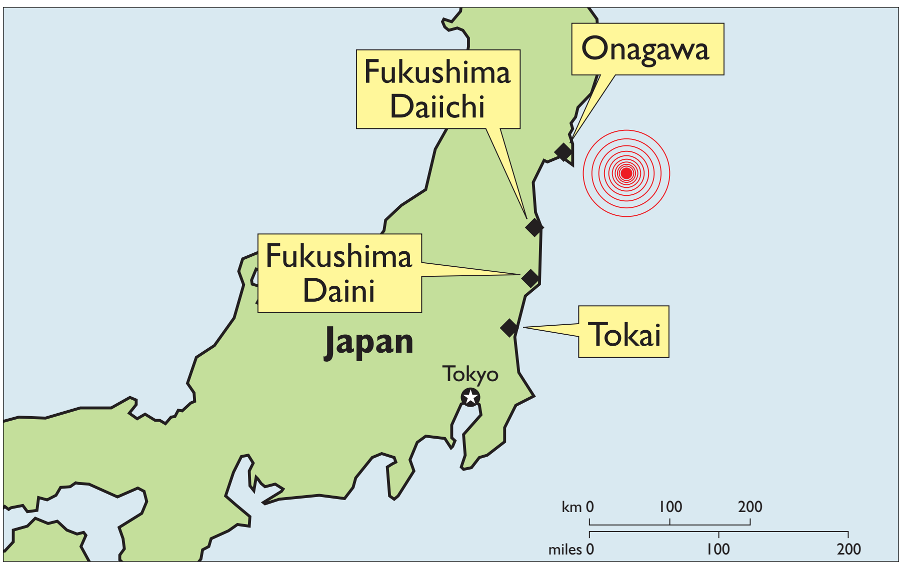
Nuclear News Special Report: Fukushima Daiichi after the Earthquake and Tsunami

Natural disasters lead to nuclear emergency at Japan's Fukushima Daiichi

This report was prepared by the Nuclear News *staff, based on the best information available to us through March 24. Special thanks are due our contacts in Japan—Yoshiaki Oka, head of the Joint Department of Nuclear Engineering in the Graduate School of Advanced Science and Engineering at Waseda University and emeritus professor of the University of Tokyo, and Akira Omoto, a professor at the University of Tokyo and a commissioner on the Japan Atomic Energy Commission—who provided us with invaluable information and answers, via e-mail, to the many questions we presented to them. (Their input is based on their personal expertise and does not necessarily represent the viewpoints of the organizations for which they work.) The other main sources used to gather information include the Japan Atomic Industrial Forum, Japan's Nuclear and Industrial Safety Agency, and the International Atomic Energy Agency.*

This satellite image, released by DigitalGlobe on March 18, shows the substantial damage to the external structures of the reactor buildings of (from left) Units 4, 3, 2, and 1 of the Fukushima Daiichi plant. The hydrogen explosions that caused the damage occurred outside of the reactor containments. (Photo: Reuters/DigitalGlobe/Handout)



Onagawa was the nuclear plant closest to the epicenter of the earthquake, but it was not significantly affected by the tsunami that inundated northeast Honshu, and it was quickly taken to cold shutdown. The one operable reactor at Tokai also reached cold shutdown without incident. Two reactors at Fukushima Daini experienced pressure control problems, but eventually all four reached cold shutdown.

On Friday, March 11, an earthquake and a tsunami of unprecedented magnitude led to major problems in the stabilization of nuclear power reactors in northeast Japan. While all operating reactors in the earthquake zone underwent automatic shutdown, with control rods inserting into the reactor cores as intended because of ground acceleration, efforts to bring the reactors at Tokyo Electric Power Company's (Tepco) Fukushima Daiichi plant to cold shutdown and to maintain spent fuel pool cooling were hampered by the effects that the tsunami had on plant property and on nearby infrastructure.

Radioactive material was released to the environment as a result of the venting of the containments to reduce pressure, as normal cooling was not available, and hydrogen explosions that damaged the external structures of the reactor buildings. Readings from neutron detectors, however, indicate that no nuclear chain reactions have taken place since the control rod insertions. Tepco personnel have concluded that fuel has been damaged in all three of the reactors that were in operation before the quake, and a containment breach is believed to have occurred in the vicinity of the Unit 2 suppression pool, but new fission has not taken place. The released radioactive material has been attributed to fuel damage within the three reactors and perhaps in the spent fuel pools of Units 3 and 4.

According to the U.S. Geological Survey, the quake began at 2:46:23 p.m. (Japan time). The quake's epicenter (the point on the earth's surface directly above the quake) was in the Pacific Ocean, 80 miles east of the city of Sendai, which is located on the eastern coast of Japan's central island of Honshu. The center of the quake was at a depth of 20 miles below sea level. Originally measured at 8.8 on the Richter scale, on March 14 the earthquake was officially designated a 9.0 magnitude. Reports from some locations in Japan described the duration of the quake to be as long as three minutes. The quake set off a massive tsunami, which not only brought devastating floods to the northeast coast of Honshu but caused more damage and loss of life when the vast quantity of water receded.

