Japanese Implementation of Seismic Probabilistic Risk Assessment

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Contents

• Lessons-Leaned from Fukushima Daiichi Accident
• Looking Back: Since 1995 to Present
  – NRA Regulatory Requirement
  – AESJ Standards for Seismic PRA
• Integrated Quantitative Seismic Risk Assessment and AESJ PRA Standards Development
• Conclusions
• Lessons-Leaned from Fukushima Daiichi Accident
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:46</td>
<td>Earthquake</td>
<td>14:46 Earthquake</td>
</tr>
<tr>
<td>15:00</td>
<td>Loss of offsite power</td>
<td>Many aftershocks</td>
</tr>
<tr>
<td>15:27</td>
<td>Tsunami</td>
<td>Station blackout</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of ultimate heat sink</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequent tsunami alarms</td>
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<td></td>
<td></td>
<td>Darkness in buildings</td>
</tr>
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<td></td>
<td></td>
<td>No communication tool</td>
</tr>
<tr>
<td>17:41</td>
<td>Sunset</td>
<td>Complete darkness</td>
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<tr>
<td>22:00</td>
<td>Power Vehicle</td>
<td>High radioactivity level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17:50 Increased in RB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21:51 High in RB</td>
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</tbody>
</table>
 Accident Progression at Fukushima Dai-ichi NPS

Earthq. Tsunami | Off-site Power | Emergency DG | Core Cooling | AC Power Recovery | H2 Control
---|---|---|---|---|---

Fukushima Dai-ichi NPS

- March 11, 15:37
- CV venting in Unit 1 and 3
- Alternative water injection

Unit 3 March 13, 2:42
Unit 2 March 14, 13:25

Unit 2

Unit 3

Unit 5

Unit 1

March 14, 11:01

March 12, 15:36 pm

H2 Expl.

AC power available

Massive Release of Radioactive FPs at March 15, 06:10 from Unit 2

Ultimate Heat Sink was lost in all the NPPs
Major Events

• March 11, 14:46pm Earthquake, LOSP
• March 11, 15:27pm~ Tsunami, SBO
• Unit 1
  – March 11, 15:37pm IC stopped operation
  – March 12, 15:36pm H₂ explosion
• Unit 2
  – March 14, 13:25pm RCIC stopped operation
  – March 15, 6:10am FP large release
• Unit 3
  – March 13, 2:42am HPCI intentionally stopped
  – March 14, 11:01am H₂ explosion
• Looking Back: Since 1995 to Present
  – NRA Regulatory Requirement
  – AESJ Standards for Seismic PRA
Recent Earthquake Occurrence in Japan

No Loss of Safety Function

- **Hyogo-Ken Nammbu Earthquake**
  - (January 17, 1995, Magnitude 7.3)

- **Miyagi-Oki Earthquake**
  - Onagawa NPP
  - (August 16, 2005, Magnitude 7.2)

- **Noto Peninsula Earthquake**
  - Shika NPP
  - (March 25, 2007, Magnitude 6.9)

- **Niigata-Ken Tyuetsu-Oki Earthquake**
  - K-K NPP
  - (July 16, 2007, Magnitude 6.8)

- **Suruga-Bay Oki Earthquake**
  - Hamaoka NPP
  - (August 11, 2009, Magnitude 6.5)

- **The Great East Japan Earthquake**
  - Fukushima NPP
  - (March 11, 2011, Magnitude 9.0)
Regulatory Requirement

• Level 1 and level 2 PRAs for internal and external events (seismic and tsunami)
• State-of practice methodology and data
• Step-by-step extension of the PRA scope
  – Internal flooding and fire
  – Couples seismic and tsunami event
  – Other external events
  – Spent fuel pool
  – Multi-unit events

Organization of AESJ/Risk Technology Committee

- AESJ Standards Committee
  - Risk Technical Committee (RTC)
    - Steering Task for PRA Standard Development, Maintenance and Application
  - System Safety Technical Committee (SSTC)
  - Nuclear Fuel Cycle Technical Committee
  - Advanced and Fundamental Systems Technical Committee
  - Level 1 PRA Subcommittee
  - Level 2 PRA Subcommittee
  - Level 3 PRA Subcommittee
  - External Events PRA Subcommittee
    - Seismic PRA WG
    - Tsunami PRA WG
    - Internal Flooding PRA WG
    - Fire PRA WG
  - Nuclear Fuel Facility Risk Assessment Subcommittee
    - PRA Qualification Subcommittee
  - Safety Improvement Subcommittee
## Current status of AESJ PRA Standards

