Fukushima: how the nuclear reactors' cores melted and containment vessels were damaged?

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Slowly and reluctantly, Tepco is releasing more information on the gravity of the state of Fukushima Daichi nuclear reactors. Below, the latest information as published in the English language Japanese press.

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Meltdown speed varied by reactor

Nuclear fuel rods in the No. 2 reactor at the Fukushima No. 1 plant are believed to have mostly melted and dropped to the bottom of the pressure vessel 101 hours after the March 11 earthquake, and those in the No. 3 reactor likely reached the same state in 60 hours, according to Tokyo Electric Power Co.'s worst-case scenario.

The worst-case speculation was based on the assumption the water level in the pressure vessels was lower than originally thought—similar to what happened in the No. 1 reactor.

TEPCO's analysis of the state of the plant's reactors was submitted Monday to the Economy, Trade and Industry Ministry's Nuclear and Industrial Safety Agency. The report was the first admission by the utility that the reactors were in a critical condition soon after the plant automatically shut down when the earthquake hit.

It is highly likely the pressure chambers of the Nos. 2 and 3 reactors were damaged when the melted fuel dropped down, which caused the hydrogen explosions, TEPCO's report said.

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Fuel in No. 1 melted in 15 hours

The No. 1 reactor building was the first to be struck by a hydrogen explosion.

Immediately after the earthquake, the reactor was halted when control rods were automatically inserted to slow down power output. When outside power was cut off, two emergency diesel generators started up. Valves that send steam to the turbine closed and an isolation condenser to convert steam back into water started six minutes after the earthquake.

When the tsunami struck, however, all electricity supplies at the plant were destroyed, rapidly aggravating the situation in the No. 1 reactor.

According to TEPCO's analysis, the water level in the pressure vessel declined in the two hours after power was lost, exposing fuel rods in the reactor's core. An hour later, the temperature in the reactor apparently shot up to as high as 2,800 C. The heat melted the casing for the fuel rods and nuclear fuel pellets inside began to melt and fall apart—a meltdown.

It is believed all the fuel rods had melted and dropped to the bottom of the pressure vessel within 15 hours of the earthquake.

The fuel rods' casing is made of zirconium, which forms zirconia when it combines with oxygen in water. Hydrogen left over from this chemical reaction—water is composed of hydrogen and oxygen—quickly filled the reactor. TEPCO's report said about 800 kilograms of hydrogen was produced by this reaction, which leaked from the pressure and containment vessels to fill the building that houses the reactor. This massive amount of hydrogen is believed to be what caused the explosion at 3:36 p.m. on March 12.

Freshwater was poured into the vessel to try to cool the reactor core shortly before 6 a.m. on March 12. According to the report, the fuel had completely melted by the time this began. Freshwater injections stopped at 2:30 p.m. and seawater injections started at about 8:20 p.m.

TEPCO had initially started injecting seawater into the reactor at 7:04 p.m. on a trial basis, but stopped after 20 minutes because the company had not properly informed the government of its plan. Monday's analysis did not mention the effect of this 55-minute gap.

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No. 2 cooled for 3 days after quake

A reactor core isolation cooling system, which injects water into a reactor core in emergencies, began running at the No. 2 reactor in the time after the earthquake and before the tsunami.

According to a TEPCO worker's log and other sources, staff switched the cooling system off and on trying to deal with fluctuations in the water level in the pressure vessel. The cooling system stopped working at about 1:25 p.m. on March 14, meaning it ran for about three days after the earthquake hit at 2:46 p.m. on March 11.

After the cooling system failed, seawater was sprayed on the reactor from fire trucks starting at 4:34 p.m. the same day, but the water level continued to decline. By 6 p.m. on March 14, the tips of the fuel rods were exposed, and just an hour later they were almost totally out of the water, according to the report.

Since water gauges for the reactors may have been damaged and are no longer accurate, TEPCO speculated on the situation inside the reactor cores based on worst-case scenarios, in which the water levels in the Nos. 2 and 3 reactors sank despite the injection of seawater.

Based on these assumptions, TEPCO concluded damage to fuel rods in the No. 2 reactor began

about 8 p.m. on March 14, an hour after the fuel rods were fully exposed. The rods melted and fell to the bottom of the pressure vessel by 8 p.m. on March 15. Eight hours later, or at about 4 a.m. on March 16, the bottom of the pressure vessel was damaged, according to TEPCO's analysis.

Although "the worst" has likely happened, TEPCO said recent temperature measurements near the No. 2 reactor's pressure vessel showed the situation is relatively stable.

