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

Toyoshi Fuketa
Nuclear Regulation Authority

P1-5, Plenary Session I
Water Reactor Fuel Performance Meeting

Sendai International Center
Sendai, Miyagi, Japan
September 15, 2014

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 provision 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 (b-DBAs).
- ✓ 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 Structures, Systems and Components (SSCs) failures
2. Measures to Prevent Common Cause Failures (CCFs)
3. Prevention of Core Damage
4. Mitigation of Severe Accident
5. Emergency Preparedness
6. Continuous Improvement of Safety
7. Use of Probabilistic Risk Assessment (PRA)
8. Post-accident Regulation on Fukushima Dai-ichi

1. Prevention of SSCs 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 nuclear regulation in Japan, of course, defined design requirements but it focused on provision for random failures of SSCs and aseismatic design. Although all the initiators were conceptually required to be considered in plant design, most of external hazards, except earthquakes, had not been coped with enough to address their respective risks.

1. Prevention of SSCs failures

Lessons (2/2)

- ✓ In particular for tsunami, its design-basis heights had been postulated based on the historical records, which covered only 400 years. There was no countermeasure 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 SSCs failures
Responses (1/4)

- ✓ The Nuclear Regulation Authority (NRA), accordingly, enhanced design requirements significantly.
- ✓ Due considerations are required for all the significant internal and external initiators.
- ✓ The new requirements include; (i) identification of potential hazards, (ii) design against hazards exceeding their respective thresholds for screening, (iii) definition of design basis hazard (DBH), (iv) design to cope with the DBH with safety margin, and (v) evaluation of adequacy of safety design.

1. Prevention of SSCs failures

Responses (2/4)

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

1. Prevention of SSCs failures
Responses (3/4)

- ✓ The NRA develops specific requirements regarding fire and flooding, and includes requirements of countermeasures for extremely aggravated situations, e.g., intentional airplane crash.

- ✓ While many new requirements were developed against both internal and external initiators, the graded approach was applied to determine the necessity of such specific design provision based on their respective risks.

1. Prevention of SSCs failures
Responses (4/4)

- ✓ The new requirements aim at “function-based” approach to allow flexibility in choosing acceptable measures.

- ✓ However, based on recognition that adequate requirements had not been made for fire protection, specific requirements for physical separation of safety-related systems, fire hazard analysis, etc. are introduced considering current international practices. The NRA, of course, continues the development and application of fire PRA including data accumulation towards risk-informed regulations.

2. Measures to Prevent CCFs

Lessons (1/2)

- ✓ In the 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 SSCs.

- ✓ Although all the water-cooled EDGs were lost 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 (reactor core isolation cooling) system worked under the station blackout (SBO) conditions at Units 2 and 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 instrumentation and communication, closure of isolation valves in isolation condenser at Unit 1, unavailability of reactor depressurization, loss of control of RCIC and HPCI (high pressure coolant injection) systems, inoperability of containment venting, etc. These underline 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 (CCFs) of safety-related systems. Accordingly, the diversity of electric power systems should be improved to secure the plant safety.

2. Measures to Prevent CCFs
Responses (1/2)

- ✓ The new requirements extend design-basis events and strengthen protective measures against natural phenomena and other initiators which may lead to CCFs.
- ✓ They put a particular importance in due consideration to ensure diversity and independence (shift of emphasis from "redundancy centered").
- ✓ Diversity of operating mechanisms, e.g., diesel and gas turbine generators, motor-driven and diesel-driven pumps, is important as well as physical separation.

2. Measures to Prevent CCFs

Responses (2/2)

✓ 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 intentional aircraft crash, and
- easily and surely connectable to the target system by preparing spatially-dispersed multiple connecting ports.

3. Prevention of Core Damage

Lessons (1/2)

- ✓ Before the accident there was no provision against prolonged 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 industry's 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 regarded as highly unlikely scenarios, leading to lack of further studies 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 should 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 the NRA, the definitions of some DBAs are changed. Design provision is now required against prolonged SBO and LUHS.
- ✓ Also required is provision against some b-DBAs involving multiple failures, including anticipated transient without scram (ATWS), loss of core cooling, and loss of reactor depressurization.
- ✓ The new regulation requires 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 nuclear power plants (NPPs) in Japan on an industry's voluntary basis to improve the plant safety, referring the results of individual plant examinations (IPEs).

- ✓ 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.

- ✓ In the Fukushima Dai-ichi accident, many attempts to activate the AM measures were unsuccessful due to 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 phenomena and terrorisms, flexibility should be incorporated into the design and implementation of AM measures. In addition, 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 regulation requires licensees to design and implement AM measures for mitigating severe accident conditions.
- ✓ The feasibility and effectiveness of AM measures are strictly examined in licensing processes.
- ✓ Containment cooling/depressurization system, e.g., 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 guidelines for emergency preparedness existed before the Fukushima Dai-ichi accident primarily and excessively relied on code predictions on source terms and radionuclide diffusion. This was far different from international practices, and SBO in Fukushima Dai-ichi accident paralyzed the computational tools for estimating the source terms. Accordingly, diffusion simulations were made only based on hypothetical source terms and regarded unpractical. It is naturally recognized that source term prediction during severe accident is unrealistic and non-enforceable.

- ✓ It is risky and improper to prepare protection relying heavily on simulations and/or multiple judgments.

5. Emergency Preparedness

Responses

- ✓ 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 by the NRA 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.

- ✓ The new guidelines also define requirements on roles and functions of off-site emergency response centers, execution of nuclear emergency drills, 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 periodically for both internal and external initiators 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 even before the accident, the IPEEE (individual plant examination for external events) should have had a relatively higher priority in Japan. However, PRA technologies for external initiators had not been developed or improved in Japan where they were most needed.
- ✓ Although PRAs for external initiators have relatively large uncertainties, implementing those PRAs can provide important technical insights regarding, e.g., relative importance of SSCs.

7. Use of PRA
Responses (1/2)

- ✓ The NRA recognizes that the PRA methodology is very useful and applicable to develop and propose effective and efficient protection against the specific initiators. The NRA promotes utilization of PRA recognizing its usefulness and limitations.

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

7. Use of PRA

Responses (2/2)

- ✓ 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 accident analysis for the severest scenario in each group.
- ✓ 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

- ✓ The NRA designated the Fukushima Dai-ichi as "Disaster-experienced Nuclear Power Plant" on November 7, 2012.
- ✓ In order to keep reducing the existing risk in the Fukushima Dai-ichi, the NRA should regulate and promote the decommissioning processes at the same time.
- ✓ 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.
- ✓ The NRA considers that a risk of water leakage from underground trenches connected to the reactor turbine buildings on the seaward side is significant.

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;
  - extending the definition of DBAs by including multiple failures such as prolonged SBO and LUHS,
  - enhancing preventions against CCFs, in particular those due to external hazards, by strengthening the diversity/independence,
  - enhancing protection against core damage by preparing alternative measures with use of mobile equipment, and
  - enhancing mitigation of severe accidents to eliminate a large radioactive release from the containment and to minimize the radioactive consequences by mobile and immobile equipment.

NRA

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.

- ✓ The NRA continues to address the lessons learned from the Fukushima Dai-ichi accident, keeps updating regulatory requirements where appropriate, and never becomes complacent.

With thanks to

Kiyoharu Abe
Tomoho Yamada
Hiroshi Yamagata
NRA

Norio Watanabe
NSRC, JAEA