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IES269
May 2012

Fukushima Daiichi Nuclear Power Station (NPS)[1]

"Dad, I place my son and wife in your care; please look after them," entreated an operator at Fukushima Daiichi's Central Control Room, via SMS, on March 12, 2011 – a day after the site had been flooded by the tsunami resulting from the East Japan Earthquake.[2] That day, the building lodging the Unit 1 reactor was destroyed by a hydrogen explosion. At the time of the earthquake there were 24 operators scared to death and lost in the blacked-out control room, without any data from the reactors in Units 1 and 2.

When instructed by Prime Minister Naoto Kan to coordinate the police, fire authorities and Self Defense Forces, General Toshinobu Miyajima, the then head of the CRF (Central Readiness Force) – a group specialized in dealing with terrorism and natural disaster emergencies at Japan's Self Defense Ministry – felt desolate at the prospect that eastern Japan, including the Tokyo Metropolitan Area, might be affected irreparably by the nuclear radiation. Simulations personally conducted by him in secret suggested the need for an ever-expanding evacuation zone.[3]

In fact, two weeks after the accident, on March 25, a report was submitted to the prime minister estimating the worst-case scenario (see **Exhibit 1**). In his 20-page report on Fukushima Daiichi, Shunsuke Kondo, the author and head of the Atomic Power Committee at the Cabinet Office, identified the loss of cooling capability at the Unit 1 reactor as being caused by a lack of electricity, hydrogen explosions in the Unit 1, 3 and 4 reactors, and a meltdown in the Unit 2 reactor. The cooling of the reactors was being carried out through the injection of seawater.

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[1] Unless otherwise indicated, this case study draws on the report by the Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident – abbreviated as the "Independent Panel" (2012). The Independent Panel was organized by the Rebuild Japan Initiative Foundation.

[2] http://www.asahi.com, accessed on December 28, 2011.

[3] http://www.mainichi.jp, accessed on December 31, 2011.

This case was prepared by Professor Kimio Kase, Professor Ikujiro Nonaka from Hitotsubashi University, and Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident, as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation. May 2012.
This case was written with the support of the IRCO (International Research Center on Organizations), IESE.

Last edited: 6/8/12
2-312-071

In the worst-case scenario, it was believed that further hydrogen explosions in any of the Unit 1 to 3 reactors would cause the radiation level inside the power station to shoot up, and the fuel bars inside the Unit 4 reactor pool would melt due to the cooling operations being interrupted. This would: (1) increase the level of radiation in soil within a 170 km radius from the station to 1.48 million Bq (becquerels[4]) per square meter – equivalent to the evacuation standard in the case of Chernobyl; and (2) consequently make it necessary to evacuate all inhabitants of Tokyo, as well as those of Yokohama, located within a 250 km radius of Fukushima.[5]

Media around the world, initially shocked at the magnitude of the catastrophe brought on by the earthquake that hit eastern Japan on March 11, 2011, kept the world on tenterhooks by broadcasting the increasingly alarming news that a nuclear power station[6] in the affected area had been flooded, and that an immeasurable disaster was taking place on the site.

What happened? And how did Japan and its people attempt to cope with this unprecedented catastrophe?

Fukushima Daiichi NPS

The Fukushima Daiichi NPS[7] consists of six light water boiling water reactors (BWR[8],[9]), driving electrical generators with a combined power of 4.7 GW, making it one of the 25 largest nuclear power stations in the world.

Unit 1 is a 439 MWe-type [...] reactor [...]. It commenced commercial electrical production on March 26, 1971 [...], designed for a peak ground acceleration of 0.18 g (1.74 m/s^2), and a response spectrum based on the 1952 Kern County earthquake. Units 2 and 3 are both 784 MWe-type BWR-4 reactors [...] [commissioned] in July 1974 and [...] in March 1976 [respectively]. The earthquake design basis [...] ranged from 0.42 g (4.12 m/s^2) to 0.46 g (4.52 m/s^2)[...].

