Risk-Informing ESBWR Design with Probabilistic Safety Assessments

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INPRO Criteria Evaluated:

- IN 1.3.1 Calculated frequency of design basis events
- IN 1.6.1 Independence of different levels of defense in depth
- IN 4.4.1 Use of a risk-informed approach
IN 1.3.1: Calculated frequency of occurrence of design basis accidents

Acceptance Limit:
*Reduced* frequency of accidents that can cause plant damage *relative to existing facilities*.

Background:
Development and use of a PSA in the ESBWR design process allowed the designers to assess design options that reduced the risks of core damage and radiological release.

Extensive use of operating experience and advanced light water reactor design principles (e.g. passive safety) have significantly reduced the plant risks.
IN 1.3.1: Calculated frequency of occurrence of design basis accidents

Example 1: Comparison of Core Damage Frequencies

Internal Events CDF

- Regulatory Goal
- Reference BWR 6
- ABWR
- ESBWR

Example chart showing the comparison of core damage frequencies for different reactors.
### Example 2: Contributions to Core Damage Frequency

<table>
<thead>
<tr>
<th>Internal Events Accident Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (1/a)</td>
</tr>
<tr>
<td><strong>Reference BWR</strong></td>
</tr>
<tr>
<td><strong>Station Blackout</strong></td>
</tr>
<tr>
<td><strong>ATWS</strong></td>
</tr>
<tr>
<td><strong>Transient Condition</strong></td>
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<tr>
<td><strong>LOCA</strong></td>
</tr>
<tr>
<td><strong>Safety Architecture</strong></td>
</tr>
</tbody>
</table>
IN 1.6.1 Independence of different levels of defense in depth (DID)

Acceptance Limit: *Adequate independence is demonstrated, e.g., through deterministic and probabilistic means...*

Background:
The ESBWR design incorporates independence between accident mitigation and severe accident management

Example: PSA severe accident insights were used to develop the Basemat internal Melt and Coolability (BiMAC) device
IN 1.6.1 Independence of different levels of defense in depth (DID)

Defense Levels

1. Prevention of abnormal operation and failures
2. Control of abnormal operation and detection of failures
3. Control of accidents within the design basis
4. Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents
5. Mitigation of radiological consequences of significant releases of radioactive materials
BiMAC concept

BiMAC - Basemat internal Melt Arrest and Coolability

BiMAC designed to:
- Passively quench high temperature corium
- Mitigate core-concrete reactions
- Controlled by an independent logic platform
IN 4.4.1 Risk-informed approach

Acceptance Limit:
A careful use of risk informed approaches based on proven data sets has been performed by the designer

Background:
Insights from the ESBWR PSA have been used to implement several design enhancements, and consequently, have contributed a significant improvement to nuclear safety.
IN 4.4.1 Risk-informed approach

Example 1 - PSA used in ESBWR design:

Added redundant, physically separated flow paths in response to fire analysis.

Alternative cooling system

Fail-safe actuation of ICS

Added parallel injection line valves for ICS to eliminate a dependency on power supplies.

Changed fire suppression piping route to reduce room flooding frequency.
Isolation Condenser System - Standby
IN 4.4.1 Risk-informed approach

Example 2 – Operator Actions

PSA was intentionally pessimistic on estimating Human Error Probabilities

No recovery actions are credited

Identify PSA accident sequences where operator actions are important, and then improve them with physical design changes
References

ESBWR

Safety Evaluation Report (NRC):
http://pbadupws.nrc.gov/docs/ML1034/ML103470210.html

Design Certification Document (DCD) Rev. 9:
http://pbadupws.nrc.gov/docs/ML1034/ML103440266.html

NEDO-33201, Revision 6, Probabilistic Risk Assessment ESBWR Design Certification
http://pbadupws.nrc.gov/docs/ML1028/ML102880536.html

NRC Final Design Approval:
http://pbadupws.nrc.gov/docs/ML1105/ML110540310.pdf

Reference BWR (Grand Gulf NPP) NUREG-1150
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1150/