EPR,
an Evolutionary Advanced Reactor for a New Nuclear Era

D. REICHENBACH – June 2004
The European Pressurized Water Reactor EPR
The Franco-German cooperation brought together, from the start of the project:

- the power plant Manufacturers Framatome and Siemens
- EDF and the major German electric Utilities (E.ON, EnBW, RWE Power)
- the Safety Authorities of both countries, to harmonize safety regulations applicable to the next series of Pressurized Water Reactors
Building on Experience

Enhanced safety level

Competitive with alternative power sources

Framatome N4

Siemens KONVOI

Evolutionary development keeps references

Solid basis of experience with outstanding performance
The EPR, a Generation–III Plant, with an Evolutionary Design

<table>
<thead>
<tr>
<th></th>
<th>South Texas plant</th>
<th>French N4 series</th>
<th>EPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power</td>
<td>3853 MWth</td>
<td>4250 MWth</td>
<td>4300 MWth</td>
</tr>
<tr>
<td>Electric power</td>
<td>1251 MWe</td>
<td>1450 MWe</td>
<td>1600 MWe</td>
</tr>
<tr>
<td>Efficiency</td>
<td>32%</td>
<td>34%</td>
<td>37%</td>
</tr>
<tr>
<td>Secondary pressure</td>
<td>68 bar</td>
<td>71 bar</td>
<td>78 bar</td>
</tr>
<tr>
<td>No of primary loops</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Safety Trains</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Containment</td>
<td>Single wall</td>
<td>Single wall</td>
<td>Double wall</td>
</tr>
<tr>
<td>Core catcher</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>No of fuel assemblies</td>
<td>193</td>
<td>205</td>
<td>241</td>
</tr>
<tr>
<td>Linear power (kW/Ft)</td>
<td>5.2 (non-accident)</td>
<td>5.5</td>
<td>4.7</td>
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<tr>
<td>Discharge burnup</td>
<td>50 to 55 GWd/tU</td>
<td>45 GWd/tU</td>
<td>&gt;60 GWd/tU</td>
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<tr>
<td>Design life time</td>
<td>40 years</td>
<td>40 years</td>
<td>60 years</td>
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Safety objectives: a two fold strategy

1. **Enhancement of the prevention level of the defense in depth safety concept, particularly to reduce significantly severe accident probability**

2. **Mitigation of severe accidents consequences up to and including core meltdown accidents**
First fold: improvement of prevention level

- Simplification of safety systems
- Combination of multiple redundancy and diversity of safety systems
- Systematic physical separation
- Increased time for action by enlarged water inventories of primary components
- Improved man-machine interface
- Systematic evaluation by means of probabilistic studies
- Systematic consideration of shutdown states
Primary side safety systems

- Four train safety injection system
- In-containment borated water storage pool
- No necessity for containment spray for design basis accidents
- Combined residual heat removal system and low-head safety injection system
- Extra borating system (two trains not shown on this figure)
Second fold: mitigation of severe accident consequences

- Short and long-term function of the containment must be ensured
- Corium shall be stabilized within the containment
- Direct leakage from the containment into the environment shall be prevented
- Cooling of the corium must be provided for, even for a long period of time

**TARGET**

Offsite emergency response actions (people evacuation or relocation) shall be restricted to the nearby plant vicinity and limited in time
Approach for mitigation of severe accident consequences

- The EPR is designed for bringing safe solutions to the severe accident consequence issues
  - Elimination of high pressure core melt sequences
  - Management of produced Hydrogen
  - Management of steam explosion risk
  - Stabilisation of core melt within the containment
  - Containment heat removal
  - Containment robustness and radioactivity confinement
  - Mastering of the radioactivity source term
Stabilization of the core melt within the containment

Main design features

- Temporary retention of melt within reactor pit after RPV failure, thanks to a passive melt plug
- Spreading on a large surface (170 m²) within a dedicated spreading compartment
- Provision of sacrificial material in reactor pit and spreading compartment
- Passive flooding of melt with water from IRWST resulting in quenching and cooling of the melt from both sides with water
- Long term heat removal from melt and containment via an active cooling system
Stabilization of the core melt within the containment