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[4] The SI unit of radioactivity, equal to one disintegration per second (symbol Bq) (Shorter Oxford Dictionary).

[5] http://www.maichin.jp, accessed on December 24, 2011.

[6] Japan has 17 commercial-use nuclear power stations totaling 54 reactors (48.85 million kW), of which 30 are BWR-type and 24 are PWR-type (Kamoshita, 2011).

[7] Based on the Investigation Committee (2012) and http://en.www.wikipedia.org/wiki/fukushima_daiichi_nuclear_disaster, accessed on January 21, 2012.

[8] "The boiling water reactor (BWR) is a type of light water nuclear reactor used for the generation of electrical power. It is the second most common type of electricity-generating nuclear reactor after the pressurized water reactor (PWR), also a type of light water nuclear reactor. The main difference between a BWR and PWR is that in a BWR, the reactor core heats water, which turns to steam and then drives a steam turbine. In a PWR, the reactor core heats water, which does not boil. This hot water then exchanges heat with a lower pressure water system, which turns to steam and drives the turbine. The BWR was developed by the Idaho National Laboratory and General Electric in the mid-1950s. The main present manufacturer is GE Hitachi Nuclear Energy, which specializes in the design and construction of this type of reactor."
http://en.wikipedia.org/wiki/Boiling_water_reactor, accessed on April 16, 2012.

[9] Whereas BWR-type reactors have a simpler structure, driving turbines within the reactors make the handling of radioactive materials more difficult, since the turbines and their vicinity are contaminated by radiation; PWR, on the other hand, drives turbines outside the reactor vessel, which means that handling of radiation is easier, but its structure is more complicated because of the need to supply a steam generator for the secondary cooling water.

> Units 1 - 5 have a Mark 1-type [...] containment structure; Unit 6 has a Mark 2-type [...] containment structure [...].[10]

These details are shown in Table 1.

Table 1
Units at Fukushima Daiichi NPS

			Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Nuclear Reactor	Output (thousand kW)		460	784	784	784	784	110
	Construction started in		xi-1967	v-1969	x-1970	ix-1972	xii-1971	v-1973
	Commissioned in		iii-1971	vii-1974	iii-1976	x-1978	iv-1978	x-1979
	Reactor type		BWR-3			MWR-4		
	Main contractor		GE	GE-Toshiba	Toshiba	Hitachi	Toshiba	GE-Toshiba
	Heat output (thousand kW)		1,380	2,381				
	No. of fuel rod sets		400	548				
		kPa gage	427		427			310
		ºC	140	140	140	140	138	D/W 171
								S/C 105

Source: Independent Panel (2012), p. 23.

March 11

The Earthquake

On March 11, 2011, at 2:46 p.m., the Pacific Coast area of northeastern Japan was hit by an earthquake with a magnitude of 9.0 – the largest ever recorded in Japan. Afterwards, tsunamis struck that part of Japan in a series of seven waves inundating 561 km^2. According to reports, as of June 2011, 25,000 people have been killed or are missing on account of the earthquake and tsunamis.[11]

Tsunami Hit

On the day the earthquake hit,

> "a total of six external power supply sources had been connected to the Daiichi Power Station [...]. However, all power supplied from these six lines stopped due to the damage to the breakers, etc., [...] due to the earthquake" (Nuclear Emergency Response Headquarters, 2011).

In Units 1 - 6 the external power supply was lost after the earthquake, which made the fail-safe mechanism work. This closed the steam isolation valve, which enabled the isolation of the nuclear reactors from turbines.

After control rods were inserted and the main steam isolation valve shut, water was injected into Units 1 - 3.

[10] Investigating Committee on the Accidents at Fukushima Nuclear Power Stations of Tokyo Electric Power Company (2011).

[11] Wikipedia, http://en.wikipedia.org, accessed 2012.

