Risk Assessment & Long Term Operation

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Outline

- Risk assessment studies & long-term operation
- Risk Issues for Operating Plants
- Risk of operating versus new designs
- Status of Containment Challenging Issues for Operating Plants vs. New Designs
- Risk of Operating Plants vs. New plants
- Summary
Risk Assessment Studies

- Probabilistic Safety/Risk Assessment (PSA/PRA) have been performed for most if not every operating plant world-wide. These include:
  - Level-1 (core damage frequency) PSAs for various initiators (internal events, fires, floods, seismic, refueling, low power, shutdown, refueling, etc.)
  - Level-2 (severe accident impact of containment integrity and estimation of radiological releases to environment) – for all U.S., Swiss and most of other European plants.
  - Level-3 (offsite health and other consequences) for few plants.
Long-term Operation

- Systematic process to guide safety improvement for NPPs. NPPs operate for a long-term (over 40 years).
  - Safety is highest priority (i.e., risk of continued operation must remain low).
  - Even though risk studies are not “perfect”, nonetheless, the PSA/PRA process has proven very effective in identifying vulnerabilities and in focusing attention:
    - Operators – focus on most risk/beneficial backfits and operational/maintenance improvements.
    - Regulators – focus on issues that drive safety to protect public health/safety and the environment.
  - Important that PSAs (as for all Swiss plants):
    - Include “non-full power” (outage/refueling) modes of operation.
    - Living (up to date).
    - Follow technically acceptable “standards/guidelines”.
Examples of PSA/PRA Limitations

- PSAs model all active (including stand-by) and some passive (pipes, SGs, RPV, etc.) systems, structures, and components (SSCs, operator actions, and impacts of various systems interactions)
  - Snap-shots in time, using average failure rates based on actuarial observations and statistics ("short lived" SSCs)

- PSAs do not include:
  - Time change of service-related characteristics and properties of equipment
  - Models for passive or long-lived SSCs. Failure mechanisms such as:
    - Reactor pressure vessel embrittlement;
    - Steam generator tube corrosion and cracking;
    - Environmental qualification for in-containment cables & other electrical equipment; and
    - Fatigue, stress corrosion cracking, and other mechanisms that may affect a variety of metal components,
  - Adequate (generally acceptable) models for computer hardware & "software" reliability.
Results of PSA/PRA studies for operating plants have shown that risk is dominated by:

- Loss of AC power, support system transients
- Human errors
- Induced LOCAs (pump seal leakage) (PWRs)
- Internal fires and flooding initiators for some units
- Seismic initiators for units at location with higher seismicity (most important contributor for Swiss plants)
- Phenomena/processes that result in early failure of the reactor containment

Events that result in containment bypass:

- **PWRs:**
  - Steam Generator Tube Rupture (SGTR) – as initiator and/or induced
  - Interfacing system breaks outside containment (ISLOCA)
- **BWRs:**
  - Unisolated steamline breaks outside containment
  - Other breaks outside containment
## Status of Containment Challenging
### Issues for Operating Plants vs. New Designs

<table>
<thead>
<tr>
<th>Severe Accident Challenge</th>
<th>Operating Plants</th>
<th>New Designs</th>
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<tbody>
<tr>
<td><strong>In-Vessel Steam Explosions (α-mode)</strong></td>
<td>CCFP &lt;10^{-4}. Issue resolved from regulatory perspective</td>
<td>Same as operating plants</td>
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<tr>
<td><strong>Ex-Vessel Steam Explosions</strong></td>
<td>Dynamic loads on structures:</td>
<td>Concerns about structures in cavity/pit (&quot;protective&quot; layers) &amp; core catcher. More significant for BWRs.</td>
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<tr>
<td></td>
<td>• PWRs: not significant to CF</td>
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<tr>
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<td>• BWRs: some significance to CF</td>
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<tr>
<td><strong>High Pressure Reactor Vessel Breach (Vessel Rocketing)</strong></td>
<td>Not significant (CCFP &lt;10^{-4}) for most plants (especially those with lower vessel head penetrations)</td>
<td>Most new designs are equipped with depressurization system. CCFP same or lower.</td>
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<tr>
<td><strong>High Pressure Reactor Vessel Breach (Direct Containment Heating)</strong></td>
<td>• Extensively studied (NRC) &amp; shown that CCFP &lt;0.10 (PWRs) (Issue resolved from regulatory perspective) (even without induced failure).</td>
<td>Most new designs are equipped with depressurization system. CCFP same or lower (stronger containments).</td>
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<td>• Limited studies for BWRs (lower CCFP due to ADS and/or induced failures/depressurization).</td>
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<td><strong>Molten Core Concrete Interactions (MCCI)</strong></td>
<td>Significant contributor to containment pressurization &amp; fission product releases (both PWRs &amp; BWRs)</td>
<td>Engineered “methods” (core catcher) to avoid CCI:</td>
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<tr>
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<td>• Spreading compartment (EPR)</td>
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<td>• Lower Head Cooling (AP1000)</td>
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<td>• BiMAC (ESBWR)</td>
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### Status of Containment Challenging

