Lessons Learned from Fukushima Daiichi Nuclear Power Plant Accident

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It is imperative to learn from the Fukushima Daiichi Nuclear Power Plants Accident and to reflect the lessons in the safety regulations of nuclear power plants operating in the world. Based on the publicly available information, Technical Investigation Subcommittee of Atomic Energy Society of Japan's "Nuclear Safety" Special Committee has analyzed the accident and its responses and summarized into 12 sections; the results were published on the society's website on May 9. We analyzed the accident from our own academic viewpoints and extracted new lessons such as design issues in the emergency cooling device and venting line. Moreover, we proposed improvement methods to the government, which has not published enough information not only immediately after the accident but also at the current stage; we expect more aggressive information disclosure. We believe that many of these lessons will be useful for both the field of nuclear energy and improvement in safety of general artificial systems.

Introduction

The Fukushima Daiichi Nuclear Power Plant Accident overturned the people's trust in nuclear safety to its core, and once again revealed the potential danger of nuclear power plants. The struggle to deal with the accident is still ongoing. It is important to learn our lessons from this accident and ensure that similar accidents never occur at any nuclear power plant operating across the world. Based on publicly available information, the Technical Investigation Subcommittee of Atomic Energy Society of Japan (AESJ)'s "Nuclear Safety" Special Committee summarized and analyzed this accident and its responses into 12 sections, compiled the lessons learned from them into 36 cases, and published this information together with proposed examples of possible countermeasures on May 9, 2011 1).

The 12 items thus summarized are as follows: 1. Earthquake, 2. Tsunami, 3. Station blackout, 4. Total loss of cooling system, 5. Accident management, 6. Hydrogen explosion, 7. Spent fuel storage pool, 8. Safety research, 9. Safety regulation and safety design, 10. Organization/Crisis management, 11. Information disclosure, and 12. Emergency safety management. Furthermore, 70 suggestions were made in total.

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In addition, the government published a report for IAEA on June 7, 2011, which contained 28 lessons and corresponding countermeasures, and classified the divided sections into 5 groups[2)]. Although, many lessons present in the AESJ report are absent in the government report, and vice versa, roughly similar lessons are discussed in both. Herein, we present the lessons to be learned and the measures to be taken primarily based on the lessons discussed in the AESJ report, while also referring to the government report.

Moreover, in addition to the Fukushima Daiichi Nuclear Power Plant (hereinafter referred to as Fukushima Daiichi), we have also referred to the events that occurred at the Fukushima Daini Nuclear Power Plant (hereinafter referred to as Fukushima Daini), the Onagawa Nuclear Power Plant (hereinafter referred to as Onagawa), and the Tokai Daini Nuclear Power Plant (hereinafter referred to as Tokai Daini).

We believe that these lessons will be useful not only for safety improvement at nuclear power plants around the world, but many of them will also be useful for the safety improvement of general artificial systems besides of nuclear energy.

I. Lessons Learned from the Earthquake Tremors

1. Seismic Resistant Design

Following the revision of seismic resistance guidelines published on 2006 and related back-checks, design basis seismic ground motion Ss was reconsidered and seismic strengthening was conducted. The scale of this earthquake is considered to be approximately within the range of the design basis seismic ground motion Ss. Moreover, based on the facts that there was enough margin in the structure of equipments and the cooling was stable and continued for 1 h until the tsunami arrived, it is estimated that the important S-class equipments were generally intact. Note that, however, detailed seismic resistance evaluation must be conducted in the future. On the contrary, it is considered that C-class piping equipment of low importance was partially damaged. Detailed evaluations and investigation on the effect of the damages must be conducted in the future.

2. Seismic Resistance of the Power Supply System

The importance of power supply systems was rediscovered in this accident from the shaking of overhead wires, damages on pylons, and resulted loss of external power supplies caused by the earthquake. Moreover at Onagawa, a power panel with low importance caught fire due to the earthquake[3)]. Reviewing the seismic resistance importance of external power supplies and power panels is also necessary.