In the main control room of Units 1 and 2, decay heat was conducted to the sea. The Unit 1 reactor containment cooling system was in operation between 3:04 p.m. and 3:11 p.m.; Unit 2 operated the residual heat elimination system between 3 p.m. and 3:07 p.m.; however, Unit 3 did not activate a cooling system, in order to protect seawater pumps.

At 3:27 p.m., the first four-meter high tsunami wave hit Fukushima Daiichi.[12] The next wave, higher than 7.5 m – the maximum height measurable by the gauge on-site – came at 3:35 p.m., passing over the ten-meter high tide embankment (suspected to be more than 15 m over Onahama Peil, a reference sea level). This flooded the main buildings, rendering all seawater pumps in Units 1 - 6 useless in releasing decay heat into the sea.[13]

Between 3:37 p.m. and 3:42 p.m., Units 1 – 5 lost all AC power supply; in addition, in Units 1, 2 and 4, DC power supply was also lost. (See Table 2 regarding the cooling devices and their situations.)

Table 2
Cooling Devices

	Unit 1	Unit 2	Unit 3	Damages	Measures
HPCI (High-pressure coolant injection system)	x	x	o	Loss of power supply in the control system	–
FDW (Condensate water supply)	x	x	x	Water-injection made impossible	–
CS (Core spray)	x	x	x	Power supply and seawater cut	–
SHC (Cooling system at shutdown)	x	x	x	Power supply and seawater cut	–
MUWC (Supplementary condensate water supply)	x	x	x	Power supply cut and motors flooded	–
FP (Fire extinguishing)	x	x	o	Fire pumps rendered useless	Fire vehicles
IC (Emergency water condensation)	Δ	–	–	Almost all functions rendered useless due to the isolation valves' closure because of power supply cut	–
RCIC (Reactor core isolation cooling system)	–	o	o		–

Source: Independent Committee (2012), p. 24.

[12] "The license for the establishment of nuclear reactors at the Fukushima Daiichi NPS was based on the assumption that the maximum design basis tsunami height expected was 3.1 meters [...]."(Nuclear Emergency Response Headquarters, 2011).

[13] "At the time of the earthquake Units 1 to 3 were in operation at the Fukushima Daiichi NPS, while Units 4 to 6 were in maintenance modes. Units 1 to 3 appeared to have automatically scrammed at the earthquake, but external power suppliers and almost all in-house AC power supplies were lost [...]. Reactors and spent fuel pools [...] lost their cooling capabilities." (Nuclear Emergency Response Headquarters, 2011), p. 5.

Cooling Situation in Units 1 and 2

As a result of the DC power supply loss in Units 1 and 2, the control parameters for nuclear reactor power generation, such as the water level, were lost track of, which meant that it was impossible to verify if the nuclear reactors were being fed with water or not.

At around 5:10 p.m., Masao Yoshida, director of Fukushima Daiichi, instructed the injection of water into the reactors from external diesel-driven fire pumps or fire vehicles, in line with the accident management philosophy.

The IC of Unit 1's reactor partially recuperated its indicator function between 6:18 p.m. and 9:30 p.m. thanks to the operators who had tried to activate it several times. However, in reality, the IC had been rendered useless, and the water injection to the reactor did not take place. Based on their observation of the steam coming out of the IC, the operators suspected that the IC's heat exchange capability was not sufficient. This suspicion was not conveyed to TEPCO's Headquarters for Disaster Control in Tokyo.

It is speculated that this lack of information on the Unit 1 cooling situation led to the reduction of the water level at the nuclear reactor, which resulted in the exposure of nuclear fuel to the air and the severe core damage accident.

At 9:19 p.m., the water gauge of the Unit 1 reactor recovered its function and showed that the water level of the No. 1 reactor had dropped to 200 mm higher than TAF (top of active fuel).

At 9:50 p.m., the repaired water gauge at the Unit 2 reactor showed the water level at 3,400 mm from TAF.

