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Lessons Learned from the Fukushima Dai-ichi Accident and Responses in New Regulatory Requirements

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Introduction

- ✓ TEPCO's Fukushima Dai-ich accident revealed the weakness of the foregone regulatory requirements, e.g.
  - Insufficient design provisions against tsunami,
  - Unpractical management measures under severe accident conditions, and
  - Insufficient provisions for accidents far-exceeding the postulated design conditions.
- ✓ We re-realized the importance of the Defense in Depth (DiD) approach in design and preparations of countermeasures against beyond design basis accidents.
- ✓ We learned from the accident that we must evaluate in advance the potential and consequences of a wide spectrum of internal and external initiators.

This presentation covers;

1. Prevention of SSC (Structures, Systems and Components) failures
2. Measures to Prevent CCFs (Common Cause Failures)
3. Prevention of Core Damage
4. Mitigation of Severe Accidents
5. Emergency Preparedness
6. Continuous Improvement of Safety
7. Use of PRA (Probabilistic Risk Assessment)
8. Post-accident Regulation on Fukushima Dai-ichi
9. International Cooperation

1. Prevention of SSC failures

Lessons (1/2)

- ✓ The Fukushima Dai-ichi accident revealed vulnerability of SSCs against extreme loads and conditions caused by some specific internal/external initiators.
- ✓ The past regulations in Japan specified design requirements focusing on random failures of SSCs and the provisions on aseismatic design, although there were conceptual design requirements to cope with all the initiators.

1. Prevention of SSC failures
Lessons (2/2)

- ✓ In Japan, seismic loads were addressed well in the regulations, while less considerations were made for other external hazards including tsunami.
- ✓ As for tsunami, its design-basis heights had been postulated based on the historical records, which covered only 400 years. There was no countermeasures against tsunami with a recurrence period of 1,000 years or more.
- ✓ These facts underscore the need to revisit the regulatory requirements for a wide spectrum of external hazards.

1. Prevention of SSC failures

Responses (1/4)

- ✓ Enhancement of safety design requirements.
- ✓ Consideration of all the significant internal/external initiators.
- ✓ Confirmation of general approach for design provisions against the initiators, i.e. (i) identification of potential hazards, (ii) requirement of design against hazards exceeding their respective thresholds for screening, (iii) definition of design basis hazard (DBH), (iv) design requirements to cope with DBH with safety margin, and (v) evaluation of adequacy of safety design.

1. Prevention of SSC failures

Responses (2/4)

- ✓ Re-evaluation of external hazards, particularly natural phenomena, based not only on historical data but also on expert judgment to cover very rare events.
- ✓ As for earthquakes, more stringent criteria were prepared for active faults, more precise methods were provided for design-basis ground motions, etc.
- ✓ As for tsunami, design-basis tsunami which exceeds the highest historical record is defined, countermeasures such as coastal levee and watertight doors are required, etc.

1. Prevention of SSC failures

Responses (3/4)

- ✓ Development of specific requirements regarding internal fire and flooding.
- ✓ Requirement of countermeasures for extremely aggravated situations, for example, by intentional airplane crash.
- ✓ While many new requirements are developed against both internal and external initiators, the graded approach is applied to determine the necessity of such specific design provisions based on their respective risks.

1. Prevention of SSC failures

Responses (4/4)

- ✓ The new requirements aim at “function-based” for providing flexibility in choosing acceptable measures.
- ✓ However, based on recognition that adequate requirements have not been made for fire protection, specific requirements for physical separation of safety systems, fire hazard analysis, etc. are introduced considering current international practices. As well, we need to continue the development and application of fire PRA including data accumulation towards risk-informed regulations.

2. Measures to Prevent CCFs

Lessons (1/2)

- ✓ In the Fukushima Dai-ichi accident, emergency diesel generators (EDGs) and station butteries lost their functions simultaneously due to the tsunami since they were located on the floors at similar elevations. This fact highlights the necessity of enhanced physical separation for safety-related systems/components.

- ✓ Although all the water-cooled EDGs were damaged by tsunami directly or indirectly, one air-cooled EDG survived and supplied power to both Units 5 and 6 because it was located at a higher elevation. The turbine driven RCIC worked under the SBO situation at Units 2/3 and delayed accident progressions. These imply the importance of diversity of systems.

2. Measures to Prevent CCFs

Lessons (2/2)

- ✓ Loss of station batteries resulted in loss of control room functions including instrument, closure of isolation valves in isolation condenser (IC), unavailability of reactor depressurization, loss of control of reactor core isolation cooling and high pressure injection systems, inoperability of containment venting, etc. The fact underlines the need to prepare alternative DC power sources.

- ✓ Electrical power system is essential to actuate and control the safety-related systems including the control room and its loss might lead to common cause failures of safety-related systems. Accordingly, the diversity should be improved to secure the plant safety.