II. Lessons Learned from the Tsunami

1. Estimation of the Tsunami

Tsunami (~15 m high) that far exceeded the design estimation (~5 m high) hit the power plant. This indicates that the scale of the tsunami considered during the design stage was inadequate.

Based on this finding, reviewing the design basis of the tsunami estimation method is necessary; however, incorporating a risk assessment method and reviewing the method of predicting the tsunami, instead of blindly determining its estimated height, is also required. Note that the tsunami height to be estimated here is not the highest imaginable tsunami; rather it is the height of the tsunami to be assumed during the design stage. Hence, this assumed height must be decided rationally while considering potential risks.

2. Damages Caused by the Tsunami to Equipment Important for Safety

As will be shown below, the absence of the layer for defense in depth against the tsunami that occurred in reality led to this major accident. Due to the destruction of seawater pumps and tanks installed on the side of the ocean that was expecting a tsunami of ~5 m, station blackout occurred after the seawater cooling-type emergency diesel generator (D/G) stopped. Moreover, the function of the seawater-cooling system was lost, leading to a total loss of the cooling system, which will be discussed later. Note that at Fukushima Daini, the effect was slightly mitigated owing to its seawater pump building. Furthermore, because the flooding defense of the building installed around 10 m from sea level was insufficient, and because shutters were destroyed by the powerful tsunami, many equipments that were important for safety were flooded. In particular, as the power panel was flooded and thus damaged owing to the tsunami, recovering the electricity system became difficult.

Thus, to protect important equipment from being damaged during a tsunami, implementing hardware measures such as preventing seawater from flooding buildings containing such equipment important for safety is necessary. Moreover, considering the fact that flooding occurred through trenches and narrow gaps in the building of Onagawa, ensuring adequate water-tightness is also necessary.

Specifically, these measures include sealing doors and strengthening the sealing of cable trays and conduits. Moreover, it is believed that underground structures and buildings such as trenches do not consider water-tightness during design; hence, strengthening their water-tightness is necessary to ensure efficient water-tightness of the building.

Moreover, equipment close to the sea such as seawater pumps should be protected with buildings and walls when necessary to avoid any direct effect of the tsunami.

Furthermore, severe accident measures that consider tsunamis exceeding the estimated levels should also be undertaken. For instance, draining methods should be considered when a tsunami rises over the tide embankment, measures should be undertaken for situations when flooding breaches a building’s water-tightness, and situations should be predicted where the power supply system could be lost.

3. Flooding of the Underground Structure

When a large amount of seawater flooded underground structures such as trenches and pits, electric cables and electric equipment for the seawater-cooling system were flooded and, a large amount of contaminated water was generated when the floodwater was mixed with contaminated water following the core meltdown. The flooding of the underground structures by seawater and contaminated water prevents the recovery effort.

Even pits of low importance in terms of safety must be watertight if they are located close to the shore to prevent the tsunami from entering. If necessary, their seismic resistance should also be reviewed.

III. Lessons from the Station Blackout

1. Responsibility of Safety Review

In the safety design guidelines of the Nuclear Safety Commission, the situation of station blackout is considered only for a short duration; thus, the guidelines were deemed inadequate. Overseas, station blackout accidents have already occurred, and design evaluations that consider a station blackout that lasts for a longer duration are being conducted. Important lesson was the fact that the regulatory authorities and the government were in a situation that prevented them from applying such latest knowledge to their regulation methods.

2. Long-Term Station Blackout

In addition to the loss of external power supply (AC power source) and emergency diesel power supply, the power panel also stopped functioning, making recovery difficult. Moreover, arranging power supply vehicles and connecting them took time, delaying the recovery of electricity supply. Although Unit 3 could use a DC power supply, this supply was eventually exhausted, and running the turbine-powered water supply system and various valves in addition to the control panel and measurement equipment became difficult. Thus, it was inferred that systems important for safety did not run efficiently. The impact of the loss of function of the power panel was particularly significant, and only limited systems have been recovered.