Spreading concept overall arrangement
Stabilization of the core melt within the containment

Spreading area
Containment and confinement features

- A double wall containment
  - The outer wall is a reinforced concrete shell resistant to external hazards
  - The inner wall is a pre-stressed concrete shell with a metallic liner or a “partial liner” on critical areas like penetrations and transition zones between the cylindrical wall and the containment floor and dome
- Leak-rate, for a 24-hour period: less than 1% by volume
- Prevention of non-controlled leakages by design of the penetrations
- Collection of all leakages in the annulus, inside the double wall, and filtration prior to release via the stack
EPR containment and confinement features

EPR double-containment
Main EPR safety systems

- Double confinement with ventilation and filtration
- Water reserves inside the confinement
- Cooling air in the melted core
- Confinement heat dispersion system
- Four redundant safety systems
Increased protection against external hazards

- **Backup diesel building**
- **Division 1 auxiliary safeguard building**
- **Division 2 auxiliary safeguard building**
- **Division 3 auxiliary safeguard building**
- **Division 4 auxiliary safeguard building**
- **Access building**
- **Fuel building**
- **Auxiliary nuclear systems building**
- **Equipments entrance**

- **Reinforced concrete protection**
- **Protection by separation**
- **Standard protection**
Mastery of the radioactivity source term

Determination of a very conservative source term, called "Reference Source Term" in an early stage of the project under simplified assumptions. This source term was used for dose calculations in order to show that the EPR meets the requirements of:

- No need for stringent counter measures
- No long-term relocation outside the immediate vicinity of the plant
- No long term restriction of consumption of food, especially for the second harvest
Instrumentation & Control
Design basis for I&C
Safeguard systems structure

- 4 train systems distributed in 4 divisions
- 4 electrical power supply systems backed up by 4 Diesel (plus 2 additional emergency Diesel to supply power, in case of station black out)
- 4 I&C divisions
- Each division is located in a separate building (safeguard building)
**Man-machine interface**

**Main control room equipment**

- 4 computerised operator workstations
- 1 emergency control panel located between operator workstations
- 1 plant overview display (large screens)
- 1 conventional auxiliary panel
- Service centre for I&C configuration and maintenance located next to the main control room
EPR heavy components
Heavy reflector replacing conventional core baffle assembly

- Fuel cycle cost reduction
- Improvement of long term mechanical behaviour of internals:
  - No bolt in the most irradiated areas
  - Well managed temperature distribution in the structure
  - Very low depressurization effects in case of LOCA
- Protection of RPV core shell against radiation embrittlement
Steam generator (SG)

- The SG is a boiler equipped with an axial economizer
- The axial economizer provides a steam pressure boost of about 3 bar
- Saturation pressure: 78 bar
- Heat exchange area: 8000 m²
- 6000 tubes, Inconel 690 or 800, triangular lattice
- A loose part trapping device is implemented on the main feedwater distribution ring
ECONOMICS
Several recent studies carried out in Europe about new nuclear reactors MWh generation cost

<table>
<thead>
<tr>
<th>Reference</th>
<th>BELGIUM</th>
<th>GERMANY</th>
<th>FINLAND</th>
<th>FRANCE</th>
<th>U.K.</th>
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<tbody>
<tr>
<td>Ampère Commission</td>
<td>PWR 1300 MW</td>
<td>EPR 1500 MW</td>
<td>PWR 1250 MW</td>
<td>EPR 1580 MW</td>
<td>AP 1000</td>
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<tr>
<td>(2000)</td>
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<td>IER Stuttgart</td>
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<td>(2001)</td>
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<td>Lappeenranta</td>
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<td>University (2002)</td>
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<td>Charpin Study</td>
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<td>(2000)</td>
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<td>BNFL (2001)</td>
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<table>
<thead>
<tr>
<th>Investment cost (€/kWe)</th>
<th>Belgium</th>
<th>Germany</th>
<th>Finland</th>
<th>France</th>
<th>U.K.</th>
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<tbody>
<tr>
<td>2010</td>
<td>1550</td>
<td>1350</td>
<td>1600</td>
<td>1333</td>
<td>1000</td>
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<td>OVN (total)</td>
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<td></td>
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<tr>
<td>2010</td>
<td></td>
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</tbody>
</table>

| Discount rate | 5 % | 6 % | 5 % | 6 % | 11 % |
| Lead factor    | 85,6%| 85,6%| 91,3%| 90,5%| About 90% |
| Lead time      | 8 to 10 years | n.d. | 5 years | 5 years | n.d. |
| Economical lifetime | 40 years | 35 years | 40 years | 40 years | 30 years |

