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Lessons learned from the accident at the Fukushima Daiichi Nuclear Power Plant

Technical Analysis Subcommittee
Committee for Investigation of Nuclear Safety
Atomic Energy Society of Japan

We would like to express our deepest sympathy for all those affected by the tragic chain of events, especially the nuclear accident at Fukushima Daiichi Nuclear Power Plant, following the devastating earthquake and tsunami that struck Tohoku region on March 11, 2011.

As academic and technical experts specialized in a broad range of nuclear technology, which remains a matter of public concern, we frequently issue press release about our main activities to contribute to society by providing information.

The accident at the Fukushima Daiichi Nuclear Power Plant destroys the trust in nuclear safety, and brought to light the potential risks of nuclear power plants. All-out efforts are continuing to bring an end to the accident.

It is important to draw lessons learned from this accident and take measures so that the same sort of accident does not occur again at any of the nuclear power plants operating in the world. We at the Technical Analysis Subcommittee of the Committee for Investigation of Nuclear Safety (Atomic Energy Society of Japan) have analyzed the accident and response in the following 12 areas based on the disclosed information, summarized the lessons which can be derived, and listed examples of possible countermeasures as proposals.

Two types of proposals are listed: examples of measures which should be taken in the short term of less than about one year, and examples of medium-term measures involving careful reform over the course of 2 or 3 years. These lessons will be useful not only for improving the safety of nuclear power plants throughout the world, but also for improving safety of man-made systems outside the field of nuclear power. In the future, we plan to revise this document as appropriate to reflect changes in the situation.

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If you have any questions or comments, please contact QandA_gb@aesj.or.jp.

1. Lessons relating to seismic design

a. The conventional seismic design were considered to be basically effective

The standard earthquake ground motion S_S was reviewed due to action such as re-checking relating to the seismic design guidelines amended in 2006, and, in addition, measures such as earthquake-resistance reinforcement were taken. It is presumed that the strength of the recent earthquake was roughly within the range of the standard earthquake ground motion S_S. Furthermore, since the margins for the equipment structure was adequately estimated, and stable cooling continued for one hour until the tsunami arrived, it is presumed that S class equipment was basically sound. However, there were also events such as the observation at Unit 1 of the Fukushima Daini Nuclear Power Plant of a rise in containment vessel pressure after the earthquake, and a detailed seismic evaluation will need to be conducted in the future.

On the other hand, it is presumed that some C class equipment, pipe and similar systems were damaged, and going forward there will need to be a detailed evaluation, as well as an investigation of the effects of the damage.

b. Seismic countermeasures for the external power supply were inadequate and did not protect against enlargement of the accident.

The earthquake caused overhead cables to sway, and caused damage to transmission towers (C class), resulting in loss of the external power supply.

Proposals (short-term)

(1) The effects due to earthquake tremors will need to be quantitatively evaluated for the Onagawa Nuclear Power Plant and the Tokai Daini Nuclear Power Plant, where the standard earthquake ground motion S_S was partially exceeded. If necessary, safety will need to be enhanced for restarting.

(2) A seismic evaluation for the recent earthquake should be conducted for the Fukushima Daiichi and Daini Nuclear Power Plants, and the obtained findings should be used to help improve seismic design.

Proposals (medium-term)

(3) If necessary, the standard earthquake ground motion S_S should be reviewed for power plants inside Japan based on the mechanism of the recent earthquake, and re-checking should be done as quickly as possible.

(4) The basic approach to earthquake resistance of the external power supply must be reconsidered.

2. Lessons relating to the tsunami

a. The scale of tsunamis considered in earthquake-resistant design was inadequate.

The plant was hit by a tsunami whose size (approx. 15 m) greatly exceeded the height considered in the earthquake-resistant design (approx. 5 m).

b. Due to infiltration of seawater, safety critical equipment shutdown, and did not protect against enlargement of the accident.

Equipments such as the seawater pump and tanks, placed on the ocean side assuming a maximum tsunami height of about 5 m, were destroyed by the tsunami. As a result, the emergency diesel generator for seawater cooling stopped, and the entire AC power supply was lost. In addition, function of the seawater cooling system was lost, and thus the entire cooling system was lost.

The buildings located at an elevation of 10 m were inadequately protected against water infiltration, and many pieces of equipment were submerged. In particular, the power panel was submerged and damaged by the tsunami, and that made it difficult to restore the electrical system.

c. Underground structures were inadequately protected against water infiltration, and this interfered with recovery work.