It is important to introduce diverse generators such as gas turbine generators as a measure against such a situation. Furthermore, not only system diversification but also diversification of positioning and installation sites, such as seismic isolation floors, is deemed important. Preparing an air-cooled generator that is independent of seawater cooling is also considered a part of the diversification. If required, the power panel should also be diversified; for instance, by preparing a spare power panel. Measures such as preventing the flooding of the high-voltage distribution panel or shutting down the control power source during an emergency must be planned. In addition, sufficient seismic resistance must be considered to prevent fire.

3. Inability to Measure the Parameters Inside the Nuclear Reactor

Sufficient information of the nuclear reactor or primary containment vessel (PCV) could not be obtained owing to the power loss of the measurement equipment. Hence, considering a situation where all AC power sources are lost, it is important to provide alternative electricity supply for important equipment as well as the monitoring system of the reactor core. The minimum amount of information necessary would be obtained through this measure. Additionally, the power supply capacity necessary for such a measure is quite small. Preparing in advance for such an electricity supply method for the measurement equipments and valves used in accident management measures that are considered for final severe accident measures, is especially important.

4. Reconfirmation of the Importance of Power Supply

If the power supply is partially available, the progress of the incident could be halted. The cooling of the nuclear reactors and fuel pools of Units 5 and 6 was possible because the air-cooled diesel generator worked. At Fukushima Daini, the power supply was available, which enabled controlling the emergency cooling system, thus delaying the event sequence despite losing the seawater-cooling system. Meanwhile, the seawater-cooling system recovered, Units 5 and 6 went into the shutdown mode safely.

5. Design Issues in the Emergency Cooling Device

Following the power loss, we point out that the emergency cooling system's design needs improvement. The reactor core isolation cooling system, which is a steam turbine-powered core injection system, does not require a power source and was able to delay the core damage at Units 2 and 3. However, after having lost the DC power supply that was necessary for control, the turbine-powered pump also stopped working finally. While being turned by the steam turbine that uses the high pressure steam of the reactor core, the pump injects water into the core. By installing a small generator that utilizes the rotation energy of the turbine, it would be possible to charge the control batteries while the core injection is carried out. These batteries would enable the control of solenoid valves and other devices, thereby facilitating autonomous operation even after total loss of power supply sources for a long time.

In contrast, however, it is reported that the isolation condenser installed in Unit 1 mistakenly recognized the signal of the loss of DC power supply due to the tsunami as the signal for a pipe rupture, and closed the valve automatically. Accessing the isolation valve (motor driven valve) inside the PCV is not possible, and hence, opening the closed valve without electricity is not possible. The principle of Fail Close (close the valve while failure) is not wrong in itself when considering the loss of coolant accident. However, compliance with the regulations against the short-term station blackout considered in the safety evaluation should be respected. According to the analysis of Nuclear and Industrial Safety Agency (NISA), the damage on the fuel rods began within the first hour following the failure of the isolation cooling system. Thus, future examinations including the accident scenario of short-term station blackout in the safety evaluation are required, distinguishing between the pipe rupture signal and that of the loss of power supply in the logic circuit is considered to be possible.

IV. Lessons Learned from the Total Loss of the Cooling System

1. Seawater Cooling is Vulnerable to Tsunami

The core heat removal function was lost at Fukushima Daiichi and Fukushima Daini because the seawater pump became inoperative. Currently, as seawater cooling is still difficult at Fukushima Daiichi, air-cooling is being considered as an alternative, and has been partially adopted.

On the contrary, because external power supplies were available at Fukushima Daini, stable and continuous water supply to the nuclear reactors was possible. Using this spare time to change or repair the seawater pump motors, the seawater pumps were restored and the reactors were cooled safely. Moreover, some of the seawater pumps used in the emergency diesel cooling system at both Onagawa and Tokai Daini were flooded and stopped by the tsunami. However, as either external power supplies or other emergency diesel cooling systems were functioning, the reactors at both locations were shut down safely.