The quake's ground acceleration was great enough to cause automatic shutdowns at four nuclear power plants along Honshu's northeast coast: Tohoku Electric Power Company's three-reactor Onagawa plant, in Miyagi Prefecture; Japan Atomic Power Company's Tokai plant, in Fukui Prefecture (where there is one operable boiling water reactor and a gas-cooled reactor that closed in 1998); and two Tepco plants in Fukushima Prefecture, known as Fukushima Daiichi (Daiichi translates roughly as "first") and Daini ("second"). All of these plants are north of Tokyo (see map on previous page).

(There is a nuclear power plant in Japan named Sendai, but it is on the southern island of Kyushu, and it was not affected by the quake or tsunami. Tohoku's Onagawa plant is near the city of Sendai. Although Sendai was inundated by the tsunami, the Onagawa plant was not significantly damaged; a fire began in the turbine building, but it was extinguished.)

While the quake was the most powerful ever recorded in the vicinity of Japan and was well beyond what was anticipated as an initiating event for a design basis accident, the greatest damage—both to Japan in general and to the effort to bring all of Fukushima Daiichi to cold shutdown—was caused by the tsunami that spread from the quake's epicenter.

Fukushima Daiichi event sequence

The following was derived from information collected by Japan's national nuclear regulator, the Nuclear and Industrial Safety Agency. All times are Japan time.

March 11

2:46 p.m. The 9.0-magnitude earthquake strikes. Ground acceleration triggers automatic shutdown of all three reactors in operation.

3:42 p.m. A 14-meter tsunami triggered by the earthquake disables all AC power to Units 1, 2, and 3.

3:45 p.m. Fuel tanks for emergency diesel generators are carried off by the tsunami.

4:46 p.m. Water injection fails in the emergency core cooling systems of Units 1 and 2.

March 12

9:07 a.m. A pressure relief valve is opened on the Unit 1 pressure vessel.

3:36 p.m. A hydrogen explosion damages the external structure of the Unit 1 reactor building.

8:20 p.m. Seawater injection to the Unit 1 pressure vessel begins.

March 13

5:58 a.m. Water injection fails in the emergency core cooling system of Unit 3.

9:20 a.m. A pressure relief valve is opened on the Unit 3 pressure vessel.

1:12 p.m. Seawater injection to the Unit 3 pressure vessel begins.

March 14

11:01 a.m. A hydrogen explosion damages the external structure of the Unit 3 reactor building.

1:25 p.m. The water level in the Unit 2 pressure vessel is found to be low, leading operators to conclude that reactor cooling is no longer functional.

4:34 p.m. Seawater injection into the Unit 2 pressure vessel begins.

March 15

6:20 a.m. An explosive sound is heard at Unit 2 and is concluded to indicate an abnormality in the pressure suppression pool. At the same time, part of a wall in the operation area of Unit 4 is damaged.

9:38 a.m. A fire breaks out in the Unit 4 reactor building.

12:29 p.m. The Unit 4 fire is extinguished.

March 16

8:37 a.m. A large quantity of white smoke issues from the Unit 3 reactor building.

March 17

9:48 a.m. Self-Defense Force helicopters drop water on the Unit 3 reactor building for the first of four times.

7:05 p.m. A police water cannon truck begins injecting water into the Unit 3 reactor building.

7:35 p.m. Self-Defense Force pumper trucks begin injecting water into the Unit 3 reactor building for the first of five times.

March 18

10:00 a.m. It is confirmed that the common spent fuel pool for Fukushima Daiichi (which is separate from the pools for the individual reactors) is filled with water, and no abnormalities are observed in the spent fuel dry cask storage buildings.

1:30 p.m. Work is begun to open holes in the roof of the Unit 5 reactor building in order to keep hydrogen from accumulating within the building.

2:42 p.m. A water cannon from the U.S. armed forces is used to inject water into the Unit 3 reactor building.

5:00 p.m. Work is begun to open holes in the roof of the Unit 6 reactor building.

5:50 p.m. Initial power connection from an external transmission line to a temporary substation for backup power is completed.

Impact of the tsunami

Roughly one hour after the quake, the tsunami reached the Fukushima Daiichi site, and all alternating current power sources (off-site power and on-site emergency diesel generators) were lost to the ongoing effort to cool down the reactor cores of Units 1, 2, and 3. (Units 4, 5, and 6 were already off line for inspection, and Unit 4 was completely defueled.) The tsunami also disabled the seawater pumps, depriving the reactors of their ultimate heat sink. The tsunami was originally thought to have had a height of roughly 10 meters (33 feet), but it was later determined that the height was 14 meters (about 46 feet). Fukushima Daiichi was originally designed to withstand a 3-meter tsunami, based on a tsunami observed in Chile in 1960, but around 2000 the plant was modified to withstand a design basis tsunami with a height of 5.7 meters.

The tsunami did more than disable the emergency diesel generators. Plant workers reported seeing the diesel fuel tanks being pulled out to sea by the receding waves.

The plant staff—management and workers—began implementing severe accident management requirements as soon as possible, focusing on controlling and cooling the reactor cores. Throughout the course of the accident, according to reports issued by Tepco and government agencies, procedures to protect workers and the public were considered before actions were taken. The procedures are based on an understanding of how a severe accident progresses, taking into account the possibility of a loss of circulation and coolant that would cause a rise in pressure, and of a loss of reactor integrity that could lead to the release of radioactivity to the environment.

