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)) were under periodic inspection outage, and 11 reactors (Units 1, 2 and 3 at Onagawa NPS; Units 1, 2 and 3 at Fukushima I NPS; Units 1, 2, 3 and 4 of Fukushima Dai-ni (II) NPS; and an unit of Tokai Dai-ni (II) NPS) were automatically shut-down.

Tsunami damaged the emergency generators and the cooling systems at the Fukushima Dai-ichi (I)

Since the external power supply was cut off upon the earthquake occurrence, 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 14 meters high from the seawater level.
Fresh water is being injected to the spent fuel pool and the reactor.

After the reactor was automatically shut-down and the Tsunami disabled the equipments. The pressure of containment vessel unusually increased and the water level inside the reactor pressure vessel dropped. Vent of the primary containment vessel was operated at 10:17am on March 12th; thereafter, hydrogen explosion occurred at the upper-part of the reactor building at 15:36.

Water injection to the reactor pressure vessel
- Seawater had been injected into the reactor pressure vessel since March 12th; thereafter, fresh water has been injected since March 25th, instead of seawater.

Water injection to the spent fuel pool
- On March 31st, spray of fresh water over the spent fuel pool of Unit 1 using the concrete pump truck was carried out.

Power supply
- Lighting in the main control room was recovered on March 24th. And the power supply for the fresh water injection to the reactor pressure vessel was switched to the external power supply on April 3rd.

Stagnant water
- 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 March 24th, the stagnant water has been transferred to the condenser until it was fulfilled.
- In order to prepare to transfer the stagnant water in the turbine building to the condenser, the water in the condensate storage tank was transferred to the surge tank of suppression pool water and finished on April 2nd. The transfer of the water in the condenser to the condensate storage tank was completed on April 10th.

Nitrogen injection
- Aiming at reducing the possibility of hydrogen combustion in the primary containment vessel of Unit 1, the operations for the injection of nitrogen to the vessel were started at 22:30 on April 6th. The start of nitrogen injection to the primary containment vessel of Unit 1 was confirmed. (1:31am April 7th)

Confirmation by unmanned robots
- Confirmation of situation, etc. was carried out by unmanned robots at the reactor building for Unit 1 on April 17th.

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*Report concerning incidents at the Fukushima Dai-ichi (I)*

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**Confirmation by unmanned robots**
- Confirmation of situation, etc. was carried out by unmanned robots at the reactor building for Unit 1 on April 17th.
Unit 2  Fresh water is being injected to the spent fuel pool and the reactor.

After the automatic shut-down of the reactor, the water injection function was sustained. And vent of the primary containment vessel was operated at 11:00am on March 13th and at 0:02am on March 15th. But the reactor water level tended to decrease. At 6:10am on March 15th, there was an explosion sound at Unit 2. Given that the fact that the pressure in the suppression chamber decreased, it is presumed that there is possibility of certain damage on the suppression chamber.

Water injection to the reactor pressure vessel
- Seawater had been injected into the reactor pressure vessel since March 14th; thereafter, fresh water has been injected since March 26th, instead of seawater.

Water injection to the spent fuel pool
- The seawater injection to the spent fuel pool using the fire pump truck started on March 20th. On March 29th, the injection was switched to the fresh water injection using the temporary motor-driven pump.

Power supply
- On March 26th, lighting of the main control room was recovered. And the power supply for the fresh water injection to the reactor pressure vessel was switched to the external power supply on April 3rd.

Stagnant water
- 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 March 29th till April 1st. Thereafter, the water in the condenser was transferred to the condensate storage tank and completed on April 9th. The stagnant water in the trench of the turbine building was transferred to the condenser from April 12th till 13th.

Water in the pit
- 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) 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 on April 2nd. In order to stop the outflow, concrete was put inside, then high polymer absorbent etc. was used, but the outflow did not stop.
- After the coagulant (soluble glass) started to be injected from the holes around the pit on April 5th, the outflow of the water was confirmed to stop on April 6th. Furthermore, the measures to stop water by means of rubber board and jig (prop) were implemented at the outflowing point. (Finished on April 6th)
Unit 3  Fresh water is being injected to the spent fuel pool and the reactor.

After the automatic shut-down of the reactor, fresh water and subsequently seawater were injected into the reactor pressure vessel. And vent of the primary containment vessel was operated on March 13th and 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.

Water injection to the reactor pressure vessel
- The seawater had been injected into the reactor pressure vessel since March 13th, thereafter; fresh water has been injected since March 25th, instead of seawater. On March 28th, the pump for the fresh water injection was switched from the fire pump truck to the temporary motor-driven pump.

Water injection to the spent fuel pool
- In order to pour water into the spent fuel pool, helicopters, water cannon trucks, fire engines and concrete pump trucks discharged water to the spent fuel pool of Unit 3 from sky and ground. Since March 29th till April 14th, fresh water spray over the spent fuel pool using the concrete pump truck had been carried out.

Power supply
- On March 22nd, lighting in the main control room was recovered. And the power supply for the fresh water injection to the reactor pressure vessel was switched to the external power supply on April 3rd.

Stagnant water
- 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 March 28th till March 31st.

Confirmation by unmanned robots
- Confirmation of situation, etc. was carried out by unmanned robots at the reactor building for Unit 3 on April 17th.
Unit 4  No fuel is in the reactor. Fresh water is being injected to the spent fuel pool.

There is no fuel in the reactor pressure vessel due to replacement of the shroud. 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 March 15th, but the fire was extinguished spontaneously as of 11:00am. Another fire took place on March 16th, but no fire could be confirmed from the ground.

