Earthquake and automatic shut-down of nuclear reactors

The Tohoku Pacific Earthquake of historic magnitude 9.0 struck the northeastern part of Japan at 14:46 on March 11th, 2011.

At the time of the earthquake occurrence, 3 reactors (Units 4, 5 and 6 at Fukushima Dai-ichi (I) Nuclear Power Station (NPS) of Tokyo Electric Power Co. Inc.(TEPCO)) were under periodic inspection outage, and 11 reactors (Units 1, 2 and 3 at Onagawa NPS of Tohoku Electric Power Co. Ltd.; Units 1, 2 and 3 at Fukushima I NPS of TEPCO; Units 1, 2, 3 and 4 of Fukushima Dai-ni (II) NPS of TEPCO; and an unit of Tokai Dai-ni (II) NPS of Japan Atomic Power Co. Ltd.) were automatically shut-down.

After the automatic shut-down, Units 1, 2 and 3 at Onagawa, Unit 3 at Fukushima II, and the Unit at Tokai II have been cold shut down safely. As for the Units 1, 2 and 4 at Fukushima II, TEPCO operator of the station reported the nuclear emergency situation to Nuclear and Industrial Safety Agency (NISA), but afterward the three units have been cold shut down.
Since the external power supply was cut off upon the earthquake occurrence at 14:46 on March 11th, the emergency diesel power generators at Fukushima I automatically started generating electricity and the cooling systems began their operation. Then, the massive earthquake triggered the devastating Tsunami wiping away houses, buildings, cars along the widespread areas of the northeast coast.

The emergency diesel power generators and the pumps supplying seawater to the cooling system were halted at 15:41 on March 11th due to the Tsunami estimated more than 10 meters high from the seawater level. Fukushima I lost the AC power sources for Unit 1, 2, 3 and 4 and lost function necessary for cooling down the reactor cores (Unit1,2 and 3) and spent fuel kept in the pools (Unit1,2,3 and 4) inside reactor buildings. Consequently, the pressure and temperature of reactor cores and the water temperature of spent fuel pools went up.

For counter measures, water is being injected into the reactor pressure vessels of Units 1, 2 and 3. At the same time, police, fire brigade and the Self Defense Forces are attempting to pour water into the spent fuel pool of Units 3 and 4 by spraying seawater from helicopters, water cannon trucks and fire engine. Further, TEPCO engineers are working to restore external power supply to Units 1, 2, 3 and 4 (power supply to Units 5 and 6 was completed) by installing the electricity cable connecting to the transmission line of Tohoku Electric Power Co. Ltd. and other transmission route.
Unit 1  Fresh water is being injected to the spent fuel pool and the reactor pressure vessel.

- After the reactor was automatically shut-down and the Tsunami disabled the equipments, the temperature of the reactor core went up and the water level inside the pressure vessel dropped and the reaction of cladding metal of fuel and water generated hydrogen. Vent of the primary containment vessel was operated at 10:17am on March 12th. The hydrogen leaked outside of the containment vessel and caused the explosion at the upper-part of a concrete building housing at 15:36 on March 12th.

- Seawater was being injected into the reactor pressure vessel; thereafter, fresh water is being injected as of 16:00 April 5th, instead of seawater. On March 29th, the pump for the fresh water injection was switched from the fire pump truck to the temporary motor-driven pump.

- On March 31st, spray of fresh water over the spent fuel pool of Unit 1 using the concrete pump truck was carried out. On April 2nd, a test water spray over the spent fuel pool was carried out in order to confirm the appropriate position for water spray.

- Lighting in the main control room was recovered on March 24th. On April 2nd, lighting in the turbine building was partially turned on. And the power supply for the fresh water injection to the reactor pressure vessel was switched to the external power supply on April 3rd.

- White smoke was confirmed to generate continuously as of 6:30am April 5th.

- As the result of concentration measurement in the stagnant water on the basement floor of the turbine building, $2.1 \times 10^5 \text{Bq/cm}^3$ of $^{131}\text{I}$ (Iodine) and $1.8 \times 10^6 \text{Bq/cm}^3$ of $^{137}\text{Cs}$ (Caesium) were detected as major radioactive nuclides. Since around 17:00 March 24th, the stagnant water has been transferred to the condenser. As the condenser was confirmed to be almost filled with water, pumping out the water to the condenser was stopped at 7:30am on March 29th.

- In order to prepare to transfer the stagnant water on the basement floor of the turbine building to the condenser, the water in the condensate storage tank was transferred to the surge tank of suppression pool water (A) (12:00 March 31th). After switching the place where the water was to be transferred to the surge tank of suppression pool water (B) (15:25 March 31th), the transfer was restarted and finished. (15:26 April 2nd) Thereafter, the water in the condenser was transferred to the condensate storage tank at 13:55 on April 3rd.
After the automatic shut-down of the reactor, the water injection function was sustained, but the reactor water level tended to decrease. And vent of the primary containment vessel was operated at 11:00am on March 13th and at 0:02am on March 15th.