With the diesels unavailable and off-site power lost because of damage to transmission lines, plant personnel tried to maintain core cooling and other shutdown activities through battery power, which could last for eight hours at most. Less than an hour after the arrival of the tsunami, the emergency core cooling systems of Units 1 and 2 stopped delivering water. This was reported to the national government, and a nuclear emergency response headquarters was set up in the Tokyo residence of Prime Minister Naota Kan.

There is an isolation condenser for Unit 1 and there are reactor core isolation cooling (RCIC) systems at the other reactors. The

March 19

12:01 a.m. Fire engines from the Tokyo Fire Department Hyper-Rescue Team begin injecting water into the Unit 3 reactor building, continuing for one hour.

5:00 a.m. The residual heat removal system pump for Unit 5 resumes operation, cooling the spent fuel pool.

7:42 a.m. Two Unit 6 emergency diesel generators resume operation, providing power for Units 5 and 6.

2:10 p.m. The Tokyo Fire Department team begins injecting water into the Unit 3 reactor building, continuing for the next 13 hours and 30 minutes.

10:14 p.m. The residual heat removal system pump for Unit 6 resumes operation, cooling the spent fuel pool.

March 20

8:21 a.m. Self-Defense Force fire trucks begin injecting water into the Unit 4 reactor building, delivering about 81 tons over the next hour and 19 minutes.

2:30 p.m. Unit 5 enters cold shutdown.

3:05 p.m. Utility fire trucks begin injecting water into the Unit 2 spent fuel pool, delivering 40 tons over the next two hours and 15 minutes.

3:46 p.m. Electricity is restored to the Unit 2 power center.

6:30 p.m. (approx.) Self-Defense Force fire trucks resume injecting water into the Unit 4 reactor building, delivering another 81 tons over roughly the next hour and 16 minutes.

7:27 p.m. Unit 6 enters cold shutdown.

8:39 p.m. A Tokyo Fire Department team resumes water injection into the Unit 3 reactor building, continuing for the next seven hours and 19 minutes.

March 21

6:37 a.m. Self-Defense Force fire trucks and utility personnel use the U.S. water cannon truck to begin injecting water into the Unit 4 reactor building, continuing for the next two hours and four minutes.

10:37 a.m. Utility fire trucks begin injecting water into the common spent fuel pool, continuing for the next four hours and 53 minutes.

3:55 p.m. Gray smoke emerges from the Unit 3 reactor building, ending two hours later.

6:22 p.m. White smoke emerges from the roof of the Unit 2 reactor building.

March 22

10:35 a.m. Electricity is restored to the Unit 4 power center.

3:10 p.m. A Tokyo Fire Department team resumes injecting water into the Unit 3 reactor building, continuing for the next 49 minutes.

4:07 p.m. Utility fire trucks begin injecting water into the Unit 2 reactor building, continuing for the next 54 minutes.

5:17 p.m. A concrete-pumping truck begins injecting water into the Unit 4 reactor building, continuing for the next three hours and 15 minutes.

10:43 p.m. Lighting is restored to the Unit 3 central control room.

March 23

2:33 a.m. At Unit 1, a water feeding line is added to the water injection line to the pressure vessel.

10:00 a.m. The concrete-pumping truck resumes injecting water into the Unit 4 reactor building, continuing for the next three hours and 20 minutes.

11:03 a.m. Water injection begins into the Unit 3 spent fuel pool through the cooling and purification line, continuing for the next two hours and 17 minutes.

4:20 p.m. (approx.) Black smoke is observed coming from the Unit 3 reactor building.

March 24

5:35 a.m. Water injection resumes into the Unit 3 spent fuel pool through the cooling and purification line, continuing for the next 10 hours and 30 minutes.

11:30 a.m. Lighting is restored to the Unit 1 central control room.

2:36 p.m. The concrete-pumping truck resumes water injection into the Unit 4 reactor building, continuing for the next two hours and 54 minutes.

RCIC system uses a turbine-driven pump powered by the steam from the reactor to inject water from the suppression chamber beneath the reactor, as well as from the water storage tank, into the reactor. As the water in the suppression chamber heats up, these pumps become ineffective.

If getting Fukushima Daiichi safely to cold shutdown had been the only problem in Japan at the time, it might have been possible to deliver ample resources to the site quickly and perhaps allow the resumption of the cooling process soon enough to avoid damage to the facility and the release of radioactive material, assuming that the availability of the ultimate heat sink was restored. At the time, however, much of northeast Honshu was being inundated by the tsunami, and local and national authorities understandably devoted considerable attention to rescue attempts and to setting up emergency care facilities. The tsunami (and perhaps also the quake—it is difficult to know at this time) also knocked out infrastructure all along the coast, including roads, transmission lines, and railroads. An oil refinery in Chiba, within about 20 miles of Tokyo, went up in flames and burned nonstop for 10 days. As a result, there were limits on what could be done from outside the plant property in the near term.

The damage caused by the tsunami inland of Fukushima Daiichi was not as extensive as it was on the coast, but many houses were affected. During the evening of March 11, Fukushima Prefecture issued an evacuation order for residents within 2 kilometers (1.2 miles) of Fukushima Daiichi who had not already been displaced by the tsunami. About half an hour later, Prime Minister Kan ordered the evacuation of residents within a 3-km radius (1.8-mi.), and sheltering by residents between 3 km and 10 km (6 mi.) from the plant.