Large amounts of seawater flowed into underground structures such as trenches and pits, and power cables and electric equipment for the seawater cooling system were inundated. This made tasks such as removal of seawater necessary, and interfered with recovery work.

Proposal (short-term)

(1) Measures must be taken in terms of equipment and facilities, such as preventing seawater infiltration into buildings where equipments important to safety is housed, to prevent damage to such equipment in case the plant is hit by a tsunami.

Specific measures include: sealing doors, checking and if necessary reinforcing the sealing of cable trays and electric conduits, and checking and improving watertightness of trenches and other water infiltration paths from underground structures to buildings.

Proposals (medium-term)

(2) Review tsunami assumptions based on the recent findings.

Incorporate risk assessment techniques, and promote standardization of assumed tsunamis.

(3) Build sea walls to prevent tsunami infiltration onto the site.

(4) Improve watertightness of buildings so that equipments important to safety are protected even if the facility is hit by a tsunami greater than the assumed size. This should involve not only watertight doors, but also blocking all paths for water infiltration such as electric

conduits and small bore pipes.

(5) Consider measures to deal with the possibility that buildings may be damaged because equipment, structures or rubble are carried along by the tsunami.

(6) Install drainage pumps beforehand.

(7) Prepare spares for equipment which may be washed away or malfunction due to the tsunami at a location where it will not be affected by the tsunami.

(8) Prepare beforehand crane, power shovel and other tools for removing rubble scattered by the tsunami.

(9) Improve watertightness and take measures to prevent tsunami infiltration at pits near the sea shore, even if they have low safety class. Also review earthquake resistance if necessary.

3. Lessons relating to station blackout

   a. Safety review was inadequate.

      The safety review guidelines only assumed the possibility of station blackout for a short term.

   b. The power supply was totally lost for a long term, and it was impossible to prevent progression of the event.

      In addition to losing the external power supply (AC power source) and the emergency diesel power supply, the function of the power panel was also lost, making recovery difficult. It also required time to dispatch equipment such as power supply trucks and to connect from the power supply trucks.

      The capacity of batteries (DC power source) is approx. 8 hours, and after that it became difficult to drive control panels and instrumentation, as well as the turbine driven feedwater system and valves.

      As a result, systems important to safety adequately function.

   c. It became difficult to ascertain the situation inside the reactors.

      The instrumentation power supply was lost, and it became impossible to adequately obtain information on the reactors.

   d. If even part of the power supply remained, it may have been possible to stop the progression of the event.

      An air-cooled diesel generator was operational, and thus it was possible to cool the reactors and fuel pools of Units 5 and 6.

Proposals (short-term)

(1) Supply power using various methods (such as power trucks and small generators) so that all AC power is not lost.
(2) Take measures so that power can be supplied to critical equipment and the reactor core monitoring system in case all AC power is lost. In particular, it is essential to consider beforehand the supply of power to valves and other equipment used in accident management.
(3) When installing multiple generators, connect power cables beforehand.

Proposals (medium-term)

(4) Proceed with a re-examination of safety review guidelines etc.
(5) Adopt various types of generators, such as gas turbine generators. Strive for diversity in their placement, and consider measures such as quake-proof floors for stationary generators.
(6) Do not depend only on seawater cooling. Prepare air-cooled generators.
(7) Prepare a spare power panel. Take measures to prevent water infiltration into equipment

such as high-voltage distribution panels, and formulate countermeasures such as quickly shutting off control power in case of an emergency.

(8) Perform power sharing with other power plants (for example, hydroelectric plants). Also, provide a permanent power sharing cable and terminal panel for power truck cable connection.

(9) Install a small generator for the steam turbine driven core water injection pump, and charge the battery for control.

4. Lessons relating to loss of ultimate heat sink

   a. Seawater cooling is vulnerable to tsunamis.

      Core heat removal function was lost because the seawater pump became unusable. At present, seawater cooling is difficult at the Fukushima Daiichi nuclear power plant, and thus air cooling is being considered.

   b. If necessary, there is a comparatively long time margin until core damage.

      At the Fukushima Daini Nuclear Power Plant the seawater pump became unusable, but external power was available, and thus it was possible to stably and continuously inject water into the reactors. Reactor cooling could be achieved by using this time margin to replace or repair seawater pump motors.

Proposal (short-term)

(1) Conduct drills of water injection into the cooling system using fire trucks etc., and improve equipment.

