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Lessons at the Fukushima Daiichi Accident

Sang Jin Son [a*], Moosung Jae[a]
Nuclear Safety Analysis Laboratory in Hanyang Univ, PA+82-2-2220-1346
[*]Corresponding author: jae@hanyang.ac.kr

1. Introduction

Technology provides affluence and convenience to humankind, while at the same time acting as a threat to humanity. There have been external damage-causing accidents such as the Three Mile Island (TMI) and Chernobyl accidents, which have also been exposed as a threat to humanity. Nevertheless, since nuclear power is a collection of the latest science and technology and has various advantages that cannot be given up, efforts have been made since the accident to overcome shortcomings and further reinforce the safety system. Various efforts have been made to improve safety, including the strengthening of the exhaust system and the introduction of safety culture, and a new paradigm for safety has been pioneered.

Eight years have passed since the Fukushima Daiichi accident occurred in 2011. Uncertainties of accidents at the time of the accident have been studied and confirmed for eight years, and various [1,2]. As with previous accidents, it is time to identify the exact cause and progress of the accident and make efforts to further improve safety by learning lessons learned from post-accident measures [6]. The existing safety system should be further strengthened and improved to ensure the safety of nuclear power generation, thereby building reliability with the people. Therefore, this paper summarizes the cause and progress of the Fukushima accident and contains the lessons.

2. Progress of the Fukushima accident

On March 11, 2011, "East Japan Earthquake" with a maximum intensity of 9.0 occurred at a depth of 24 kilometers under the sea off the Sanriku coast in the Pacific Ocean, some 200 kilometers from the east of Japan. The reactors at Fukushima 1 Nuclear Power Plant units 1, 2 and 3 which were in power operation after the earthquake occurred, were automatically tripped by the reactor protection system as the seismic monitoring system installed in the building detected vibrations exceeding the reactor shutdown [8]. The reactor was shut down automatically, but it was necessary to cool down decay heat. The loss of offsite power occurred as power lines and substations for receiving power from the outside world collapsed due to the earthquake. Although external power is not available, the emergency diesel generators installed in the reactor itself were operated in units 1 to 6 to maintain the safety functions of the plant.

The massive tsunami, which reached its highest level of 15 meters after the quake, hit the Fukushima Daiichi nuclear power plant. The tsunami and the resulting floaters damaged the reactor, making normal heat removal difficult, and because the emergency diesel generator was installed underground, it was submerged by the tsunami and became unusable, leading to SBO (Station Black Out) situation where the pumps supplying cooling water for the reactor could not supply.

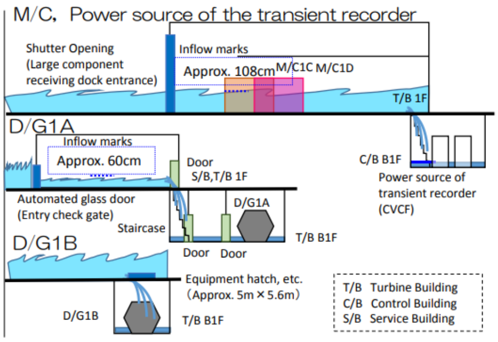


Fig. 1. Tsunami inflow into turbine building [TEPCO]

2.1 Unit 1

The BWR-3 unit 1 developed by GE(General Electric) lost its cooling water supply for cooling decay heat while the monitoring and measurement functions were lost, making it impossible to verify the condition of the reactor and other equipment. It is estimated that the meltdown of nuclear fuel began around 19:30 pm on March 11, followed by meltdown of the core. Hydrogen and radioactivity were continuously generated by meeting cooling water where core melt was present, but there was no way to accurately check the condition of the reactor due to power supply cut off, and it was difficult to take proper action. Around 07am on March 12, the Japanese prime minister finally authorized air discharge to reduce pressure in the pressure vessel and began work to lower pressure vents in unit 1 at 09am [6]. Although complete exhaust was not achieved, some of exhaust were made through maximum effort such as manually turning the valve. However, the coolant was not allowed into the reactor until this moment because it still exceeded the pressure of the fire truck pump.

The high temperature and high pressure inside the containment vessel persisted for a long time the pellet and cladding melted as all the coolant evaporated, and finally the reactor pressure vessel melted. With the explosion of hydrogen gas at unit 1, the radiation dose rate near MP-4 was measured by mobile vehicles and it was shown that it soared to approximately 1100µsv per hour.

