INPRO Criterion 1.1.1
‘Robustness of Design’
Position of the EPR™ reactor
Part 2

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EP1.1.1.3 – Quality of Manufacture and Construction
General improvements on RPV structure

- Systematic use of Alloy 690 replacing the Alloy 600
- Reduction of the neutron fluence on the core shell region
- One piece RPV upper part instead of two welded pieces for N4
- Irradiation surveillance program
Reactor Pressure Vessel Internals
Main Design Features

USE OF A GENERAL ARRANGEMENT SIMILAR TO N4:

- Similar flow distribution in upper plenum and closure head dome
- Forged core support plate
- Fuel assemblies resting directly on the core support plate
- Same principles regarding centering and maintaining inside the RPV
- Same materials with more stringent requirement on Co residual content

INCORPORATION OF 3 MAIN MODIFICATIONS

- Adaptation to an in-core instrumentation introduced through the RPV closurehead (KONVOI design)
- Installation of a dedicated annular structure under the core support plate to ensure a proper flow distribution at core inlet
- INCORPORATION OF AN INNOVATIVE COMPONENT: THE HEAVY REFLECTOR
General improvements on RPV internals

- Increased margin with respect to RPV embrittlement achieved through neutron fluence reduction:
  - New heavy reflector design reducing neutron leakage at the core periphery
  - RPV diameter enlarged

- Prevention of low induced vibrations

- Better inspectability and easier replacement thanks to new design
REPLACEMENT OF CONVENTIONAL CORE BAFFLE ASSEMBLY BY A HEAVY REFLECTOR

- fuel cycle cost reduction
- Improvement of long term mechanical behavior of lower 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
Quality of Manufacture and Construction
Reactor Coolant Lines

Reactor Coolant Lines have significantly reduced number of welds.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>EPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piping inner diameter</td>
<td>780 mm</td>
</tr>
<tr>
<td>Piping wall thickness</td>
<td>76 mm</td>
</tr>
<tr>
<td>Piping manufacturing</td>
<td>forged</td>
</tr>
<tr>
<td>Large connect. nozzles</td>
<td>machined</td>
</tr>
</tbody>
</table>

CL: Cold Leg
HL: Hot Leg
UL: Cross-over Leg
Quality of Manufacture and Construction Reactor Coolant Lines Layout

EPR™ Safety Benefit:
Improvement of the Leak-Before-Break concept

A minimum number of auxiliary nozzles, they are provided on top of RCLs → reduction of leak risk

The Extra Borating System injection is introduced into the Reactor Coolant Line via CVCS or SIS nozzles.

CVCS: Chemical & Volume Control System
SIS: Safety Injection System
RHR: Residual Heat Removal (System)
PZR: Pressurizer
SL: Surge Line
Improvements on Pressurizer

Lance redesign
2 Lances instead of 3
Redesign in 20MND5

Optimised support

Heaters’ circular implementation

Risk Reduction
Strategic
Reduce welding length on support

► Support welding optimization

» Fatigue analysis performed to confirm feasibility
Heaters installed on 4 circles instead of on a square net

Heaters in circle to reduce manufacturing risk

- Installation (welding) of sleeves is much easier (less radii to be considered: 4 vs 18)
- Benefit for mechanical behaviour
- Accessibility for the required maintenance around the heaters flanges was checked
Quality of Manufacture and Construction

From reviewing the publicly available information (e.g. regulatory bodies who have licensed the EPR™ reactor or which are about to deliver Design Certification) an INPRO assessor may conclude that the evaluation parameter on ‘Quality of Manufacture and Construction’ is satisfied.

Some examples to support this conclusion were discussed above:

- RPV
- Main Coolant Lines
- Pressurizer
EP1.1.1.4 – Quality of Material
Organization of AREVA Technical Centers

Technical Center France
Chalon / Le Creusot / Montpellier 123 p

Technical Center Germany
Erlangen / Karstein/Offenbach 242 p

Technical Center US
Lynchburg 3 p

Fluid & Structural Mechanics
Components Testing

Manufacturing Materials

Metallurgy & Corrosion

Chemistry

Thermal Hydraulics & Components Testing

Materials, Corrosion, Welding Technology

Chemistry, Radiochemistry

Components Qualification

Components Testing

Chemistry, Radiochemistry

Components Qualification
R&D programs, focussed on degradation modes of PWR components were conducted inter alia in AREVA’s technical centers.

Preventive measures were integrated in the design of the EPR™ reactor regarding ageing of materials during plant operation.

