Timeline of the Fukushima Daiichi nuclear disaster

Coordinates: 37°25′17″N 141°1′57″E

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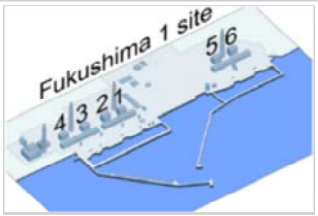
(Redirected from Timeline of the Fukushima I nuclear accidents)

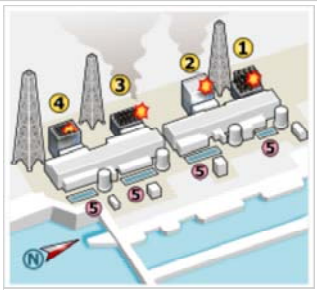
See also: Timeline of the Fukushima II nuclear accidents, Fukushima Daiichi nuclear disaster, and 2011 Japanese nuclear incidents

Fukushima Dai-ichi (*dai-ichi* means "first"), was a multi-reactor nuclear power site in the Fukushima Prefecture of Japan. The Fukushima I nuclear accidents occurred after the 9.0 magnitude Tōhoku earthquake and subsequent tsunami on 11 March 2011, only 14 days before the reactor was to be shut down. This offshore earthquake near the island of Honshu[1] produced a large tsunami in Japan, and a tsunami warning for over 20 countries within and around the Pacific Rim.

The earthquake triggered the shut down of the three active reactors at the Fukushima I Nuclear Power Plant (Fukushima Dai-Ichi). The tsunami that followed stopped Fukushima I station's backup diesel generators, causing a station blackout. The subsequent lack of cooling led to explosions and meltdowns at the Fukushima I facility, with problems at three of the six reactors and one of the six spent fuel pools.



Fukushima Daiichi I nuclear powerplant site close-up.



Schematic representation of the Fukushima Daiichi nuclear accidents.

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Timeline

Times are given in Japan Standard Time (JST), unless noted, which is UTC plus nine hours.

March event tree

Main article: Fukushima nuclear accident log, March 2011

The nuclear accident event tree[2] developed quickly in the early weeks after the earthquake and tsunami caused a number of accident sequences to begin.

First week

11 March

- 14:46: A 9.0 magnitude earthquake strikes off the coast of Honshu Island at a depth of about 24 kilometres (15 mi). The Fukushima I power plant's nuclear reactors 1, 2, and 3 are automatically shut down by the shake. Nuclear reactors 4, 5, and 6 were undergoing routine maintenance and were not operating, (reactor 4 was defueled in November 2010). The tremor has the additional effect of causing the power plant to be cut off from the Japanese electricity grid, however, backup diesel generators kick in to continue cooling. Tokyo Electric Power Company (TEPCO), the plant's operator, finds that units 1 and 2 are not operating correctly and notifies the proper officials.[3]
- 14:52: Reactor 1's emergency cooling system, which is capable of running even without external power, turns on automatically.[4]
- 15:03: Reactor 1's emergency cooling system is manually shut down.[4]
- 15:27: The first tsunami strikes the plant.[5]
- 15:30: The emergency condenser designed to cool the steam inside the pressure vessel of the No. 1 reactor fails[6]
- 15:46 (approximate): A 14-metre (46 ft) tsunami unleashed by the earthquake overtops the seawall designed to protect the plant from a tsunami of 5.7 metres (19 ft), inundating the Fukushima facility and disabling the backup diesel generators, all but one of which were housed underground, and washing away their fuel tanks.[7] The generators were intended to run pumps to keep the water in the reactor from boiling. (Later) As the temperature rose, a system started that used steam-powered pumps and battery-powered valves.[8][9]

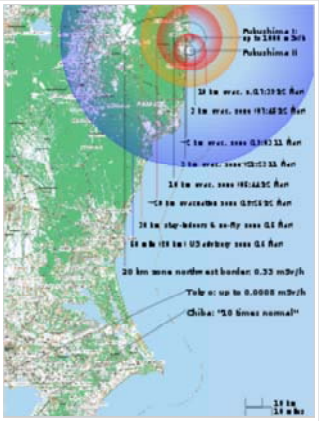
According to a report in the New York Times, "[A]t the start of the crisis Friday, immediately after the shattering earthquake, Fukushima plant officials focused their attention on a damaged storage pool for spent nuclear fuel at the No. 2 reactor at Fukushima I, said a nuclear executive who requested anonymity.... The damage prompted the plant's management to divert much of the attention and pumping capacity to that pool, the executive added. The shutdown of the other reactors then proceeded badly, and problems began to cascade."[10]

- 16:00: The Nuclear and Industrial Safety Agency of Japan (NISA) initiates an emergency headquarters in an attempt to gather information on the 55 nuclear reactors in Japan.[11] There is no report that radiation was detected outside plant borders.[12]
- 18:00: The falling water level in reactor 1 reaches the top of the fuel, and the core temperature starts climbing.[13]
- 18:18: Reactor 1's emergency cooling system is once again back on.[4]

- 19:03: Prime Minister Naoto Kan declares a nuclear emergency status.[14] This is announced by Yukio Edano, Chief Cabinet officer in Japan. Japanese government officials try to comfort the people of Japan by telling them that the proper procedures are being undertaken. They also announce that no radioactive leaks have been detected.[11]
- 19:30: The fuel in reactor 1 becomes fully exposed above the water surface, and fuel damage begins soon after in the central core.[13]
- 21:00: An evacuation order is issued by the government to persons within a 3 kilometres (1.9 mi) radius of the Fukushima I station. Those within a 10 kilometres (6.2 mi) radius are told that they can remain in their homes and carry on with regular activities until told otherwise.[11] TEPCO announces that pressure inside reactor unit 1 of Fukushima I is more than twice normal levels.[11]

12 March

- 02:44: Emergency battery power for the High Pressure Core Flooder System for reactor 3 runs out.
- 04:15: Fuel rods in reactor 3 are exposed.
- 05:30: Despite the high risk of the hydrogen igniting after combining with oxygen from water or in the atmosphere, in order to release some of the pressure inside the reactor at Fukushima I unit 1, the decision is taken to vent some of the steam (which contained a small amount of radioactive material) into the air in the metal container building surrounding the unit.
- 05:50: Fresh water injection into reactor 1 is started.[13]
- 06:50: Although unknown at the time, the core of reactor 1 has now completely melted and falls to the bottom of the reactor pressure vessel.[13]
- 10:09: TEPCO confirms that a small amount of vapor has been released into the air to release pressure in reactor unit 1 at Fukushima I.[15]
- 10:58: Pressure still remains too high inside reactor unit 2 at Fukushima I. In order to alleviate some of this pressure, a consensus is once more reached to vent radioactive vapor into the air.[15]
- 14:50: Fresh water injection into reactor 1 is halted.[13]



Overview map showing evacuation and other zone progression and selected radiation levels.