At 6:10am on March 15th, TEPCO reported that there was an explosion sound at Unit 2. Given the fact that the pressure in the suppression chamber decreased, it is presumed that there is possibility of certain damage on the suppression chamber.

Seawater was being injected into the reactor pressure vessel; thereafter, fresh water is being injected as of 16:00 April 5th, instead of seawater. On March 27th, the pump for the fresh water injection was switched from the fire pump truck to the temporary motor-driven pump.

The seawater injection to the spent fuel pool of Unit 2 using the fire pump truck was switched to the fresh water injection using the temporary motor-driven pump on March 29th. On March 30th and April 4th, the injection of fresh water was resumed. On April 1st, fresh water injection to the spent fuel pool via the spent fuel cooling line using the temporary pump was carried out. At 6:00am on April 5th, the temperature in the spent fuel pool was 71.0 degree centigrade.

The power center of Unit 2 received electricity on Match 20th. On March 26th, lighting of the main control room was recovered. On April 2nd, lighting in the turbine building was partially turned on. And the power supply for the fresh water injection to the reactor pressure vessel was switched to the external power supply on April 3rd.

White smoke was confirmed to generate continuously as of 6:30am April 5th.

In order to prepare for transferring the stagnant water on the basement floor of turbine building to the condenser, the water in the condensate storage tank was transferred to the surge tank of suppression pool water from 16:45 March 29th till 11:50am April 1st. Thereafter, the water in the condenser was transferred to the condensate storage tank at 17:10 on April 2nd, and 13:55 on April 3rd.

One more pump for the transfer of the water in the condenser of Unit 2 to the condensate storage tank was installed at 15:40 April on 5th.

The water, of which the dose rate was at the level of more than 1,000 mSv/h, was confirmed to be collected in the pit (a vertical portion of an underground structure) for laying electric cables, located near the intake channel of Unit 2. In addition, the outflow from the crack with a length of around 20 cm in the concrete portion of the lateral surface of the pit into the sea was confirmed. (as of around 9:30 April 2nd) In order to stop the outflow, concrete was started to be poured into the pit. (16:25 and 19:02 April 2nd)

As the measure to prevent the outflow of the water accumulated in the pits for conduit in the area around the inlet bar screen of Unit 2, the upper part of the power cable trench for power source at the intake channel was crushed and sawdust, high polymer absorbent and cutting-processed newspaper were put inside. (From 13:47 till 14:30 April 3rd)

The tracer solution was put in from the two holes dug around the pit for the conduit near the inlet bar screen of Unit 2 and was confirmed to be flowed out from the crack to the sea at 14:15 April 5th. The coagulant (soluble glass) started to be injected from the holes around the pit in order to prevent the out flowing of the water at 15:07 April 5th.
Unit 3  Fresh water is being injected to the spent fuel pool and the reactor pressure vessel.

- After the automatic shut-down of the reactor, fresh water and subsequently seawater were injected into the reactor pressure vessel through the fire extinguishing system line. And vent of the primary containment vessel was operated at 20:41 on March 12th, at 8:41am on March 13th and at 5:20am on March 14th. However, the pressure in the primary containment vessel rose up unusually and the explosion took place around the reactor building at 11:01am on March 14th.

- On March 16th, 21st and 23rd, the smoke (sometimes whitish, grayish or slightly blackish one) was generated from Unit 3 and died down. As of 6:30am April 5th, white smoke was confirmed to generate continuously.

- For counter measures, seawater was being injected into the reactor pressure vessel, thereafter; fresh water is being injected as of 16:00 April 5th, instead of seawater. At the same time, to pour water into the spent fuel pool, helicopters, water cannon trucks, fire engines and concrete pump trucks discharged water to Unit 3 from sky and ground. On March 29th, the water spray (fresh water) using the concrete pump truck was carried out.

- Injection of seawater to the spent fuel pool via the cooling and purification line was carried out on March 23rd and March 24th. On March 28th, the pump for the fresh water injection was switched from the fire pump truck to the temporary motor-driven pump. From March 31st till April 4th, fresh water spray over the spent fuel pool using the concrete pump truck had been carried out three times.

- The pressure in the primary containment vessel of Unit 3 rose. (320 kPa as of 11:00 March 20th) Judging from the situation, immediate pressure relief was not required, and monitoring of the pressure continues. (107.1 kPa as of 10:20am April 5th)

- Works for the recovery of external power supply is being carried out. At 22:43 on March 22nd, lighting in the main control room was recovered. On April 2nd, lighting in the turbine building was partially turned on. And the power supply for the fresh water injection to the reactor pressure vessel was switched to the external power supply at 12:18 on April 3rd.

