Our Contribution to the Forum

► General presentation of the EPR™ Reactor

► CR1.1.1 ‘Robustness’
  ◆ PART 1 – Margins - Simplicity
  ◆ PART 2 – Quality of design and construction – Quality of materials – Redundancy
  ◆ PART 3 – Robustness to external hazards

► UR1.4 ‘Release into the Containment’

► CR3.1.1 ‘Occupational Dose’
Presentation of the EPR™ reactor

Franck Lignini
Reactor & Services / Safety & Licensing
AREVA Reactor Range

* In partnership with MHI
The EPR™ Reactor
The EPR™ Reactor
EPR™ reactor
Design Key drivers
Gen 3+ Pressurized Water Reactor:

1. Take advantage of lessons learned from existing commercial plants
   - Evolutionary PWR Design

2. Reduce power generation costs
   - Large size PWR (~1600 MWe)
   - Longer plant lifetime (60 years)
   - Increase availability (target >92%)
   - Decrease O&M costs (typical outage reduced to 16 days)
   - Reduced fuel cost (7 to 15%)

3. Further increase safety levels

4. Further decrease volumes of ultimate waste
Gen 3+ Pressurized Water Reactor:

1. Take advantage of lessons learned from existing commercial plants

2. Reduce power generation costs

3. Further increase safety levels
   - Reduce collective doses during normal operations
   - Reduce probability of core meltdown by a factor of 10
   - Reinforce deterministic defense in-depth (core meltdown included)
   - Reinforce resistance to external aggressions (such as airplane crash)

4. Further decrease volumes of ultimate waste
The EPR™ Reactor
Overall Design Key Drivers (3/3)

Gen 3+ Pressurized Water Reactor:

1. Take advantage of lessons learned from existing commercial plants
2. Reduce power generation costs
3. Further increase safety levels
4. Further decrease volumes of ultimate waste
   - Reduce liquid waste (by ~10% vs EDF existing best plants)
   - Reduce gaseous waste (by 30 to 50% vs EDF existing best plants)
   - Reduce irradiated material by 20 to 30% (thanks in particular to 60GWh/t fuel burn-up)
The EPR™ Reactor
Building on N4 and Konvoi achievements (1/3)
Plant - Overview

- Reactor Building
- Safeguard Building Division 1
- Diesel Building 1+2
- Safeguard Building Division 2+3
- Turbine Building
- Fuel Building
- Nuclear Auxiliary Building
- Radioactive Waste Processing Building
- Safeguard Building Division 4
- Diesel building 3+4
- Office Building
- Turbine Island Electrical Building
- Access Building
The EPR™ Reactor

Building on N4 and Konvoi achievements (2/3)

<table>
<thead>
<tr>
<th>N4</th>
<th>Konvoi</th>
</tr>
</thead>
<tbody>
<tr>
<td>High output (1475 MWe)</td>
<td>Military aircraft resistance</td>
</tr>
<tr>
<td>Large core (205 FA)</td>
<td>4 independent safety trains</td>
</tr>
<tr>
<td>High steam pressure (73 bar)</td>
<td>No spray system</td>
</tr>
<tr>
<td>Fuel building</td>
<td>Top mounted instrumentation</td>
</tr>
<tr>
<td>Computerized main control room</td>
<td>4x100% independent safety trains</td>
</tr>
<tr>
<td>Concrete cylindrical containment</td>
<td>No containment spray system for design basis accident</td>
</tr>
<tr>
<td></td>
<td>Top mounted instrumentation</td>
</tr>
</tbody>
</table>

- Very high output: ~1600 MWe net
- Very large core: 241 FA
- Very high steam pressure: 77 bar
- Fuel building
- Computerized main control room
- Best-in-class airplane crash
- No containment spray system for design basis accident
- Top mounted instrumentation
The EPR™ Reactor
Building on N4 and Konvoi achievements (3/3)