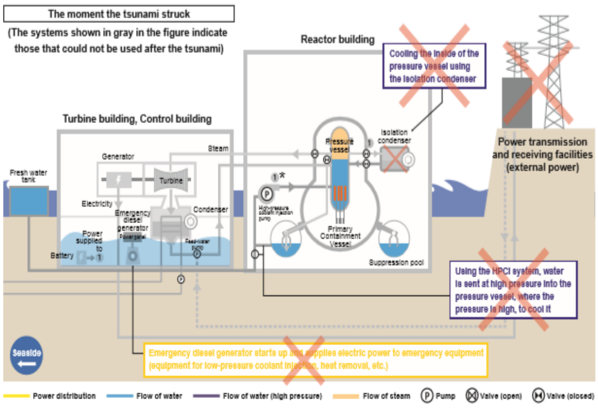


Fig. 2. The unit 1 after tsunami [TEPCO]

2.2 Unit

Emergency diesel generators were also flooded at the plant 3 after the tsunami arrived. Unlike the unit 1, however, direct current batteries remained intact, which allowed them to activate safety systems for post- accident response. BWR-3 and BWR-4 were different types of the safety systems. Unlike Unit 1, unit 2-4 had a Reactor Core Isolation Cooling system(RCIC) installed instead of the Isolation Condenser(IC) and it was operated after the accident using a direct current battery that was not submerged in unit 3 At 11:36 am on March 12, there were no mechanical defects in the RCIC, but the Turbine Steam Stop Valve designed as a trip mechanism closed, causing the RCIC to stop and the water level of the reactor to decrease. As a result, the High Pressure Coolant Injection (HPCI) was operated to inject cooling water and the core level began to recover. The HPCI operation allows the release of steam that had been overpressure the reactor, thus reducing the pressure. The operator considered that the safety release valve could be operated and the pressure of the reactor could be reduced to the point of injecting cooling water using the diesel-driven firewater pump and decided to manually shut down the HPCI accordingly. However, attempts to manually open the safety release valve remotely failed and the pressure of the reactor rose as the HPCI was stopped. Eventually, it is started to vent and the measurement of the radiation dose rate near MP-4 showed that it had risen to 1300µsv per hour, and by 12:30 p.m., it was raised to about 1,800µsv per hour [1].

Despite efforts to vent the containment vessel, hydrogen gas explosion occurred at unit 3. 36 hours after the reactor was shut down following the hydrogen explosion of unit 3, the radiation dose rate was increased to 3,200µsv per hour as measured by the main gate using mobile vehicles.

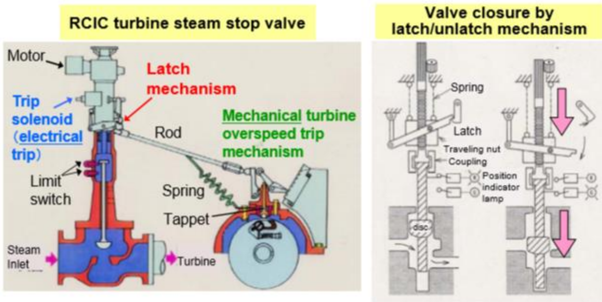


Fig. 3. Schematics of RCIC turbine steam stop valve and its trip mechanism [3]

