XII. Lessons Learned From the Accident Thus Far

The Fukushima NPS accident has the following aspects: it was triggered by a natural disaster; it led to a severe accident with damage to nuclear fuel, Reactor Pressure Vessels and Primary Containment Vessels; and accidents involving multiple reactors arose at the same time. Moreover, as nearly three months have passed since the occurrence of the accident, a mid- to long-term initiative is needed to settle the situation imposing a large burden on society, such as a long-term evacuation of many residents in the vicinity, as well as having a major impact on industrial activities including the farming and livestock industries in the related area. There are thus many aspects different from the accidents in the past at the Three Mile Island Nuclear Power Plant and the Chernobyl Nuclear Power Plant.

The accident is also characterized by the following aspects. Emergency response activities had to be performed in a situation where the earthquake and tsunami destroyed the social infrastructure such as electricity supply, communication and transportation systems across a wide area in the vicinity. The occurrence of aftershocks frequently impeded various accident response activities.

This accident led to a severe accident, shook the trust of the public, and warned those engaged in nuclear energy of their overconfidence in nuclear safety. It is therefore important to learn lessons thoroughly from this accident. We present the lessons classified into five categories at this moment bearing in mind that the most important basic principle in securing nuclear safety is having defenses in depth.

Thus the lessons that have been learned to date are presented as classified in five categories. We consider it inevitable to carry out a fundamental review on nuclear safety measures in Japan based on these lessons. While some of them are specific to Japan, these specific lessons have been included regardless, from the standpoint of showing the overall structure of the lessons.

The lessons in category 1 are those learned based on the fact that this accident has been a severe accident, and from reviewing the sufficiency of preventive measures against a severe accident.

The lessons in category 2 are those learned from reviewing the adequacy of the responses to this severe accident.

The lessons in category 3 are those learned from reviewing the adequacy of the emergency responses to the nuclear disaster in this accident.

The lessons in category 4 are those learned from reviewing the robustness of the safety infrastructure established at nuclear power stations.

The lessons in category 5 are those learned from reviewing the thoroughness in safety culture while summing up all the lessons.

Lessons in category 1

Strengthen preventive measures against a severe accident

(1) Strengthen measures against earthquakes and tsunamis

The earthquake was an extremely massive one caused by plurally linked seismic centers. As a result, at the Fukushima Dai-ichi Nuclear Power Station, the acceleration response spectra of seismic ground motion observed on the base mat exceeded the acceleration response spectra of the design basis seismic ground motion in a part of the periodic band. Although damage to the external power supply was caused by the earthquake, no damage caused by the earthquake to systems, equipment or devices important for nuclear reactor safety at nuclear reactors has been confirmed. However, further investigation should be conducted as the details regarding this situation remain unknown.

The tsunamis which hit the Fukushima Dai-ichi Nuclear Power Station were 14-15m high, substantially exceeding the height assumed under the design of construction permit or the subsequent evaluation. The tsunamis severely damaged seawater pumps, etc., causing the failure to secure the emergency diesel power supply and reactor cooling function. The procedural manual did not assume flooding from a tsunami, but rather only stipulated measures against a backrush. The assumption on the frequency and height of tsunamis was insufficient, and therefore, measures against large-scale tsunamis were not prepared adequately.

From the viewpoint of design, the range of an active period for a capable fault which needs to be considered in the seismic design for a nuclear power plant is considered within 120,000-130,000 years (50,000 years in the old guideline). The recurrence of large-scale earthquakes is expected to be appropriately considered. Moreover, residual risks must be considered. Compared with the design against earthquake, the design against tsunamis has been performed based on tsunami folklore and indelible traces of tsunami, not on adequate consideration of the recurrence of large-scale earthquakes in relation to a safety goal to be attained.

Reflecting on the above issues, we will consider the handling of plurally linked seismic centers as well as the strengthening of the quake resistance of external power supplies. Regarding tsunamis, from the viewpoint of preventing a severe accident, we will assume appropriate frequency and adequate height of tsunamis in consideration of a sufficient recurrence period for attaining a safety goal. Then, we will perform a safety design of structures, etc. to prevent the impact of flooding of the site caused by tsunamis of adequately assumed heights, in consideration of the destructive power of tsunamis. While fully recognizing a possible risk caused by the flooding into buildings of tsunamis exceeding the ones assumed in design, we will take measures from the viewpoint of having defenses-in-depth, to sustain the important safety functions by considering flooded sites and the huge destructive power of run-up waves.