<table>
<thead>
<tr>
<th>Subcommittee</th>
<th>Standard (Current Edit.)</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Events PRA Subcommittee</td>
<td>Seismic PRA Standard: 2015</td>
<td>at-power, Level 1 (including CV failure analysis)</td>
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<tr>
<td></td>
<td>Tsunami PRA Standard: 2011 (Under revision)</td>
<td>at-power, Level 1, focused on tsunami effects only</td>
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<td></td>
<td>Case Studies for Tsunami PRA Standard: 2012</td>
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<tr>
<td></td>
<td>Internal Flooding PRA Standard: 2012</td>
<td>at-power, Level 1</td>
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<tr>
<td></td>
<td>Internal Fire PRA Standard: 2014</td>
<td>at-power, Level 1</td>
</tr>
<tr>
<td></td>
<td>Standard for Risk Analysis Methodology Selection of External Hazards: 2014</td>
<td>Selection of an appropriate risk analysis methodology in terms of a character of individual external hazard</td>
</tr>
</tbody>
</table>
• Integrated Quantitative Seismic Risk Assessment and AESJ PRA Standards Development
Dynamic and Multi-Unit Risk Profile

Core Damage Probability

SBO: Station Blackout, PCV: Primary Containment Vessel
Dynamic and Multi-Unit Risk Profile
Large Release Probability

SBO: Station Blackout, PCV: Primary Containment Vessel
地震と津波の重畳リスクの観点で影響を及ぼし得る建屋などの損傷の可能性は低い。

耐震壁の損傷、部材の局部損傷、周辺機器への波及的影響の可能性あり。

例)・転倒、・滑り

例)・曲げ破壊、・せん断破壊、など

例)・大開口近傍の破壊、・床の破壊、・接合部の破壊、・部材の一部の剥落、など

建屋などの崩壊シーケンスを構成する損傷モード非構造部材の局部損傷、建屋基礎の安定性の損傷

例)・間仕切り壁の損傷、・扉の損傷

例)・防潮壁どの損傷、傷、・水密扉の損傷

津波防護施設、設備などの損傷

地震リスクの観点で影響を及ぼし得る建屋などの損傷の可能性は低いが、津波リスクの観点で影響を及ぼし得る建屋損傷の可能性あり。

機器の支持機能、耐漏洩機能喪失の可能性あり。剥落塊による周辺機器への波及的影響の可能性あり。

建屋全体崩壊の可能性あり。
Spent Fuel Pool

- Collapse of SFP structure
  - True
  - False
    - e.g. Collapse of operational floor and/or lower stories: bending fracture; shear fracture
- Local failure of wall or floor of SFP
  - True
  - False
    - False
      - e.g. Local failure of reinforced concrete: bending fracture; shear fracture
      - Ductile failure of pool liner
    - True
      - True
      - False
- Secondary failure by falling objects
  - True
  - False
- Little possibility of SFP failure that results in seismic risk
  - SFP and fuel assemblies may fail locally by falling objects
    - Loss of cooling capability of SFP and fuel assemblies damage is probable
    - SFP structural integrity and fuel assemblies failure is likely
## Prioritization of PRA Standard Development

- **High necessity**
  - High: A+  
  - Medium: A  
  - Low: B(A)  
  - Very Low: B  
  - Lowest: C  
  - Least: C  
- **Large workload**
  - High: Large  
  - Medium: Medium  
  - Low: Small  
- **High priority standards**
  - Priority 1, Priority 2

### Table

<table>
<thead>
<tr>
<th>At Power</th>
<th>Internal event</th>
<th>Internal flooding</th>
<th>Internal fire</th>
<th>Tsunami</th>
<th>Seismic</th>
<th>Seismic-induced/caused</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
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### Box

- Developed
- Priority 1
- Priority 2
# Quantitative Risk Assessment Approach

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<th>QRA Approach</th>
<th>Note</th>
<th>Hazard Analysis</th>
<th>Sequence Analysis</th>
</tr>
</thead>
<tbody>
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<td>Hazard frequency Analysis</td>
<td>Quantify based on hazard frequency</td>
<td>Conservative Simplified</td>
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<tr>
<td>Consequence Analysis</td>
<td>Quantify risk based on plant level capacity</td>
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<td>Plant level capacity (conservative)</td>
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<td>Safety margin Analysis</td>
<td>Quantify risk based on accident scenario analysis and safety margin analysis</td>
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<tr>
<td>Deterministic CDF Analysis</td>
<td>Quantify risk based on hazard frequency and accident scenario analysis</td>
<td>Conservative</td>
<td>Deterministic</td>
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<tr>
<td>Probabilistic Risk Assessment</td>
<td>Investigate Risk Triplet: Scenario; Frequency; Consequence</td>
<td>Realistic hazard curve + uncertainties</td>
<td>Realistic load + Uncertainties</td>
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</table>

<table>
<thead>
<tr>
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<th>Load (Capacity)</th>
<th>Response</th>
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<tr>
<td>Consequence Analysis</td>
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<td>Plant level capacity (conservative)</td>
</tr>
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<td>Safety margin Analysis</td>
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</tr>
<tr>
<td>Probabilistic Risk Assessment</td>
<td>None</td>
<td>Realistic load + uncertainties</td>
</tr>
</tbody>
</table>
Conclusions - Future Perspectives

• Seismic-induced combined hazard
• Multi-unit and dynamic seismic risk
  – LPSD seismic risk (e.g. Unit 3 and Unit 4)
• Seismic level 2 and level 3 PRAs
• Flexible and various quantification approaches
• Plant risk, site risk and regional risk