- 15:30: Evacuation of residents within 3 km of Fukushima II and within 10 km of Fukushima I are underway.[16]
- 15:36: Massive hydrogen explosion on the outer structure of the unit 1. The concrete building surrounding the steel reactor vessel collapses as a result of the explosion; however no damage is believed to have been sustained by the reactor itself. Four workers injured.
- 20:00: Sea water injection into reactor 1 is started.[13]
- 21:40: The evacuation zone around Fukushima I is extended to 20 km, while the evacuation zone around Fukushima II is extended to 10 km.[16]

To release pressure within reactor unit 1 at Fukushima I, steam is released out of the unit into the air. This steam contains water vapor, hydrogen, oxygen and some radioactive material, mostly tritium and nitrogen-16.

TEPCO engineers decided to directly inject sea water inside the pressure vessel of the reactors by means of the mobile trucks of the firemen. The pressure relief was also necessary to allow the firemen to inject seawater into the reactors vessels.

13 March

- 02:42: The high pressure coolant injection system for reactor 3 stops, and shortly thereafter, the water level within the reactor starts falling.[17]
- 07:00 (approximate): The water level in reactor 3 reaches the top of the fuel.[17]
- 09:00: Core damage starts occurring in reactor 3.[17]

A partial meltdown was reported to be possible at unit 3.[18] As of 13:00 JST, both reactors 1 and 3 were being vented to release overpressure and re-filled with water and boric acid for cooling and inhibition of further nuclear reactions.[19] Unit 2 was possibly suffering lower than normal water level but was thought to be stable, although pressure inside the containment vessel was high.[19] The Japan Atomic Energy Agency announced that it was rating the situation at unit 1 as level 4 (accident with local consequences) on the International Nuclear and Radiological Event Scale.[20][21]

14 March

- 11:01: The unit 3 reactor building explodes, injuring six workers.[22] According to TEPCO there was no release of radioactive material beyond that already being vented but blast damage affected water supply to unit 2.[23]
- 13:15: The reactor core isolation cooling system for reactor 2 stops, and shortly thereafter, the water level within the reactor starts falling.[17]
- 15:00: A major part of the fuel in reactor 3 drops to the bottom of the reactor pressure vessel.[17]
- 18:00 (approximate): The water level in reactor 2 reaches the top of the fuel.[17]

- 20:00: Core damage starts occurring in reactor 2.[17]

The president of the French nuclear safety authority, Autorité de sûreté nucléaire (ASN), said that the accident should be rated as a 5 (accident with wider consequences) or even a 6 (serious accident) on INES.[24]

15 March

- 20:00: A major part of the fuel in reactor 2 drops to the bottom of the reactor pressure vessel.[17]

Damage to temporary cooling systems on unit 2 by the explosion in unit 3 plus problems with its venting system meant that water could not be added, to the extent that unit 2 was in the most severe condition of the three reactors.[25] An explosion in the "pressure suppression room" causes some damage to unit 2's containment system.[25][26] A fire beaks out at unit 4 involving spent fuel rods from the reactor, which are normally kept in the water-filled spent fuel pool to prevent overheating. Radiation levels at the plant rise significantly but subsequently fall back.[27] Radiation equivalent dose rates of 400 millisieverts per hour (400 mSv/h) are observed at one location in the vicinity of unit 3.[20][28][29]

16 March

At approximately 14:30 on 16 March, TEPCO announces its belief that the fuel rod storage pool of unit 4—which is located outside the containment area[30]—may have begun boiling, raising the possibility that exposed rods could reach criticality. By midday, NHK TV is reporting white smoke rising from the Fukushima I plant, which officials suggest is likely coming from reactor 3. Shortly afterward, all but a small group[31] of remaining workers at the plant are placed on standby because of the dangerously rising levels of radiation up to 1 Sv/h.[32][33]TEPCO had temporarily suspended operations at the facility.[34] A TEPCO press release states that workers had been withdrawn at 06:00 JST because of abnormal noises coming from one of the reactor pressure suppression chambers.[35] Late in the evening, Reuters reports that water is being poured into reactors 5 and 6.[36]

17 March

During the morning, Self-Defense Force helicopters drop water four times on the spent fuel pools of units 3 and 4.[37] In the afternoon it is reported that the unit 4 spent fuel pool was filled with water and none of the fuel rods were exposed.[38] Construction work is started to supply a working external electrical power source to all six units of Fukushima I.[39] Starting at 7 pm, police and fire water trucks with high pressure hoses attempt to spray water into the unit 3 reactor.[40] Japanese authorities inform the IAEA that engineers are laying an external grid power line cable to unit 2.[20] After watching the helicopter effort on TV, Kazunori Hasegawa, president of Chuo Construction, calls the government and offers the use of his two truck-mounted concrete boom pumps to spray water directly into the reactors. TEPCO did not respond for three days, and then stated it would wait until for the arrival of similar pumps obtained elsewhere.[41]