2. Measures to Prevent CCFs

Responses (1/2)

- ✓ Extend design-basis events strengthen protective measures against natural phenomena and others which may lead to common cause failure
- ✓ Due consideration to ensure diversity and independence (shift of emphasis from “redundancy centered”)
- ✓ Diversity of operating mechanisms

  Examples:
  Diesel Generator and Gas Turbine Generator
  Motor Driven Pump and Diesel Driven Pump

2. Measures to Prevent CCFs

Responses (2/2)

✓ Physical Separation

Safety-related system trains shall be

- located at different elevations and/or different areas,
- compartmentalized by installing bulkhead, or
- distanced enough from each other.

Mobile equipment shall be

- stored in different locations, which are not easily affected by external initiators including terrorisms, and
- easily and surely connectable to the target system by preparing spatially-dispersed multiple connecting ports.

3. Prevention of Core Damage
Lessons (1/2)

- ✓ There was no provision against prolonged station blackout (SBO) and prolonged loss of ultimate heat sink (LUHS).
- ✓ The duration of loss of offsite power, 30 minutes, was assumed based on the operating experience in Japan, which showed high reliability and short-term restoration of offsite power and high reliability of EDGs. As well, the interconnection of safety busbars between units was incorporated into accident management (AM) procedures on an industries' voluntary basis.
- ✓ For the ultimate heat sink, the hardened venting system together with alternative water injection was prepared as one of the voluntary based AM measures.

3. Prevention of Core Damage
Lessons (2/2)

- ✓ As a result, SBO and LUHS were considered a highly unlikely scenario, leading to lack of further discussions on these scenarios.
- ✓ Although the regulation had applied the single failure criterion to the safety analysis of design-basis accidents over years, the Fukushima Dai-ichi accident suggested that multiple failures due to specific initiators must be considered more seriously in the licensing bases and/or safety cases.
- ✓ The regulation should specify the requirements on AM measures as a licensing basis and licensees should prepare the sophisticated AM measures and procedures in consideration of multiple failures.

3. Prevention of Core Damage

Responses

- ✓ In the new requirements by NRA, the definitions of some DBAs were changed. Design provisions are now required against prolonged SBO and LUHS.
- ✓ Also required are provisions against some beyond design-basis accidents (b-DBAs) involving multiple failures, including anticipated transient without scram (ATWS), loss of core cooling, and loss of reactor depressurization.
- ✓ The new regulations require the licensees to validate the effectiveness of countermeasures against b-DBAs.

4. Mitigation of Severe Accident

Lessons (1/2)

- In 1990s, a series of AM measures were prepared at individual NPPs in Japan on a licensees' voluntary basis to improve the plant safety.
- However, these AM measures mainly focused on the prevention of core damage and a few mitigation measures, such as molten core cooling, had been implemented so far.
- In the Fukushima Dai-ichi accident, many attempts to take AM measures were unsuccessful under the aggravated plant conditions, such as loss of power, loss of control air, aftershocks, and high radiation.

4. Mitigation of Severe Accident

Lessons (2/2)

- ✓ The Fukushima Dai-ichi accident brought to light the necessity of implementing AM measures for mitigating severe accident and radiological consequences as well as those for preventing core damage.
- ✓ Considering the extremely severe natural hazards and terrorisms, the flexibility should be incorporated into the design and implementation of AM measures. Also, plant personnel should be well trained so that they could execute the AM procedures under the aggravated conditions in a timely manner.

4. Mitigation of Severe Accident

Responses

- ✓ The new regulations require the licensees to design and implement AM measures for mitigating severe accident conditions.
- ✓ The effectiveness and feasibility of AM measures is strictly examined in licensing processes.
- ✓ Containment depressurization system, such as filtered venting system, shall be installed to prevent the containment failure due to over-pressurization and to minimize the radioactive consequences.

5. Emergency Preparedness

Lessons

- ✓ The plan prepared before the accident primarily and excessively relied on code predictions on source term and radionuclide diffusion. This was far different from international practices, and SBO in Fukushima Dai-ichi accident paralyzed the estimation system for the source term. Accordingly, diffusion simulations were made only based on hypothetical source term and regarded unpractical. It could be naturally recognized that source term prediction during severe accident is unrealistic and non-enforceable.
- ✓ It is risky and improper to prepare protections relying heavily on simulations and/or multiple judgments.

5. Emergency Preparedness

Responses

New guidelines were developed by NRA on October 31, 2012.

- ✓ Introduce operational criteria

  Projected dose and dose that has been received are not measurable quantities and cannot be used as a basis for quick actions in an emergency.

  The new guidelines accordingly introduce operational criteria (values of measurable default quantities or observables, such as the emergency action level, EAL, and the operational intervention level, OIL) as a surrogate for the generic criteria for undertaking different protective actions and other response actions.

