Fukushima Nuclear Crisis

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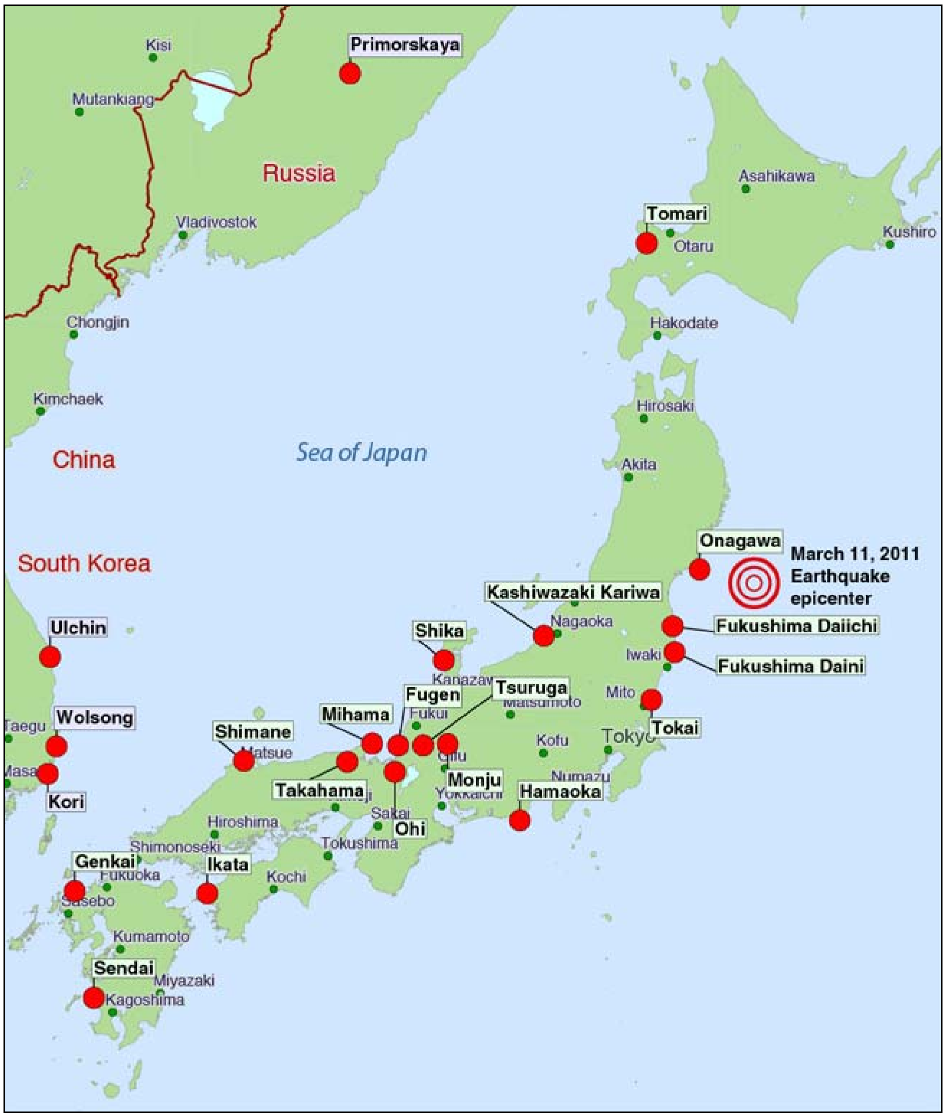
Summary of the Crisis

The earthquake on March 11, 2011, off the east coast of Honshu, Japan's largest island, reportedly caused an automatic shutdown of eleven of Japan's fifty-five operating nuclear power plants.[1] Most of the shutdowns proceeded without incident. However, the plants closest to the epicenter, Fukushima and Onagawa (see **Figure 1**), were damaged by the earthquake and resulting tsunami. The Fukushima Daiichi plant subsequently suffered hydrogen explosions and probable nuclear fuel damage, releasing significant amounts of radioactive material into the environment.

Figure 1. Japan and Earthquake Epicenter



Source: Nuclear Energy Institute, edited by CRS.

Notes: http://i1107.photobucket.com/albums/h384/reactor1/japan_map1.jpg.

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[1] *BBC News*, "Timeline: Japan Power Plant Crisis," March 13, 2011, http://www.bbc.co.uk/news/science-environment-12722719.