Second week

18–24 March

- 18 March: Tokyo Fire Department dispatches thirty fire engines with 139 fire-fighters and a trained rescue team at approximately 03:00 JST. These include a fire truck with a 22 m water tower.[42] For the second consecutive day, high radiation levels are detected in an area 30 kilometers (18.6 miles) northwest of the damaged Fukushima I nuclear plant. The reading is 150 microsieverts per hour.[43] Japanese authorities upgrade INES ratings for cooling loss and core damage at unit 1 to level 5 and issue the same rating for units 2 and 3.[20] The loss of fuel pool cooling water at unit 4 is classified as level 3.[20] In a 24-hour period ending at 11 am local time, radiation levels near the plant decline from 351.4 to 265 μSv/h, but it is unclear if the water spraying efforts were the cause of the decrease.[44]
- 19 March: A second group of 100 Tokyo and 53 Osaka firefighters replaces the previous team. They use a vehicle that projects water from a height of 22 meters for cooling spent nuclear fuel storage pool inside the reactor of unit 3.[45][46] Water is sprayed into the reactor for a total of 7 hours during the day. TEPCO reports afterward that the water was effective in lowering the temperature around the spent fuel rods to below 100 °C.[47]
- 20 March: External power is reconnected to unit 2 but work continues to make equipment operational. Repaired diesel generators at unit 6 provide power to restart cooling on units 5 and 6 which are returned to cold shutdown and their fuel cooling ponds returned to normal operating temperatures.[48][49] TEPCO announces that pressure in reactor 3's containment vessel is rising, and that it might be necessary to vent air containing radioactive particles to relieve pressure, as reported by Japanese broadcaster NHK at 1:06.[48] The operation is later aborted as TEPCO deems it unnecessary.[48] While joining in a generally positive assessment of progress toward overall control, chief cabinet secretary Edano confirms for the first time that the heavily damaged and contaminated complex will be closed once the crisis is over.[50]
- 21 March: Ongoing repair work is interrupted by a recurrence of grey smoke from the south-east side of unit 3 (the general area of the spent fuel pool) seen at 15:55 and dying down by 17:55. Employees are evacuated from unit 3 but no changes in radiation measurements or reactor status are seen. No work was going on at the time (such as restoring power) which might have accounted for the fire. White smoke, probably steam, is also seen coming from unit 2 at 18:22 JST, and this is accompanied by a temporary rise in radiation levels. A new power line is laid to unit 4 and unit 5 is transferred to its own external power from transmission line instead of sharing the unit 6 diesel generators.[51][52]
- 21 March: Officials learn that the crisis will not end with power recovering as the cooling pumps are damaged beyond repair and must be replaced. An emergency order has been placed for new pumps for unit 2 that suffered less damage than the units 1 and 3.[53][54]
- 22 March: Smoke is still rising from units 2 and 3 but is less visible and is theorized to be steam following operations to spray water onto the buildings. Repair work resumes, after having been halted because of concerns over the smoke; it is felt safe because no significant changes in radiation levels have occurred. Work continues to restore electricity, and a supply cable is connected to unit 4. Injection of seawater into units 1

–3 continues.[55] External power cables are reported to be connected to all six units. Lighting is back on again in the control room of unit 3.[56][57]

- 23 March: In the late afternoon, smoke again starts belching from reactor 3, this time black and grey smoke, causing another evacuation of workers from around the area. Aerial video from the plant shows what looks like a small fire at the base of the smoke plumes from within the heavily damaged reactor building. Feed water systems in unit 1 are restored increasing the rate water could be added to the reactor.[58] The Japanese Chief Cabinet Secretary also advises that high levels of radioactivity (around twice the legal limit for children) have been found in Tokyo's drinking water and that it should not be used to reconstitute baby formula.[59]
- 24 March: Seawater injection to units 1, 2 and 3 continues,[60] and radiation levels near the plant decline to 200 μSv/h.[61] Lighting is restored to the unit 1 control room.[62] Three workers are exposed to high levels of radiation which cause two of them to require hospital treatment after radioactive water seeps through their protective clothes.[63][64] The workers are exposed to an estimated equivalent dose of 2–6 Sv to the skin below their ankles.[65][66] They were not wearing protective boots, as their employing firm's safety manuals "did not assume a scenario in which its employees would carry out work standing in water at a nuclear power plant".[65] The activity concentration of the water is about 3.9 GBq/L. Infra-red surveys of the reactor buildings by helicopter show that the temperatures of units 1, 2, 3 and 4 continue to decrease, ranging from 11–17 °C, and the fuel pool at unit 3 is recorded to be 30 °C.[67]

Third week

25–31 March

- 25 March: NISA announces a possible breach in the containment vessel of the unit 3 reactor, though radioactive water in the basement might alternatively have come from the fuel storage pool.[68][69] Highly radioactive water is also found in the turbine buildings of units 1 and 2.[70] The US Navy sends a barge with 1,890 cubic metres (500,000 USgal) of fresh water, expected to arrive in two days.[71] Japan announces transportation will be provided in a voluntary evacuation zone of 30 kilometres (19 mi). Tap water is reported to be safe for infants in Tokyo and Chiba by Japanese authorities, but still exceeds limits in Hitachi and Tokaimura.[72] Iodine-131 in the ocean nearby measures 50 Bq/ml, a "relatively high" 1,250 times normal.[73]
- 26 March: Fresh water becomes available instead of seawater to top up reactor water levels.[74] The fresh water is provided by two United States Navy barges holding a total of 2,280 metric tons of fresh water which were towed by the Japan Maritime Self-Defense Force from Yokosuka Naval Base to Fukushima.[75] Radiation levels near the plant decline to a still high 170 μSv/h.[76]
- 27 March: Levels of "over 1000" and 750 mSv/h are reported from water within unit 2 (but outside the containment structure) and 3 respectively. A statement that this level was "ten million times the normal level" in unit 2 is later retracted and attributed to incorrectly high levels of iodine-134 (which is later reported to be below the limit by TEPCO).[77][78][79][80] Japan's Nuclear and Industrial Safety Agency indicate that "The level of radiation is greater than 1,000 millisieverts. It is certain that it comes from atomic fission [...] But we are not sure how it came from the reactor."[81] The high radiation levels delay technicians working to restore the water cooling systems for the troubled reactors.[82] USAF technicians at Yokota AB complete the fabrication of compatibility valves to allow the connection of deployed pump systems with the existing infrastructure at Fukushima.[83] An aerial video recorded by a Ground Self-Defense Force helicopter reveals, according to NHK, the clearest and most detailed view of the damaged plant to date. Significant observations include:[84]
  - White vapour, possibly steam, emanating from the buildings of reactors 2, 3, and 4.
  - The roof of the reactor 2 building has been badly damaged but is still intact.
  - The reactor 3 building is largely uncovered, its roof blown off in a hydrogen explosion over two weeks prior.
  - The walls of the reactor 4 building have also collapsed.
- 28 March: The Japanese Nuclear Safety Commission states that it "assumed" melted fuel rods in unit 2 have released radioactive substances into cooling water which subsequently leaked out through an unknown route to the unit 2 turbine building basement. To reduce the amount of water subject to leaking, TEPCO reduced the amount of water pumped into unit 2 reactor from 16 tons per hour to 7 ton per hour, which could lead to higher reactor temperatures. The highly radioactive water halts work on restoring the cooling pumps and other powered systems to reactors 1–4.[85] TEPCO confirms finding low levels of plutonium in five samples from 21 March and 22 March.[86] Enriched levels of Pu238 relative to Pu239 and Pu240 at two of the sites in the plant (solid waste area and field) indicate that contamination has occurred at those sites due to the “recent incident”. Nonetheless, the overall levels of Pu for all samples are about the same as background Pu levels resulting from atmospheric nuclear bomb testing in the past.[87]
- 29 March: TEPCO continues to spray water into reactors 1–3 and discovers that radioactive runoff water is beginning to fill utility trenches outside the three reactor buildings. The highly radioactive water in and around the reactor buildings continues to limit progress by technicians in restoring the cooling and other automated systems to the reactors.[88]
- 30 March: TEPCO Chairman Tsunehisa Katsumata announces at a news conference that it is presently unclear how the problems at the plant will be resolved. An immediate difficulty is the removal of large quantities of radioactive water in basement buildings, but also salt built up inside the reactors from using seawater for cooling will need to be removed. Building new concrete walls around the reactors is being considered as had been done at Chernobyl.[89] The EPA (Environmental Protection Agency) finds radioactive iodine in milk in the United States.[90]
- 31 March: Workers pump radioactive water from a utility trench near reactor No. 1. into a storage tank near reactor No. 4.[91] Water in the condensers for the No. 2 and No. 3 reactors is shifted to outside storage tanks so that the condensers can receive more contaminated water from the reactors.[92] The world's largest concrete pumping plant is shipped from the United States to Fukushima.[93] The pumping truck has been slightly modified to be able to pump cooling water initially, then later possibly to be used to pump concrete for any eventual permanent radiative-materials containment structure.[93][94] A 62m-tall pumping truck, donated by Chinese manufacturer SANY is used.[95]