Dry well pressure gauges recovered at 11:25 p.m. and 11:50 p.m. at Unit 2 and Unit 1, respectively. It turned out that, while the pressure was low at Unit 2, it was in excess of the maximum-use pressure value at Unit 1, which signified that the No. 1 reactor urgently needed venting.

March 12

Preparing to Vent the Unit 1 Reactor Container

Director Yoshida ordered vent preparations at 12:06 a.m. Venting was usually done by remote control, but the loss of the power supply forced Director Yoshida to opt for one of the two alternative methods: to wait for the repair of the remote control; or to do it manually. Fukushima Daiichi's Emergency Committee began to study the necessary procedure and operation, but it needed time.

This delay was one of the circumstances that caused the *Kantei* (the prime minister and his cabinet office) to distrust Tokyo Electric Power Company (TEPCO). At 6:50 a.m., the *Kantei* decided to consider the area within a 10 km radius of the Fukushima Daiichi Power Station as an evacuation area. At 6:50 a.m., Banri Kaieda, the minister of economy, trade and industry, by virtue of Article 64 of the Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors (Nuclear Reactor Regulation Law), ordered the

nuclear container's pressure to be brought under control. At 7:11 a.m., Prime Minister Naoto Kan travelled to Fukushima Daiichi by helicopter.

Freshwater Injected Into Unit 1

At 2:45 a.m., it was confirmed that the pressure of the Unit 1 nuclear reactor had been reduced. For this reason, it was decided that freshwater would be injected from a fire vehicle.

At 5:46 a.m., it became possible to inject water uninterruptedly from the water deposit in front of the Unit 1 reactor building, using a fire vehicle and two hoses. Over 14 hours had elapsed since the loss of power supply before the reactor was injected with water for cooling.

Between 6 a.m. and 7 a.m., two fire vehicles from the Self Defense Force arrived, followed by another from the Kashiwazaki Nuclear Power Station at 10:52 a.m. By 2:53 p.m., a total of 80 tons of water had been injected.

Work Gets Under Way on the Power Supply

At around 7:20 a.m., a power-generating vehicle began to supply 100 V of alternative electricity. Inside the power station, three sets of alternate current (6900 V, 480 V and 100 V) were used. Power generating vehicles were used for the supply of 6900 V and 100 V electricity.

Director Yoshida set 9 a.m. as the target for the start of the venting process. At 8:37 a.m., the Headquarters for Disaster Control in Tokyo informed the Fukushima prefectural government of its intention to carry out venting around the said hour. The government asked for the venting to begin when the evacuation of inhabitants was complete.

At 9:02 a.m., with the understanding that the evacuation had been completed, the Headquarters for Disaster Control at Fukushima Daiichi instructed the chief of operators at Units 1 and 2 to begin the venting process.

At 9:04 a.m., the task to organize a vent line began. It required the opening of two valves. Team No. 1 succeeded in manually opening the first valve on the second floor of the Unit 1 reactor building; at 9:30 a.m., Team No. 2 had to abandon its attempt to open the second valve due to the extremely high level of radiation (in excess of the permitted 100 mSv).

To remedy this failure, it was decided to repair the remote control, in spite of it being a less reliable measure. At 10:24 a.m., the second valve was opened by remote control. First, a provisional compressor was connected to the compressed air piping in order to supply compressed air for instrumentation. At 2:50 p.m., dry well pressure dropped to 0.58 (MPa[abs]), which meant that Unit 1 was vented – more than 14 hours after Director Yoshida's decision, and after over five hours of work.

Water Injected Into Units 1 and 3

At 2:54 p.m., Director Yoshida ordered the injection of seawater into the Unit 1 reactor in light of the exhaustion of water in the water deposit. Parallel to the injection of water from fire vehicles, the repair work of the power supply in Units 1 and 2 was being carried out

using high-pressure power generation vehicles; and the injection of boric acid water was being prepared.