Proposals (medium-term)

(2) Prepare spares beforehand for the seawater pump motor and similar equipment at a location which will not be affected by a tsunami.

(3) Take measures to prevent water infiltration to the seawater pump. For example, provide a floodwall or a dedicated building.

(4) Prepare a cooling system which does not depend on seawater and secure redundancy. It is also important to install air cooling equipment or a similar system with the capacity to remove decay heat in case the seawater cooling system becomes completely unusable.

(5) Consider a natural circulation cooling system which does not require power to operate. This will enable decay heat to be passively removed under all circumstances. Past design studies and research on next-generation reactors can serve as reference here.

(6) Diversify water sources (e.g., rivers, dams, fire fighting water). If necessary, further duplicate power transmission lines.

5. Lessons relating to accident management

a. Accident management (AM) measures prevented drastic worsening of the accident.

Since AM measures were taken beforehand, an alternative water injection system was available, and it was possible to inject fresh water/seawater using fire trucks and fire pumps. If this injection system were not available, the accident would have been even more serious. Rubble and other debris due to the tsunami interfered with the laying of hoses, and thus it was necessary to make preparations beforehand such as installing hoses in pits.

b. Accident management (AM) for station blackout may have been inadequate.

Heat removal was done by injecting fresh water/seawater and using the containment vessel vent, but it could not be done adequately. Since there was no power supply, it required considerable trouble to open the vent line valve. A large amount of power is not needed for the compressed air equipment and solenoid valves needed to open these valves, but it was difficult to provide that power. Due to the loss of power, parameter measurement (temperature, pressure, water level etc.) inside the reactor and containment vessel did not function adequately.

It is important to investigate how emergency cooling systems (such as the condenser during isolation and the cooling system during isolation) functioned, and use this to help improve AM measures.

c. AM measures for after cores were damaged and radioactive material was released were not adequately considered.

To a certain extent, AM measures to prevent core damage were considered beforehand. Consideration of AM measures for after core damage occurred and AM measures for after radioactive material was actually released was not always adequate, and this likely led to confusion.

Proposals (short-term)

(1) As an AM measure for a severe accident, prepare spare power supplies which can be used for a few days for the following purposes. It will also be effective to always have nitrogen tanks ready for operating air actuated valves.

i) Power supply for monitoring crucial core parameters and exhaust stack radioactivity.

Prepare a power supply line to enable vent line control. For example, a spare power supply for opening/closing solenoid valves, and operating motor driven valves and spare compressors.

ii) Power supply for the hydrogen recombiner and the emergency gas treatment system.

(2) Take measures so that venting can be done at the discretion of the manager on site.

(3) Conduct training for AM measures assuming the actual situation (e.g., rubble scattered due to a tsunami). Preparations must be made beforehand, such as installing hose for reactor feedwater in pits, in case rubble is scattered.

Proposals (medium-term)

(4) Review AM based on several initiating events, not only station blackout, and take any necessary measures for permanent equipment. It is important to evaluate the specific AM response and plant behavior for the recent accident, and use this to help improve AM.

(5) Install components such as filtered vents containing zeolite sand and water in vent lines.

(6) Evaluate AM simultaneous response measures for the case where multiple reactors are located on the same site.

(7) Prepare beforehand mobile contaminated water treatment equipment to address the possibility of large amounts of contaminated water being produced. (Transport to the facility involved in a disaster after the accident.)

(8) Systematically review techniques for reactor cooling and containment for after core damage has occurred. Also consider any necessary response in terms of equipment or facilities.

(9) Review techniques for reactor cooling and containment after radioactive material has been released. Also consider any necessary response in terms of equipment or facilities.

6. Lessons relating to hydrogen explosions

   a. <u>Reactor buildings were damaged due to hydrogen explosions.</u>

      Part of the containment function was lost, and this created problems for recovery work.

   b. <u>Hydrogen explosions outside the containment vessel were not taken into consideration.</u>

      Many studies have been conducted on hydrogen explosions inside the containment vessel, but hydrogen explosions inside the reactor building have not been considered. It is likely that equipment such as the hydrogen recombiner and hydrogen concentration gauge were not operating when power was lost.

   c. <u>The path of hydrogen leakage to the outside of the containment vessel is unknown.</u>

      Possibilities include leakage from the vent line or leakage from seals such as the containment vessel head flange or hatch due to excessive pressure. This will need to be examined in the future.