April event tree

The nuclear accident event tree (http://www-ns.iaea.org/downloads/ni/training/specific_expert_knowledge/psa-level1/III1_2_A%20Accident%20sequence%20modelling.pdf) continued to evolve in the second month after the earthquake and tsunami caused the accident sequence to begin.

Fourth week

Saturday, 2 April

TEPCO observed for the first time that contaminated water from the unit 2 was flowing into the sea.[96] Workers discovered a crack about 20 cm (8 inches) wide in the maintenance pit, which lies between the reactor 2 and the sea and holds cables used to power seawater pumps.

Sunday, 3 April

The radioactive water leaked into the sea by unit 2 continued despite concrete pumped Saturday evening. Workers injected a mixture of a water-absorbing polymer, sawdust and shredded paper.[97] Radiation levels in the water were estimated at 1 Sv/h.

TEPCO announced that the bodies of two workers killed by the tsunami were discovered on 30 March.[98]

On Sunday, 3 April, Japanese government officials said the Daiichi plant may continue to release dangerous radiation into the air for several months.[99]

Monday, 4 April

TEPCO began dumping water tainted with low levels of radioactivity into the Pacific Ocean on Monday night, 4 April, so that a central waste facility could be used to store more dangerously radioactive water, officials said. The company said it could release up to 11,500 tons of radioactive water into the sea. A spokeswoman for Japan's Nuclear and Industrial Safety Agency said the less-contaminated water must be disposed of so that workers can secure a place to store more highly contaminated water on the site.[99]

Engineers consider plans to inject inert nitrogen gas into the containment buildings of units 1, 2 and 3 to expel atmospheric oxygen and to dilute accumulated hydrogen, which combine explosively.[100]

Tuesday, 5 April

It was determined that the leak in the cable storage pit by unit 2 was likely due to a faulty joint where the pit meets a duct, leading to a gravel layer beneath, resulting in highly radioactive water pouring directly into the sea.[101][102]

Wednesday, 6 April

TEPCO announced that an injection of 6,000 litres (1,600 USgal) of polymer coagulant into the pit mitigated the leaking;[103] however, the IAEA and others credit additional factors.[104] Sodium silicate, also known as "water glass", and additives were injected into the ground in order to stop the leakage of radioactive water.[105] The residual heat carried by the water used for cooling the damaged reactors accelerated the setting of the injected mixture.

Despite protests from the South Korean government, Russian scientists, and Japanese fishermen, Japan authorized the release of the 11,500 tonnes (12,700 tons) of less radioactive water into the ocean to make room to store more highly contaminated water.[102][106]

Iodine-131 levels reached 7.5 million times the legal limit in a seawater sample taken near the facility.[102]

Thursday, 7 April

Nitrogen injection into the pressure containment vessel of unit 1 was commenced at 01:31.[107]

A large aftershock, later downgraded from a 7.4 to a 7.1 by USGS, occurred. A tsunami warning was also issued but lifted after 90 minutes. Most of the workers at the nuclear plant were evacuated. TEPCO reported that no further damage to the nuclear plant was detected after this earthquake. [*citation needed*]

Official measures at Fukushima I reactor unit 1, however, showed a rise in temperature consecutive to the aftershock and a spiking amount of radiation in the Dry Well which exceeded the instrument maximum of 100 Sv/h.[108] Gauge B, in the meantime, has recorded a steady increase of the pressure for the previous ten days, in the same reactor.[109] Reporting the rise to 100 Sv/h up from the earlier 30 Sv/h TEPCO declared that the "validity of the measurement is questioned" both for radiation levels and pressure.