If the water gauge is accurate, it would mean the seawater injection worked to a certain extent, meaning meltdown did not occur until at least a week after the earthquake, according to the report.

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Multiple failures doomed No. 3

It was early on March 13, or 36 hours after the Great East Japan Earthquake happened on March 11, that conditions at the No. 3 reactor began to clearly worsen.

Though the No. 3 reactor lost its power source in the tsunami, TEPCO had managed to continue pouring water into the nuclear reactor, albeit with a gap of one hour, using two different types of emergency cooling systems—the high-pressure core flooding system and the reactor core isolation cooling system.

However, the high-pressure core flooding system, which was considered the last resort, automatically stopped at 2:42 a.m. on March 13 because of falling pressure inside the reactor. The conditions inside the reactor drastically deteriorated after all batteries ran out and the reactor became uncontrollable.

The reactor's pressure rapidly rose from 0.58 megapascals to more than 7 megapascals in only two hours.

Operators tried to reactivate the reactor core isolation cooling system, but they could not.

TEPCO then reported to the government at 5:10 a.m. that all functions to inject water into the reactor had been lost.

During that time, the water level at the No. 3 reactor kept going down. According to TEPCO's estimates, fuel rods became exposed above the water's surface at around 7 a.m.

When operators released steam from inside the pressure vessel to the containment vessel to relieve pressure in the reactor shortly after 9 a.m., fuel rods were exposed to the air completely, and they began to be damaged.

At 9:20 a.m., operators vented steam from the containment vessel to the outside. Soon after the operation, at 9:25 a.m., operators started to inject freshwater into the pressure vessel for the first time since the loss of cooling functions about seven hours earlier.

On the afternoon of March 13, they changed the water injected into the vessel from freshwater to seawater. But, in the early hours of March 14, they stopped injecting water for about two hours to replenish their seawater supply.

According to TEPCO's worst-case estimates, fuel rods remained exposed and most of them melted and dropped down to lower parts of the reactor during that time. TEPCO believed the reactor's condition continued to get worse even after the company started to inject water and the pressure

vessel was damaged at 9 a.m.

About 59 percent of the metal covering the fuel rods apparently reacted chemically with water to produce a huge amount of hydrogen, which exploded around 11 a.m. on March 14.

On the other hand, according to TEPCO's estimates, if the water injection had been conducted successfully, the pressure vessel would not have been damaged, but about 70 percent of the metal covering the fuel rods would have reacted with water. This still could have generated enough hydrogen to cause an explosion.

The Yomiuri Shimbun , May 25, 2011

* http://www.yomiuri.co.jp/dy/national/T110524005872.htm

Two damaged reactors may have holes in their containment vessels: TEPCO data

At least two reactors at the crippled Fukushima No. 1 Nuclear Power Plant may have holes in their containment vessels, according to a report released by Tokyo Electric Power Co. (TEPCO) on May 24, a finding that could hamper efforts to meet a government-sanctioned timetable to end the crisis.

TEPCO, the operator of the troubled nuclear power plant, said in the report that meltdowns had occurred at the No. 1, 2 and 3 reactors. The report revealed for the first time the possibility of the No. 1 and 2 reactors having a hole about 7 centimeters in diameter and multiple holes about 10 centimeters in diameter in their respective containment vessels.

TEPCO said the damage caused by meltdowns to the pressure vessels of the No. 2 and 3 reactors was "limited." But experts had questioned the status of their pressure vessels as well as their containment vessels because highly contaminated radioactive water was leaked into their turbine buildings. Therefore, it has become increasingly unclear whether the utility and the government can deliver on the roadmap that seeks to bring the nuclear power plant under control within six to nine months.

At around 8 p.m. on March 14, about 77 hours after the March 11 earthquake, the reactor core of the No. 2 reactor started to get damaged, the TEPCO report said. At about 9 a.m. on March 13, the core of the No. 3 reactor had started sustaining damage, it said. TEPCO concluded that either about half of the fuel had fallen onto the bottoms of the pressure vessels of the two reactors while the other half had remained where it should be, or most of the fuel had melted and dropped to the bottoms of the pressure vessels.

TEPCO, however, tends to believe that most of the fuel actually dropped to the bottom of the pressure vessels. Meltdowns had occurred at the No. 2 reactor at around 8 p.m. on March 15, about 101 hours after the magnitude-9.0 earthquake, and at the No. 3 reactor at around 3 a.m. on March 14, about 60 hours after the earthquake, TEPCO said in the report.

