Lessons Learned from the Accident at the Fukushima Daiichi Nuclear Power Plant

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Introduction

- Acknowledging the lessons learned from Fukushima-Daiichi nuclear accident is crucial to take measures to never let a similar accident happen at worldwide nuclear power plants.
- Based on publicized information, we summarized the lessons in several topics and put together examples of countermeasures as proposals.
- The proposals are categorized into short-term and mid-term measures. The former should be done immediately, and the latter should be achieved in two or three years with thorough consideration.

Topics

1. The seismic design
2. The tsunami
3. Station Blackout
4. Loss of ultimate heat sink
5. Accident management
6. Hydrogen explosions
7. Spent fuel storage pools
8. Safety research
9. Safety regulations and safety design
10. Organization/crisis management
11. Information disclosure
12. Safety management during an emergency

1. The Seismic Design

a. Seismic Design for the earthquake was considered effective in many cases.
b. The expansion of the accidents was caused by insufficient seismic countermeasures for external power system.

Short-Term Activities

(1) Quantitative evaluation of the Seismic Design for Onagawa and Tokai-Daini NPP is strongly recommended, where seismic response is partly higher than that of basic earthquake ground motion Ss.
Additional Seismic countermeasures may be necessary .

(2) Seismic Evaluation for the quake-hit Fukushima-Daiichi and Fukushima-Daini NPP should be carried out. The results must be used for the Seismic design improvement.

Mid-Term Activities

(3) Revision of the basic earthquake ground motion Ss, if necessary. Also back-check for all NPPs should be done as soon as possible, in line with the present earthquake mechanism.

(4) Reconsideration for the seismic design of external power systems.

2. The Tsunami

a. Estimated tsunami was too small.

b. Safety System and Components were damaged because of seawater flooding, resulting in severe accidents.

c. Insufficient countermeasure against flooding for underground structures. Injected seawater prevents recovery efforts.

Short-Term Activities

(1) Hardware preparation to protect safety System, Structure and Components (SSC) from tsunami.

Mid-Term Activities

(2) Revision of tsunami estimation. Quantitative Risk Analysis for tsunami must be introduced and standardized.

(3) Equipment of sea embankment to protect tsunami.

(4) Improvement of water-tightness of buildings. All route of water leak passages such as conduit must be closed.

(5) Consideration for building damage caused by tsunami-stricken equipments and structures

(6) Equipment of drainage pumps.

(7) Preparation for spare components at the place where tsunami hardly come.

(8) Preparation for heavy machines to remove tsunami debris.

(9) Improvement of water-tightness of pits close to sea shore, even if its safety importance is low.

3. Station Blackout

a. Safety review for station blackout was insufficient.

b. Long-term Station blackout caused the accidents progression.

c. Reactor parameter monitoring was difficult without electricity.

d. The accidents might have been recovered, if supply was partially available.

Short-Term Actions

(1) diversifying power supplying system including power supply cars and small generators.

(2) Preparation for power supply to important components and reactor monitoring system in case of station blackout.

(3) Preparation for wiring between standby generators and the power system.

Mid-Term Actions

(4) Revision for guidelines in safety reviews.

(5) Diversifying types and settings of power generators such as gas turbine generators. Consideration for seismically isolated floor for generators.

(6) Equip air-cooling generators in stead of seawater cooling system.

(7) Equip spare electric power components such as power center.

(8) Preparation of power interchanges between other power plants such as hydraulic plants.

(9) Equip a small power generator with RCIC turbine to charge the battery for control unit.

4. Loss of Ultimate Heat Sink

a. Seawater cooling system is vulnerable to tsunami.

b. Core damage might be delayed if the power was available.

Short-Term Activities

(1) Training for water injection using fire-engine. Preparation of hardware.

Mid-Term Actions

(2) Preparation of the spare components such as seawater pump motor at the place where tsunami hardly come.

(3) Water-tightness of seawater pump, such as waterproof wall or waterproof building.

(4) Ensure the redundancy by equipping cooling system in stead of seawater-cooling system. Air-cooling system which has enough capacity to remove decay heat is a candidate.

(5) Development of natural circulation cooling system.

(6) Preparing variety of water sources, such as river, dam, and reservoir for fire fighting. Multiplying power transmission lines.

5. Accident Management (1/2)

a. Accident management (AM) activities prevent significant deterioration of the accidents.

b. AM for long-term station blackout may be insufficient.

c. Consideration for AM after core damage and radioactive emission was insufficient.