Summary

Overview and analysis, 1–7 April
Distilling significance, 1–7 April

- 1 April: TEPCO said that groundwater near unit 1 contained radioiodine at levels 10,000 times normal, but NISA later disputed the numbers.[110][111] The Japanese government was reported to be considering injecting nitrogen into reactor vessels.[112][113] Two more concrete pumping trucks, used initially to pump cooling water, were shipped to Japan from the Putzmeister factory in Germany.[94]
- 2 April: A crack leaking radioactive water into the ocean was discovered in pit housing electrical cables near the unit 2 seawater inlet. Workers were preparing to pour concrete into the 20-centimetre (7.9 in) long crack to stop the water, emitting radiation at 1 Sv/h.[114][115]
- 3 April: TEPCO confirmed the first deaths at the Fukushima facility, two workers who had been missing since 11 March and who appear to have died in the basement of reactor No. 4 from bleeding from multiple injuries inflicted by the tsunami.[113][116] The attempt to plug the leak near unit 2 failed when the concrete failed to set and TEPCO then reattempted to plug up the trench leading to the damaged storage pit with a combination of superabsorbent polymer, sawdust and shredded newspaper, which also failed.[117] Measured radiation levels in the area around the plant continues to decrease.[118][119]
- 4 April: TEPCO begun to release 10,000 metric tons of lightly radioactive water from storage tanks into the ocean. This is claimed as necessary in order to make room for more highly radioactive water which is preventing workers from making progress on restoring the cooling and other systems to reactors 1–4.[120][121] Samples of seawater near the plant revealed radioactive cesium at 1.1 million times the legal limit.[122]
- 5 April: Levels of radioactive iodine-131 in seawater near the facility were found to be 7.5 million times the legal limit.[122] TEPCO drilled a hole into the pit near reactor No. 2 from which highly radioactive water was leaking and injected water glass (sodium silicate) into the pit to prevent further leaking.[123]
- 6 April: TEPCO announced that the leak of highly radioactive water from the utility pit near reactor No. 2 has stopped.[123] According to U.S. Representative Ed Markey, the Nuclear Regulatory Commission says that the core of unit 2 has gotten so hot that part of it has melted through the reactor pressure vessel,[124] however a NRC spokesperson said, "That's not clear to us, nor is it clear to us that the reactor has penetrated the vessel."[125] TEPCO begins injection of nitrogen into unit 1 to lower the possibility of hydrogen explosions.[126]
- 7 April: Workers were evacuated following a magnitude 7.1 aftershock off the northeastern coast of Japan, 118 kilometers from the plant. TEPCO reported communications and power were not affected and no additional damage was observed as a result.[127][128]

Fifth week

Friday, 8 April

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Fuel integrity	Damaged (70% estimated)	Damaged (30% estimated)	Damaged (25% estimated)	Spent fuel possibly damaged	Not damaged	Not damaged
Reactor pressure vessel integrity	Unknown	Unknown	Unknown	Not damaged (defueled)	Not damaged	Not damaged
Containment integrity	Not damaged (estimation)	Damage and leakage suspected	Not damaged (estimation)	Not damaged	Not damaged	Not damaged
Core cooling system 1 (ECCS/RHR)	Not functional	Not functional	Not functional	Not necessary (defueled)	Functional	Functional
Core cooling system 2 (RCIC/MUWC)	Not functional	Not functional	Not functional	Not necessary (defueled)	Functional (in cold shutdown)	Functional (in cold shutdown)
Building integrity	Severely damaged due to hydrogen explosion	Slightly damaged, also panel removed to prevent hydrogen explosion	Severely damaged due to hydrogen explosion	Severely damaged due to hydrogen explosion	Panel removed to prevent hydrogen explosion	Panel removed to prevent hydrogen explosion
Pressure vessel, water level	Fuel exposed partially or fully	Fuel exposed partially or fully	Fuel exposed partially or fully	Safe (defueled)	Safe (in cold shutdown)	Safe (in cold shutdown)
Pressure vessel, pressure (Two instrument trains)	Increasing to 0.456 MPa absolute (Train A) / 0.836 MPa absolute (Train B – suspected faulty[129]) at 7 April 02:00 JST [130]	Stable at 0.090 MPa absolute (Train A) / 0.083 MPa absolute (Train B) at 7 April 02:00 JST [130]	Stable at 0.103 MPa absolute (Train A) / 0.022 MPa absolute (Train C) at 7 April 02:00 JST[130]	Safe (defueled)	Safe (in cold shutdown)	Safe (in cold shutdown)
Pressure vessel, temperature	Stable at 224 °C on 7 April[131]	Stable at 143 °C on 7 April[131]	Stable at 115 °C on 7 April[131]	Safe (defueled)	Safe (in cold shutdown)	Safe (in cold shutdown)
Containment pressure	Stable at 0.150 MPa (absolute) at 7 April 02:00 JST [130]	Stable at atmospheric pressure on 6 April [131]	Stable at 0.1071 MPa (absolute) at 7 April 02:00 JST [130]	Safe	Safe	Safe
Seawater injection into core	Continuing (switched to freshwater 25 March)[74]	Continuing (switched to freshwater 26 March)[74]	Continuing (switched to freshwater 25 March)[74]	Not necessary (defueled)	Not necessary	Not necessary
Seawater injection into containment vessel	To be decided	To be decided	To be decided	Not necessary	Not necessary	Not necessary
Containment venting	Temporarily stopped	Temporarily stopped	Temporarily stopped	Not necessary	Not necessary	Not necessary
INES	Level 5	Level 5	Level 5	Level 3	–	–
Environmental effect	■ Radiation levels: ■ South side of office building: 650 μSv/hour at 8 April 15:00 JST ■ Main gate: 94 μSv/hour at 8 April 15:00 JST ■ West gate: 40 μSv/hour at 8 April 15:00 JST					

	■ Levels of radioactive iodine 4,385 times higher than regulatory limits were detected in seawater samples on 30 March ■ Levels of radioactive iodine 7.5 million times higher than regulatory limits were detected in seawater samples near the unit 2 water intake on 2 April ■ On 2 April, highly radioactive (over 1 Sv/hour) water was discovered leaking from a concrete structure housing electrical cables into the sea through cracks in the concrete wall; as of 6 April, this leakage has been stopped ■ On 4 April, the release of 10,000 tons of low-level radioactive waste water began in order to make room for the highly radioactive water discovered on 2 April ■ Radioactive material was detected in underground water sampled near the turbine buildings on 30 March ■ Radioactive material has been detected in milk and agricultural products from Fukushima and neighboring prefectures, prompting government limits on shipments (21 March) and intake (23 March) for some products ■ Radioactive iodine was found in tap water in some prefectures between 21 and 27 March, prompting government warnings not to drink the water in those regions; as of 2 April, these warnings have been lifted ■ Levels of radioactive caesium above regulatory limits were detected in small fish caught off the coast of Ibaraki on 4 April					
Evacuation radius	20 km from the nuclear power station, but 30 km should consider leaving as of 25 March 11:30 JST[132]					
General status from all sources regarding reactor cores	Stabilized by injecting sea water and boron	Stabilized by injecting sea water and boron	Stabilized by injecting sea water and boron; pressure elevated on 20 March	Defueled	Cold shutdown on 20 March 14:30 JST	Cold shutdown on 20 March 19:27 JST
General status from all sources regarding Spent Fuel Pools	Sprayed freshwater injection started, 60 °C on 20 March by infrared helicopter measurement[133]	Freshwater injection continues, 71.0 °C on 5 April 06:00 JST [134]	Sprayed freshwater injection continues, 60 °C on 20 March by infrared helicopter measurement[133]	Sprayed freshwater injection continues after hydrogen explosion from pool on 15 March, 40 °C on 20 March by infrared helicopter measurement [133]	Cooling system restored, 34.8 °C on 4 April 13:00 JST [134]	Cooling system restored, 27.5 °C on 4 April 13:00 JST [134]
Information sources[135][136][137][138][139][140][141][142][143][144][145][146][147][148][149][150][151][152][153][154][155][156][157][158][159][160]						