Tokyo Electric Power Company (TEPCO) operates the Fukushima nuclear power complex in the Futaba district of Fukushima prefecture in Northern Japan, consisting of six nuclear units at the Daiichi station and four nuclear units at the Daini station. All the units at the Fukushima complex are boiling water reactors,[2] with reactors 1 to 5 at the Daiichi site being the General Electric Mark I design (see **Figure 2**).[3] The Fukushima Daiichi reactors entered commercial operation in the years from 1971 (reactor 1) to 1979 (reactor 6). At the time of the earthquake, reactors 1, 2, and 3 at Daiichi were operating and shut down after the quake, while reactors 4, 5, and 6 were already shut down for routine inspections. All four of the Daini reactors were operating at the time of the earthquake and taken down after the quake.

Nuclear reactors produce power by fissioning (splitting) the nuclei of heavy isotopes, such as uranium-235 and plutonium-239, through the absorption of neutrons. Each fission event generates additional neutrons that induce more fission events, creating a continuous nuclear chain reaction. The heavy nuclei split into lighter isotopes called fission products, many of which are highly radioactive, such as iodine-129, iodine-131, strontium-90, and cesium-137. To shut down the nuclear chain reaction, neutron-absorbing control rods[4] are inserted into the reactor core. However, even though the fission process has stopped, the fission products and other radioactive isotopes in the reactor core continue to generate significant heat through radioactive decay. Until the decay heat sufficiently diminishes, a source of electricity is needed to operate pumps and circulate water in the reactor. Under normal conditions, it would take a few days for a reactor core to cool down to a "cold shutdown" state.[5]

The magnitude 9.0 earthquake triggered a tsunami that struck the coast, devastating much of the area and overtopping a six-meter-high seawall at Fukushima Daiichi station. TEPCO estimated the tsunami's height at Fukushima Daiichi to be 14 meters (46 feet).[6] The station was cut off from Japan's national electricity grid, leaving the plant dependent on backup diesel generators. The tsunami flooded the generators, sweeping away the diesel fuel tanks, and knocking out the backup cooling capability for the station's nuclear reactors.[7]

[2] A common nuclear power reactor design in which water flows upward through the core, where it is heated by fission and allowed to boil in the reactor vessel. The resulting steam then drives turbines, which activate generators to produce electrical power. BWRs operate similarly to electrical plants using fossil fuel, except that the BWRs are powered by 370–800 nuclear fuel assemblies in the reactor core rather than burning coal or natural gas to create steam. U.S. Nuclear Regulatory Commission, "Boiling-Water Reactor (BWR)," http://www.nrc.gov/reading-rm/basic-ref/glossary/boiling-water-reactor-bwr.html.

[3] Nuclear Information and Resource Service, "Fact Sheet on Fukushima Nuclear Power Plant," http://www.nirs.org/reactorwatch/accidents/Fukushimafactsheet.pdf.

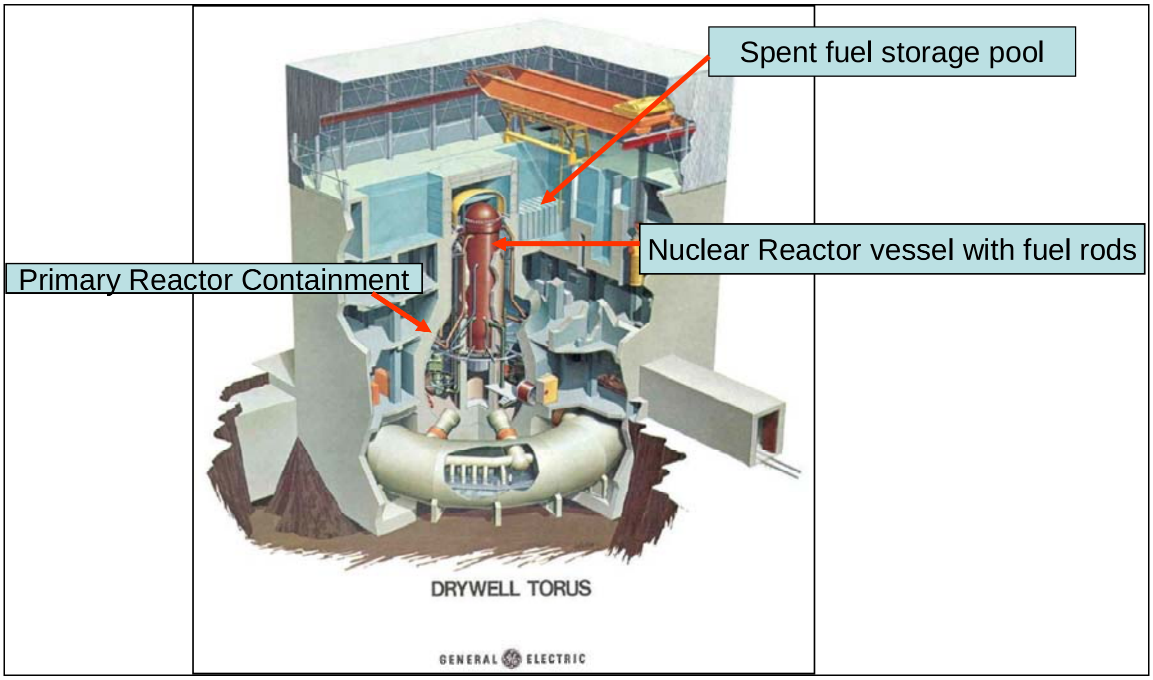
[4] A rod, plate, or tube containing a material such as hafnium, boron, etc., used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fissions. U.S. Nuclear Regulatory Commission, "Control Rod," http://www.nrc.gov/reading-rm/basic-ref/glossary/control-rod.html.