<table>
<thead>
<tr>
<th>Type of plants</th>
<th>N4</th>
<th>EPR</th>
<th>KONVOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core thermal power (MWth)</td>
<td>4250</td>
<td>4590</td>
<td>3850</td>
</tr>
<tr>
<td>Electrical output (MWe)</td>
<td>1475</td>
<td>1660</td>
<td>1365</td>
</tr>
<tr>
<td>Number of loops</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>N° of fuel assemblies</td>
<td>205</td>
<td>241</td>
<td>193</td>
</tr>
<tr>
<td>Type of fuel assemblies</td>
<td>17x17</td>
<td>17x17</td>
<td>18x18</td>
</tr>
<tr>
<td>Active length (cm)</td>
<td>427</td>
<td>420</td>
<td>390</td>
</tr>
<tr>
<td>Total F.A. length (cm)</td>
<td>480</td>
<td>480</td>
<td>483</td>
</tr>
<tr>
<td>Rod linear heat rate (W/cm)</td>
<td>179</td>
<td>166.7</td>
<td>167</td>
</tr>
<tr>
<td>N° of control rods</td>
<td>73</td>
<td>89</td>
<td>61</td>
</tr>
<tr>
<td>Total flowrate (kg/s)</td>
<td>19420</td>
<td>22256</td>
<td>18800</td>
</tr>
<tr>
<td>Vessel outlet temp. (°C)</td>
<td>330</td>
<td>330</td>
<td>326</td>
</tr>
<tr>
<td>Vessel inlet temp. (°C)</td>
<td>292</td>
<td>295.2</td>
<td>292</td>
</tr>
<tr>
<td>S.G.: heat exch. Surface (m²)</td>
<td>7308</td>
<td>7960</td>
<td>5400</td>
</tr>
<tr>
<td>Saturation Steam Pressure (bar)</td>
<td>73.1</td>
<td>77.2</td>
<td>65.5</td>
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</tbody>
</table>
## The EPR™ Reactor
### Key Technical Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Thermal power</td>
<td>~ 4600 MWth</td>
</tr>
<tr>
<td>Gross output</td>
<td>&gt; 1750 MWe</td>
</tr>
<tr>
<td>Net output</td>
<td>&gt; 1600 MWe</td>
</tr>
<tr>
<td>Net efficiency</td>
<td>Up to 37%</td>
</tr>
<tr>
<td>Target availability</td>
<td>92%</td>
</tr>
<tr>
<td>Number of loops</td>
<td>4</td>
</tr>
<tr>
<td>Steam pressure (secondary)</td>
<td>~ 77 bars at 100% power</td>
</tr>
<tr>
<td>Operation cycle length</td>
<td>Up to 24 months</td>
</tr>
<tr>
<td>Design service life</td>
<td>60 years</td>
</tr>
</tbody>
</table>
The EPR™ Reactor

Key Characteristics of reactor coolant system

<table>
<thead>
<tr>
<th>Reactor Coolant System</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Core thermal power</td>
<td>~ 4600 MWth</td>
</tr>
<tr>
<td>Nominal flow per loop</td>
<td>~ 28,000 m³/h</td>
</tr>
<tr>
<td>Reactor pressure vessel inlet temperature</td>
<td>295°C</td>
</tr>
<tr>
<td>Reactor pressure vessel outlet temperature</td>
<td>330°C</td>
</tr>
<tr>
<td>Design pressure</td>
<td>176 bar</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>155 bar</td>
</tr>
</tbody>
</table>

**Secondary Side**

| Design pressure                            | 100 bar                     |
| Saturation pressure at nominal conditions (SG outlet) | 77 bar                     |
| Main steam pressure at hot standby         | 90 bar                      |
The EPR™ Reactor
Reactor Core Characteristics

- Large size core: 241 fuel assemblies
- Large power output: ~4600MWth
- Low linear power: 167 W/cm
- Better Fuel utilization
  - High Burn-up: 60GWD/t
  - Neutron reflector
- Flexibility in fuel utilization: Possibility of 100% MOX fuel taken into consideration right from design

<table>
<thead>
<tr>
<th>Fleet</th>
<th>Number of assemblies</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>157</td>
</tr>
<tr>
<td>1300</td>
<td>193</td>
</tr>
<tr>
<td>N4</td>
<td>205</td>
</tr>
<tr>
<td>EPR</td>
<td>241</td>
</tr>
</tbody>
</table>
The EPR™ Reactor
Overview of Safety Systems
The EPR™ Reactor
Diversity of Safety Systems

Safety systems passive parts
- Gravity driven control rod
- Accumulators with high boron concentration
- Pressurizer safety valves
- Passive H₂ recombiners
- Core-catcher
- IRWST + flooding valves
- Double containment

Safety functions
- Bringing the reactor to subcritical state
- Maintaining subcriticality whatever temperature
- Maintaining coolant inventory on the core
- Ensuring primary circuit integrity
- Long-term heat removal
- Ensuring containment integrity
- Minimize radioactive products release

Safety system active parts
- SCRAM system
- Extra Borating System
- Safety Injection System
- Depressurization Severe Accident Valves
- Essential Service Water System
- IRWST + RHR/LHSI
- Containment Heat Removal System
- Annulus ventilation System
The EPR™ Reactor - Installation in the Safeguard and Auxiliary Buildings (SAB)

division 1
Steam lines penetrations
Feedwater lines penetrations

division 2
ESWS
CCWS
SIS/RHRS
EFWS

division 3
ESWS
CCWS
SIS/RHRS
EFWS

division 4
ESWS
CCWS
SIS/RHRS
CHRS
EFWS

Control room

IRWST

SPREADING
AREA

SL FW

SL FW

EBS

Spent Fuel Storage Pool

FPCS

Airplane crash protected buildings
The EPR™ Reactor - Principles for safety classification of systems

F1 Functions

- F1A Functions: all safety functions which are required to reach a controlled state after a DBC event
- F1B Functions: all safety functions required, once the controlled state is reached, to reach and maintain a safe shutdown state after a DBC event