Unit 3 had been in a stable situation after the earthquake thanks to the availability of cooling water feeding based on RCIC. However, at 11:36 a.m., RCIC automatically came to a stop, which provoked the automatic commissioning of HPCI (which did not require an alternative electricity power supply) as a consequence of the lowering of the water level at the reactor at 12:35 p.m.

Hydrogen Explosion at Unit 1 and Seawater Injection

At 3:36 p.m., the Unit 1 reactor building experienced destruction, seemingly owing to a hydrogen explosion. The fourth and fifth floors of the building lodging the reactor lost their walls, leaving only their metal structures. Five operators were injured. The injection of seawater was suspended, to be resumed at 7:04 p.m., and from 8:45 p.m. onwards the boric acid water mixed with seawater was injected into the reactor core.

DC Power Supply Ran Out at Unit 3

Unit 3 had been injected with water by HPCI (high-pressure coolant injection system), but on the night of March 12, the pressure of HPCI diminished so much that it was level with the pressure inside the reactor, which made the injection difficult. However, around that same time the reactor pressure also dropped to below the design specification. At around 8:36 p.m., the water gauge of Unit 3's reactor lost its 24 V DC power supply, making it impossible to measure the reactor's water level.

March 13

Unit 3 HPCI Manually Halted

At 2:42 a.m., on March 13, the operators manually halted HPCI and switched to the injection of water from the fire piping, driven by diesel fire pumps. At 2:45 a.m. and 2:55 a.m., they tried, and failed, to reduce the pressure from the reactor by releasing the main steam and manipulating the SR valve from the control panel. This failure could be attributed to the exhaustion of the DC current in the batteries. Feeding in water therefore also failed. They also attempted to restart HPCI and RCIC, to no effect.

Water Injection Into Unit 3 and Venting

The Headquarters for Disaster Control at the nuclear power station recognized that HPCI was coming to a standstill at 3:55 a.m. Consequently, operations were undertaken to repair the SR valve. At around 6 a.m., they located a passenger car parked on a hill that had escaped damage by the tsunami, the battery of which was used to connect in series to the control panel of SR valve in the central control room of Units 3 and 4. It made the reduction of the reactor core pressure, through the control panel, possible.

After HPCI's halt, the pressure inside the reactor container shot up. Accordingly, in addition to the reduction of the pressure in the reactor, vent operation was commenced. At 4:50 a.m., the first valve was opened by remote control. At 8:35 a.m., the second valve was opened manually by 15% inside the building lodging the reactor. At 8:41 a.m., the vent line was put into place, except for the rupture disk.

The power supply being resumed, the valves opened, which enabled the reduction of pressure inside the reactor core at 9:08 a.m. The reactor pressure as of 8:55 a.m. was 7.30 MPa[gage], which came down to 0.35 MPa[gage] at 9:25 a.m., the time at which the water supply from a fire vehicle was also resumed. However, the seven-hour interruption of water injection seemed to have had already caused the core damage.

Between 9:10 a.m. and 9:24 a.m., the pressure in dry wells reduced from 0.637 MPa[14][abs] to 0.54 MPa[abs]. In the meantime, the rupture disk exploded and venting was carried out.

White Fumes Coming Out of Unit 1

Early in the morning on March 13, it was reconnoitered that white fumes were emitted from the Unit 1 reactor building after the explosion and was conjectured to be steam vaporizing from the spent fuel pool at Unit 1. The attention of the Emergency Committee at the power station and at the headquarters turned to the spent fuel pool.

Vent Operation and Water Injection Into Unit 2

Around the same time, the vent operation was being carried out at Unit 2. At 8:10 a.m., the operators at Units 1 and 2 got to work, managing to put the vent line into place, except for the rupture disk, at around 11 a.m., at which point in time the pressure of dry wells was less than 0.4 MPa[abs], which impeded the vent due to the explosion of the rupture disk.