(2) Ensure power supplies

A major cause of this accident was the failure to secure the necessary power supply. This was caused by the facts that power supply sources were not diversified from the viewpoint of overcoming vulnerability related to failures derived from a common cause arising from an external event, and that the installed equipment such as a switchboard did not meet the specifications that could withstand a severe environment such as flooding. Moreover, it was caused by the facts that battery life was short compared with the time required for restoration of the AC power supply and that a time goal required for the recovery of the external power supply was not clear

Reflecting on the above facts, Japan will secure a power supply at sites for a longer time set forth as a goal even in severe circumstances of emergencies, through the diversification of power supply sources by preparing various emergency power supply sources such as air-cooled diesel generators, gas turbine generators, etc., deploying power-supply vehicles and so on, as well as equipping switchboards, etc. with high environmental tolerance and generators for battery charging, and so on.

(3) Ensure robust cooling functions of reactors and PCVs

In this accident, the final place for release of heat (the final heat sink) was lost due to the loss of function of the seawater pumps. Although the reactor cooling function of water injection was activated, core damage could not be prevented due to the drain of the water source for injection and the loss of power supplies, etc., and furthermore, the PCV cooling functions also failed to run well. Thereafter, difficulties remained in reducing the reactor pressure and, moreover, in injecting water after the pressure was reduced, because the water injection line into a reactor through the use of heavy machinery such as fire engines, etc. had not been developed as measures for accident management. In this manner, the loss of cooling functions of the reactors and PCVs aggravated the accident.

Reflecting on the above issues, Japan will secure robust alternative cooling functions for its reactors and PCVs by securing alternative final heat sinks for a durable time. This will be pursued through such means as diversifying alternative water injection functions, diversifying and increasing sources for injection water, and introducing air-cooling systems.

(4) Ensure robust cooling functions of spent fuel pools

In the accident, the loss of power supplies caused the failure to cool the spent fuel pools, requiring actions to prevent a severe accident due to the loss of cooling functions of the spent fuel pools concurrently with responses to the accident of the reactors. Until now, a risk of a major accident of a spent fuel pool had been deemed small compared with that of a core event and measures such as alternative means of water injection into spent fuel pools, etc. had not been considered.

Reflecting on the above issues, Japan will secure robust cooling measures by introducing alternative cooling functions such as a natural circulation cooling system or an air-cooling system, as well as alternative water injection functions in order to maintain the cooling of spent fuel pools even in case of the loss of power supplies.

(5) Thorough accident management (AM) measures

The accident reached the level of a so-called “severe accident.” Accident management measures had been introduced to the Fukushima NPSs to minimize the possibilities of severe accidents and to mitigate consequences in the case of severe accidents. However, looking at the situation of the accident, although some portion of the measures functioned, such as the alternative water injection from the fire extinguishing water system to the reactor, the rest did not fulfill their roles within various responses including ensuring the power supplies and the reactor cooling function, with the measures turning out to be inadequate. In addition, accident management measures are basically regarded as voluntary efforts by operators, not legal requirements, and so the development of these measures lacked strictness. Moreover, the guideline for accident management has not been reviewed since its development in 1992, and has not been strengthened or improved.

Reflecting on the above issues, we will change the accident management measures from voluntary safety efforts by operators to legal requirements, and develop accident management measures to prevent severe accidents, including a review of design requirements as well, by utilizing a probabilistic safety assessment approach.

(6) Response to issues concerning the siting with more than one reactor

The accident occurred at more than one reactor at the same time, and the resources needed for accident response had to be dispersed. Moreover, as two reactors shared the facilities, the physical distance between the reactors was small and so on. The development of an accident occurring at one reactor affected the emergency responses at nearby reactors.