2.3 Unit 2

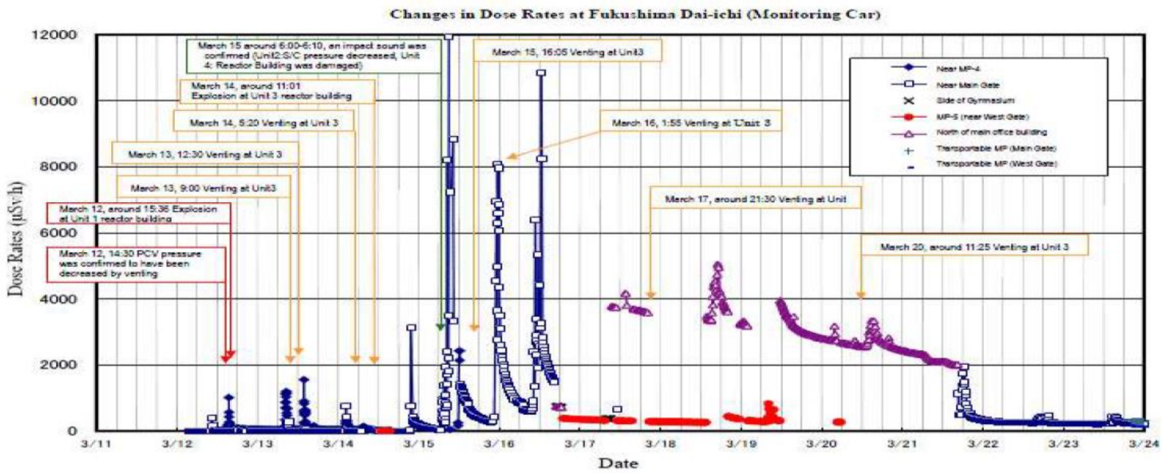
The RCIC and HPCI could be operated for unit 2 as well as for unit 3 and started manually around 16 pm on March 12, but the control and observation systems could not be operated due to the loss of all power sources and accordingly, it was not possible to verify actual operation. . If the RCIC is operated, containment integrity can be ensured and time is guaranteed until appropriate action is taken. Therefore, operators needed to verify the operation of the RCIC through the reactor level indicator clock and made efforts to secure power to operate it. Due to hydrogen explosions at Units 1 and 3, it was difficult to take post-accident actions, such as manually opening the valves when performing exhaust operations, such as taking a long time to figure out the valve location and method, but the RCIC worked normally to prevent hydrogen explosions at Units 2 [1].

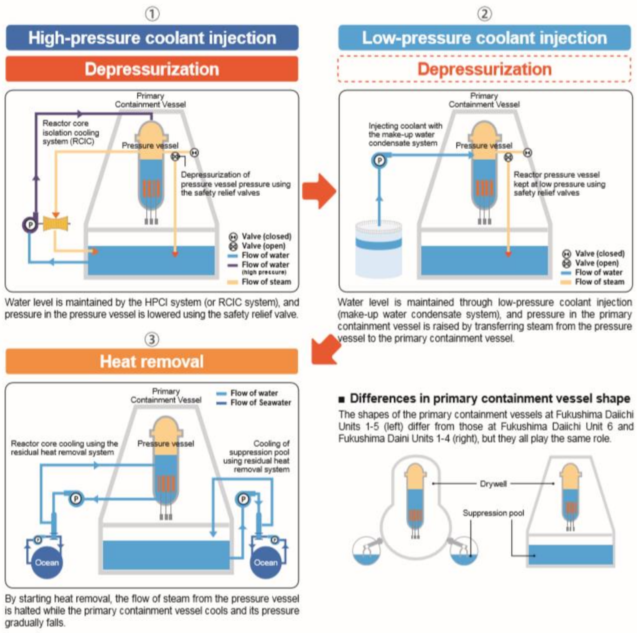
However, when the radiation dose rate was measured near the Main Gate with mobile vehicles, it was able to soar to 12000µsv per hour. It is assumed that the containment at Unit 2 caused damage and release of radioactive materials directly into the atmosphere through this area has affected the elevated dose rate.

Fig. 5. Operating process of safety systems [1]
Fig. 5. Radiation dose rate measured by moving vehicle [6]

2.4 Unit 4

The unit 4 reactor had been suspended since November 2010, due to a decomposition check, and all nuclear fuel had been removed from the reactor and kept in the spent fuel pool. However, hydrogen gas explosion occurred at the reactor building of unit 4 around 6 am on March 15 [6]. The spent fuel pool was safe, but hydrogen gas explosion occurred due to backflow of exhaust from the third vent. As shown in Figure 6, units 3 and 4 appear to have been moved to the system of units 4 in reverse during the venting process of units 3 because they are used for public exhaust chimney. The results showed that the radiation dose rate with the moving vehicle soared to 12000μsv per hour when measured near the main gate.





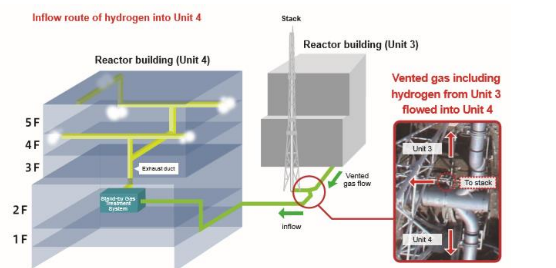


Fig. 6. Hydrogen gas transfer path through public exhaust chimney of units 3and 4 [TEPCO]

3. The causes and worse of the Fukushima accident

3.1 Design flaws

Although the Fukushima plant design did not take into account the tsunami, the site design basis at the time of the Fukushima plant construction set the maximum ground acceleration by the earthquake at 0.18g and the tsunami at 3.1m, which did not adequately reflect Japan's unique geological and natural environment. If realistic tsunami conditions were prepared at the Fukushima plant, the ability to respond could have been greatly improved by changing the location of key safety facilities or strengthening the design against flooding. However, there were no signs of improvement in preparation for the tsunami, including the installation of emergency diesel generators underground, an essential means of power supply for operating the safety system in the event of an accident and the core facilities lost their function when they were flooded after the tsunami arrived.