<u>Proposals (short-term)</u>

(1) Provide a system so that reserve power can be supplied to equipment, such as the containment vessel parameter measurement system and the hydrogen recombiner, and take measures to enable remote monitoring of parameters.

(2) Recheck the vent line, and inspect for leaks. Also conduct venting training.

<u>Proposals (medium-term)</u>

(3) Evaluate the mechanism of hydrogen explosions outside the containment vessel.

(4) Take AM measures so that hydrogen does not leak outside of the containment vessel. For example, possibilities include installing a static catalytic recombiner.

7. Lessons relating to cooling of spent fuel storage pools

   a. There was a failure to cool spent fuel storage pools.

      After station blackout, the water level in spent fuel storage pools dropped, and heat removal from spent fuel became inadequate. There is time margin of at minimum a few days until the fuel is damaged.

      There is a possibility that pool water boiled due to the decay heat of spent fuel, and hydrogen was produced by oxidation of fuel cladding. The heating value of the spent fuel was known, and thus it is possible that the time margin was misunderstood, or it was not possible to respond due to the staff being completely occupied dealing with accidents at other units.

      At present, the cause of the destruction of the Unit 4 reactor building has still not been identified.

   b. There are issues with containment of spent fuel after the buildings were damaged.

      Radioactive materials were released directly into the atmosphere in the unlikely event that spent fuel was damaged when the buildings were damaged by hydrogen explosions. In this case it is crucial to ensure the water level.

Proposals (short-term)

(1) Review AM for the spent fuel storage pools. Specific measures which can be taken include: making preparations so that water can be injected using a fire truck immediately after power is lost; making preparations so that water can be injected from a fire hydrant on the operation floor where the pool is located; and installing flexible hose and other equipment beforehand so that water can be injected easily from the ground.

(2) Prepare a power supply so that fuel pool temperature and leakage can be monitored using a spare power supply etc., even if AC power is lost.

Proposals (medium-term)

(3) Adopt a natural circulation cooling system for used fuel storage pools. This will enable removal of decay heat even without a power supply.

(4) Adopt an air-cooled intermediate storage facility.

(5) Investigate and identify the cause of damage to the Unit 4 building by evaluating accident behavior with a simulation. Also, investigate the situation of the used fuel storage pool using a fiberscope etc.

8. Lessons relating to the promotion of safety research

   a. Severe accident research and application of its results were insufficient.

      Presumptions regarding the core damage situation have not been clarified.

      The Emergency Response Support System (ERSS) and the System for Prediction of Environment Emergency Dose Information (SPEEDI) have not being used to the expected extent due to problems such as inadequate data caused by station blackout.

      Basic safety research has not been stressed at the Japan Atomic Energy Agency (JAEA), and in the future there will be a need to examine whether the agency was able to respond adequately to the recent accident.

   b. There is a lot of waste in how the national budget is being used.

      Items produced through R&D by a national project are not permitted to be used for other purposes due to budget issues, and in many cases the items are scrapped after research has ended. Important results must be preserved so that developed items can be effectively used in case of a disaster.

Proposal (short-term)

(1) Incorporate into regulations the existing results of severe accident research through the JAEA and Japan Nuclear Energy Safety Organization (JNES).

Proposals (long-term)

(2) Development of human resources

    Systematically develop human resources relating to safety design and safety research including severe accidents.

(3) Promotion of severe accident research

    In particular: hydrogen behavior analysis, hydrogen combustion, and spent fuel pool evaluation etc.

(4) Promotion of modeling/simulation technology

    In particular: raising the level of nuclear power safety, and V&V (Verification & Validation for Simulation) etc.

(5) It is necessary to take budgetary measures and preserve research results needed in case of a disaster. In some cases, laws will also need to be amended.

9. Lessons relating to safety regulations and safety design
   a. The safety design approach for external events was inadequate.
   b. Evaluation was inadequate for extremely unlikely, high impact events.
   c. Preparation for a common cause failure was inadequate.

The response for high impact, but highly uncertain events such as tsunamis was not adequately considered. In the case of internal events, the causes of common cause failures are primarily "soft" issues such as human factors, and research on such issues has progressed greatly since TMI. In addition, the defense in depth concept has been adequately established for internal events as a result of research. The defense in depth concept for internal events has been applied to external events in the same way, but here it is likely that the understanding of common cause failures was overly optimistic.