- In order to prepare for transferring the stagnant water on the basement floor of turbine building to the condenser, the water in the condensate storage tank is being transferred to the surge tank of suppression pool water from 17:40 March 28th till around 8:40am March 31st.
Unit 4  No fuel is in the reactor pressure vessel. Fresh water is being injected to the spent fuel pool.

- There is no fuel in the reactor pressure vessel due to replacement work of the shroud.

- The temperature of water in the spent fuel pool went up. At 4:08am on March 14th, the temperature in the spent fuel pool of Unit 4 was 84 degree centigrade.

- It was confirmed that a part of wall of the operation floor of the reactor building of Unit 4 was damaged at 6:14am on March 15th. A fire took place at Unit 4 at 9:38am, but the fire was extinguished spontaneously as of 11:00am. And at 5:45am on March 16th, it was reported that a fire occurred at Unit 4; however, no fire was confirmed by TEPCO staff on the ground at 6:15am.

- White smoke was confirmed to generate continuously as of 6:30am April 5th.

- Water spray over the spent fuel pool of Unit 4 by Self-Defense Force was carried out three times from March 20th till March 21st. And water spray using a concrete pump truck had been carried out eight times from March 22nd till April 3rd. Injection of seawater to the spent fuel pool via the fuel pool cooling line was carried out on March 25th.

- The power center received electricity on March 22nd. On March 29th, lighting in the main control room was recovered. On April 2nd, lighting in the turbine building was partially turned on.

- From April 2nd, the stagnant water in the main building of radioactive waste treatment facilities was being transferred to the turbine building of Unit 4. As the water level in the vertical portion of the trench for Unit 3 rose from 3 April, by way of precaution, the transfer was suspended notwithstanding that the path of the water was not clear.(9:22am April 4th)
Unit 5 & 6  Unit 5 & 6 is under cold shut down.

- The emergency generator (B) for Unit 6 was operating and supplying electricity to Unit 5 and Unit 6. Fresh water was being injected into the reactor pressure vessels and the spent fuel pools by make-up water condensate system.

- The pump for residual heat removal system (RHR) (C) for Unit 5 and RHR (B) for Unit 6 started up on March 19th and recovered heat removal function. (power supply: emergency diesel generators for Unit 6)

- Unit 5 was under cold shut down at 14:30 and Unit 6 was under cold shut down at 19:27 on March 20th.

- Unit 5 and Unit 6 received electricity reached to the starting transformer on March 20th. The power supply of Unit 5 and Unit 6 was switched from the emergency diesel generator to the external power supply on March 21st and March 22nd.

- The temporary pump of RHR seawater system (RHRS) for Unit 5 was automatically stopped at 17:24 on March 23rd when the power supply was switched from the temporary to the permanent. Thereafter, repair of the temporary pump of RHRS was completed at 16:14 and cooling was started again at 16:35 on March 24th.

- Power supply for the temporary pumps for RHRS of Unit 6 was switched from the temporary to the permanent at 15:38 and 15:42 on March 25th.

- The temperature of water in the spent fuel pool of Unit 5 and Unit 6 were 34.8 degree centigrade and 27.5 degree centigrade, respectively as of 13:00 April 5th.

- The groundwater with low-level radioactivity in the sub drain pits of Units 5 and 6 (around 1,500t) was started to be discharged through the water discharge canal to the sea at 21:00 April 4th.

Common Spent Fuel Pool

- The power supply was started at 15:37 and cooling was also started at 18:05 on March 24th. As of 7:10am April 5th, the water temperature of the pool was around 29 degree centigrade.
Unit 5 as of 13:00 April 5th

Water Temperature in the Pool: 34.8°C
Condition: Recovery of heat removal function

Spent Fuel Pool Cooling System

External Power

RHRS*

Residual Heat Removal System

Reactor Pressure: 0.106 MPa*
Reactor Water Level: 1,710 mm
Reactor Water Temperature: 42.4°C
Condition: Pressure is under control.
*converted to absolute pressure

Reactor Pressure Vessel Temperature:
Monitoring by Reactor Water Temperature

※Heat removal was carried out alternately with the water in the Reactor Core and in the Spent Fuel Pool.