**Issues for Operating Plants vs. New Designs (Cont)**

<table>
<thead>
<tr>
<th>Severe Accident Challenge</th>
<th>Operating Plants</th>
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</thead>
<tbody>
<tr>
<td><strong>Induced Failures of Reactor Coolant System</strong></td>
<td><strong>PWRs:</strong> At locations other than SG: $0.95 &lt; CP &lt; 1.0</td>
<td>Similar, if not depressurized.</td>
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<td><strong>PWRs:</strong> Hot Leg Nozzles, Hot Leg Pipe, Pressurizer Surge Line, SG Tubes.</td>
<td><strong>Steam Generator Tube Rupture (SGTR):</strong> $0 &lt; CP &lt; 0.05$ (depending on material, extent of flaws [foreign objects], if secondary side depressurized, etc.). Studies on-going – Issue not yet closed</td>
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<td><strong>BWRs:</strong> Steam Line Nozzles, Failure of SRVs, and Relief Line Vacuum Breakers (that may result in suppression pool bypass).</td>
<td><strong>BWRs:</strong> At all locations (SL, SRVs): $0.90 &lt; CP &lt; 1.0</td>
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<tr>
<td><strong>Hydrogen Combustion</strong></td>
<td>• Distribution of $\text{H}_2$ difficult to assess (especially for compartmentalized containments). Large, open containments (e.g., Beznau) less susceptible to pocketing (detonable mixtures).</td>
<td>Engineered systems to promote mixing and prevent combustion:</td>
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<td>• PSA/PRA studies show $0 &lt; \text{CCFP} &lt; 0.10</td>
<td>- Inert (ABWR, ESBWR),</td>
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<td>• Hydrogen combustion mitigated by inerting (Mühleberg), deliberate ignition systems (Leibstadt) or Passive Autocatalytic Recombiners (PARs) (Beznau)</td>
<td>- Igniters (AP1000, APWR),</td>
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<td>- PARs (EPR)</td>
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Ref: F. Boyd and K. Armstrong (NRC 2009)
Core Damage Frequency: Operating Plants vs New LWRs

Internal Events at-power for U.S. Plants Only

- Operating PWRs
- Operating BWRs
- New LWRs (active)
- New LWRs (passive)

NRC Goal (New Reactors)

Source: D. A. Dube 2009
Large Early Release Frequency: Operating Plants vs New LWRs

Internal Events at-power Only

- Operating PWRs (IPE)
- Operating BWRs (IPE)
- New LWRs (active)
- New LWRs (passive)

NRC Goal (New Reactors)

Source: D. A. Dube 2009
Summary

- Risk of operating plants generally understood:
  - Risk and severe accident issues for the most part, understood, and regulatory closure achieved
  - Research that continues is confirmatory and should help in reducing lingering uncertainties.

- Safety issues for operating plants understood (even though some uncertainties linger):
  - Risk insights being used increasingly to improve operations, guide backfits & new plant designs
  - Safe long-term operation is being assured through various programs (e.g., accident management programs, aging management programs, etc.)
Summary (Cont.)

- Safety improvements for new designs, for the most part, are based or guided by PSA/PRA insights for operating plants
  - Increased separation and diversity
  - Reduction in frequency of interfacing systems LOCAs for PWRs (Refueling Water Storage Pool moved into the containment)
  - Reduction in frequency of high pressure accident scenarios (automatic and improved depressurization systems)
  - Reduction in containment failure probability due to combustion (hydrogen mixing & control systems)
  - Elimination of potential for core concrete interactions and late containment pressurization & failure (lower head cooling or passive cooling of core debris ex-vessel [“core-catchers”] & containment venting for some designs)
  - Generally, strong containments without any potential for direct melt attack (e.g., shell melt-through for some BWR/MARK I)