JAPANESE NUCLEAR POWER PLANTS NEAR EARTHQUAKE ZONE

				Constr. Stage	Initial Criticality	Comm. Start	Reactor Supplier
• Unit 2	1060	BWR	BWR-5	100	1/78	11/78	GE
Tohoku Electric Power Co., Inc.							
• Unit 1	498	BWR	BWR-5	100	10/83	6/84	Toshiba
• Unit 2	796	BWR	BWR-5	100	11/94	7/95	Toshiba
• Unit 3	796	BWR	BWR-5	100	4/01	1/02	Toshiba
Tokyo Electric Power Co.							
• Unit 1	439	BWR	BWR-3	100	10/70	3/71	GE
• Unit 2	760	BWR	BWR-4	100	5/73	7/74	GE
• Unit 3	760	BWR	BWR-4	100	9/74	3/76	Toshiba
• Unit 4	760	BWR	BWR-4	100	1/78	10/78	Hitachi
• Unit 5	760	BWR	BWR-4	100	8/77	4/78	Toshiba
• Unit 6	1067	BWR	BWR-5	100	3/79	10/79	GE
• Unit 1	1067	BWR	BWR-5	100	6/81	4/82	Toshiba
• Unit 2	1067	BWR	BWR-5	100	4/83	2/84	Hitachi
• Unit 3	1067	BWR	BWR-5	100	10/84	6/85	Toshiba
• Unit 4	1067	BWR	BWR-5	100	10/86	8/87	Hitachi

Containment venting

On the morning of March 12, pressure rose above design limits in the primary containment vessel of Unit 1, a General Electric BWR-3 model (an earlier design than any of the other units), and in the afternoon, plant personnel initiated primary containment venting to prevent damage to the vessel. This involved the release of steam, radioactive gases, and hydrogen (produced by the reaction of the hot zirconium fuel cladding with the water in the reactor) into the reactor building.

As it was likely that the water in the core had dropped below the top of the fuel rods, it became apparent that considerable amounts of water needed to be added to the core to prevent overheating and further core damage. As soon as it became possible, seawater with boron was injected into the reactor cores through the fire protection lines. This would have to continue until the plant's own cooling systems returned to operation.

At 3:36 p.m. on March 12, a hydrogen explosion occurred at the top of the Unit 1 reactor building, blowing out a large section of the roof and the walls of the top floor. Four Tepco technicians were injured and hospitalized. At the time, the explosion did not appear to damage the reactor pressure vessel or primary containment vessel. As radiation levels also increased substantially, it became clear that there was fuel damage and possibly some melting. Later that day, the evacuation zone was enlarged to a 20-km (12-mi.) radius.

While the conditions of Units 2 and 3 (BWR-4 models) were slightly different, they followed similar paths. It was possible to inject water into the Unit 3 reactor pressure vessel through the use of the high-pressure coolant injection system until the morning of March 13. The containment vessel was later vented, as reports indicated that the fuel was partially uncovered. Initial attempts to cover the fuel were successful, but

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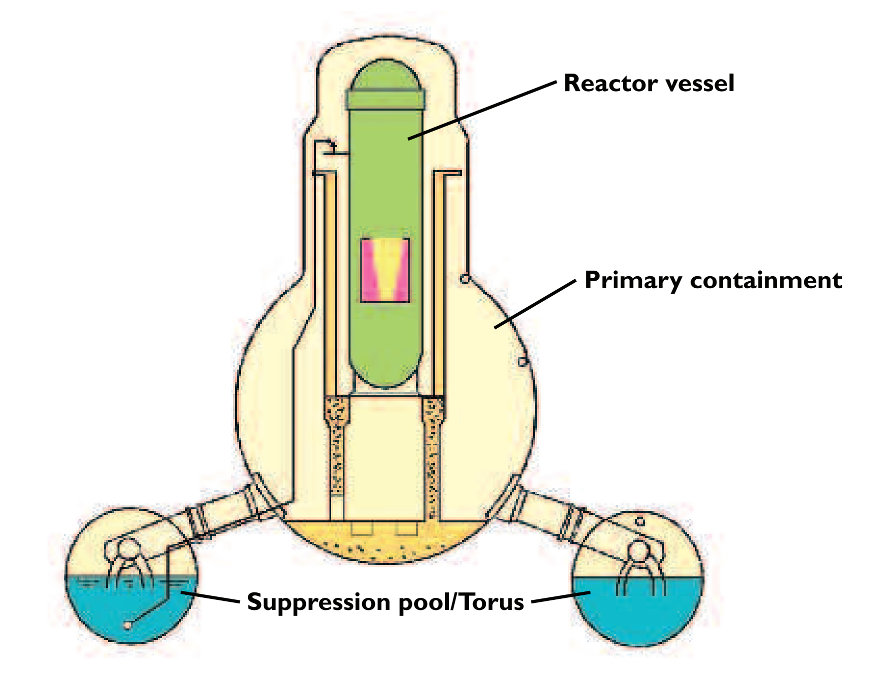
On March 18, workers repair equipment in an effort to restore off-site power to Units 3 and 4 at Fukushima Daiichi. (Photo: Tokyo Electric Power Company/Kyodo via AP Images)

Continued from page 18B

the water level soon dropped again, and some core melting occurred. Then, at 11:01 a.m. on March 14, a hydrogen explosion occurred in the upper part of the Unit 3 reactor building, blowing out large sections of walls and injuring 11 people.