- ✓ Define requirements of off-site emergency response centers, nuclear emergency drills, enhancement of measures after emergency, etc.

6. Continuous Improvement of Safety

Lessons

- Before the Fukushima Dai-ichi accident, licensees had re-evaluated tsunami height and some of them reinforced the protection against tsunami. As a result, some NPPs could be brought into a safe shutdown although they were hit by very high tsunami. This shows the importance of "Continuous Improvement".

- On the other hand, the regulatory requirements on tsunami were not reviewed over years before the Fukushima Dai-ichi accident. This implies lack of "Continuous Improvement" in regulation.

6. Continuous Improvement of Safety

Responses (1/2)

- ✓ The amended "Reactor Regulation Act" stipulates licensees' responsibility for "safety improvement" and requires licensees to conduct "self-assessment for safety improvement" periodically.
- ✓ This framework strongly encourages licensees' initiatives towards continuous improvement of safety by requesting licensees to prepare the final safety analysis report which provides "as-built" or "as-is" plant description and to update it when major design modifications or procedural changes take place.

6. Continuous Improvement of Safety

Responses (2/2)

- ✓ Licensees are also requested to carry out the periodic safety review (PSR) to incorporate the state-of-the-art knowledge into the plant design, operation and maintenance activities.
- ✓ In addition, it is required to conduct level 1 and 2 PRAs for both internal and external events including hazard re-evaluation to demonstrate the effectiveness of the plant modifications.

7. Use of PRA

Lessons

- ✓ The importance of PRA is dependent on initiators. The priority should be determined according to risk profile (a relative importance of the initiator).
- ✓ Since natural hazards were thought to be dominant initiators, the IPEEE should have had a relatively higher priority in Japan. However, PRA technologies for external initiators had not been maintained and improved in Japan where they were most needed.
- ✓ Although PRAs for external initiators have relatively large uncertainties, implementations of those PRAs can provide important technical insights regarding, e.g., relative importance of SSCs.

7. Use of PRA

Responses

- ✓ In the new regulatory framework, licensees are requested to conduct the plant-specific level 1 and 2 PRAs for both internal and external events as voluntary initiatives.

- ✓ Using the plant-specific PRA, licensees shall identify the severe accident scenarios and classify them into several groups. Also, licensees shall check the adequacy and sufficiency of AM measures by conducting deterministic analysis for each scenario.

- ✓ Licensees shall analyze all the “generic severe accident sequence groups” and “generic containment failure modes” that were defined by the NRA regardless of the results from the plant-specific PRAs.

8. Post-accident Regulation on Fukushima Dai-ichi

- ✓ NRA designated the Fukushima Dai-ichi NPS as “Disaster-experienced Nuclear Power Plant” on November 7, 2012.
- ✓ Except for the Fukushima Dai-ichi NPS, maintaining and improving safety is an only goal for the NRA. As for the Fukushima Dai-ichi, on the other hand, the NRA share the promotion of decommissioning as a common goal with TEPCO, as well as the maintaining and improving safety.
- ✓ The important challenge is to maintain harmonization between the implementation and acceleration of the decommissioning and the protection of people and the environment during the processes.
- ✓ NRA considers that a risk of water leakage from trenches in coastal area is significant.

9. International Cooperation

- ✓ The Fukushima Dai-ichi accident confirmed the benefit of international cooperation.
- ✓ For examples, even before the accident, NEA and member countries pointed out the importance of, e.g., continuous improvement of nuclear safety, effective and efficient regulation referring PRA results, and sustainment of key nuclear safety technologies.
- ✓ The NRA will continue to cooperate with international community in order to share information and knowledge, including insights obtained from the accident, and to establish internationally-harmonized regulation by participating in international activities.

Closing Remarks (1/2)

- ✓ In the light of the Fukushima Dai-ichi accident, the NRA developed the new design requirements and established the new regulatory framework to ensure the NPP safety.
- ✓ The new requirements aim at primarily;
  - changing the definition of DBAs by including prolonged station blackout and loss of ultimate heat sink,
  - enhancing the prevention measures against common cause failures, in particular due to external hazards, by strengthening the diversity/independence,
  - enhancing the prevention of core damage by preparing alternative measures with use of mobile equipment, and
  - enhancing the mitigation measures against severe accident to eliminate a large radioactive release from the containment and to minimize the radioactive consequences by mobile and immobile equipment.

Closing Remarks (2/2)

- ✓ The new regulatory framework encourages licensees' initiatives towards continuous improvement of safety and requests licensees to:
  - conduct "self-assessment for safety improvement" periodically,
  - prepare and update the final safety analysis report which provides "as-built" or "as-is" plant description, and
  - carry out PSR and plant-specific level 1 and 2 PRAs for both internal and external initiators to demonstrate the effectiveness of the plant modifications.

- ✓ In-depth discussions in international community are essential regarding, for example, the DiD concept applied to protections against specific external initiators.

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