Saturday, 9 April

Japan is still struggling to keep water on the reactors to cool them and prevent further meltdown. Russian Antonov An-124 cargo planes fly out of Atlanta and Los Angeles, each carrying a huge concrete boom pump. The two 95-ton boom pumps which TEPCO purchased for $2million each, can be operated from two miles away by remote control. Each boom pump can direct focused streams of water into the damaged reactors.[161]

Currently TEPCO does not plan to take a Chernobyl approach to resolving nuclear power plant crisis by entombing the radioactive material in concrete.[162] If this decision were to change, the boom pumps could be retrofitted to deliver concrete for that purpose.[161]

Monday, 11 April

Coolant injection into reactors 1 and 3 is interrupted for 50 minutes due to a loss of power after a strong earthquake.[163]

Tuesday, 12 April

Japan officially raises Fukushima to INES Level 7, the same as Chernobyl.[164][165] This new rating considers the accidents as a single event and uses estimated total release to the atmosphere as a justification.[166]

Following the hydrogen explosion in the No. 1 reactor building on 12 March and releases from the No. 3 reactor building, the equivalent of 190,000 terabecquerels of radioactive iodine had been spewed from the reactor buildings by 15 March, according to calculations by the Nuclear Safety Commission of Japan. A terabecquerel is equivalent to 1 trillion becquerels. That high level meant that by 15 March the Fukushima plant accident had already reached the worst level 7 on the International Nuclear and Radiological Event Scale, matching the assessment given to the 1986 Chernobyl nuclear disaster, in Mid March.[167] Since that time, the Fukushima reactors have continued to emit radiation, including atmospheric, water, and gamma ray releases.

At Chernobyl, approximately 10 times the amount of radiation was released into the atmosphere as was released from Fukushima I through 12 April 2011.[168] The total amount of radioactive material still stored at Fukushima is about 8 times that stored at Chernobyl, and leakage at Fukushima continues.

After cooling efforts at spent fuel pool 4 were halted due to an erroneous warning about the pool filling up,[169] the temperature of the pool rises to 90 °C and the dose rate 6 meters above the pool spikes at 84 mSv/h.[170]

Summary

Before the crisis evaluation was elevated by Japanese authorities to level 7, the highest level, experts already recognized that Fukushima is the most complicated nuclear accident ever.[171]

Overview and analysis, 8–14 April

Distilling significance, 8–14 April

Prior to the elevation to level 7 by the Japanese authorities, James Acton, Associate of the Nuclear Policy Program at the Carnegie Endowment for International Peace, was of the opinion that "Fukushima is not the worst nuclear accident ever but it is the most complicated and the most dramatic ... This was a crisis that played out in real time on TV. Chernobyl did not."[172]

A 9 April survey of radiation in seawater outside unit 2 shows radioactive isotope concentrations (iodine-131, caesium-134 and caesium-137) falling for the third straight day since the leak was plugged. However, the levels are still high, at several thousand times legal levels. Other nuclides are being investigated, but Japan regulator NISA has flagged up problems with TEPCO's sampling methodology.[173]

(11 April) Workers plan to pump the water into turbine condensers, but need to pump water out of them first. Work to transfer water from the unit 2 and 1 condenser to a central storage tank was completed on 9 and 10 April. Also, workers have knocked holes through the turbine hall buildings of units 2 and 4 to accommodate hoses for the water transfer. At unit 3, work continues to make space for water in the turbine condenser by pumping operations in other tanks. Japanese news wire NHK reports that workers are laying hoses to transfer water to a LLW waste processing facility, which continues to be inspected. TEPCO says that it cannot start work switching on emergency systems on site until the turbine hall is dry. NHK also reported that radioactive water filling a tunnel near unit 2 has risen 12 cm since a leak in a trench was stopped on Wednesday 6 April.[173]

Sixth week

Plans are announced for a large-scale study on the environmental and health effects of radioactive contamination from the nuclear plant. Academics and researchers from across Japan will work with the Fukushima Prefectural Government starting in May.[174]

Nuclear fuel is reported to have melted and fallen to the lower containment sections of reactors one, two and three. The melted material is not expected to breach a container (which might cause a massive radiation release). Instead, the melted fuel is thought to have dispersed fairly uniformly across the lower portions of the containers of the three reactors, which would make the resumption of the fission process, to the extent of a recriticality accident, 'most unlikely'.[175] However, it is only during future dismantling of the three damaged reactors that it would be possible to verify this hypothesis and to know what really occurred inside the reactor cores.

Monday, 18 April

The Associated Press is reporting that two PackBot ground robots from iRobot have entered unit 1 and unit 3 of the crippled Fukushima nuclear power plant and performed temperature, pressure, and radioactivity measurements. The remote-controlled robots entered the two reactors over the weekend. The devices opened closed doors and explored the insides of the reactor buildings, coming back with radioactivity readings of up to 49 millisieverts per hour inside unit 1 and up to 57 millisieverts per hour inside unit 3. TEPCO officials say that the radiation data from the robots do not change their plans for shutting down the plant by the end of this year. And though more robots will be used, a TEPCO official, Takeshi Makigami, says that robots are limited in what they can do and eventually "people must enter the buildings".[176] Robots also entered unit 2, but the probe was hindered by fogging of the robot's camera lens from the high humidity, over 90%, inside the building.[177]

Test spraying of an "anti-scattering agent" on the ground to prevent further spread of radioactive materials from the site is carried out over an area of about 1200 m^2.[178]

Tuesday, 19 April

TEPCO begins transferring excess radioactive cooling water from the reactor No. 2's basement and maintenance tunnels to a waste processing facility.[179] Operations to pump radioactive water present in the basements of buildings of units 1, 2, 3 and tunnels start with unit 2.[180]

Seventh week

Friday, 22 April

Prime Minister Naoto Kan states additional towns might be asked to evacuate, which largely involve agricultural lands.[181] Also mentioned, the government plans to build 30,000 temporary homes by the end of May, and an additional 70,000 will follow.