Nuclear power plants across the world are built adjacent to coasts, rivers, and lakes to secure cooling water. It is important to incorporate a backup cooling system using a coolant other than the seawater to remove the decay heat. As the decay heat is relatively low, the air-cooling is deemed effective. From the viewpoint, although the Sizewell B Nuclear Power Plant in the UK normally utilizes seawater cooling, an emergency air-cooling device is also installed.

V. Lessons for Accident Management

1. Good Practices of AM

An alternative water injection system was readily available thanks to the accident management (AM) plan made in advance, which enabled freshwater/seawater supply through the fire engines and fire prevention pumps. It is believed that the accident would have been even more severe without this water supply system.

2. Bad Practices of AM

AM that considered the station blackout was insufficient. Heat removal through freshwater/seawater supply and prevention of PCV failure through PCV venting were supposed to be conducted; however, they were insufficiently performed. Specifically, opening the valve of the venting line took a long time owing to the power loss that caused a significant delay. This led to the leakage of hydrogen into the reactor building (R/B) and resulted in the hydrogen explosion. Even though the air compressor and solenoid valve necessary to open the valve of the venting do not require much power, securing the source for this small amount of power took time. Moreover, maintaining the energized state of the solenoid valve was not possible and it closed frequently. As the power source required for alternative water injection and venting is relatively small, securing it under any circumstance is imperative. To repeat, the insufficient functioning of parameter measurement inside the nuclear reactor and PCV due to the power loss is also deemed as a contributing factor toward the inadequate implementation of AM measures.

Design issues of the venting line are also pointed out. According to the report on the emergency plan of the Shimane Nuclear Power Plant submitted in April 4), the venting line of the Shimane Unit 2 is connected to the air-conditioning system of the building, and the valve between them operates on the Fail Open principle (i.e., it opens when power supply or operational air is lost). Conversely, at Shimane Unit 1, the venting line and the air-conditioning system are separated during a blackout as the valve operates on the Fail Close principle. Therefore, at Shimane Unit 2, the valve between the venting line and the air-conditioning is closed by supplying the valve with electricity and air during venting.

However at Fukushima Daiichi, there was insufficient electricity and air pressure, and hence, the venting line closed frequently (due to the Fail Close principle). The risks at Shimane Unit 2 should be evaluated, and examining the necessity of measures such as switching its valve to the Fail Close is worth considering. Note that the design of the valve of the venting line of Fukushima Daiichi is hardly made open except for the partial disclosure made during a press conference.

Furthermore, the alternative water supply that was discussed as a good practice in the previous section also presents many issues to be addressed. The water supply was not provided in time, causing a delay. Securing the water source took time and mistakes were made owing to which the water supply had to be halted. These are some of the many issues that must be examined to stop further progress of the accident. It is important to reflect on these issues and structure a better accident management plan.

3. AM Measures to be Implemented Following Core Damage

During the accident, alternative water injection was provided and PCV vent was conducted after the core damage. Therefore, the dose in the building is extremely high, which poses a major obstruction to recovery. The dose of the main control room is particularly high, which severely limits the work. Hence, sufficiently evaluating the AM measures under the high radiation doses in advance is necessary.

Hydrogen explosion occurred in all units from Unit 1 to Unit 3 within 18 to 24 h after the isolation condensers or the reactor core isolation cooling system stopped, and cooling the reactor core became impossible. Therefore, the need for AM measures to prevent hydrogen explosion is obvious. However, it is necessary to fully understand the short availability of time. Conversely, there are 18 h, and devising a mitigative measure that can be implemented 18 h in advance would be important.

Moreover, it is considered that there were issues to be discussed in the simultaneous AM measures for multi-reactor units built on the same sites. Hence, it is necessary to devise a system to manage several AM plans implemented in parallel, including the chain of command.

VI. Lessons Concerning Hydrogen Explosions

1. R/B Damaged by the Hydrogen Explosion

Part of the containment function was lost, and debris with high radiation dose were scattered, disturbing the recovery work.

