Adding Qualification for Severe Accident and External Hazards in the Risk Management Regulatory Framework Post-Fukushima

Jim Gleason, P.E.

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The Accident at Fukushima Dai-ichi NPS

- The accident at Fukushima Dai-ichi NPS was caused by long lasting complete power loss due to common cause failure (CCF) of electrical equipment following tsunami, and insufficient provision against severe accident.
- It is temporarily rated at INES Level 7, and people where lived in the specific area including those within 20 km radius from the site are still not able to return home.

The moment when tsunami attacked Fukushima Dai-ichi NPS (Source: TEPCO)

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General View of root causes of the Accident

CCF of electric equipment and insufficient severe accident provision were induced by following root causes:

- Too late or missed incorporation of new tsunami knowledge into hazard evaluation,
- The regulatory system not covering severe accident,
- Insufficient application of state-of-the-art technologies and international good practices to the regulatory programs.

New Nuclear Regulatory Systems

NRA will implement new regulatory systems stipulated in amended laws, including:

- Regulation taking severe accidents into consideration.
- Regulation applying latest scientific/technical knowledge on safety issues to existing facilities. (backfitting)
- An operation limit of 40 years to deal with aged reactors

Scorecard

Plant	Severe Accident	Cause : Line Break	Cause: Seismic	Cause: NPH	Cause: Human Error	
TMI	Yes	No	No		Yes	✓
Fukushima D I	Yes	No	No	Yes		✗
Fukushima D II	Yes	No	No	Yes		✗
Fukushima D III	Yes	No	No	Yes		✗
Fort St Vrain	Near Miss	No	No	Yes		✗
Grand Gulf	Near Miss	No	No	Yes		✗
Forsmark	Near Miss	No	No	No	Yes	✗

IEEE Std 308 Criteria for Class 1E Power Systems for Nuclear Power Generating Stations

Table 2—Illustrative malfunctions, accidents, etc.

Natural phenomena	
Earthquake	Rain, ice, and snow
Wind	Floods
Hurricane	Lightning
Tornado	Extreme temperature conditions
Postulated phenomena	
1) Postulated accident environment (humidity, temperature, pressure, chemical properties, radiation)	
2) Fires	
3) Accident-generated missiles, pipe whip	
4) Fire protection system operation	
5) Accident-generated flooding, sprays, or jets	
6) Postulated loss of the preferred power supply combined with any of the phenomena listed in item 1) through item 5) of this table.	
7) Postulated loss of all alternating current electric power (station blackout)	
8) Single equipment malfunction	
9) Single act, event, component failure, or circuit fault that can cause multiple equipment malfunctions	
10) Single equipment maintenance outage	

