Safety Challenges for New Nuclear Power Plants

Implementing Design Extension Conditions and Fukushima Changes in the Context of SSR-2/1

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Outline of Presentation

• NRC’s Historical Perspective on Design Extension Conditions (DECs)

• TECDOC Success – 5 Key Issues

• NUSSC TECDOC Issues
NRC Commission Policy Statements on DEC Issues

• In policy statements first issued in 1986, the Commission stated that it expected that new reactor vendors would achieve a higher standard of severe accident performance than their prior designs, and that the advanced reactors would provide enhanced safety margins and/or utilize simplified, passive, or other innovative means to accomplish their safety functions.
NRC Regulations on DECs

• 10 CFR 50.62: Anticipated Transients Without Scram (ATWS)
• 10 CFR 50.63: Station Blackout (SBO)
• 10 CFR 52.47(a)(23): For light water reactor designs, the FSAR must include a description and analysis of design features to prevent and/or mitigate severe accidents, e.g., challenges to containment integrity caused by core-concrete interaction, steam explosion, high-pressure core melt ejection, hydrogen combustion, and containment bypass
• 10 CFR 52.47(a)(27): The FSAR must include a description of the design specific probabilistic risk assessment (PRA) and its results
• 10 CFR 50.150: Aircraft Impact Assessment
• Fukushima Changes
Commission and Staff Guidance on DECs

- Staff guidance in SECY-90-016 and SECY-93-087, and their Staff Requirements Memoranda (SRM) addressed safety goals, severe accident challenges, and severe accident prevention and mitigation features for new reactors
- Commission performance goals
  - $10^{-4}$ per reactor-year for core damage frequency goal
  - $10^{-6}$ per reactor-year for large release frequency goal
- Commission containment performance goals
  - Probability of containment failure given core damage should not exceed approximately 0.1. This is not a requirement in and of itself.
  - Containment should maintain its role as a reliable leak-tight barrier for a minimum of 24 hours following the onset of core damage.
- Standard Review Plan (SRP) Chapter 19 PRA and Severe Accident Evaluation for New Reactors
- SECY-15-0065: Proposed Rule on Mitigation of Beyond-Design-Basis Events (MBDBE)
Implications for TECDOC Development

- DEC requirements have evolved over a long period of time
- DEC requirements cover a range of design, site, and regulatory conditions
- Some DEC requirements from Fukushima lessons learned are still evolving
- TECDOC should illuminate and maintain the flexibility of the SSR-2/1 requirements
- TECDOC should bring coherence to the implementation of DEC requirements (Requirement 20) and the Fukushima changes
- TECDOC should capitalize on related work where a common understanding has been accomplished (e.g., CNRA’s Green Book on Defense-in-Depth)
TECDOC Success – 5 Key Issues
Issue 1: Provide Linkage to Defense-in-Depth Concepts

- SSR-2/1 provides a robust discussion of Defense-in-Depth principles in Section 2 including the introduction of the concept of practical elimination
- Requirement 7 provides discussion on how Section 2 concepts are applied in the design requirements of Nuclear Power Plants including guidance on independence of levels
- Additional TECDOC discussions may be appropriate for issues such as independence of Defense-in-Depth levels and distinctions between multiple failure events and core melt events in Level 4
- Maximum advantage should be taken on the CNRA consensus Green Book on Defense-in-Depth
TECDOC Success – 5 Key Issues
Issue 2: Develop a Typical Set of DECs

- Requirement 20 of SSR-2/1 describes a set of DECs derived from engineering judgement, deterministic assessments, and probabilistic assessments.
- A typical set of DECs would be a significant enabling objective for use in safety guides on the reactor coolant system, containment, spent fuel pool, etc.
- A typical set of DECs should be developed for the plant and the containment challenges from core melt consistent with Requirement 20, paragraph 5.30.
- A typical set of DECs provides the linkage to the system level Fukushima changes in Requirement 53 (ultimate heat sink), Requirement 80 (spent fuel pool), and Requirement 68 (emergency power supply).
- NRC set of DECs are described in documents such as SECY-90-016, SECY-93-087, SRP on Severe Accidents, and SECY-15-0065.
Typical Set of DECs for LWR Plants