Reflecting on the above issues, Japan will take measures to ensure that emergency operations at a reactor where an accident occurs can be conducted independently from operation at other reactors if one power station has more than one reactor. Also, Japan will assure the engineering independence of each reactor to prevent an accident at one reactor from affecting nearby reactors. In addition, Japan will promote the development of a structure that enables each unit to carry out accident responses independently, by choosing a responsible person for ensuring the nuclear safety of each unit.

(7) Consideration of NPS arrangement in basic designs

Response to the accident became difficult since the spent fuel storage pools were located at a higher part of the reactor buildings. In addition, contaminated water from the reactor buildings reached the turbine buildings, meaning that the spread of contaminated water to other buildings has not been prevented. .

Reflecting on the above issues, Japan will promote the adequate placement of facilities and buildings at the stage of basic design of NPS arrangement, etc. in order to further ensure the conducting of robust cooling, etc. and prevent an expansion of impacts from the accident, in consideration of the occurrence of serious accidents. In this regard, as for existing facilities, additional response measures will be taken to add equivalent levels of functionality to them.

(8) Ensuring the water tightness of essential equipment facilities

One of the causes of the accidents is that the tsunami flooded many essential equipment facilities including the component cooling seawater pump facilities, the emergency diesel generators, the switchboards, etc., impairing power supply and making it difficult to ensure cooling systems.

Reflecting on the above issues, in terms of achieving the target safety level, Japan will ensure the important safety functions even in the case of tsunamis greater than ones expected by the design or floods hitting facilities located near rivers. In concrete terms, Japan will ensure the water-tightness of important equipment facilities by installing watertight doors in consideration of the destructive power of tsunamis and floods, blocking flooding routes such as pipes, and installing drain pumps, etc.

Lessons in Category 2

Enhancement of response measures against severe accidents

(9) Enhancement of measures to prevent hydrogen explosions

In the accident, an explosion probably caused by hydrogen occurred at the reactor building in Unit 1 at 15:36 on March 12, 2011, as well as at the reactor in Unit 3 at 11:01 on March 14. In addition, an explosion that was probably caused by hydrogen occurred at the reactor building in Unit 4 around 06:00 on March 15, 2011. Consecutive explosions occurred as effective measures could not be taken beginning from the first explosion. These hydrogen explosions aggravated the accident. A BWR inactivates a PCV and has a flammability control system in order to maintain the soundness of the PCV against design basis accidents. However, it was not assumed that an explosion in reactor buildings would be caused by hydrogen leakage, and as a matter of course, hydrogen measures for reactor buildings were not taken.

Reflecting on the above issues, we will enhance measures to prevent hydrogen explosions such as by installing of flammability control systems that would function in the event of a severe accident in reactor buildings, for the purpose of discharging or reducing hydrogen in the reactor buildings, in addition to measures to address hydrogen within the PCVs.

(10) Enhancement of containment venting system

In the accident, there were problems in the operability of the containment venting system. Also, as the function of removing released radioactive materials in the containment venting system was insufficient, the system was not effective as an accident management countermeasure. In addition, the independence of the vent line was insufficient and it may have had an adverse effect on other parts through connecting pipes, etc.

Reflecting on the above issues, we will enhance the containment venting system by improving its operability, ensuring its independence, and strengthening its function of removing released radioactive materials.

(11) Improvements to the accident response environment

In the accident, the radiation dosage increased in the main control room and operators could not enter the room temporarily and the habitability in the main control room has decreased, as it still remains difficult to work in that room for an extended period. Moreover, at the on-site emergency station, which serves as a control tower for all emergency measures at the site, the accident response activities were affected by increases in the radiation dosage as well as by the worsening of the communication environment and lighting.

Reflecting on the above issues, we will enhance the accident response environment that enables continued accident response activities even in case of severe accidents through measures such as strengthening radiation shielding in the control rooms and the emergency centers, enhancing the exclusive ventilation and air conditioning systems on site, as well as strengthening related equipment, including communication and lightening systems, without use of AC power supply.

(12) Enhancement of the radiation exposure management system at the time of the accident

As these accidents occurred, although adequate radiation management became difficult as many of the personal dosimeters and dose reading devices became unusable due to their submergence in seawater, personnel engaged in radiation work had to work on site. In addition, measurements of concentration of radioactive materials in the air were delayed, and as a result the risk of internal exposure increased.