Commissioner George Apostolakis
April 2012

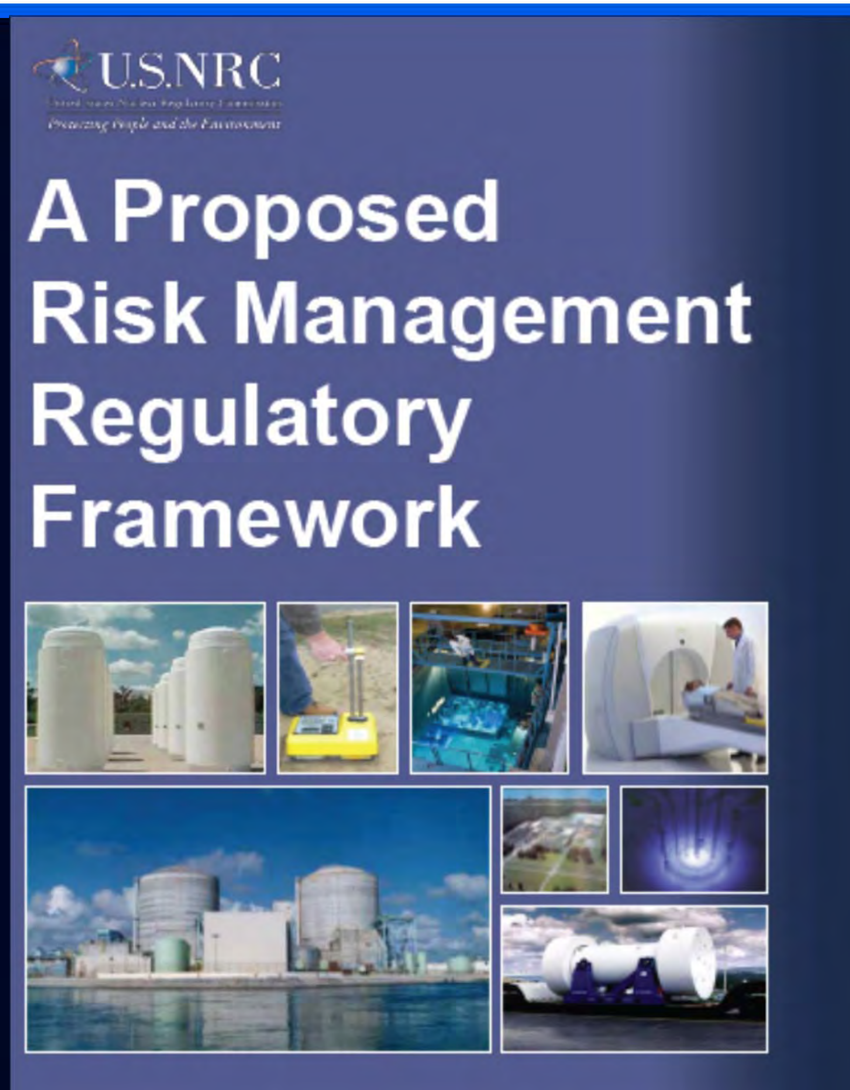

Table F-2 Licensing Approach to Events (current approach)

	PIEs	Key Assumptions	Acceptance Criteria
Normal Ops	n/a	n/a Maintain initial conditions, standby equipment	Part 20, ALARA
AOOs	Functional list (e.g., ANS 51.1/52.1 Cond II) (PIE frequency $> \sim 10^{-2}$/yr)	Credit SR SSCs single failure	Maintain safety limits, such as SAFDLs, RCS pressure
DBAs	Functional list (e.g., ANS 51.1/52.1 Cond III/IV) (PIE frequency $> \sim 10^{-4}$/yr)	Credit SR SSCs single failure	Maintain coolable core, containment
Design-basis External Events	Maximum credible scenario (e.g., frequency of exceedance $> \sim 10^{-7}$ for tornado conditions)	Engineering analysis, safety margins	Codes and standards related to barrier design and equipment qualification
Design-enhancement (in concept but term not currently used)	Specific events: ATWS SBO A/A	As defined in each rule – generally best estimate	As defined in each rule (alternate shutdown, coping time, A/A functions)
Residual Risks (in concept but term not currently used)	n/a	n/a	n/a
Beyond-design-basis External Events	n/a	n/a	n/a

Proposed Risk Management Regulatory Framework

The RMTF assessed this regulatory structure in the context of the proposed risk management framework and developed a number of findings. The most important findings are listed below.

- Finding: The concept of design-basis events and accidents continues to be a sound licensing approach, but the set of design-basis events and accidents has not been updated to reflect insights from power reactor operating history and more modern methods, such as probabilistic risk assessment (PRA).

- Finding: Requirements for beyond-design-basis accident scenarios (e.g., station blackout) were established at different times and in different ways. Differences in implementation approaches have reduced the efficiency and consistency of the NRC's regulatory and oversight activities.

- Finding: The extent to which licensee activities undertaken as part of voluntary industry initiatives can be credited has been a source of contention in the Reactor Oversight Process and has reduced the efficiency of that process.

- Finding: The process for establishing the external hazard design basis does not use consistent event frequency or magnitude methods.

- Finding: Differences in regulatory language and approaches between power reactor security and safety regulation may have reduced the efficiency and effectiveness of the NRC's work.

Proposed Risk Management Regulatory Framework

Recommendations (Power Reactors):

- The set of design-basis events and accidents should be reviewed and revised, as appropriate, to integrate insights from the power reactor operating history and more modern methods, such as probabilistic risk assessment (PRA).
- The NRC should establish through rulemaking a *design-enhancement category* of regulatory treatment for beyond-design-basis accidents. This category should use risk as a safety measure, be performance-based (including the provision for periodic updates), include consideration of costs, and be implemented on a site-specific basis.
- The NRC should reassess methods used to estimate the frequency and magnitude of external hazards and implement a consistent process that includes both deterministic and PRA methods. Consideration of the risks from beyond-design-basis external hazards should be included in the proposed design-enhancement category.
- The NRC should develop and implement guidance for use in its security regulatory activities that uses a common language with safety activities and harmonizes methods with risk assessment and the proposed risk-informed and performance-based defense-in-depth framework.