Sources: published studies
The generation cost, with newly invested reactors, is around 30 € per MWh.
Nuclear competitiveness corroborated by Finnish economic studies performed in 2001 and updated in 2002

**Finnish assumptions:** 1,250 MW nuclear power plant, 400 MW CCG plant with efficiency of 57%; November 2001 prices

<table>
<thead>
<tr>
<th>Discount rate (excluding inflation)</th>
<th>5.0%</th>
<th>6.5%</th>
<th>8.0%</th>
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<tr>
<td><strong>In €/MWh</strong></td>
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<td>Investment</td>
<td>13.8</td>
<td>16.7</td>
<td>19.9</td>
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<td>Operation &amp; Maintenance</td>
<td>7.2</td>
<td>7.2</td>
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<tr>
<td>Fuel</td>
<td>3.0</td>
<td>3.0</td>
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<tr>
<td><strong>Total</strong></td>
<td>24.1</td>
<td>26.9</td>
<td>30.1</td>
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</table>
EPR features to provide an even more competitive nuclear MWh generation cost

- Unit power increased to 1,600 MWe
- Increased efficiency
- Increased burnup rates
- Simplified maintenance
- Reduced refueling outage times
- Forecast availability factor 92%
- Service lifetime increased to 60 years
OLKILUOTO 3
NEW NUCLEAR POWER PLANT
FOR FINLAND
Finland: TVO Chooses the EPR

Artist rendition of Olkiluoto 3 – source: TVO
Why Additional Nuclear Power?

- New nuclear power plant
- Covers partly the additional electricity demand and replaces old power plants
- Enables, together with renewables, the fulfilment of the Kyoto commitments
- Secures stable and predictable electricity price
- Reduces the dependence on electricity imports

Source: TVO
Olkiluoto 3 Overall Schedule
Subject to Change

PHASE:

**Licensing**
- Environment impact assessment
- Decision-in-principle (DIP)
- Constructing license
- Operating license

**Procurement**
- Feasibility studies
- Bid request
- Bids
- Bid evaluation
- Main contracts

**Implementation**
- Site preparations
- Construction
- Commercial operation

Source: TVO
Licensing and Plant Selection Process

- Application for “Decision-in-Principle”  November 2000
- Favorable decision by Government  January 2002
- Ratification by Parliament with votes-107 in favor, 92 against  May 24, 2002
- Bid competition launched  September 2002
- Bids received  March 2003
- Preliminary selection of site and plant  October 16, 2003
- Signing of contract  December 18, 2003

Source: TVO
Olkiluoto 3 - Project

- EPR pressurized water reactor plant, supplier consortium Framatome ANP/Siemens AG
- Reactor thermal output 4,300 MW, electric output about 1,600 MW
- Location Olkiluoto
- Capital structure: equity, subordinated shareholders loan and debt
- Construction license application submitted to the Government on 8.1.2004

Source: TVO
Bid Evaluation Criteria

About 20 criteria based on:

- Safety features
- Technical solutions
- Supplier’s competence and future expectations
- Electricity generating cost

Source: TVO
Olkiluoto 3

- Location: Olkiluoto, Eurajoki
- Reactor supplier: Framatome ANP
- Reactor’s country of origin: France/Germany
- Reactor type: Pressurized water reactor, PWR
- Turbine supplier: Siemens AG, Germany
- Electric output: approx. 1,600 MW
- Net efficiency: 37%
- Total building volume: 950,000 m³

Source: TVO
Olkiluoto 3 – A Fast-track Project

Nozzle Shell Flange

poured on Oct. 22, 2003

June 2, 2004
And There is More to Come

Figure 1
Renouvellement étalé sur 30 ans (2020-2050)
rythme de construction 2000MW/an

Powering France in the 21st Century

Source: EDF