Short-Term Activities

(1) Preparation of the backup power capable of running for several days, for the following purposes:

i) Monitoring important reactor parameters, measuring radiation monitor on exhaust tower, and control system for vent-line.

ii) Power source for hydrogen recombiner and standby gas treatment system.

(2) Preparation of nitrogen gas container to operate air-operated valves.

(3) Venting should be judged by the on-site manager.

(4) AM training should be carried out considering realistic situations (e.g. lots of debris scattered by tsunami). Equipment of water supplying hose on site.

5. Accident Management (2/2)

a. Accident management (AM) activities prevent significant deterioration of the accidents.

b. AM for long-term station blackout may be insufficient.

c. Consideration of AM after core damage and radioactive material emission was insufficient.

Mid-Term Activities

(4) Reconsideration of all AM activities, including all considerable events. Preparation of the required equipments. The evaluation of AM and analysis of plant response to the present accident should be used to revise AM activities.

(5) Equipment of filtered vent line, in which sand, zeolite, and water are filled .

(6) Evaluation of multiple and simultaneous AM actions for multi-reactors site.

(7) Construction of mobile waste water treatment facility. The facility will be moved to the crisis-hit site.

(8) Research for reactor cooling method and enclosure method after core damage. Development of the hardware.

(9) Research for reactor cooling method and enclosure method after radioactive material emission. Development of the hardware.

6. Hydrogen Explosions

a. Reactor buildings were destroyed by hydrogen explosions.

b. Hydrogen explosions at outside the containment vessel (CV) were not postulated.

c. Hydrogen leakage pass to outside CV is unknown.

Short-Term Activities

(1) Backup power for CV parameter measurement system and hydrogen recombiner. Remote monitoring for CV parameter should be enabled.

(2) Implementing leakage inspection for vent-line. Training for venting.

Mid-Term Activities

(3) Evaluation of the of hydrogen explosion mechanism at outside CV.

(4) AM to prevent hydrogen leakage from CV, such as equipment of static catalyst recombiner.

7. Spent Fuel Storage Pools

a. Spent fuel pool cooling was failed.

b. Enclosure of radioactive materials at spent fuel pool is difficult if reactor building was damaged.

Short-Term Activity

(1) Reconsideration of AM for spent fuel pool under Station blackout. For example:

- Preparation of water injection using fire engine.
- Preparation of pumping system using fireplug equipped on operation floor.
- Equipment of flexible hose to enable water injection from outside.

(2) Equipment of standby power to enable monitoring of spent fuel pool temperature and leakage detection monitor.

Mid-Term Activity

(3) Natural circulation cooling system for spent fuel pool.

(4) Interim storage facility using air-cooling system.

(5) Research on the cause of damage in 1F-4 reactor building by simulation of accident behavior. Investigation of spent fuel pools.

8. Safety Research

a. Research on severe accident was insufficient. Application of the research to prepare for AM was also insufficient.
b. National budget for safety researches is spent ineffectively.

Short-Term Activities

(1) Reflection of the present Severe Accident researches on regulation.

Mid-Term Activities

(2) Sustainable development of human resources for safety researches including severe accidents and safety design.

(3) Enhancement of research on severe accident. Hydrogen behavior analysis, hydrogen explosion, and evaluation for spent fuel pool are especially needed.

(4) Enhancement of modeling and simulation studies. Innovation in nuclear safety, verification and validation of the simulations are especially needed.

(5) Sustainable budget for practical safety researches. Revision of the related law may be required.

9. Safety Regulations and Safety Design

a. Insufficient safety design for external event.

b. Insufficient evaluation for the events whose probability is very low and the effects are huge.

c. Insufficient preparation for common cause failure.

d. Japanese safety regulation system is also insufficient.

Short-Term Activities

(1) Evaluation for the AM for tsunami.

Mid-Term Activities

(2) To external events, establishment of quantitative risk evaluation.

(3) To internal events, reconfirmation of defense in depth and Innovation of quantitative risk evaluation.

(4) Establishment of the risk evaluation method for the events whose uncertainty is high and effects are huge.

(5) AM for the events which can not be covered by quantitative risk analysis.

(6) Revision of safety importance. Variety and multiplicity of the components. Revision of electric system is especially required.