Unit 2 also experienced difficulty in keeping the fuel covered. Late on March 14, part of the wall of the top floor of the reactor building was removed to prevent hydrogen from accumulating. The containment vessel was then vented. A few hours later, however, on March 15, an explosion was heard, believed to be in the suppression chamber, which is located under the reactor, and radioactivity was released into the reactor building. In both cases, seawater with boron was pumped into the reactor pressure vessels as soon as possible.

Problems were also experienced at the spent fuel pools, which in these plants are located on the upper levels of the reactor buildings. (These pools are for initial cooling. The fuel is later moved to a common pool, which was not damaged, and the 6375 fuel assemblies it holds remained covered by water.) In the case of Units 1 through 4, neither pool cooling nor water makeup could be maintained following the loss of power. This allowed fuel temperatures to rise and the water in the pools to evaporate. This became a particular issue in the Unit 4 pool, which contained a considerable amount of very hot fuel recently removed from the reactor before a planned maintenance outage. It appears that the fuel was hot enough to release hydrogen, which eventually exploded, destroying a large part of the building's roof and walls. The focus since then has been on replenishing the water in the pools of Unit 4 (and also Unit 3), mainly by fire engine pumps spraying through gaps in the roof. Helicopters were also used on occasion to drop water onto the pools.



A very general schematic diagram of the Mark I containment used in many early General Electric boiling water reactors. (Graphic: Tepco via Yoshiaki Oka)

Concerns have also been raised about the possibility of mixed-oxide (MOX) fuel—containing uranium and plutonium—being released into the spent fuel pools, but no MOX fuel had yet been discharged to the pools.

Moving toward final shutdown

In the days following the hydrogen explosions at Fukushima Daiichi, progress to make the reactors and the spent fuel pools safe has been slow because of the conditions in and around the plant. There have also been setbacks. Without instruments to monitor plant conditions, it has been difficult to manage the situation. On a number of occasions, smoke was seen issuing from the roofs of the reactor buildings, requiring the temporary evacuation of workers. It was not initially possible to determine what produced the smoke.

The first time that smoke was seen to emerge from Unit 3 was on Wednesday, March 16. Because of the high radiation field above the plant site, an initial attempt by Japan's Self-Defense Force (SDF) to douse it with water from helicopters was abandoned. Not until the next day were the helicopters able to drop water onto the Unit 3 reactor building, while later that day SDF fire trucks and police water-cannon vehicles were employed on the ground. The following day, high-pressure water-cannon trucks, provided by the U.S. Armed Forces in Japan, were used.

While it was possible to inject seawater into the pressure vessels, there was still the considerable problem of the inability to remove the heat. On some occasions, the injection of seawater into the core of Unit 1—which had to be increased to ensure that the fuel was covered—had to be stopped because pressure was rising in both the pressure vessel and the drywell. According to experts at the International Atomic Energy Agency, until heat could be removed from the reactor, pressure would tend to increase as water was injected.

Work to reconnect the units to an off-site transmission line moved forward slowly. Power for Units 5 and 6, which achieved cold shutdown on March 20, switched from emergency diesel generators to an off-site power source on March 22. For the damaged Units 1–4, however, power reconnection was a slow process. Several systems required a great deal of repair work before it was possible to connect the units and pow-

Fukushima Daiichi fuel inventory

At Fukushima Daiichi, irradiated fuel is contained in the reactor cores; in the spent fuel pool for each reactor; in a common pool for fuel that has cooled somewhat; and in dry casks. The number of assemblies does not necessarily indicate relative activity because of the different fuel types used and the extent to which assemblies in different locations have cooled. The small Unit 1 uses one type of fuel, the large Unit 6 uses another, and the similar Units 2 through 5 generally have the same fuel specifications. At this writing, the common pool, the dry casks, and the pools for Units 5 and 6 had not been damaged or endangered.

IRRADIATED FUEL ASSEMBLIES BY LOCATION

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Reactor core	400	548	548	0	548	764
Unit pool	292	587	514	1331	946	876
Common pool: 6375 Dry casks: 408						

er them up. At this writing, power had been restored to the Unit 2 and Unit 4 power centers, and to lighting in the Unit 1 and Unit 3 control rooms.

In the meantime, a number of incidents occurred in which workers were contaminated by radioactivity in runoff water and debris.

INES accident ratings

There has been some uncertainty and disagreement on how the Fukushima Daiichi accident should be placed on the International Nuclear Event Scale. Japanese authorities initially declared the accident to be at level 3 ("serious incident"), but on March 18, the incident report for Units 1, 2, and 3 rated the accident as level 5 ("accident with wider consequences"), the same as the Three Mile Island accident. Level 5 typically refers to the occurrence of core damage, as well as to an abnormal rise of radiation at the site boundary. The situation at Unit 4 was still defined as level 3.