F2 Functions

- Functions related to the monitoring and controlling of radioactivity during normal operation
- Safety functions required to reach and maintain, from 24 hours up to 72 hours, the safe shutdown state after a DBC event
- Safety functions needed to reach final state for DEC-A sequences or to prevent significant releases in DEC-B sequences

Non-Classified Functions

Definitions of shutdown state:

- Controlled state (for DBC 2 to 4): the core is sub critical, heat removal is assured on short-term basis (max. 24h), core water inventory is stable and radioactive releases remain acceptable.
- Safe shutdown state (for DBC events): the core is sub critical, residual heat removed on a long term basis through the Cooling Chain and radioactive release remain acceptable.
- Final state (for DEC-A): the core is sub critical, residual heat is reliably removed at least up to the plant autonomy limits, and radioactive releases remain acceptable.
The EPR™ Reactor - Allocation of main I&C functions

► Preventive line of defense: Normal and Anticipated Operational Occurrences
  ◆ Process Automation System (PAS) for functions which do not use control rods as actuator
  ◆ Reactor Control Surveillance and Limitation system (RCSL) for functions which use control rods as actuator

► Main line of defense: Design Basis Accident
  ◆ Reactor Protection System (PS) to reach controlled state: Monitor safety parameters and actuation of reactor protection and safety features
  ◆ Safety Automation System (SAS) to reach safe state: Post accident management to bring the plant into a safe shut-down state and maintain the safe shut-down state

► Risk reduction line: Design Extension Conditions
  ◆ Diverse Actuation System (DAS) to cope with a common cause failure of I&C systems
  ◆ Severe Accident I&C (SA-I&C) to mitigate severe accidents
The EPR™ Reactor - I&C Human Machine Interface

▸ The Primary Human Machine Interface (Primary HMI):
  ◆ is used to monitor and control the plant in all conditions
  ◆ is screen based, integrated and fully computerized
  ◆ is implemented in the main control room as well as in the remote shut-down station

Name of the system: Process Information and Control System (PICS)

▸ The Secondary Human Machine Interface (Secondary HMI):
  ◆ It is mainly used if PICS is not available
  ◆ It mainly consist of conventional monitoring and control means dedicated to the individual automation systems
  ◆ It is implemented in a dedicated area in the main control room

Name of the system: Safety Information and Control System (SICS)
The EPR™ Reactor - I&C Overall Architecture

Level 0: process interface  
Level 1: control and protection  
Level 2: operation and information management  
Level 3: site management

Risk Reduction Line  
Main Line  
Preventive Line
99.9% of EPR™ features comply with EUR requirements*

* Statistics established over 4678 requirements

The certificate attesting to the EPR™ reactor’s compliance with European utility requirements was officially awarded to AREVA on July 15 2009

The EPR™ reactor has outstripped the EUR specifications in the following areas:

- Protection against the airplane crash (the risk of the large commercial aircraft is covered),
- Spent fuel storage capacity
- Life expectancy of 60 years against 40 required by the EUR
The EPR™ reactor is:
- The only Gen3 model under construction in the EU
- The only reactor designed within the EU
- The only reactor licensed by 3 independent European regulators
The value of Experience
Standardization of early engineering activities

System activities:
Input data for other disciplines ready earlier and better defined

- P&ID: Important input for layout in order to validate Civil Works (CW) interfaces
- DSE stage 2: important input for I&C

NSSS engineering standardized and streamlined

Number of engineering hours for NSSS completion (for Taishan: estimate)

- P&ID First issue (months)
  - OL3: 14 (9% improvement)
  - Taishan: 9 (36% improvement)

- System Description Stage 2 - First issue (months)
  - OL3: 30
  - Taishan: 20 (33% improvement)

- Piping isometrics Nb of revisions
  - OL3: 10 (70% improvement)
  - Taishan: [data not visible]
The value of experience
Illustration, from OL3 to TSN: first main milestones

Construction duration (# months)

- Dome lifting
- Slab +1,5m
- Start of inner containment
- Gusset pouring
- 1st concrete

<table>
<thead>
<tr>
<th>Event</th>
<th>OL3 Duration</th>
<th>TSN1 Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dome lifting</td>
<td>17</td>
<td>47</td>
</tr>
<tr>
<td>Slab +1,5m</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>Start of inner containment</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Gusset pouring</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>1st concrete</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

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Vienna – 19-22 November 2013
Key Messages

- The EPR™ Reactor is an evolution of mature French and German reactors, incorporating proven technologies as well as innovations validated through R&D programmes.

- The Safety features of the EPR™ Reactor integrate the lessons learned from the past. They have been deemed necessary and sufficient by the safety authorities of advanced nuclear countries as fulfilling the most stringent GEN III safety objectives, until March 2011:
  - The lessons learned from the Fukushima event are not yet all drawn.
  - A preliminary evaluations show that the EPR™ reactor would have withstood the earthquake and the subsequent tsunami.
  - The soundness of the EPR™ reactor design was confirmed by the complementary safety evaluations (stress tests) performed by the European Regulators; however light improvements may be incorporated to satisfy new requirements.
Thank you for your attention