Proposed Risk Management Regulatory Framework

- The proposed design-enhancement category would clarify the attributes of all requirements established as substantial safety (beyond-design-basis) improvements. This approach may contribute to the resolution of the "patchwork" issue identified by the Fukushima Near-Term Task Force.

Recommendation PR-R-2: The NRC should establish through rulemaking a *design-enhancement category* of regulatory treatment for beyond-design-basis accidents. This category should use risk as a safety measure, be performance-based (including the provision for periodic updates), include consideration of costs, and be implemented on a site-specific basis.

As stated above, the NRC's approach to addressing the risk from naturally occurring hazards varies among the hazards. Methods to address earthquakes are the most advanced, perhaps because this hazard is judged to be of the highest risk significance. Information on earthquake frequencies is periodically updated. Even for this hazard, however, the risk assessment expertise within the NRC and the industry is very limited. In addition, studies have shown that there are serious limitations in attempting to address seismic hazards or other natural events (including related uncertainties) at extremely low frequencies (Johnson and Apostolakis, 2012).

Proposed Risk Management Regulatory Framework: Security

Security

The NRC's security requirements are established to protect the same radioactive hazards as safety requirements. However, the regulatory approach used is somewhat different.[5] In discussions with NRC staff, the RMTF found that differences in language and methods exist that reduce the efficiency of the NRC's interactions with licensees. The proposed RMTF characterization of risk-informed and performance-based defense-in-depth, applied to security regulatory activities, could help to remedy this inefficiency.

Recommendation PR-R-6: The NRC should develop and implement guidance for use in its security regulatory activities that uses a common language with safety activities and harmonizes methods with risk assessment and the proposed risk-informed and performance-based defense-in-depth framework.

Proposed Risk Management Regulatory Framework: Beyond Design Basis Accidents

Beyond-design-basis Accidents

In Appendix H, the RMTF defined a number of alternatives that could be used to implement the creation of the design-enhancement category. These alternatives included 1) the NRC defining additional specific events or conditions (including acceptance criteria) to be addressed for power reactors, 2) the NRC requiring licensees to perform risk assessments to identify design-enhancement events exceeding a defined threshold and reducing risks to levels as low as is reasonably achievable (ALARA), and 3) the NRC requiring licensees to perform risk assessments to identify design-enhancement events exceeding a defined threshold and reducing risks to levels below defined acceptance risk criteria. The RMTF does not recommend any of these alternatives, but provides them to assist in staff implementation.

Recommendation OR-R-2: For operating reactors, the RMTF recommends that the NRC should establish through rulemaking a design-enhancement category of regulatory treatment for beyond-design-basis accidents.

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Proposed Risk Management Regulatory Framework: External Hazards

External Hazards

As discussed above, the RMTF has found that the NRC's consideration of external hazards varies in the establishment of the design basis and the assessment of their risk. Although the Fukushima accident may not be directly relevant to all U.S. power reactors, it did highlight that the potential safety significance of external hazards needs to be addressed more systematically for U.S. reactors.

> Recommendation OR-R-3: The NRC should reassess the methods used to estimate the frequency and magnitude of external hazards and implement a consistent process that includes both deterministic and PRA methods. For operating reactors, the RMTF recommends that the design-enhancement category rulemaking include consideration of external hazards.
>
> Recommendation OR-R-4: For operating reactors, the RMTF recommends that the NRC develop and implement guidance for the collection and dissemination of external hazard information.

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Proposed Risk Management Regulatory Framework: New Reactors

Recommendation NR-R-1: For new reactors, the RMTF recommends that the NRC be amenable to and promote, where practical, the adoption of more risk-informed and performance-based approaches for the selection of more relevant scenarios for design-basis events. Changes pursued for operating reactors (OR-R-1) should also consider applicability to new reactors.

Recommendation NR-R-2: Apply Recommendation PR-R-2 (design-enhancement category) to new reactors.

Recommendation NR-R-3: Apply Recommendation PR-R-3 (include external events in design-enhancement category) to new reactors.

Recommendation NR-R-4: Apply Recommendation PR-R-4 (periodically evaluate new information regarding external hazards) to new reactors.