The level rating for any of the units could be changed as the accident is further analyzed. France's Nuclear Safety Authority declared on March 16 that it considered Fukushima Daiichi to be at level 6 ("serious accident"). Level 7 ("major accident") has thus far been used only for the 1986 Chernobyl-4 accident in the Soviet Union, in what is now Ukraine.

At the other reactors

Fukushima Daiichi-5 and -6 are physically separate from Units 1 through 4, and many of the support facilities for these two units are independent of those for the other reactors. Units 5 and 6 also experienced problems, and although they had been taken off line for inspection before the quake, fuel was still in the reactors. The loss of off-site power interfered with efforts to maintain a normal environment, but Unit 6's emergency diesel power, which was not damaged by the tsunami and could be restarted, was used for cooling operations at Units 5 and 6. The water temperature in the spent fuel pools increased slightly, and the water levels in the reactor vessels decreased slightly.

On March 18–19, holes were made in the roofs of the reactor buildings to prevent the accumulation of hydrogen. Off-site power was restored to Units 5 and 6 on March 20, and both reactors reached cold shutdown later that day. At this writing, it appeared that there was no damage to these reactors as a result of the shutdown effort.

To the south, Fukushima Daini faced many of the same problems that existed at Fukushima Daiichi. At Fukushima Daini, however, not all reserve power was lost. Early on March 12, Tepco reported to the government that it lost pressure control on Units 1 and 2. That morning, Prime Minister Kan ordered the evacuation of residents within a 3-km (1.8-mi.) radius, which was enlarged to a 10-km (6-mi.) radius later that day.

While there continued to be some difficulties, none of the reactors or spent fuel pools at Fukushima Daini required extreme measures or underwent significant damage. By the morning of March 15, all four reactors had been taken to cold shutdown, and there were no reports of fuel damage, spent fuel uncovering, or major system failures.

While reports of a fire at the Onagawa plant in the immediate aftermath of the quake gained some news coverage, the fire was in a turbine building and was quickly extinguished. Despite being closer to the epicenter than the other nuclear sites, all three reactors at Onagawa were in cold shutdown early on March 12, less than 11 hours after the quake.

Of the sites where ground acceleration was great enough to cause an automatic shutdown, Tokai was the farthest from the epicenter. No significant issues were reported for either the operable Unit 2 or the long-closed Unit 1. Unit 2 entered cold shutdown early on March 15.

Brief pressure control issues arose at Fukushima Daini-1 and -2, but by the morning of March 15, all four reactors at the site had been taken to cold shutdown. (Photo: Tepco)

Response in the United States

In the United States the political and public policy ramifications of the Fukushima Daiichi situation will continue to develop over the next several months, and there will be no speculation here about possible outcomes. Following is a summary of the most significant statements and specific actions.

Immediately after the quake and tsunami, the United States offered help to Japan for both the nuclear emergency and disaster recovery in general. The Nuclear Regulatory Commission sent two staff professionals to Tokyo on March 12, and nine more two days later. Their role was to monitor the situation and provide advice if and when Japan's Nuclear and Industrial Safety Agency requested it.

On March 14, the Department of Energy and its National Nuclear Security Administration sent 33 people (including consequence management response teams) and over eight tons of equipment (including aerial measurement systems) to Japan. In aerial surveys taken on March 17, 18, and 19, all readings were below 30 millirem per hour, and the vast majority were below 3 mrem/h. The illustration on the opposite page shows the airplanes' flight paths and the readings taken on those flights.

On March 16, the NRC advised the evacuation of all residents within 50 miles of Fukushima Daiichi, based on protective actions that would be taken if the same situation existed in the United States. In the NRC's view, within the 50-mile radius, projected radiation doses could exceed 1 rem to a whole human body or 5 rem to the thyroid. The U.S. ambassador to Japan issued a statement to this effect, advising Americans to stay at least 50 miles from the plant.