[5] U.S. Nuclear Regulatory Commission, "Cold Shutdown," http://www.nrc.gov/reading-rm/basic-ref/glossary/cold-shutdown.html.

[6] *World Nuclear News*, "Fukushima Faced 14-Metre Tsunami," March 23, 2011, http://www.world-nuclear-news.org/RS_Fukushima_faced_14-metre_tsunami_2303113.html.

[7] *BBC News*, "Timeline: Japan Power Plant Crisis," March 13, 2011, http://www.bbc.co.uk/news/science-environment-12722719.

Figure 2. General Electric Mark I Boiling Water Reactor and Containment Building



Source: http://www.nrc.gov/.

TEPCO immediately began to experience problems with the Daiichi units, as temperatures began to rise in the reactors. With the primary and secondary cooling systems for the Daiichi reactors offline, TEPCO began trying to cool the reactor cores with seawater. Neutron-absorbing boron[8] has been added to the seawater to prevent restart of the nuclear chain reaction. Despite those efforts, cooling water levels in the reactor cores remained low for many days, probably resulting in fuel melting and other damage.

Loss of cooling capacity also affected the plant's spent fuel pools (shown in **Figure 2**), which hold fuel rods that have been removed from the reactors after their ability to sustain a nuclear chain reaction has diminished. Although much of the radioactivity in the spent fuel has been decaying for many years, the large volumes of spent fuel in the pools represent a significant total heat load. If water in the spent fuel pools boils away or leaks out, the spent fuel rods may overheat and release radioactive material into the air.

A major hazard posed by overheated nuclear fuel is the generation of hydrogen through a chemical reaction between the fuel's zirconium cladding and high-temperature water or steam. Hydrogen is believed to be responsible for major explosions that occurred at the plant after cooling capacity was lost.

Abnormal releases of radioactive material have occurred at the plant, most likely from leaking or venting from the primary containment structure that surrounds the reactor pressure vessel, and from at least one of the spent fuel pools. Radioactive contamination exceeding regulatory limits has been found in seawater around the plant, as well as contamination of agricultural products

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[8] Boron is the main material that goes into control rods used to halt or slow fission reactions in nuclear reactors. *Japan Times Online*, "Seoul to Send Boron in Bid to Cool Reactors," March 16, 2011, http://search.japantimes.co.jp/cgi-bin/nn20110317a9.html.

exceeding legal standards in surrounding prefectures.[9] Radioactive contamination in Tokyo drinking water was measured at "more than twice the accepted level for infants."[10]

Status of the Fukushima-Daiichi Reactors

All units of the plant were reconnected to off-site electrical power by March 23, although cooling pumps and other equipment were awaiting integrity checks before being activated. Diesel-generated backup power had been available at units 5 and 6 since March 19. Top priorities are restoring core cooling to units 1-3 and to the spent fuel pools in units 1-4.[11]

Unit 1

Unit 1 was generating electricity when the earthquake occurred and shut down automatically, but the resulting tsunami halted emergency core cooling. A large hydrogen explosion occurred on March 12, severely damaging the reactor building. Plant workers began injecting seawater into the reactor pressure vessel on March 12 through a fire extinguisher line. Nuclear fuel in the reactor core is partially uncovered by water and believed to be damaged, and the integrity of the reactor pressure vessel is unknown. The reactor's primary containment structure is not believed to be damaged. The condition of spent fuel in the spent fuel pool is unknown.