External Hazards

The licensing of new reactors has benefited from updates to the guidance related to specific external hazards. However, the same inconsistency in handling various external hazards that was discussed for operating reactors is also applicable to new reactors. This leads the RMTF to

Impact on Loss of Function of Containment Systems

- Radioactive material leakage presumably occurred when the pressure of the PCV was increased before the venting because the radioactive dose had increased after increasing of the pressure of the PCV of the Unit 1. Possible location of leakage was top flange, penetration of the containment vessel and/or equipment hatches.
- It is highly possible that the leakages were caused by deterioration of the organic sealing as a result of high temperatures by thermal radiation directly from the pressure vessel.
- When venting was conducted, the standby gas treatment systems (SGTS) was not properly isolated, thus hydrogen gas back flew into the reactor building. (in particular, Unit 4)

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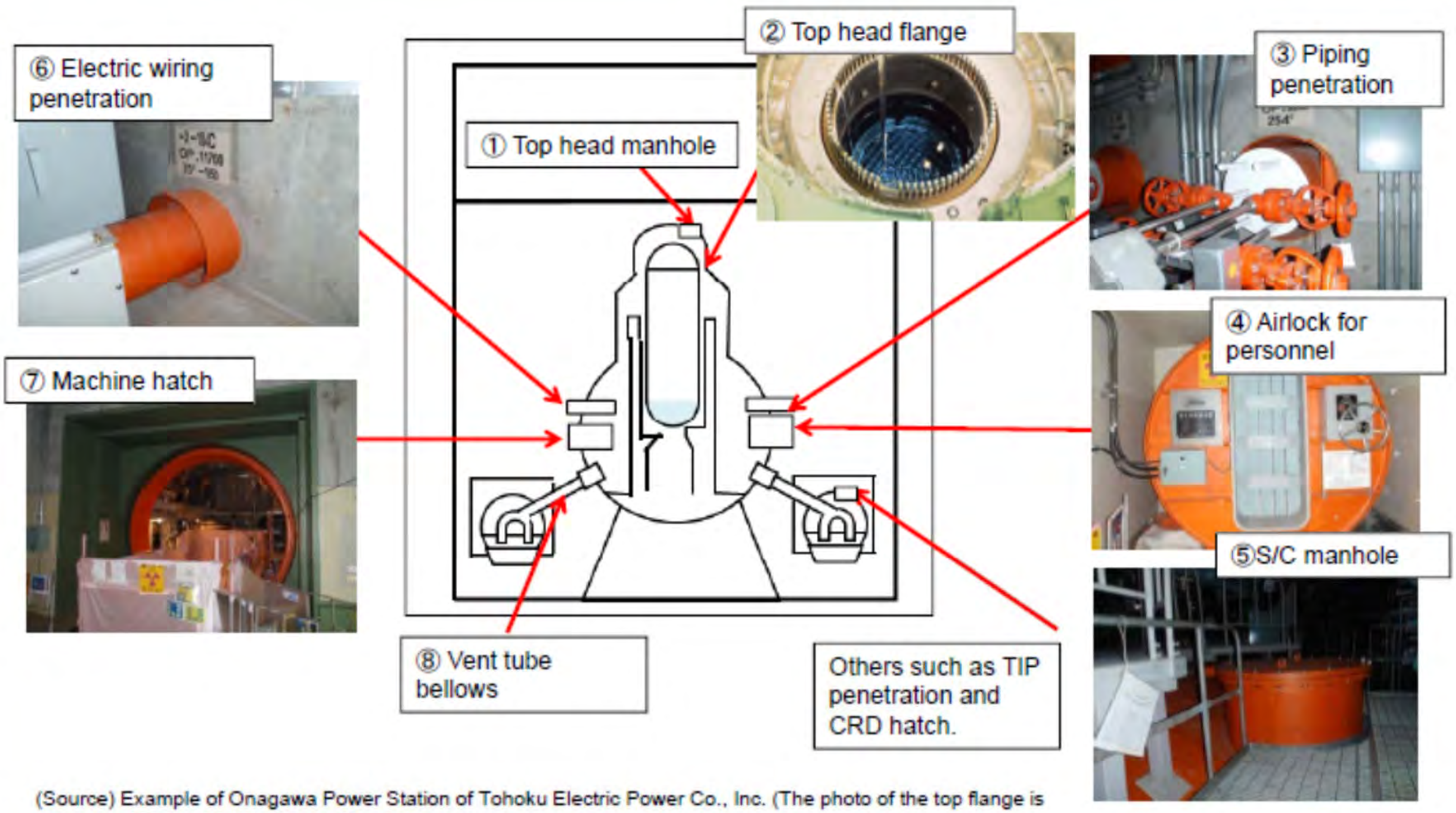
Places of Possible Leackage (Example of Mark-I type Reactor)