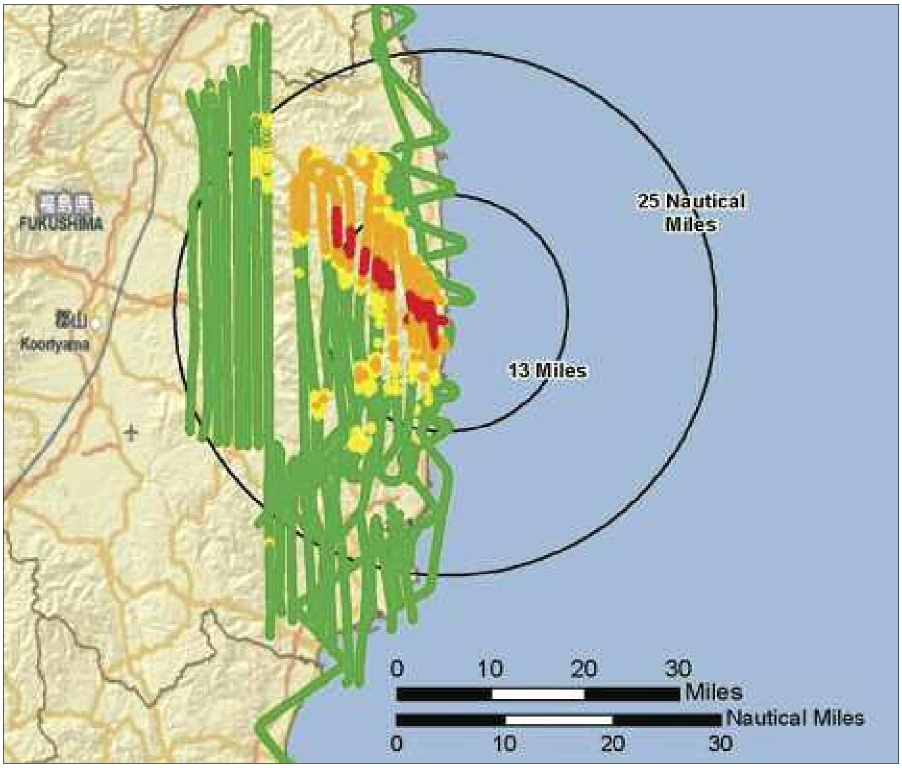
On March 18, the DOE reported that radioactive material from the Fukushima Daiichi accident had been detected in the United States. At Pacific Northwest National Laboratory, in Richland, Wash., xenon-133 was detected at about 100 millibecquerels per cubic meter of air. At a Sacramento, Calif., station of the International Monitoring System (of the Comprehensive Nuclear-Test-Ban Treaty Organization), the readings were much lower: iodine-131, 0.165 mBq/m^3; iodine-132, 0.03 mBq/m^3; tellurium-132, 0.04 mBq/m^3; and cesium-137, 0.002 mBq/m^3. The DOE pointed out that normal background radiation is more than 100 000 times greater than the radiation from any material that had migrated to the United States from Japan.

On March 21, the NRC held a public meeting on the events in Japan. The meeting, which was broadcast via the Internet, was limited to discussion among the commissioners and agency staffers (mainly William Borchardt, the executive director for operations). The webcast is archived on the NRC's Web site, at <www.nrc.gov>. The main development at the meeting was the commissioners' general concurrence with the staff's plan to review operating power reactor safety in the United States for issues arising from the effects of the earthquake and tsunami in Japan.

The NRC is already at work on the incorporation of new seismic data into its analyses of operating reactors. Borchardt noted that the U.S. Geological Survey updates its data every five years, and the NRC's work on the 2008 update is intended to resolve Generic Safety Issue 199, "Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States on Existing Plants." Thus far, there have been no indications that overall conclusions about power reactor seismic safety will be changed.

(The revised seismic data have been incorporated into the new reactor licensing process. Applicants for plants in the Southeast and Mid-Atlantic regions have been required to assess the influence, if any, on their projects from what has been learned about the East Tennessee Seismic Zone.)

On March 23, the NRC announced the formation of a task force made up of current senior managers and former agency experts to carry out the seismic review. Both short- and long-term analyses will be conducted, with the former to be delivered in updates in 30, 60, and 90 days. The long-term evaluation will begin within 90 days. The commissioners revised their meeting schedule to add two more public meetings, on April 14 and 28, on the NRC's response to the situation at Fukushima Daiichi, and meetings on May 3 and June 16 on the 30- and 60-day short-term analyses, respectively.



The U.S. National Nuclear Security Administration's aerial survey of Fukushima Daiichi, conducted on March 17, 18, and 19, shows that the most significant migration of radioactive material from the site has been to the northwest. The black concentric rings are 13 and 25 nautical miles from the plant. The colored lines follow the survey flight paths. Green indicates less than 1.19 millirem per hour; yellow, 1.19 to 2.17 mrem/h; orange, 2.17 to 12.5 mrem/h; and red, greater than 12.5 mrem/h. No reading exceeded 30 mrem/h. (Graphic: DOE/NNSA)

Section continued

Other issues

In addition to providing answers to our specific questions, Akira Omoto addressed some other issues related to the Fukushima Daiichi accident, including the following. (Note: "Gal" is the abbreviation for galileo, which is a unit of ground acceleration, with 1 Gal equal to 1 cm/sec^2.)

How do the observed ground acceleration of the earthquake and the height of the tsunami compare with the design basis of the Fukushima Daiichi reactors?

The acceleration was within the design basis event (DBE) except at Unit 3, where the observed acceleration was 507 Gal, and the DBE was 449 Gal. However, the height of the tsunami far exceeded the design basis. The original design basis was around 3 meters, based on the Chile tsunami in 1960. In the early 2000s, the basis was upgraded to around 6 m, based on the possibility of a big earthquake in the region of the March 11 earthquake, which triggered a tsunami more than 14 m high. The ground level is 10 m high at Fukushima Daiichi.

What kind of severe accident management (SAM) procedure was in place at Fukushima Daiichi, and what changes could potentially be necessary in the future?

The SAM procedure and modifications were established in the 1990s, including hardened containment scrubbing and venting to the main stack via the wet-well air space, makeup water that uses the fire protection system from a large portable water storage tank, electrical bus interconnection of one reactor to others, and so forth. The bus interconnection worked very well in Units 5 and 6, since one emergency diesel generator continued operating and supported both reactors.

It is still a bit early to discuss potential modifications, but the implementation of the SAM faced problems such as the loss of ultimate heat sink, the loss of equipment availability from the tsunami and flooding, and a harsh radiation environment for field work, requiring the use of nonconventional tools and methods.