The president of the Tokyo Electric Power Company (TEPCO) Masataka Shimizu formally apologizes at the prefectural government office in Fukushima to the Fukushima Governor Yuhei Sato for the nuclear crisis following the 11 March 2011 massive earthquake and tsunamis.[182] In response, the Governor requests better working conditions for the workers.

Tuesday, 26 April

Prevention of the proliferation of dust: TEPCO initiates spraying a synthetic resin to contain contaminated dust and continues.[180]

Wednesday, 27 April

Junichi Matsumoto, a general manager at Tokyo Electric Power Co. reports that radiation readings taken by two iRobot Corp. PackBot robots inside reactor No. 1 building are as high as 1120 mSv/h which is the highest level disclosed to date.[183]

May event tree

Monday, May 2

T. Matsui of the University of Tokyo Institute of Physics releases a scientific paper analysing the ratio of Iodine-131 to Cesium-137 taken from water samples, which concludes that a recriticality may have occurred at least 10 - 15 days after the attempted shutdown.[184]

Thursday, 5 May

Workers enter the reactor 1 building. This is the first time since the start of the crisis that a reactor building in the plant is visited by a human being. The workers will connect a ventilation system that should absorb radiation inside the building for the next 4-5 days, allowing them to start installation of the cooling system replacement. Because of protective gear the workers were only exposed to a small amount of radiation (about 2 mSv). [185] TEPCO expects to bring the plant into a cold shutdown within six to nine months. IAEA releases a briefing.[186]

Tuesday, 10 May

In a press release[187], TEPCO reports that levels of cesium-134, cesium-136, cesium-137, and iodine-131 (half-life of ~ 8 days), had spiked since last sampled on March 2, 2011, when these four nuclides were below detection limits. TEPCO's report[188] gives the newly measured concentration (Bq/cm^3) of each nuclide as of sampling date, May 8.

Thursday, 12 May

TEPCO engineers confirm that a meltdown occurred, with molten fuel having fallen to the bottom of the reactor's containment vessel.[189] The utility says fuel rods of the No. 1 reactor are fully exposed with the water level 1 meter (3.3 feet) below the base of the fuel assembly. The government and Tepco are described as "*consistently appeared to be underestimating the severity of the situation.*" According to a Japanese press report, there are holes in the base of the pressure vessel, and most of the fuel has likely melted. The nuclear fuel has possibly leaked into the containment vessel, which was damaged by an explosion during the crisis.[190] However, the Nuclear Energy Institute, a nuclear lobbying firm, states that the situation "*is in no way alarming. It was anticipated that there was fuel damage in reactors 1, 2 and 3. This is confirmation.*"[191]

Saturday, 14 May

A third TEPCO (contractor) employee dies, after falling ill at 06:50, being brought to the plant's medical room unconscious. The likely cause of death is a heart attack.[192] TEPCO says he was exposed to 0.17 millisieverts of radiation on Saturday. [193]

Sunday, 15 May

A robot sent to the first floor of unit 1 records a radiation level of 2,000 mSv/h. At this level, workers would only be allowed to stay in the area for 8 minutes. In addition, the reactor's containment vessel is leaking large amounts of water into the basement. A TEPCO worker is able to peer into the basement and determines that the 11 m deep basement is approximately half full of water.[194]

TEPCO releases a report on the core status of reactor 1, revealing that fuel elements had become exposed above the water just 4 hours after the earthquake and SCRAM, and had fully melted after 16 hours.[13]

Wednesday, 18 May

Four workers in protective suits and SCBA enter unit 2 for the first time since the March 15 explosion, to check on radiation levels and other conditions inside the building. The workers receive a dose of between 3 and 4 mSv each.[195]

Friday, 20 May

TEPCO president Masataka Shimizu resigns after reporting the largest financial losses in the company's history.[196]

Sunday, 22 May

TEPCO reports that reactor No. 3 leaked at least 250 tons of radioactive water into the Pacific Ocean over a period of 41 hours beginning on May 10, 2011.[197]

Tuesday, 24 May

On the eve of the arrival in Tokyo of a delegation from the International Atomic Energy Agency, TEPCO admits that the cores of reactor 2 and reactor 3 also melted down in the days immediately following the earthquake in mid-March, 2011.[198] 16 hours after the earthquake and SCRAM[13], the fuel rods of reactor 1 had "mostly melted and fallen into a lump at the bottom of the pressure vessel — a state that TEPCO officials have described as a 'meltdown'".[199] A TEPCO spokesman Yoshimi Hitosugi stated last night, "The situation inside two and three is almost the same." TEPCO further stated that the fuel in reactor three took about 60 hours to melt and that the reactor melted down 100 hours after the magnitude nine quake struck.[200]

Wednesday, May 25

TEPCO informs the Nuclear and Industrial Safety Agency and the government of Fukushima Prefecture of the results of soil tests for plutonium (^{238}Pu, ^{239}Pu and ^{240}Pu) carried out around the Fukushima Daiichi plant. While the levels were comparable to the fallout in Japan from atmospheric nuclear testing, TEPCO deemed that the plutonium had originated from the accidents.[201]

Saturday, May 28

TEPCO informs the Nuclear and Industrial Safety Agency and the government of Fukushima Prefecture of the results of soil tests for uranium (^{234}U, ^{235}U and ^{238}U) carried out around the Fukushima Daiichi plant. The uranium found was considered to be natural, as its isotope ratios were consistent with the natural abundance.[202]

At 21:14 a cooling pump at reactor five stops. At 08:12 the next day, work began on a spare pump, and cooling was restored at 12:49.[203] The reactor temperature had risen to 92.2 °C. The cause of the outage is suspected to be motor failure.[204]