2. Hydrogen Explosion Outside PCV was Not Considered

Although several studies have been conducted on the hydrogen explosions inside the PCV, explosions inside the R/B were not considered. In addition, hydrogen recombiners and hydrogen densitometers were not functioning during the blackout. It is, therefore, recommended to install static catalytic recombiner that can recombine hydrogen without electricity.

3. Leakage Caused by Overpressure/Overheating of PCV

It is considered that the venting line leaked together with leakages from sealed parts such as the head flange and the hatch due to the overpressure/overheating of PCV; thus, future examination of the same is required. The result of examining this leakage should be reflected on AM measures. Obtaining important parameters such as the pressure and temperature of PCV is indispensable. Specifically, important parameters such as the pressure and temperature of PCV must have an independent power supply line to enable monitoring at all times, and hardware and software should be installed, which allows measures such as cooling and venting before the pressure and temperature become too high.

VII. Lessons Concerning the Spent Fuel Storage Pool

1. Containment of Spent Fuel after the Building is Damaged

The hydrogen explosion damaged the building and the spent fuel storage pool was directly exposed to the atmosphere. If spent fuels are damaged, there exists a high risk of radioactive materials being directly released to the atmosphere. For cooling, radiation shielding, and containment, securing the water level of the pool is of vital importance.

2. Cooling after the Hydrogen Explosion

The hydrogen explosion greatly damaged the installed pipes used for cooling the pool and other facilities. Though the cooling water is supplied using the concrete pump vehicles and other means, there are still issues with long-term cooling. Note that the cooling system using the air-cooling device was already established for the spent fuel storage pool of Unit 2, where the building was less damaged, and the pool is in a stable state of cold shutdown.

It is important to review the previously neglected AM-related issues for the pool. Specifically, measures such as facilitating water supply via fire engines immediately after the loss of power and installing a dedicated system such as a flexible hose in advance to make the use of water supply on the ground level easy should be considered. Moreover, cooling via air is deemed possible as the heat generated in the spent fuel storage pool is relatively low. By devising a natural circulation cooling system using temperature difference, removing the decay heat without power supply will be possible.

VIII. Lessons for the Promotion of Safety Research

1. Severe Accident Research

It took 2–3 months to estimate the extent of core damage using the severe accident analysis code (MAAP). Moreover the use of the emergency measures support system (ERSS) and System for Prediction of Environmental Emergency Dose Information (SPEEDI) was not fully employed as much as expected despite there being data shortage due to the power loss. The Japan Atomic Energy Agency (JAEA) excessively focused on the research of the future reactors. Accordingly, it has neglected research on the safety of the light water reactors; this imbalance is considered to have taken place partly due to the fact that the JAEA is under the control of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT).

It is important to systematically foster human resources for safety research/safety design that includes severe accidents. Moreover, the modeling/simulation technology assures the advancement of nuclear safety, and promoting verification & validation that assesses the quality of calculation results as a national strategy is important.

Furthermore, it is also important to produce an AM simulator and prepare a tool to evaluate behaviors of the reactor or fuel on real time for training the operation staff or directors.

2. Wasteful Usage of the National Budget

Projects that are researched and developed as national projects are often discarded upon completion as they are not allowed to be carried over for reasons other than their original purposes owing to budget reasons. Thus, such products/facilities cannot always be used when they are needed. It is necessary to predict their possible usages during disasters and maintain significant results for effective use.

IX. Lessons Concerning Safety Regulation and Safety Design

1. Safety Design against External Events

There was inadequate preparation for extremely high consequences but extremely rare and unpredictable events such as the tsunami. Internal events that caused the common cause failure were mainly software problems and human factors. Research on these failure modes has greatly advanced since the Three Mile Island Accident. Moreover, the research sufficiently established the philosophy of defense in depth against internal events. Although this philosophy of multilayered defense against internal events has also been applied to external events, the common cause failure was not recognized adequately.

The hardware common cause failure could prevail in the primary external events. Moreover, external events have a much lower probability of occurrence, but with high uncertainties. In such cases, the traditional three-layer defense-in-depth is inadequate, and preparing for adequate measures that include AM of severe accidents as well as disaster prevention is important.