(Editorial committee for Nuclear Energy Handbook, Nuclear Energy Handbook)

Unit 6 as of 13:00 April 5th

Water Temperature in the Pool: 27.5°C
Condition: Recovery of heat removal function

Spent Fuel Pool Cooling System

External Power

RHRS*

Residual Heat Removal System

Reactor Pressure: 0.106 MPa*
Reactor Water Level: 1,887 mm
Reactor Water Temperature: 30.9°C
Condition: Pressure is under control.
*converted to absolute pressure

Reactor Pressure Vessel Temperature:
Monitoring by Reactor Water Temperature

※Heat removal was carried out alternately with the water in the Reactor Core and in the Spent Fuel Pool.

(Editorial committee for Nuclear Energy Handbook, Nuclear Energy Handbook)
As the result of nuclide analysis at around the southern water discharge canal, 7.4×10^1 Bq/cm^3 of ^131I (1850.5 times higher than the limit of concentration of water outside the Environmental Monitoring Aria) was detected as of 14:30 March 26th. (As the result of measurement on March 29th, it was detected as 3355.0 times higher than the limit in water.)

As the result of the analysis at the northern water discharge canal, 4.6×10^1 Bq/cm^3 of ^131I (1262.5 times higher than the limit) was detected as of 14:10 March 29th.

The water was confirmed to be collected in the vertical parts of the trenches (an underground structure for laying pipes, shaped like a tunnel) outside of the turbine building of Units 1 to 3. The dose rates on the water surface were 0.4 mSv/h of the Unit 1’s trench and 1,000 mSv/h of the Unit 2’s trench. The rate of the Unit 3’s trench could not measure because of the rubble. (Around 15:30 March 27th) The water of the Unit 1’s was transferred to the storage tank in the main building of radioactive waste treatment facilities by the temporary pump. Thereafter the water level from the top of the vertical part went down from approximately -0.14m to approximately -1.14m. (From 9:20am till 11:25 March 31st)

In the samples of soil collected on March 21st and 22nd on the site (at 5 points) of Fukushima I, plutonium 238, 239 and 240 were detected (23:45 March 28th announced by TEPCO). The concentration of the detected plutonium was at the equivalent level of the fallout (radioactive fallout) that was observed in Japan concerning the past atmospheric nuclear testing, i.e. at the equivalent level of the normal condition of environment, and was not at the level of having harmful influence on human body.

On March 28th, the stagnant water was confirmed in the main building of radioactive waste treatment facilities. As the result of analysis of radioactivity, the total amount of the radioactivity 1.2×10^1 Bq/cm^3 in the controlled area and that of 2.2×10^1 Bq/cm^3 in the non-controlled area were detected in March 29th.

The barge (the first ship) of the US armed forces carrying fresh water for cooling reactors, etc. landed in the exclusive port of the power station, being towed by the ships of Japan Maritime Self-Defense Force. (15:42 March 31st) The transfer of fresh water from the barge to the filtrate tank was started. (15:58 April 1st) Thereafter it was suspended due to the malfunction of the hose (16:25 April 1st), but was carried out from 10:20am till 16:40 April 2nd.

The barge (the second ship) of the US armed forces carrying fresh water for cooling reactors, etc. landed in the exclusive port of the power station, being towed by the ships of Japan Maritime Self-Defense Force. (9:10am April 2nd)

The spraying for test scattering of anti-scattering agent was carried out in the area of about 500 m^2 on the mountain-side of the Common Pool. (From 15:00 till 16:05 April 1st)

The freshwater was transferred from the barge (the second ship) of the US armed force to the other barge (the first ship). (From 09:52 till 11:15 April 3rd)

The stagnant water with low-level radioactivity in the main building of radioactive waste treatment facilities (Around 10,000t) was started to be discharged from the southern side of the water discharge canal to the sea, using the first pump at 19:03 April 4th. Further, at 19:07 on the same day, the discharge using 10 pumps in total was carried out.
Current Situation

- Evacuation as far as 20 kilometers from Fukushima I NPS and 10 kilometers from Fukushima II NPS was almost completed (see the diagram “Fukushima prefecture”). The residents in the areas from 20 kilometers to 30 kilometers radius from Fukushima I NPS are directed to stay in-house.

- On March 16th, the Local Emergency Response Headquarter issued “the direction to administer the stable Iodine during evacuation from the evacuation area (20 km radius)” to the Prefecture Governors and the heads of cities, towns and villages.

Monitoring Data

1) The data of Monitoring Post out of 20 kilometers zone of Fukushima I NPS is available on the following website:
http://www.mext.go.jp/a_menu/saigaijohou/syousai/1303726.htm

2) The real-time radiation data collected via the System for Prediction of Environment Emergency Dose Information (SPEEDI) is available on the following website:
http://www.bousai.ne.jp/eng/
Outline of the Fukushima I Nuclear Power Station

(Fukushima Dai-ichi nuclear power station)

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(Structure of BWR)
Location of Fukushima I and II in Japan