Unit 2

Unit 2 was generating electricity and automatically shut down during the earthquake, subsequently losing cooling capacity in the tsunami. Seawater injection into the reactor vessel began March 14, but water levels in the reactor vessel were noted to still be decreasing. An explosion occurred on March 15, and pressure subsequently dropped in the drywell torus (see **Figure 2**), leading to concern that it had been damaged. Seawater injection into the spent fuel pool began March 20. White smoke from an unknown source rose from the building March 21 and stopped the next day. Nuclear fuel in the reactor core is partially uncovered by water and believed to be damaged. The condition of the reactor pressure vessel is unknown. High radiation has been measured in the Unit 2 turbine building, which is adjacent to the reactor building. The condition of spent fuel in the spent fuel pool is unknown.

Unit 3

Unit 3 was generating electricity and shut down automatically during the earthquake and lost cooling during the tsunami. Seawater injection into the reactor vessel began on March 13. Pressure in the primary containment structure rose at about 8 a.m. March 14, and a hydrogen explosion occurred about three hours later that severely damaged the reactor building. White smoke rose from the unit on March 16. Nuclear fuel in the reactor core is partially uncovered by water and believed to be damaged, and the integrity of the reactor pressure vessel is unknown. Unit 3 has operated with plutonium-based fuel since September 2010,[12] heightening concern

[9] Japan Atomic Industrial Forum, "Status of Nuclear Power Plants in Fukushima as of 22:00 March 24," March 24, 2011, http://www.jaif.or.jp/english/.

[10] U.S. Department of State, Bureau of Legislative Affairs, "Japan Earthquake Update 19," March 23, 2011.

[11] Ibid.; additional status information is from: Japan Nuclear Energy Safety Organization, "The State of Fukushima Dai-ich by the Impact of Tohoku Pacific Ocean Earthquake," March 23, 2011.

[12] World Nuclear Association, "Nuclear Power in Japan," February 24, 2011, http://www.world-nuclear.org/info/inf79.html.

about the condition of the reactor core. Although plutonium, a hazardous radioactive element, is also created during irradiation of conventional nuclear fuel, there is substantially more in the Unit 3 core than in the other units. The reactor containment structure is not believed to be damaged. Damage is suspected to the spent fuel in the spent fuel pool. Seawater was dropped by helicopters and sprayed from fire trucks into the spent fuel pool starting on March 17, but water levels remained low as of March 24.

Unit 4

Unit 4 was out of service for maintenance when the earthquake struck. All its nuclear fuel had been moved to the spent fuel pool, which eliminated the need for cooling the reactor core but greatly increased the spent fuel pool's heat load. A hydrogen explosion severely damaged the reactor building on March 15. Spraying of water into the spent fuel began on March 20. Water levels remained low in the spent fuel pool on March 24, and damage was suspected to the stored fuel.

Units 5 and 6

Units 5 and 6, which are located separately from units 1-4, were not operating during the earthquake. Diesel backup power was restored by March 19, and cold shutdown of both units was declared on March 20. Holes were opened in the roofs of the reactor buildings to prevent hydrogen buildup. No other damage has been reported to the reactor buildings or spent fuel.

Fukushima Daini

The Fukushima Daini station is approximately 12 kilometers south of the Daiichi station, and further removed from the epicenter of the earthquake. The earthquake and tsunami apparently caused damage to the emergency core cooling systems at reactors 1, 2, and 4, while reactor 3 was apparently able to shut down without problems. The station reportedly retained offsite power to maintain its ability to circulate cooling water in the reactor. The makeup water and condensate systems were used as an emergency measure to maintain cooling water levels in reactors 1, 2, and 4. TEPCO has since made repairs to the cooling systems, and stable, cold shutdown conditions were reported at all Daini reactors on March 14, 2011.[13]

U.S. Assistance

The United States and other countries, as well as the International Atomic Energy Agency, are providing assistance to Japan to deal with the nuclear crisis. According to the U.S. State Department, Japan has requested foreign assistance that includes consequence management support, transport of pumps, boron, fresh water, remote cameras, global hawk surveillance, evacuation support, medical support, and decontamination and radiation monitoring equipment. A U.S. Nuclear Regulatory Commission advisory team is in Japan at the Japanese government's request. The Department of Energy has sent radiation monitoring equipment, and the U.S. Department of Defense has provided high-pressure water pumps and fire trucks.

[13] *World Nuclear News*, "All Fukushima Daini Units in Cold Shutdown," March 14, 2011, http://www.world-nuclear-news.org/IT-All_Fukushima_Daini_units_in_cold_shutdown-1503114.html.

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