Sunday, May 29

It is reported that 22 out of 23 radiation monitoring systems around the Fukushima plants were disabled by the earthquake and tsunami. Some were directly damaged, but most were disabled due to communication and power lines being cut. Even monitors equipped with backup satellite links failed, probably due to antenna damage. In Miyagi prefecture, 4 out of 7 were disabled by the tsunami, with the remaining three stopping after three hours. In Ibaraki, some 40 monitors stopped working for three hours until power could be restored.[205]

The first of the typhoons of the season is due to strike the area, while Japan states radiation levels at the seabed are several hundreds of times above normal levels off the coast of Fukushima. "The Science Ministry announced late on Friday highly radioactive materials were detected in a 300-km north-south stretch from Kesennuma in Miyagi Prefecture to Choshi in Chiba Prefecture, the Kyodo news agency reported."[206]

TEPCO reports that cooling has been restored for spent fuel pools 1 to 4.[204]

Tuesday, May 31

An oil spill near reactors five and six is detected at 8:00 am, as well as an explosion heard at 2:30 pm near reactor four.[207][208] TEPCO reports that the explosion was the bursting of an oxygen cylinder damaged by unmanned machinery during debris removal.[209]

TEPCO states that there was a temporary oil leak into the sea near the plant, from an oil pipe that may have been damaged in the March disaster. It is stated as being an extremely small leak, possibly caused by recent rainy weather from Typhoon Songda. TEPCO says that the leak has stopped and oil fences have been installed to prevent the liquid from spreading into the Pacific Ocean.[210][211][212]

June event tree

Friday, June 3

The first confirmed case is released in which radiation levels in humans have exceeded the limit since the accident at the plant.[213] One worker in his thirties received 678 mSv, while another one in his forties received 643 mSv.[214] Before the accident, the limit for emergency situations was 100 mSv, but it was raised by the government to 250 mSv just after the accident. The two TEPCO workers were on duty in the central control rooms of reactors No. 3 and 4 and they have told the health and labor ministry that they don't remember whether they wore protective masks or not when a hydrogen explosion occurred at the No.1 reactor on March 12th.[215]

Saturday, June 4

Air radiation readings of up to 4000 millisieverts per hour are recorded in the reactor number 1 building.[216]

Monday, June 6

Japan's Nuclear and Industrial Safety Agency (NISA) gives new estimates of the times at which the reactor pressure vessels were damaged and possibly dropped fuel into the containment vessels: 5 hours after the great earthquake for reactor 1 (20:00 March 11), 80 hours for reactor 2 (22:50 March 14), and 79 hours for reactor 3 (22:10 March 14).[217] In addition, NISA more than doubles its original estimate of radiation that escaped into the atmosphere in the first six days, from 370,000 terabecquerels to 770,000 terabecquerels.[218]

Wednesday, June 8

The ministry of education says that strontium ^{89}Sr and ^{90}Sr have been detected in soil samples 22-62 km away from Fukushima Daiichi plant, collected from late March to early May. The highest values are reported in Namie town, at 1,500 Bq/kg of strontium ^{89}Sr, and 250 Bq/kg of strontium ^{90}Sr.[219]

The Japanese government's report[220] to IAEA on the Fukushima disaster is described in an article in the Yomiuri newspaper. The government report states that nuclear fuel has possibly melted through the base of the pressure vessels in the first three reactors. With data from the government report, the newspaper compares the March timelines provided by TEPCO and by NISA, which had performed further analysis; there were differences in theoretical time of events of up to 29 hours in the days following the tsunami. The newspaper describes a melt-through as being the worst possibility in a nuclear accident.[221]

Thursday, June 9

A spokesman for TEPCO says the company is revising its earlier road-map for bringing the plant under control, including the time expected to be required to achieve cold shutdown.[222]

Tuesday, June 14

From 00:44 to 02:35 there has been a massive steam and smoke release from unit 3, recorded by the TEPCO live cam.[223][224] No explanation has been given yet by TEPCO officials.

Wednesday, June 15

TEPCO begins a trial run of a radioactive water treatment system in an effort to break away from the vicious cycle of injecting water into reactors to cool them and ending up with more contaminated water.[225] While contaminated water is treated, the system is expected to produce about 2,000 cubic meters of radioactive sludge by the end of 2011.

Saturday, June 18

The radioactive water treatment system is forced to shut down because a filter exceeds its radioactivity limit. The filter, which removes cesium from the water, was expected to last about a month before its cartridge required replacing at a radiation level of 4 millisieverts per hour. However the radiation levels near the filter cartridge replacement valves reach 4.7 millisieverts per hour after just 5 hours of operation, reportedly due to oil and sludge in the water which contained more radioactivity than expected.[226][227]

Sunday, June 19

Radiation in some areas of Tsukidate, 50 km NW of the Fukushima 1 plant, exceeds the legal limit. The government plans to help households in designated areas to evacuate, raising concern among residents. Although the Tsukidate elementary school has not detected radiation levels in excess of the legal limit, about 80 parents and teachers thoroughly wash windows and verandas with high-pressure water jets and brushes and the school suspends activities on the playground in response to concern by parents.[228]

Tuesday, June 21

A radiation reading of 430 millisieverts per hour is recorded in a mezzanine between the first floor and basement of reactor 2. This is the highest level measured up to this point in the reactor 2 building, and marks the first time that workers have entered the basement of this building since the beginning of the crisis.[229]

Monday, June 27

Although the radioactive water treatment system has not yet started full-scale operation, a total of 1,850 tons of radioactive water has been processed during test runs of the system. Today for the first time this decontaminated water is used to cool the reactors. TEPCO states that it will continue injecting 16 tons of water per hour for cooling the 3 reactors, and that 13 tons of this will be made up from the decontaminated water.[230] However, the recycling system operates for only 90 minutes before it is halted due to a burst connection which leaks about one ton of water.[231]

See also

- 2011 Japanese nuclear incidents
- Fukushima Daiichi nuclear disaster

- Radiation effects from Fukushima Daiichi nuclear disaster
- Fukushima 50
- 2011 Tōhoku earthquake and tsunami
- List of civilian nuclear incidents (2010s)
- Lists of nuclear disasters and radioactive incidents
- Nuclear safety

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