Reflecting on the above issues, we will enhance the radiation exposure management system at the time of an accident occurs by storing the adequate amount of personal dosimeters and protection suits and gears for accidents, developing asystem in which radioactive management personnel can be expanded at the time of the accident and improving the structures and equipment by which the radiation doses of radiation workers are measured promptly.

(13) Enhancement of training responding to severe accidents

Effective training to respond to accident restoration at nuclear power plants and adequately work and communicate with relevant organizations in the wake of severe accidents was not sufficiently implemented up to now. For example, it took time to establish communication between the emergency office inside the power station, the Nuclear Emergency Response Headquarters and the Local Headquarters and also to build a collaborative structure with the Self Defense Forces, the Police, Fire Authorities and other organizations which played important roles in responding to the accident. Adequate training could have prevented these problems.

Reflecting on the above issues, we will enhance training to respond to severe accidents by promptly building a structure for responding to accident restoration, identifying situations within and outside power plants, facilitating the gathering of human resources needed for securing the safety of residents and collaborating effectively with relevant organizations.

(14) Enhancement of instrumentation to identify the status of the reactors and PCVs

Because the instrumentation of the reactors and PCVs did not function sufficiently during the severe accident, it was difficult to promptly and adequately obtain important information to identify how the accident was developing such as the water levels and the pressure of reactors, and the sources and amounts of released radioactive materials.

In respond to the above issues, we will enhance the instrumentation of reactors and PCVs, etc. to enable them to function effectively even in the wake of severe accidents.

(15) Central control of emergency supplies and equipment and setting up rescue team

Logistic support has been provided diligently by those responding to the accident and supporting affected people with supplies and equipment gathered mainly at J Village. However, because of the damage from the earthquake and tsunami in the surrounding areas shortly after the accident, we could not promptly or sufficiently mobilize rescue teams to help provide emergency supplies and equipment or support accident control activities. This is why the on-site accident response did not sufficiently function.

Reflecting on the above issues, we will introduce systems for centrally controlling emergency supplies and equipment and setting up rescue teams for operating such systems in order to provide emergency support smoothly even under harsh circumstances.

Lessons in Category 3

Enhancement of nuclear emergency responses

(16) Responses to combined emergencies of both large-scale natural disasters and prolonged nuclear accident

There was tremendous difficulty in communication and telecommunications, mobilizing human resources, and procuring supplies among other areas when addressing the nuclear accident that coincided with a massive natural disaster. As the nuclear accident has been prolonged, some measures such as the evacuation of residents, which was originally assumed to be a short-term measure, have been forced to be extended.

Reflecting on the above issues, we will prepare the structures and environments where appropriate communication tools and devices and channels to procure supplies and equipment will be ensured in the case of concurrent emergencies of both a massive natural disaster and a prolonged nuclear accident. Also, assuming a prolonged nuclear accident, we will enhance emergency response preparedness including effective mobilization plans to gather human resources in various fields who are involved with accident response and support for affected persons.

(17) Reinforcement of environmental monitoring

Currently, local governments are responsible for environmental monitoring in an emergency. However, appropriate environmental monitoring was not possible immediately after the accident because the equipment and facilities for environmental monitoring owned by local governments were damaged by the earthquake and tsunami and the relevant individuals had to evacuate from the Off-site Center Emergency Response Center. To bridge these gaps, MEXT has conducted environmental monitoring in cooperation with relevant organizations.

Reflecting on the above issues, the Government will develop a structure through which the Government will implement environmental monitoring in a reliable and well-planned manner during emergencies.

(18) Establishment of a clear division of labor between relevant central and local organizations

Communication between local and central offices as well as with other organizations was not achieved to a sufficient degree, due to the lack of communication tools immediately after the accident and also due to the fact that the roles and responsibilities of each side were not clearly defined. Specifically, responsibility and authority were not clearly defined in the relationship between the NERHQs Nuclear Emergency Response Headquarters and Local NERHQs Headquarters, between the Government and TEPCO, between the Head Office of TEPCO and the NPS on site, or among the relevant organizations in the Government. Especially, communication was not sufficient between the government and the main office of TEPCO as the accident initially began to unfold.