It is necessary to evaluate the external events through the probabilistic safety assessment (PSA), focused on quantitative risks. However, discussing the uncertainty of PSA is also important. After all, it is accident management that balances this uncertainty. Restructuring the safety logic of the nuclear power plants, including AM and disaster prevention, assuming various types of natural disasters, is also necessary. It is important to formulate effective AM countermeasures by applying the results of the quantitative risk assessment and to review safety importance and diversity/multiplicity based on the risk assessment.

2. Issues Relevant to Japanese Safety Regulation

These issues include the lack of structure to assess the current design of a plant, delay in the adaptation of PSA, and insufficient implementation of new knowledge.

Although the incorporation of the severe accidents into the framework of nuclear regulations was initiated already, it was too late. Moreover, the regulatory scope of the Reactor Regulation Act (Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors) was too narrow, and the accident immediately became the subject of the Nuclear Emergency Act (Special Measures Concerning Nuclear Emergency Preparedness).

The connection between the assessment of basic design (installation permit application) and operation management is weak, and the required changes are a formality defined as the changes in the main text. The changed installation permit application does not reflect the current state of the plant. Furthermore, the structural strength regulation has been mainly focused for installation permission, construction plan approval, and pre-operation inspection; performance function and analysis of PSA were undervalued.

The reflection of new findings such as safety research and regulatory trends to be adopted from other countries was delayed. Moreover, the regulation was considered infallible, which resulted in undue focus on precedents and generated reluctance toward reviewing the regulation, which should pursue always safety. Furthermore, both the regulators and business operators were side-by-side, creating an environment where it was difficult for an individual operator to independently pursue safety.

Therefore, reviewing the legal system and restructuring the safety regulation, such as unifying the Reactor Regulation Act (Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors) and the Electricity Business Act, is necessary. The purpose and permission standard of the Reactor Regulation Act must be changed to "the protection of citizens from radiation hazard," and severe accidents must be included in the regulatory scope of the Reactor Regulation Act. Moreover, the effectiveness of the AM process (organization, role, response to multiple units, process validity, feasibility, training, material, and equipment) must be secured. Comprehensive safety analysis manuals should be introduced to the installation permit, and the analysis that postulates the conditions of operation management should be focused on. In addition, it must be ensured that the changes in the plant are always reflected on the comprehensive safety analysis manual, which should always be an as-built document created by defining the change from the perspective of nuclear reactor safety. A private third-party certification system should be introduced to the construction plan permit together with pre-operation inspection and an integrated inspection system that inspects its enforcement and monitors observance of the comprehensive safety analysis report.

X. Lessons Concerning Organization and Crisis Management

1. Issues of the System of Responsibility

Owing to the vertically-divided administration, the staff with specialized knowledge in various fields of nuclear energy is spread across different departments; thus, there is no single person who is responsible. There is no specialized organization that supervises the whole due to the distribution of law systems. In particular, the organizations for radiation regulation and nuclear energy regulation are separated. Moreover, the specialists were not adequately utilized.

Therefore, unifying the system of responsibility and creating a specialized regulatory organization is important. For example, the Nuclear Safety Commission can be turned into an article 3 agency (independent organization), nuclear and radiation regulations divided between NISA and MEXT can be unified/integrated, and also organizations with specialized knowledge such as the Japan Nuclear Energy Safety Organization (JNES) and the Nuclear Material Management Center can be integrated into one to create a regulatory organization with advanced specialization that could be a Japanese version of the United States Nuclear Regulatory Commission (NRC).

2. Issues Concerning Emergency Response

Owing to the blackout and the problem of communication, smooth response to the emergency was not possible. For instance, there was a delay in contacting and gathering the emergency response staff. Moreover, the opinions of foreign countries are too dominant, which obstructed Japan's superior knowledge (for instance in robotics and water processing) from being used. The emergency response support system (ERSS) did not work because of the blackout.