About six to eight hours later, the two reactors sustained damage to their pressure vessels, it said. Data shows the possibility of the No. 2 reactor having multiple holes about 10 centimeters in

diameter and the No. 1 reactor having a hole about 7 centimeters in diameter.

Hydrogen explosions occurred at the No. 1, 2 and 3 reactors. TEPCO believes that as a result of fuel rods being damaged, 800 kilograms of hydrogen was created at the No. 1 reactor, 400 kilograms at the No. 2 reactor and 600 kilograms at the No. 3 reactor. The temperature in the reactors rose close to 3,000 degrees Celsius, hot enough to melt fuel rods, during the several-hour period between the time when the cooling systems stopped functioning and the time when water began to be injected. “This initial response has been affecting developments for the next several months,” said Tadashi Yoshida, professor of nuclear engineering at Tokyo City University.

The Nuclear and Industrial Safety Agency said the conditions of the reactors would not greatly affect the timetable to end the ongoing crisis. But Keiji Kobayashi, former lecturer at Kyoto University Research Reactor Institute, said, “The roadmap is not based on the assumption that the pressure vessels are damaged. The government and TEPCO have been making desperate efforts to put the reactors under control as quickly as possible and are putting pressure on workers. It is absolutely out of the question to try to put the situation under control quickly in exchange for exposing workers to radiation and shortening their lives.”

Mainichi , May 25, 2011

* http://mdn.mainichi.jp/mdnnews/news/20110525p2a00m0na009000c.html

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Cooling pipe breach now laid to temblor: Reactor design rethink looms after Tepco damage report

Tokyo Electric Power Co. admitted Wednesday that one of the critical cooling pipes at its Fukushima No. 1 nuclear power plant’s reactor unit 3 may have been damaged in the March 11 megaquake.

Tepco suggested earlier that no major damage, including ruptures in the facility’s main steam pipes, had occurred at the reactor until the massive tsunami hit after the magnitude 9.0 quake.

But if the temblor had actually damaged the High-Pressure Core Flooder system Å\ which is used to supply coolant water to a reactor core in emergencies to keep nuclear fuel from overheating Å\ power suppliers across the country might be forced to reconsider the quake resistance designs for their reactors.

“If we do our analysis on the premise that there was a leak in the piping, it matches (data) in reality,” a Tepco official said at a news conference.

“We can’t deny the possibility,” the official added.

At the No. 3 reactor, a quake greater than anticipated under resistance guidelines occurred, knocking out electricity to the power plant and precipitating the current crisis.

The piping was housed in a building that was designed to resist direct damage from tsunami.

Another analysis by Tepco has shown that breaches may have occurred at containment vessels encasing reactors 1 and 2 at the power plant, possibly causing leaks of highly radioactive water

there.

The possible breaches to the containment vessels there are certain to compound efforts to deal with accumulating contaminated water at the sites, raising questions about the viability of a Tepco plan to re-establish a stable cooling system by around mid-July.

Tepco said if it hypothesizes that a breach of about 3 cm wide occurred at the reactor 1 containment vessel 18 hours after the quake and widened to about 7 cm 50 hours later, that corresponds well to changes in pressure readings inside the containment vessel.

The utility also hypothesized that a breach roughly 10 cm wide occurred at the No. 2 reactor's containment vessel 21 hours after the quake due to elevated temperatures, among other factors.

This finding also corresponds with data obtained.

Tepco also said it believes that parts used to ensure air tightness may have broken from overheating.

Kyodo, May 26, 2011

* http://search.japantimes.co.jp/cgi-bin/nn20110526a1.html

TEPCO says core meltdowns also occurred at No. 2, 3 reactors

Tokyo Electric Power Co. (TEPCO) said May 24 that meltdowns had occurred in the No. 2 and 3 reactors of its crippled Fukushima No. 1 Nuclear Power Plant — in addition to a meltdown in the No. 1 reactor that has already been made public.

Cooling systems at the plant failed after a massive earthquake and tsunami hit northeastern Japan on March 11. Officials said deterioration of nuclear fuel likely began at about 8 p.m. on March 14 in the plant's No. 2 reactor and about 9 a.m. on March 13 in the No. 3 reactor, after the level of water inside the reactors dropped, exposing the fuel.

Since plant officials have been unable to determine the actual water level inside the reactors, they analyzed the state of the reactors under two scenarios in which the water level was either 1) the same as, or 2) below the measured level.