Reflecting on the above issues, we will review and define roles and responsibilities of relevant organizations including the NERHQs, clearly specify roles, responsibilities and tools for communication while also improving institutional mechanisms.

(19) Enhancement of communication relevant to the accident

Communication to residents in the surrounding area was difficult because communication tools were damaged by the large-scale earthquake. The subsequent information to residents in the surrounding area and local governments was not always provided in a timely manner. The impact of radioactive materials on health and the radiological protection guidelines of the ICRP, which are the most important information for residents in the surrounding area and others, were not sufficiently explained. Japan focused mainly on making accurate facts publicly available to its citizens and has not sufficiently presented future outlooks on risk factors, which sometimes gave rise to concerns about future prospects.

Reflecting on the above issues, we will reinforce the adequate provision of information on the accident status and response, along with appropriate explanations of the effects of radiation to the residents in the vicinity. Also, we will keep in mind having the future outlook on risk factors is included in the information delivered while incidents are still ongoing .

(20) Enhancement of responses to assistance from other countries and communication to the international community

The Japanese Government could not appropriately respond to the assistance offered by countries around the world because no specific structure existed within the Government to link such assistance offered by other countries to the domestic needs. Also, communication with the international community including prior notification to neighboring countries and areas on the discharge of water with low-level radioactivity to the sea was not always sufficient.

Reflecting on the above-mentioned issues, the Japanese Government will contribute to developing a global structure for effective responses, by cooperating with the international community, for example, developing a list of supplies and equipment for effective responses to any accident, specifying contact points for each country in advance in case of an accident, enhancing the information sharing framework through improvements to the international notification system, and providing faster and more accurate information to enable the implementation of measures that are based upon scientific evidence.

(21) Adequate identification and forecasting of the effect of released radioactive materials

The System for Prediction of Environmental Emergency Dose Information (SPEEDI) could not make proper predictions on the effect of radioactive materials as originally designed, due to the lack of information on release sources. Nevertheless, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Nuclear and Industrial Safety Agency (NISA) and the Nuclear Safety Commission (NSC) Japan used SPEEDI to calculate the estimation with various assumptions for the internal examination of the situation. Even under such restricted conditions without adequate information on release sources, it should have been utilized as a reference of evacuation activities and other purposes by presuming diffusion trends of radioactive materials under certain assumptions, but it could not. Although the results generated by SPEEDI are now being disclosed, disclosure should have been conducted from the initial stage.

The Japanese Government will improve its instrumentation and facilities to ensure that release source information can be securely obtained. Also, it will develop a plan to effectively utilize SPEEDI and other systems to address various emergent cases and disclose the data and results from SPEEDI, etc. from the earliest stages of such cases.

(22) Clear definition of widespread evacuation areas and radiological protection guidelines in nuclear emergency

Immediately after the accident, an Evacuation Area and In-house Evacuation Area were established, and cooperation of residents in the vicinity, local governments, police and relevant organizations facilitated the fast implementation of evacuation and “stay-in-house” instruction. As the accident became prolonged, the residents had to be evacuated or stay within their houses for long periods. Subsequently, however, it was decided that guidelines of the ICRP and IAEA, which have not been used before the accident, would be used when establishing Deliberate Evacuation Area and Emergency Evacuation Prepared Area. The size of the protected area defined after the accident was considerably larger than a 8 to 10 km radius from the NPS, which had beendefined as the area where focused protection measures should be taken.

Based on the experiences gained from the accident, the Japanese Government will make much greater efforts to clearly define evacuation areas and guidelines for radiological protection in nuclear emergencies.

Lessons in Category 4
Reinforcement of safety infrastructure

(23) Reinforcement of safety regulatory bodies

Governmental organizations have different responsibilities for securing nuclear safety. For example, NISA of METI is responsible for safety regulation as a primary regulatory body, while the Nuclear Safety Commission of the Cabinet Office is responsible for regulation monitoring of the primary governmental body, and relevant local governments and ministries are in charge of emergency environmental monitoring. This is why it was not clear where the primary responsibility lies in ensuring citizens' safety in an emergency. Also, we cannot deny that the existing organizations and structures hindered the mobilization of capabilities in promptly responding to such a large-scale nuclear accident.