For external events, common cause failures are primarily due to "hard" (physical) factors. Also, external events have a dramatically low probability of occurrence, but the uncertainty of that probability is high. In such cases, the conventional 3-level defense in depth is inadequate, and it is crucial to take adequate measures up to and including severe accident management (AM) and disaster preparedness.

For external events, it will likely be necessary to conduct evaluation using probabilistic risk assessment (PRA) focused on quantitative risks. However, it will be necessary to discuss the uncertainty of PRA. What covers this uncertainty is, of course, accident management. It is necessary to reconstruct safety logic for nuclear power plants, including AM and disaster preparedness, assuming various types of natural disasters.

   d. Japan's system for safety regulation was inadequate.

Specific issues include: the fact that there was no system for reviewing the current design of a plant, the fact that incorporation of probabilistic risk assessment was delayed, and the fact that new findings were not adequately incorporated.

A trend toward incorporating severe accidents into regulations had begun, but it did not achieve results in time. In addition, in the recent accident, the scope of regulation of “The Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors” was narrow, and the accident immediately became subject to “Special Law of Emergency Preparedness for Nuclear Disaster.”

The review of basic design (application for establishment permission) is weakly tied with operation management. Also, requirements for changes are formally stipulated with changes in the main text provisions, and a changed application for establishment permission does not reflect the state of the plant. In addition in establishment permission, approval of the construction plan and inspection before use, stress was placed on structural strength regulations, while functional performance and analysis/probabilistic risk assessment (PRA) were given short shrift.

Incorporation of new findings, such as safety research and regulation trends in foreign countries, was delayed. In addition, too much faith was placed in the infallibility of regulation, resulting in a tendency to always follow precedent, and this was negative for review of regulations in order to continually pursue safety.

<u>Proposal (short-term)</u>

(1) Evaluate accident management (AM) measures for tsunamis.

<u>Proposals (medium-term)</u>

(2) Establish quantitative risk assessment techniques for external events.
In particular, establish probabilistic risk assessment techniques taking into account earthquakes and tsunamis as initiating events. Promote standardization relating to the probability of tsunami occurrence.

(3) Reconfirm defense in depth for internal events, and raise the level of quantitative risk assessment.

(4) Establish risk assessment techniques for events with high uncertainty and tremendous impact.

(5) Formulate AM response measures for events which cannot be covered by quantitative risk assessment.

(6) Review safety importance and diversity/multiplicity. Review electrical systems in particular.

(7) Review all aspects of Japan's safety regulation system.

  i) Review the legal system and make “The Electric Utility Industry Law” consistent with “The Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors.”

  ii) Change the purpose and permission criteria in “The Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors” to "protecting citizens from radiation injury," incorporate severe accidents into the regulatory scope of the Nuclear Reactor Regulation Law, and ensure viability of the AM procedure (e.g., organization, roles, response for multiple units, procedure validity/feasibility, training, equipment).

  iii) Introduce a comprehensive safety analysis report for establishment permission, stress analysis assuming operation management conditions, establish requirements for making changes from the perspective of reactor safety, and make such that documentation is always "as-built" by incorporating plant changes into the comprehensive safety analysis report.

iv) Adopt a private third party certification system for approval of the construction plan and inspection before use relating to structural strength, and adopt a unified inspection system for inspecting (by auditing) the implementation situation and compliance of the comprehensive safety analysis report.

10. Lessons relating to organization/crisis management

a. The responsibility system was inadequate.

Due to vertical administration, personnel with specialized knowledge in each field of nuclear power are dispersed, and there is no person who can make judgement.

Laws and regulations have been decentralized, and there is no specialized organization with overall control.

In particular, organizations for radiation regulation and nuclear power regulation have been separated.

Use of experts was inadequate.

b. Emergency response did not go smoothly due to issues such as power outages and problems in communicating information.

For example, notification and assembly of emergency response personnel was delayed. In addition, opinions from overseas carry a lot of weight, and outstanding knowledge within Japan has not been used. (For example, knowledge relating to robots and water treatment etc.)

The Emergency Response Support System (ERSS) did not work due to the power outage.

Proposal (short-term)

(1) A manager with specialized expertise should have overall responsibility.