It found that in the first scenario about half the fuel would be damaged, while in the second scenario, most of the fuel would melt and fall to the bottom of the reactor vessel

TEPCO official Junichi Matsumoto said at a news conference on May 24, "We can't say for certain, but based on the situation in the No. 1 reactor, it is likely that the water level in these reactors fell below the measured level.

However, the company said that based on the current temperature of the pressure vessels, damage was "limited," and added, "If we continue to cool them, then we believe that we will not see a situation involving a large-scale release of radioactive materials."

The discovery of highly contaminated water in the reactor buildings has raised the possibility that

the reactor containment vessels have been damaged, but TEPCO denied that any major damage had occurred, saying water may have leaked due to a rise in temperature that damaged gaskets.

It is believed that the water level in the reactors initially dropped to reach the bottom of the fuel rods after the reactor core isolation cooling system and other cooling functions failed in the wake of the disaster. Subsequent injections of water are believed to have raised the level to three meters below the top of the fuel rods.

TEPCO compiled its report on the state of the No. 2 and 3 reactors following an order by the Ministry of Economy Trade and Industry's Nuclear and Industrial Safety Agency, and submitted it on May 23. Commenting on the manual shutdown of emergency cooling equipment at the No. 1 reactor before the arrival of the tsunami, the company said that the temperature had rapidly decreased after starting the equipment, and that the measure was in line with procedures and was appropriate. It maintained that the shaking from the magnitude 9.0 earthquake had not damaged the plant's main facilities — suggesting that the tsunami did most of the damage.

Mainichi , May 24, 2011

* http://mdn.mainichi.jp/mdnnews/news/20110524p2a00m0na019000c.html

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'Everything was by the book' / TEPCO: Manual shutdown of reactor cooling system followed rules

An emergency cooling system for the No. 1 reactor at the Fukushima No. 1 nuclear power plant was shut down manually by plant workers on March 11, after the earthquake but before the tsunami hit the plant, it has been learned.

The revelation was made in a report submitted Monday by plant operator Tokyo Electric Power Co. to the Nuclear Safety and Industrial Safety Agency.

TEPCO said the immediate response procedures taken on March 11 were in line with the firm's operational manual.

The company has been criticized over a series of problems with cooling systems at the plant on March 11 and for days after, which some experts believe may have contributed to the meltdown of fuel rods in reactors at the plant.

According to the report submitted to the Economy, Trade and Industry Ministry's nuclear safety agency, when the magnitude-9.0 earthquake struck at 2:46 p.m., the Nos. 1-3 reactors lost all external power, but emergency power sources were still in working order.

The quake triggered an automatic shutdown of the No. 1 reactor, and control rods were inserted into the reactor core.

At 2:52 p.m., an isolation condenser—a system designed to cool the reactor—was automatically activated.

But at 3:03 p.m., just 11 minutes later, the cooling system was suspended manually by plant

workers.

The TEPCO operational manual says the reactor's temperature should not be allowed to fall at a rate of 55 C per hour or more, and isolation condenser operations should be adjusted to prevent such an occurrence.

TEPCO said its workers halted the cooling system because it had caused excessive cooling, with the reactor temperature falling more than 100 C in the time the condenser had been operating.

The workers soon reactivated the condenser, before the tsunami hit the plant shortly after 3:30 p.m.

The tsunami wiped out the direct-current power supply to the plant, and the power loss was interpreted by control systems as indicating a pipe fracture.

This set off an automatic shutdown of the condenser, closing a series of valves between it and the reactor.

Plant workers suspected the valves had been closed, and a visual check confirmed it. The workers then manually opened the valves, enabling the restart of the condenser, according to the report.

Meanwhile, the Nos. 2 and 3 reactors were using a different type of cooling system, known as a reactor core isolation system.

The report said losses of external power caused the systems at both reactors to halt several times, and on each occasion TEPCO workers manually restarted the systems, in line with the operation manual.

The system at the No. 2 reactor continued to be operated in this fashion until 1:25 p.m. on March 14.

At the No. 3 reactor, the cooling system stopped working at 11:36 a.m. on March 12.

About an hour later, another emergency cooling system called a high-pressure core-flooding system was put into use at the No. 3 reactor, but this was stopped at 2:42 a.m. on March 13.

The operation was back under way at 9:25 a.m. that day, using freshwater containing boric acid.

The relative lack of continuity in efforts to cool the No. 3 reactor is believed to have caused meltdown to occur faster there than that at the No. 2 reactor.

The Yomiuri Shimbun , May 25, 2011

* http://www.yomiuri.co.jp/dy/national/T110524005786.htm