(7) Overall revision of Japanese safety regulation system.

i) Revision of the legal system. Unification of “the Nuclear Reactor Regulation Law” and “Electric Utility Industry Law.”

ii) Severe accidents management should be introduced into the Nuclear Reactor Regulation Law.

iii) Comprehensive safety analysis should be introduced to the construction permission.

iv) Introduction of private third-party certification system and audit regulation.

10. Organization/Crisis Management

a. System for the responsibility was unclear.
b. Information was not shared smoothly because of the electric outage and problems in communication.

Short-Term Activities

(1) A responsible expert should preside all the responsibility.

Mid-Term Activities

(2) Reconstruction of the regulatory organization.

i) Revision of Nuclear Safety Commission and establishment of regulatory organization with high expertise, such as USNRC.

ii) Revision of the Nuclear Reactor Regulation Law by introducing environmental radiation monitoring into the law. Monitoring should be managed by prefectural government according to the revised law. Therefore, transparent monitoring and smooth communication to the Act on Special Measures Concerning Nuclear Emergency Preparedness are achieved.

iii) Establishment of organization to audit secretariat of regulatory committee.

iv) The organization should keep in touch with regulatory board around the world and should participate in IAEA's activity.

11. Information Disclosure

a. Public feels that the information disclosure is not enough.

b. Technical explanation was insufficient.

c. Explanation of radiation safety is not successful.

d. Evacuation ordered district was expanded in a phased manner.

e. Insufficient coordination with local governments upon specifying evacuation areas.

f. Lack of communication between disaster countermeasures office and local government.

Short-Term Activities

(1) Complete disclosure of the results of SPEEDI calculation.

(2) Improvement of technical explanation on press conference.

(3) Announcement of physical protection measures based on uniformed radiation safety logic.

Mid-Term Activities

(4) Revision of the Act on Special Measures Concerning Nuclear Emergency Preparedness. Especially, the role of national and local government should be realistically clarified.

(5) Realistic disaster prevention practice based on the revised law.

(6) Improvement of diffusion code (ERSS and SPEEDI) and clarification of their roles.

(7) Enactment of the Nuclear Transparent Law.

12. Safety Management during an Emergency

a. Problems in unifying and sharing information about radiation dose in Fukushima-Daiichi site.

b. Design of anti-seismic building (present headquarter) did not consider the inflow of radioactive materials.

c. Lack of awareness of health effects on the workers in emergency condition.

Short-Term Activities

(1) Thorough information sharing.

Mid-Term Activities

(2) Securing the staff for radiation control. Preparation for the necessary materials. Confirmation of the feasibility.

(3) Analysis of human behavior in emergency according to behavioral science and health science.

Summary of Important Lessons

a. Estimated tsunami was too small.
b. Safety System and Components were damaged because of seawater flooding, resulting in severe accidents.
c. Long-term station blackout caused the accidents progression.
d. Reactor parameter monitoring was difficult without electricity.
e. Seawater cooling system was vulnerable to tsunami.
f. Accident Management (AM) for long-term station blackout may be insufficient.
g. Hydrogen explosion at outside the containment vessel (CV) was not considered.
h. Enclosure of radioactive materials at spent fuel pool is difficult if reactor building was damaged.
i. Insufficient safety design for external event.
j. Japanese safety regulation system is insufficient.
k. Public feels that the information disclosure is not enough.
l. AM activities prevent significant deterioration of the accidents.
m. Seismic Design for the earthquake was considered effective in many cases.

Summary of Strongly Recommended Actions

1. Hardware preparation to protect the safety System, Structure and Components (SSC) from tsunami.
2. Preparation for variety of power sources, such as air-cooled gas turbine system.
3. Consideration and preparation for variety of cooling systems in addition to seawater cooling system.
4. Assume that severe accidents do surely occur. Adequate consideration for severe accident management (AM). Hardware preparation for the AM such as multiple wiring for power source. Training and education of AM.
5. AM for preventing hydrogen explosion. AM for spent fuel pool.
6. Improvement of severe accident researches and human resources development.
7. Drastic revision of the safety regulation including legal system and organizational reconstruction.
8. Establishment of quantitative risk analysis. Introduction of risk concept into the entire safety regulation.
9. Reassessment of public information disclosure and information sharing.
10. Realistic disaster prevention practice based on the recognition that severe accidents do surely occur.
11. Detailed evaluation for the seismic design, coordination design, AM, plant behaviors for the present Fukushima-Daiichi Accident. Then, improve the Nuclear safety considering wide range of countermeasures.