Proposals (medium-term)

(2) Create a regulatory organization with specialized expertise. For example:

i) Make the Nuclear Safety Commission of Japan an Article 3 organization, and unify/centralize nuclear power and radiation regulation (which are divided between the Nuclear and Industrial Safety Agency and the Ministry of Education, Culture, Sports, Science and Technology) under the Article 3 organization. Also, integrate organizations requiring experts, such as the Japan Nuclear Energy Safety Organization (JNES) and the Nuclear Material Control Center, and create a regulatory organization with a high-level of specialized expertise as a Japanese version of the NRC (US Nuclear Regulatory Commission).

ii) Integration/centralization of nuclear regulatory organizations will enable implementation of seamless, comprehensive safety regulation. In addition, incorporating environmental radiation monitoring into “The Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors” and having prefectures carry this out as a legally delegated duty will strengthen third party monitoring of nuclear power facilities, improve monitoring quality and transparency, and enable smooth linkage to “Special Law of Emergency Preparedness for Nuclear Disaster” by radiation measurement organizations.

iii) Adopt a qualification system suited to the roles in the organization, and stabilize the duties of staff in order to maintain regulatory consistency and a high level of specialized expertise.

iv) Eliminate the legal double-checking of the Nuclear Safety Commission of Japan, create a regulatory auditing organization similar to the ACRS of the NRC in the Article 3 organization, and perform secretariat auditing based on the intentions of the commission.

v) In order to make use in Japan of the latest findings from overseas, the organization should maintain close ties with regulatory organizations in foreign countries, and actively participate in activities of the IAEA.

11. Lessons relating to information disclosure

a. Information disclosure is seen as inadequate.

Disclosure by the System for Prediction of Environment Emergency Dose Information (SPEEDI) was delayed. Adequate information is still not being disclosed. For this reason, the headquarters have been seen as hiding information, and has lost credibility.

b. Technical explanation was inadequate.

Data has been simply listed, and unevaluated information has been presented.

c. Explainability of radiation safety is poor.

In the first place, concepts relating to radiation safety are complicated and hard to understand. Concepts such as the difference between emergency and normal conditions, between dose rate and dose, and the health impacts of radiation on people are not being communicated correctly, and this is causing unnecessary confusion.

d. The size of the evacuation zone has been enlarged in steps.

First it was 3 km, and then it was expanded to 10 km and 20 km.

e. Inadequate cooperation with local governments in establishing the evacuation zone etc.

Local governments were confused by a hard to understand explanation of points such as the planned evacuation zone and voluntary evacuation.

On the other hand, in United States they set a radius of 80 km (50 miles) and even greater confusion was caused by the conflicting information.

f. There is no communication between local governments and the headquarters.

Since many local governments are involved, it is hard to believe that communication is always adequate.

Proposals (short-term)

(1) Total disclosure of SPEEDI.

(2) Improve technical explanations in press releases.

(3) Announce protective measures based on a standardized approach to radiation safety.

Proposals (medium term)

(4) Review “Special Law of Emergency Preparedness for Nuclear Disaster.” In particular, clarify and coordinate the roles of the national and local governments with the actual situation.

(5) In accordance with the revised “Special Law of Emergency Preparedness for Nuclear Disaster,” conduct training assuming that an accident will occur.

(6) Raise the level of ERSS and SPEEDI, and clarify the discussion relating to how they are used.

(7) Enact a law to achieve greater nuclear power transparency.

12. Lessons relating to safety management during an emergency
    a. There are issues with centralizing and sharing information relating to radiation doses on site.

       Safety management, labor management and exposure management were probably inadequate for employees and workers during the emergency. Specific incidents include the accident where workers were exposed to radiation while standing in water and working to restore power in the Unit 3 turbine building, and cases in the early stages where individual workers were not able to carry radiation dosimeters. Precisely because this is an emergency, it is necessary to work while paying close attention to safety.
    b. An influx of radioactive materials was not considered in the design conditions of quake-proof critical buildings.

       Concentration of radioactive materials was not measured in quake-proof critical buildings for 2 weeks after the earthquake.

       There was a delay in establishing buffer areas (places to remove protective clothing) at quake-proof buildings.

       Exposure of female staff (internal exposure was more common than external exposure).
    c. There is inadequate recognition of the effects on the health and other conditions of employees and workers in an emergency situation.

       Conditions with poor food, clothing and shelter continued from the early stages for a considerable period of time.

       The response to poor health (including mental health) was inadequate or delayed._

Proposals (short-term)

(1) Thorough information sharing.

Proposals (medium-term)

(2) Secure radiation control staff for an emergency, and check the advance planning and feasibility of equipment procurement.

(3) Conduct analysis and incorporate the findings from the perspective of behavioral science (such as human behavior in case of an emergency) and health science.