, the U.S. is continuing to work on making the construction of new nuclear power plants a reality. Consortiums formed together with major power utilities are preparing concrete projects. AREVA is currently working on an application for Design Certification of the U.S. EPR that is scheduled to be submitted to the U.S. Nuclear Regulatory Commission by the end of 2007. AREVA's goal is to have the first U.S. EPR go on line in around 2015. In addition to efforts associated with new-build projects, work has been steadily progressing for some years now on extending the operating licenses of existing plants. In the meantime, altogether 44 units have been granted a license for a total service life of 60 years, with applications currently pending for another seven plants.

- In 2002, the decision was taken in a West European country for the first time in 13 years to build a new nuclear power plant: in Finland the EPR, a third-generation nuclear power plant, is being built at Olkiluoto.

- In France, the national utility EDF has likewise decided to build an EPR as a first-of-a-series plant at Flamanville in Normandy. Construction is scheduled to start in 2007. At the end of May 2005 a Memorandum of Understanding was additionally signed between the Italian utility Enel and EDF concerning cooperation in France’s nuclear program. Enel is aiming for a 12.5% share in the new EPR project Flamanville 3 as well as in any other potential projects for constructing new nuclear plants, and also wants to build up nuclear know-how again. In addition, Enel has secured itself an option for another 1000 MW of power generating capacity in five new EPR plants to be built.
• In the United Kingdom, Prime Minister Tony Blair is continuing to promote the debate surrounding the construction of new nuclear power plants. Such new units should take the place of reactors scheduled to go permanently off line in the next two decades. Financing is to come from the private sector, with foreign utilities also being allowed to take part. One of the next steps will be to optimize the licensing procedure.

• Step by step, Sweden is gradually turning its back on its decision to phase out nuclear power, although this still remains official policy. Nuclear power plant owners and operators have launched wide-ranging programs for uprating the plants that are currently in operation and for extending the plants’ service lives. In the spring of 2006 a controversial paragraph was deleted from the Atomic Energy Act that prohibited any preparations (e.g. design drawings, cost calculations, etc.) for building a nuclear power plant in Sweden. According to the latest opinion polls, 85% of those interviewed are now in favor of the 10 existing plants staying in operation and of new nuclear units being built.

• In Bulgaria, the state-owned utility Natsionalna Elektricheska Kompania (NEK) has decided to resume construction of two new units, Belene 1 and 2. On July 19, 2005, in addition to the Skoda Alliance, AtomStroyExport was prequalified for the bidding process.

• The only nuclear power plant in the Netherlands – Borssele – has been granted a 20-year extension to its operating license. This means a total service life for this plant of 60 years.

• In Switzerland discussions continue – above all, among power utilities – concerning the long-term need for a new nuclear power plant to replace the power generating capacity of existing nuclear units. In this connection the utility Axpo has mentioned the possibility of an EPR being constructed. At the same time, further steps are being taken towards being able to open a final repository for high-level radioactive waste. At the end of June 2006, the Swiss Government verified the basic technical feasibility of radioactive waste being safely stored in a final repository in Switzerland.

• An important pacesetter for upcoming new-build projects is Asia, particularly China. Just the China National Technical Import & Export Corporation (CNTIC) alone has invited bids for four third-generation reactors; AREVA also took part in this bidding process with the EPR. A "Preferred Bidder" is yet to be named. In March 2006 construction started on Quinshan II-3 and then in June on Ling Ao 4. China's plans for expansion are based on the construction of nearly 30 new nuclear units by the year 2020, something which would make nuclear power's share in the country's electricity production six times larger than it was before but still only responsible for around 4% of China's total power generating capacity.

• In Australia and Turkey, two countries that do not yet have commercially operated nuclear reactors, the introduction of nuclear power is a topic that is being talked about with great interest. Both countries have ample uranium deposits and want to use new nuclear power plants to reduce energy dependencies and also to meet their growing demand for energy without harming our climate.

Naturally, nuclear energy cannot solve our energy and climate problems all on its own. But it is, however, quite evident that the world's leading industrial nations intend to continue
relying on nuclear energy as an inexpensive and environmentally benign source of energy with a stable price level.

References

[1] Norbert Haspel, Olkiluoto 3 – Project Overview, Canada Forum 2004