3.2 Lack of Nuclear Safety Culture in Japan

The concept of nuclear safety culture is a term for nuclear safety that has been raised since the 1986 Chernobyl nuclear accident and contains the importance of changing the safety awareness of organizations and people engaged in nuclear power generation [7]. This means that safety culture is important to the organizational system responsible for the safety of nuclear power and to the attitude and belief of the safety of workers under it. Even before the Fukushima accident, there were brisk moves to secure the safety of the plant. However, it is hard to say that the disaster as caused by a tsunami and that swift follow-up of the accident was also carried out properly. This is proof that their overconfidence in nuclear power safety is underlying and that the safety concept, which is of paramount importance, is not deeply rooted in safety- related organizations and workers. Work to improve safety has been undertaken, but what is important is whether all issues that need to be considered have been identified and prepared.

3.3 Unexpected Multi Unit Accident

It was multi-unit accident occurred simultaneously at the first nuclear power plant site(six units) and the second nuclear power plant site(four units). Fortunately, actions against the secondary nuclear power plant site had been taken properly, secured a cold shutdown condition and entered a stabilization phase. But even this had been days and until it reaches stability, Tokyo Electric Power Company(TEPCO) controlled and understood the accidents of two nuclear power plant sites and 10 units at the same time. In addition, it was ignored to consider multi-unit accident before the accident.

4. Lessons at the Fukushima Daiichi Accident

4.1 Reactor Design Considering Natural Environment

Nuclear power has the design characteristic that it should be built along the coast. Japan was exposed to earthquakes and tsunamis because of its natural environment. Failure to properly prepare for it resulted in accidents due to extreme natural disasters. Korea also has nuclear power plants built along its coast. Although there are no past records of tsunamis and earthquakes as large as the size of the accident, it is required to strengthen the systems against earthquakes and tsunami.

4.2 Reinforcement of safety philosophy

To ensure the safety of nuclear power generation, the philosophy of safety should be firmly established, from business operators and research institutes to workers. Since there has been an unexpected significant loss of life and a sense of social, it is required for responsibilities of the operating institutions to be emphasized and to strengthen the related infrastructure. It is time for independent, more professional regulators to reestablish nuclear safety norms.

4.3 Considering of Multi Unit Accident

Existing nuclear power generation was preparing for single unit accidents and various research work was under way. However, the Fukushima accident was caused by the linkage of multi units at the same site, which is different from the single unit. Therefore, it is time for a new study of the multi-unit accident

4.4 Expanding environmental radiation monitoring

Korean government is working together with the businesses and local governments to measure and prepare for radiation in real time by establishing an automatic national environmental radiation monitoring network

Fig. 8. The radiation dose measurement through national environmental radiation monitoring network [IERNet]

4.5 Strengthen international safety cooperation

International cooperation has been building up safety-regulated infrastructure for decades and efforts have been under way to further strengthen it since the Fukushima accident. Asian Nuclear Safety Network(ANSN) moved to further strengthen the Asian country's nuclear safety cooperation as the accident took place in Japan. The government is stepping up various activities to improve safety, including group reorganization, rebuilding the safety system and strengthening the capacity of safety regulators. In addition, the International Nuclear Regulators Association (INRA), the IAEA, the Korea-China-Japan Nuclear Safety Regulators Association (TRM) and other international moves to secure the safety of various nuclear power plants [5].

5. Conclusion

An important lesson from the Fukushima accident that took place eight years ago was the recognition that "there is no one hundred percent absolute safety in nuclear power plants." It has already been proven through the government's policy that it cannot build up its scientific and technological prowess without regaining trust with the people. Only through the restoration of trust with the people can the development of nuclear engineering be achieved. Therefore, it is necessary to identify the exact situation and cause of the accident and follow up the lessons learned as a result to further enhance safety and eliminate safety problems.

Acknowledgements

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