Consideration must be given to the reactor/containment instrumentation and also to the diversity of emergency power sources, especially in the context of heat sink for the power generating equipment. Provisions for hydrogen monitoring and venting at the top of the reactor building (at the level of the refueling floor) could have helped prevent the roof from collapsing and debris from falling into the spent fuel pool. (On the other hand, the collapse uncovered the spent fuel pool and allowed water to be sprayed through the roof.)

The organization of the operations group and the delineation of authority to implement the SAM, plus a group to deliberate coping strategies, should be based on lessons learned, including organized international support on the assessment of possible strategies to be taken and their impacts.

Response in the EU

European Union leaders have agreed that in the aftermath of the nuclear accident in Japan, power reactors in all EU member nations should undergo a comprehensive and transparent risk and safety assessment. The decision to undertake these reviews, referred to as "stress tests," was made during the March 24–25 meeting of the European Council, whose members are the heads of the EU's national governments. A report on the initial findings of the assessments should be available to the council by the end of 2011.

Noting the urgency of this matter, the council asked the European Commission (EC) and the European Nuclear Safety Regulatory Group (ENSREG) to develop "as soon as possible" the scope and nature of these tests, taking into account the lessons learned from the accident. The member countries will also be involved in helping to develop the content of the reviews. The assessments will be conducted by independent national authorities and through peer reviews. The outcomes and any necessary measures to be taken are to be shared with the EC and the ENSREG, and are also to be made public.

The Unit 1 control room on March 24, after lighting was restored. (Photo: Tokyo Electric Power Company/Kyodo via AP Images)

At the same time, the council instructed the EC to review the existing legal and regulatory framework for nuclear safety, with the aim of identifying any improvements that may be necessary. The EC will also consider how to promote nuclear safety in neighboring (and other) non-EU countries, and will request that they carry out similar tests.

In announcing the decision regarding the reactor reviews, the council stated, "The consequences [of the accident] for the world and for the EU need to be closely monitored, paying particular attention to the volatility of energy and commodity prices, in particular in the context of the G20." NN

In other news . . .

Events not related to the earthquake and tsunami in Japan have occurred in the nuclear field since March 11. They would normally be reported in the Late News section of *NN,* but because of the need to give the Japan situation its due coverage, we only briefly mention them here and will cover some of them at greater length in the May issue.

■ **The final environmental impact statement for Vogtle-3 and -4** was issued by the Nuclear Regulatory Commission staff on March 18. This completes the environmental review for the new reactors to be built at the site in Georgia.

■ **The proposed rule to certify GE Hitachi Nuclear Energy's ESBWR design was published** in the *Federal Register (FR)* on March 24. Public comments will be accepted through June 7. The NRC has been using a target date of September for the issuance of the final rule.

■ **The mandatory hearing on the environmental review of Areva Enrichment Services' license application** has been opened to the participation of governmental agencies by the presiding Atomic Safety and Licensing Board. Areva intends to build and operate a uranium enrichment facility in Bonneville County, Idaho. More information is available in the March 2 *FR.*

■ **The renewed license for Vermont Yankee was issued** on March 21 by the NRC staff. The commissioners had taken their final action on the license renewal request on March 10 (see page 32, this issue).

■ **NextEra Energy Resources intends to apply in late June to use NFPA 805** at four of its five nuclear plants. The company told the NRC at a March 22 meeting that it will apply for amendments to switch to the risk-informed fire protection standard at Arnold, Point Beach, St. Lucie, and Turkey Point. Seabrook was not mentioned. NextEra includes Florida Power & Light Company reactors and merchant power reactors acquired by FPL Group.

■ **An environmental management partnering agreement** has been signed by the Department of Energy and Savannah River Remediation LLC. The pilot agreement, which will be used as a guide for other DOE sites, is aimed at fostering a more collaborative working relationship that will contribute to the safe, compliant, and cost-effective execution of high-level radioactive liquid waste operations at the Savannah River Site, in South Carolina. Savannah River Remediation manages the liquid waste contract for the DOE at the site.

■ **Three power uprate applications have been accepted for review** by the NRC. In a March 16 update to its power uprate Web page, at <www.nrc.gov>, the NRC indicated that it has completed its review for Florida Power & Light Company's Turkey Point-3 and -4 and St. Lucie-1, and that the acceptance review process for the St. Lucie-2 application, received on February 25, has begun.

■ **The proposed NRC fees for fiscal year 2011** were published in the March 17 *FR.* To meet its congressional requirement to recover about 90 percent of its funding from licensees, the NRC estimates that it must collect about $915.7 million for the fiscal year that ends September 30. The proposed fee for an operating power reactor is $4.669 million, down 2.4 percent from FY 2010.

■ **A 28-page report from the Blue Ribbon Commission** on America's Nuclear Future was issued in March. *What We've Heard,* available online at <www.brc.gov/>, summarizes the major themes in the testimony and comments the commission has received. The subjects covered in the report are grouped under seven broad headings: Program Governance and Execution; Nuclear Waste Fee and Fund; Approach to Siting; Reactor and Fuel Cycle Technologies; Transport of Used/Spent Fuel and High-level Wastes; Storage of Used/Spent Fuel and High-level Wastes; and Disposal System for Highly Radioactive Waste. NN