- Demonstration that the selected materials are adequate for given component taking into account all susceptible modes of degradation.
  - Ageing during operation, Neutron irradiation assisted stress corrosion cracking, Thermal ageing, etc.
    - e.g. Redesign of Pressurizer in 20MND5 (cf. previous slide)
    - Reduction of impurities in RPV material
      - P content < 0.008% and Cu content < 0.08%
    - Cast duplex autenitic-ferritic stainless steels abandoned for primary piping
    - Primary loops manufactured with austenic stainless steel with integral elbows and nozzles to reduce the number of welds.
EP1.1.1.4 Quality of Materials

Environmentally Assisted Fatigue

- Field experience on existing PWR fleet worldwide showed cracking in locations where loadings were ignored or underestimated.
- For the design of the EPR™ reactor, AREVA conducted some critical experiments to evaluate the real concern and to establish a justification methodology:
  - Tests with load signals representative of actual component
  - Loadings Tests with representative surface finish (ground surfaces, …)
From reviewing the publicly available information (e.g. regulatory bodies who have licensed the EPR™ reactor or which are about to deliver Design Certification) an INPRO assessor may conclude that the evaluation parameter on ‘Quality of Material’ is satisfied.

Some examples to support this conclusion were discussed above

- RPV
- Main Coolant Lines
- Pressurizer
EP1.1.1.5 – Redundancy of Systems
The Design of the Safety Systems is based on Redundancy, Diversity and Complementarity

- **Diversity** (against Common Cause Failures)
- **Redundancy** (against single failure)
- **Complementarity** (between active and passive systems)

The EPR is designed to resist to exceptional events and prevent damage to the surroundings.
EPR™ Reactor Safety Systems: Redundant and Diverse

- 4x100% capacity allows for preventive maintenance at power (n+2 concept)
  - MHSI, LHSI/RHR, CCWS, ESW
  - EFWS with “passive headers”
- Common cause failures – safety system diversity:
  - Every system has a diversified back-up
- External hazards through systematic physical separation of the safety systems
- Clear separation of redundancies with 4 Safeguard buildings ensures robustness against hazards (flooding, fire) and Airplane Crash
- Reactor building, Safeguard buildings and Fuel building on a single raft to cope with seismic and Airplane Crash loads

Proven yet evolutionary safety systems deliver high reliability levels
The objective of train (1) separation is to preclude possible common cause failures due to equipment failures, including headers or check valves

- No header between the different SIS trains
- For EBS, EFWS and CCWS headers are acceptable and useful (probabilistically), provided that isolation devices ensuring independency of trains in case of equipment failures, are installed
- A radial layout results in separated trains and short piping lengths
- The objective of separation into divisions (2) is to prevent common cause failures due to internal hazards (e.g., fire, flooding)

(1) "Train" designates a redundant portion of a system

(2) "Division" designates a building or part thereof housing a train

EBS: Emergency Boration System
EFWS: Emergency FeedWater System
CCWS: Component Cooling Water System
Design rules for safety systems

Four trains are needed to cope with safety analysis

◆ 1 train is unavailable by application of the Single Failure Criterion
◆ 1 train is unavailable due to the Preventive Maintenance
◆ 1 train can be affected by the accident (e.g. LOCA)
◆ The 4th train is sufficient to cope with the accident

Main systems involved:

• Safety Injection System SIS/RHRS,
• Emergency Feedwater System (EFWS),
• Electrical Power Supply System,
• Component Cooling Water System (CCWS),
• Essential Service Water System (ESWS)

◆ They are installed in 4 separate divisions providing efficient protection against internal and External Hazards which could lead to Common Mode failure (e.g.: fire, flooding, APC)

Preventive maintenance possible during power operation
Electrical Power Supply System

Main design characteristics

- 4 electrical trains

- Each train contains:
  - A 10 kV emergency busbar
  - An Emergency Diesel Generator (EDG)
  - DC busbars with batteries: they supply valves and I&C

- SBO DGs: In addition, two small diesel generators (690 V) for trains 1 and 4 used in case of failure of the 4 EDGs (Station Blackout, SBO)
From reviewing the publicly available information (e.g. regulatory bodies who have licensed the EPR™ reactor or which are about to deliver Design Certification) an INPRO assessor may conclude that the Evaluation Parameter on ‘Redundancy of Systems’ is satisfied.

Some examples to support this conclusion were discussed above
Robustness against external hazards – cf. PART 3 of this presentation

Thank you for your attention