Reflecting on the above issues, the Japanese Government will separate NISA from METI and start to review implementing frameworks, including the NSC and relevant ministries, for the administration of nuclear safety regulations and for environmental monitoring.

(24) Establishment and reinforcement of legal structures, criteria and guidelines

Reflecting on this accident, various challenges have been identified regarding the establishment and reinforcement of legal structures on nuclear safety and nuclear emergency preparedness and response, and related criteria and guidelines. Also, based on the experiences of this nuclear accident, many issues will be identified as ones to be reflected in the standards and guidelines of the IAEA.

Therefore, the Japanese Government will review and improve the legal structures governing nuclear safety and nuclear emergency preparedness and response, along with related criteria and guidelines. During this process, it will reevaluate measures taken against age-related degradation of existing facilities, from the viewpoint of structural reliability as well as the necessity of responding to new knowledge and expertise including progress in system concepts. Also, the Japanese Government will clarify technical requirements based on new laws and regulations or on new findings and knowledge for facilities that have already been approved and licensed, in other words, it will clarify the status of retrofitting in the context of the legal and regulatory framework. The Japanese Government will make every effort to contribute to improving safety standards and guidelines of the IAEA by providing related data.

(25) Human resources for nuclear safety and nuclear emergency preparedness and responses

All the experts on severe accidents, nuclear safety, nuclear emergency preparedness and response, risk management and radiation medicine should get together to address such an accident by making use of the latest and best knowledge and experience. Also, it is extremely important to develop human resources in the fields of nuclear safety and nuclear emergency preparedness and response in order to ensure mid-and-long term efforts on nuclear safety as well as to bring restoration to the current accident.

Reflecting on the above-mentioned issues, the Japanese Government will enhance human resource development within the activities of nuclear operators and regulatory organizations along with focusing on nuclear safety education, nuclear emergency preparedness and response, crisis management and radiation medicine at educational organizations.

(26) Ensuring the independence and diversity of safety systems

Although multiplicity has been valued until now in order to ensure the reliability of safety systems, avoidance of common cause failures has not been carefully considered and independence and diversity have not been sufficiently secured.

Therefore, the Japanese Government will ensure the independence and diversity of safety systems so that common cause failures can be adequately addressed and the reliability of safety functions can be further improved.

(27) Effective use of probabilistic safety assessment (PSA) in risk management

PSA has not always been effectively utilized in the overall reviewing processes or in risk reduction efforts at nuclear power plants. While a quantitative evaluation of risks of quite rare events such as a large-scale tsunami is difficult and may be associated with uncertainty even within PSA, Japan has not made sufficient efforts to improve the reliability of the assessments by explicitly identifying the uncertainty of these risks.

Considering knowledge and experiences regarding uncertainties, the Japanese Government will further actively and swiftly utilize PSA while developing improvements to safety measures including effective accident management measures based on PSA.

Lessons in Category 5

Thoroughly instill a safety culture

(28) Thoroughly instill a safety culture

All those involved with nuclear energy should be equipped with a safety culture. "Nuclear safety culture" is stated as "A safety culture that governs the attitudes and behavior in relation to safety of all organizations and individuals concerned must be integrated in the management system." (IAEA, Fundamental Safety Principles, SF-1, 3.13) Learning this message and putting it into practice is the starting point, the duty and the responsibility of those who are involved with nuclear energy. Without a safety culture, there will be no continual improvement of nuclear safety.

Reflecting on the current accident, the nuclear operators whose organization and individuals have primary responsibility for securing safety should look at every knowledge and every finding, and confirm whether or not they indicate a vulnerability of a plant. They should reflect as to whether they have been serious in introducing appropriate measures for improving safety, when they are not confident that risks concerning the public safety of the plant remain low.

Also, organizations or individuals involved in national nuclear regulations, as those who responsible for ensuring the nuclear safety of the public, should reflect whether they have been serious in addressing new knowledge in a responsive and prompt manner, not leaving any doubts in terms of safety.

Reflecting on this viewpoint, Japan will establish a safety culture by going back to the basics, namely that pursuing defenses-in-depth is essential for ensuring nuclear safety, by constantly learning professional knowledge on safety, and by maintaining an attitude of trying to identify weaknesses as well as room in the area of safety.