1. ATWS (10 CFR 50.63)
2. SBO (10 CFR 50.63)
3. Fire Protection Issues (SECY-90-016)
4. Intersystem Loss of Coolant Accident (LOCA) (SECY-90-016)
5. Multiple and Induced Steam Generator Tube Ruptures (SECY-90-016)
6. Loss of Large Areas due to Fires and Explosions (aircraft impact) (10 CFR 50.150 and 10 CFR 50.54(hh)(2))
8. Loss of core cooling in residual heat removal mode (SECY-90-016)
Typical Set of DECs – Core Melt Challenges for Containments

1. Hydrogen Generation and Control (10 CFR 52.47(a)(23))
2. Core-Concrete Interaction (10 CFR 52.47(a)(23))
3. High Pressure Core Melt Ejection/Direct Containment Heating (10 CFR 52.47(a)(23))
4. Containment Cooling and Venting to prevent overpressure (SECY-90-016)
5. Steam Explosions (10 CFR 52.47(a)(23))
6. Core Debris Coolability (SECY-90-016)
TECDOC Success – 5 Key Issues
Issue 3: Outline a Practical Elimination Process

- Requirement 20 raises an array of concepts such as “set of DECs”, “deterministic assessments”, “probabilistic assessments”, “additional safety features for DECs”, and “practically eliminating early or large release”
- No process is suggested to tie these concepts together
- The TECDOC could propose a general simplified process for DECs that could provide a valuable context for further discussion of DEC issues
- A simplified process could be:
  1. Establish a set of DECs
  2. Preferentially provide safety features to address specific DECs
  3. Alternately, provide operating provisions to address the DECs
  4. Analysis to demonstrate effectiveness of design features/operating provisions
  5. Probabilistic Safety Assessment (PSA) or equivalent check to show overall effectiveness with respect to the practical elimination criteria
- CNRA Green Booklet on Defense-in-Depth provides valuable insights that could be harmonized with the TECDOC
# Severe Accident Mitigation Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>U.S. EPR</th>
<th>US-APWR</th>
<th>ABWR</th>
<th>AP1000</th>
<th>ESBWR</th>
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<tbody>
<tr>
<td>RCS severe accident depressurization capability</td>
<td>Yes, 2 trains, manually actuated</td>
<td>Yes, MOVs</td>
<td>Yes, normal ADS</td>
<td>Yes, late actuation of ADS</td>
<td>Yes, normal ADS</td>
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<tr>
<td>Containment combustible gas control capability</td>
<td>PARs Two-room concept</td>
<td>Glow type igniters</td>
<td>Containment inerting</td>
<td>Igniters, manually actuated</td>
<td>Containment inerting</td>
</tr>
<tr>
<td>In-vessel core melt retention via ERVC</td>
<td>Not credited</td>
<td>Yes, but limited credit</td>
<td>No</td>
<td>Yes, ERVC for most accident sequences</td>
<td>No</td>
</tr>
<tr>
<td>Lower reactor cavity/drywell flooding capability</td>
<td>Yes, part of CMSS / SAHRS. Dry cavity, flood spreading room</td>
<td>Yes, containment spray and/or from fire protection system</td>
<td>Yes, lower drywell flooder system and ACIWA</td>
<td>Yes, ERVC manually actuated</td>
<td>Yes, from GDCS with firewater as back-up</td>
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<tr>
<td>Core melt stabilization (core catcher)</td>
<td>CMSS, Meltt plug, discharge channel, spreading area and cooling structure</td>
<td>No core catcher</td>
<td>No core catcher</td>
<td>No ex-vessel core catcher</td>
<td>BiMAC, passive cooling of molten debris</td>
</tr>
<tr>
<td>Severe accident heat removal system (SAHRS)</td>
<td>Yes, passive cooling of molten debris and other features</td>
<td>Yes, containment spray system and fan coolers</td>
<td>Yes, steam goes out the vent, depleting SP inventory</td>
<td>Yes. Passive containment cooling system</td>
<td>Yes, using the PCCS</td>
</tr>
<tr>
<td>Other lower reactor cavity/drywell special concrete floor features</td>
<td>Sacrificial layer in pit Protective layer in pit and discharge channel</td>
<td>Large floor area -Core debris trap to mitigate HPME &amp; prevent DCH</td>
<td>Basaltic sacrificial layer -Large floor area - Other features</td>
<td>Large floor area -Thick concrete layer</td>
<td>Sacrificial concrete</td>
</tr>
<tr>
<td>Assurance of equipment survivability</td>
<td>Yes. Bounding severe accident pressures and temperatures are acceptable.</td>
<td>Yes. Equipment can withstand expected pressures and temperatures.</td>
<td>Yes. Meets requirements of 10CFR 50.34(f) and SECY-93-087</td>
<td>Yes. Meets requirements of 10CFR 50.34(f) and SECY-93-087</td>
<td>Yes. Equipment could survive for at least 24 hrs after core damage.</td>
</tr>
<tr>
<td>Dedicated severe accident containment venting</td>
<td>No</td>
<td>No</td>
<td>Hardened vent from wetwell air space</td>
<td>No</td>
<td>Hardened vent from wetwell air space</td>
</tr>
</tbody>
</table>
TECDOC Success – 5 Key Issues
Issue 4: Illuminate the Practical Elimination Acceptance Criteria