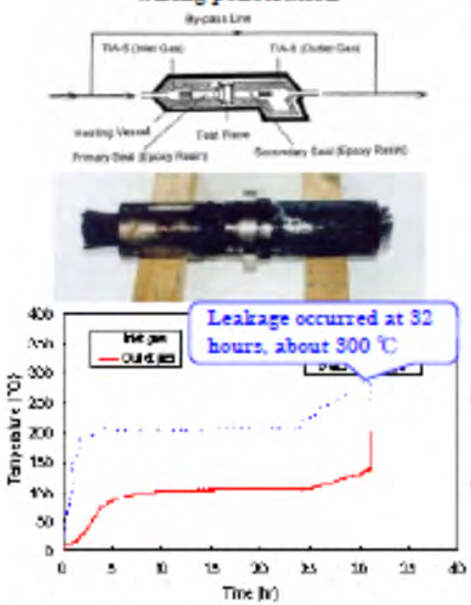
(Source) Example of Onagawa Power Station of Tohoku Electric Power Co., Inc. (The photo of the top flange is courtesy of Tokyo Electric Power Co., Inc.)

Possibility of Containment Damage due to Over-pressurization and/or Over-heating (over-Heating Damage)

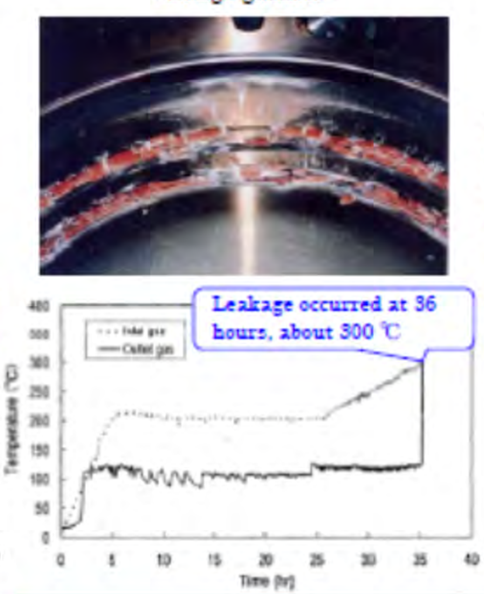
- Experiments show leakage can occur from the seal materials of wiring penetration and flange gaskets even under pressure of 0.4～1MPa if heated over 250℃.
- PCVs' temperature were estimated over 500℃ for Unit 1, about 280℃ for Unit 2, and over 400℃ for Unit 3 by MELCOR analysis.
- According to JNES experiments, the leak rate can reach 100%/day at a containment pressure of 0.2MPa, taking only the deterioration of the top flange gasket into account, which is consistent with the situation of large-scale vapor release at the accident.

Example of test results (low-voltage module)

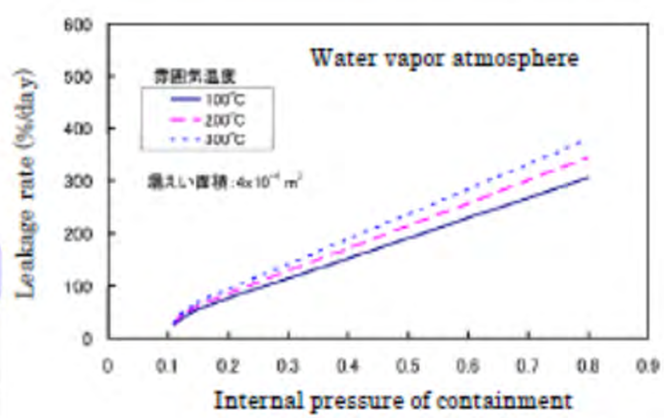
< wiring penetration >



< flange gaskets>



Estimation of leakage rate at the top flange gasket of deterioration due to over-heating



(Source) JNES materials

Fukushima Accident Considerations for IEEE 323

- Seismic and LOCA Qualification methods adequate
- Add Qualification methods for
  - Other natural phenomenon hazards (extreme wind, flood, tsunami, hurricane, and tornado)
  - Severe Accidents
    - Applicable to equipment supporting containment performance
    - Severe pressure (proof at 300% of containment design pressure) Do not allow electrical devices to be containment weak link
    - Severe Temperature (proof or fragility)

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