Water injection to spent fuel pool
- Water spray using fire engine with seawater over the spent fuel pool of Unit 4 was carried out from March 20th till March 21st. And water spray using a concrete pump truck had been carried out five times with seawater from March 22nd till March 27th and nine times with fresh water from March 30th till April 17th.

Power supply
- On March 29th, lighting in the main control room was recovered.

Stagnant water
- 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 April 3rd, 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.

One of the emergency generators 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.

**Cold shut down**
- The pump for residual heat removal system (RHR) for Unit 5 and the pump for RHR for Unit 6 started up on March 19th and recovered heat removal function.
- Unit 5 was under cold shut down at 14:30 on March 20th and Unit 6 was under cold shut down at 19:27 on the same day.

**Power supply**
- Unit 5 and 6 received electricity reached to the starting transformer on March 20th. The power supply of Unit 5 and 6 was switched from the emergency diesel generators to the external power supply on March 21st and March 22nd.
- Power supply for the temporary pumps for RHR seawater system of Unit 5 and 6 were switched from the temporary to the permanent on March 24th and 25th.

**Low-level radioactivity water discharge**
- The groundwater with low-level radioactivity in the sub drain pits of Units 5 and 6 (around 1,300t) was discharged through the water discharge canal to the sea from April 4th till 9th in order to protect the critical safety facilities of the reactors. The water was beginning to leak out to the reactor building and other buildings of Unit 6 and there was no further capacity to accommodate it.

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**Diagram:**

Unit 5 as of 6:00am April 18th

Water Temperature in the Pool: 36.7°C
Condition: Recovery of heat removal function

Reactor Pressure: 0.108MPa*
Reactor Water Level: 1,859mm
Reactor Water Temperature: 34.2°C
Condition: Pressure is under control.
*converted to absolute pressure

Spent Fuel Pool Cooling System

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

External Power

Residual Heat Removal System

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*(Editorial committee for Nuclear Energy Handbook, Nuclear Energy Handbook)*
Common Spent Fuel Pool

- The power supply was started at 15:37 on March 24th and cooling was also started at 18:05 on the same day.
- The power supply was stopped due to short-circuiting of the end of the power supply circuit. (14:34 April 17th) Thereafter the facility inspection was carried out and the power supply was recovered. (17:30 April 17th)

Other

Nuclide analysis at water discharge canal
- As the result of nuclide analysis at around the southern water discharge canal, $7.4 \times 10^4 \text{Bq/cm}^3$ of $^{131}\text{I}$ (1850.5 times higher than the limit of concentration of water outside the Environmental Monitoring Area) was detected on 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, $4.6 \times 10^4 \text{Bq/cm}^3$ of $^{131}\text{I}$ (1262.5 times higher) was detected on March 29th.

Water in the trenches
- 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 on March 27th. The rate of the Unit 3’s trench could not measure because of the rubble.

Nuclide analysis of soil
- In the samples of soil collected on March 21st, 22nd, 25th, 28th, 31nd and April 4th
on the site of Fukushima I, $^{238}\text{Pu}$ (Plutonium), $^{239}\text{Pu}$ and $^{240}\text{Pu}$ were detected. The concentration of the detected plutonium was at the equivalent level of the 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.

**Stagnant water**
- 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 $1.2 \times 10^4 \text{ Bq/cm}^3$ in the controlled area and that of $2.2 \times 10^4 \text{ Bq/cm}^3$ in the non-controlled area were detected in March 29th.

**Barges loading fresh water**
- Two barges 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 on March 31st and April 2nd. The transfer of fresh water from the barges to the filtrate tank was started.

**Low-level radioactive water discharge**
- The wastewater with high concentration of radioactive materials was trapped on the basement floor of the turbine building of Unit2 and it was necessary to immediately be transferred to another location as it was leaking out to the surrounding environment. But there was no further capacity to accommodate it.
- In order to use the main building of radioactive waste treatment facilities for accommodating the wastewater of the turbine building of Unit2, the stagnant water with low-level radioactivity in the radioactive waste treatment facilities was started to be discharged from the southern side of the water discharge canal to the sea from 19:03 April 4th till 10th. Confirmation of the remaining water is being carried out. (Total amount of discharged water is around 9,070t.)
- The stagnant water with low-level radioactivity in the building of miscellaneous solid waste volume reduction processing was discharged from the southern side of the water discharge canal to the sea using 5 pumps. (From 17:20 April 6th till 18:20 April 7th)

**Other**
- In order to prevent the contaminated water from outflowing from the exclusive port, the work for stopping water by means of large-sized sandbags was implemented around the seawall on the south side of the NPS on April 5th.
- 3 sandbags filled with Zeolite were placed between the inlet screen pump room of Unit 3 and that of Unit 4 on April 15th. Thereafter, 2 sandbags were placed between the inlet screen pump room of Unit 1 and that of Unit 2, and 5 sandbags were placed between that of Unit 2 and that of Unit 3 on April 17th.
- TThe silt fences to prevent the contaminated water from being scattered were completed to be doubly installed at the appropriate part of the seawall on the south side of the NPS on April 11th. Other silt fences were installed in front of the screen of Units 3 and 4 on April 13th, and at the curtain wall and in front of the screen of Unit 1 and 2 on April 14th.
- The test scattering of anti-scattering agent to prevent the radioactive materials on the ground surface from being scattered was carried out on the mountain-side of the Common Pool from April 1st till 17th.
- Removal of the rubble using remote-control heavy machineries was carried out from April 10th till 17th.
- On the ocean-side of the inlet bar screen of Unit 2, temporary boards to stop water were installed on April 12th, 13th and 15th.

**Countermeasures for Tsunami**
- The distribution boards, etc. for the pumps injecting water to the reactors of Units 1 to 3 were transferred to a hill on April 15th.
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/syouai/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/
Location of Fukushima I and II in Japan