- Requirement 20 establishes for the plant (paragraph 5.27) and for the containment (paragraph 5.31) an effectiveness criteria for DECs that early and large releases would be practically eliminated.
- The criterion is used as an effectiveness check for the plant or containment design as part of practical elimination process (i.e., it is not a stand alone criteria).
- The TECDOC should explore the use of a subsidiary criterion for multiple failure DECs (i.e., non-core melt).
- The TECDOC should also provide other examples of criteria that are used as surrogates for the practical elimination acceptance criteria.
- The definition of practical elimination provides two potential success paths, the condition being physically impossible or conditions are considered extremely unlikely to occur with high confidence.
- The TECDOC should cite specific examples of situations that meet the intent of those criteria and should be harmonized with the CNRA approach.
Issue 5: Outline on Equipment Survivability Strategy for DEC Equipment

- Requirement 20, paragraph 5.27 identifies two types of safety features for DECs specifically those that are “additional safety features” and those that are “extensions of the capability of safety systems”
- Requirement 20, paragraph 5.29 describes the independence, environmental qualifications, reliability, and margin design rules for DEC-related equipment
- These equipment design requirements are called “equipment survivability” rules to distinguish them from equipment design requirements that are used for normal safety-related structure, system, or components (SSCs)
- The TECDOC should make a clear distinction between those set of design rules
NUSSC TECDOC Issues

• Design Basis
  – Should cover both DBA and DEC conditions

• Defense-in-Depth
  – Subdivision of Level 4 is more consistent with SSR-2/1 and CNRA

• Use of non-permanent equipment for new Nuclear Power Plant designs
  – Proposed practical elimination process suggest permanent equipment is preferred but operating provisions allowed

• Concept of practical elimination
  – Proposed practical elimination process suggest a role for both deterministic and probabilistic analyses

• List of DECs
  – Both DECs without core melt and DEC challenges for containment should be addressed
Summary

• A TECDOC discussing key DEC issues is important
• TECDOC should maintain flexibility to cover the wide range of designs and regulatory systems
• TECDOC should provide coherence and depth to the SSR-2/1 requirements
• TECDOC should provide a list of typical DECs including both DECs without core melt and DEC challenges for containment
• TECDOC development should be done in coordination or even collaboration with CNRA