XI. Lessons Concerning Information Disclosure

1. Delay in Information Disclosure

Information disclosure during the emergency was inadequate. Information release of SPEEDI was delayed. Moreover, the information disclosure is insufficient even after three months since the accident. For example, the website of NRC in the US offers information that is unavailable in Japan 5). This situation led the people to believe that headquarters is hiding information, leading to a loss in trust.

In general, the technical explanation only lists data and the published information does not contain the evaluation of these data.

2. Lack of Understanding of Role of INES

International Nuclear Event Scale (INES) communicates the degree of seriousness of the accident to the local residents, the Japanese population, and foreign countries, initiates actions such as evacuation. The initial publication of low-level preliminary numbers such as level 3 and level 4 that do not necessitate emergency evacuation had no correspondence with the actual evacuation orders for the area within the 3, 10, or 20 km radii. Moreover, the more realistic estimated level, which should have been promptly published when the accident occurred, was not published until two months after the accident. This caused unnecessary confusion and mistrust both in and outside Japan. This is a serious matter, and undoubtedly a result of negligence toward accurate understanding and usage of INES.

3. Poor Explanation of Radiation and Nuclear Safety

To begin with, the thought behind radiation safety and nuclear safety is complex and difficult to understand. Information regarding emergency and normal circumstances, dose rate and dose, and the view on the effects of radiation on human health influence were communicated poorly, leading to unnecessary confusion.

4. Insufficient Cooperation with Local Municipality, for Instance in Setting the Evacuation Area

Unclear explanations, such as deliberate evacuation area and voluntary evacuation, confused the local municipality. Moreover, as the US designated 80 km radius (50 miles) as the evacuation area, such different and contradicting information increased the confusion.

5. Lack of Communication Between Local Municipalities and the Disaster Control Headquarters

As many municipalities are affected, communication is believed to be inadequate.

XII. Lessons Concerning Emergency Safety Management

1. Issues in the Unification and Sharing of Information about Radiation Dose within the Premises during Emergency

It is considered that safety, personnel, and exposure controls for the staff/workers during the emergency were inadequate. Specifically, examples of this inadequacy include the exposure incident that occurred at a puddle during power supply recovery work in the turbine building of Unit 3 and the fact that in the initial phase of responses to the accident, individual workers could not carry a dosimeter on themselves. Attention should be paid more to safety while working in tight emergency.

2. Delay in Response to Internal Exposure

The inflow of radioactive materials was not included in the design conditions of the seismic isolated building. The concentration of radioactive materials inside the seismic isolated building was not measured for two weeks after the earthquake. The setting up of a buffer zone (where one takes off protective clothing) in the seismic isolated building was delayed, which exposed the female staff in the seismic isolated building and the operators of the main control room. Consequently, more staff suffered internal exposure than external exposure.

3. Issues of the Emergency Work Environment

There was inadequate awareness regarding the effects on the health of the staff/workers under emergency. Poor quality of clothing, food, and accommodation continued for a long time after the accident. Further, response to health problems (including mental health) was slow and inadequate.

Conclusions

Sharing the lessons learned from this accident both within Japan and with the world is important. In hindsight, it is clear that the state of “nuclear safety” was not in good shape. There was insufficient improvement in response to the regulatory review (IRSS) conducted by IAEA a few years ago, resulting in the same problems being highlighted again in this report. We would like to believe that, finally, improvement will be made following this accident. For such improvements, it is important to first think of the ideal “nuclear safety” instead of thinking about how to change the existing system. The existing system should be improved by comparing it to the ideal system, and what is lacking should be created anew. The key is to shift from “regulation for checking the safety” to “regulation for checking the risks”. Moreover, it is important to work under the premise that “there will be an accident” and be able to respond, in addition to the premise of “prevent accidents from happening”.

Furthermore, “diversification” is the key to hardware response. By diversifying various facilities, more options will be available to respond to an emergency. However, this will also increase the risk for mistakes during normal operation. It will increase the maintenance, and occasions for potential mistakes. Therefore, blind diversification is not an answer. Instead, it is important for the regulatory authorities and the operators to recognize that true safety is the reduction of the total risk.

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