Seawater Injected Into Unit 3

At 12:20 p.m., the fire protection water tank ran out of the freshwater that was being used for injection into Unit 3. The Defense Force's fire brigade and collaborating companies' operators realigned the hose to inject seawater through the Unit 3 turbine building, which took place at 1:12 p.m. A similar arrangement was made to inject seawater into Unit 2.

Unit 3 suffered from the problem of the diminishing of the air pressure that kept open the vent valve, to remedy which operations were carried out to change the compressed-air bottle and to install a provisional air compressor during the night of March 13, as soon as venting was successfully carried out.

[14] Mega pascal, pascal being "The SI unit of pressure, equal to one newton per square meter (approx. 0.000145 pounds per square inch, 9.9×10^{-6} atmosphere)." (Shorter Oxford Dictionary).

March 14

The Temperature and Pressure Increased in Unit 2

Between March 11 and March 14, water was injected into Unit 2 by means of RCIC, and the vent line, except for the rupture disk, was in place. However, decay heat had not been released outside the plant because the steam generated by the reactor had been concentrated in the pressure control room inside the reactor container.

At 4:30 a.m., the observation of parameters at the Unit 2 pressure control room began. The temperature of the pressure control room pool showed an upward trend, and by 12:30 p.m. it had exceeded 147°C, slightly over the designed maximum temperature; the pressure had a similar upward trend but it did not go beyond the designed value.

The Pressure at the Unit 3 Reactor Container Increased and the Second Vent Line Was Put Into Place

Unit 3's dry well pressure started to increase at approximately 1 a.m., apparently due to the closure of one of the vent valves. As a solution, between 5:20 a.m. and 6:10 a.m. there was an attempt to configure the second vent line by opening another vent line valve from the central control room of Units 3 and 4. Despite this, Unit 3's dry well pressure did not stop increasing, forcing Director Yoshida to evacuate it and send the operators to the base-isolated building between 6:30 a.m. and 6:45 a.m. The pressure later stabilized around 0.5 MPa[abs], allowing evacuation instructions to be cancelled.

A Hydrogen Explosion Took Place at Unit 3

At 11:01 a.m. an explosion was observed at the Unit 3 reactor building, forcing all operators except for those on duty to seek refuge in the base-isolated building. The recovery work was interrupted due to the need to ascertain the safety of the operators.

The explosion injured four TEPCO employees and three operators from subcontracted companies, in addition to four members of the Self Defense Force who had been preparing the injection of freshwater to a pit beside the Unit 3 turbine. As a consequence, the Self Defense Force had to withdraw its vehicles to transport the injured people.

The explosion at the Unit 3 reactor building interrupted the water injection to reactor cores of Units 1 - 3, because, for example, the reversing valve pit being used to feed water was buried beneath highly radioactive debris. With the exception of two fire vehicles used to feed water into the pit, no other fire vehicles were damaged.

Seawater Injected Into Unit 2

Starting at around 12 p.m., the water level of Unit 2's reactor started to deplete and, by 1:25 p.m., RCIC seemed to have stopped working. Therefore, it became necessary to inject water into the Unit 2 reactor as well as to repair the fire hose damaged by the Unit 3 explosion.

In order to inject water into the reactors using fire vehicles, the pressure of the reactors had to be diminished, which could result in an increase in the pressure control room given the

massive quantity of steam flowing into it, which would require that the vent be in operation. It was discovered, however, that the vent valve had been closed by the impact of the explosion. Reconstruction of the vent line was now an urgent necessity.

In light of the time needed to reconstruct the vent line, priority was given to depressurizing the reactor, which commenced at 4:34 p.m. Due to the high temperature in the pressure control room, which impeded the condensation of steam, this was achieved at as late as 7:03 p.m., complicated due to the fire vehicles' running out of fuel (7:20 p.m.). The injection of seawater resumed at around 7:57 p.m. Nevertheless, by 6:22 p.m. fuel rods were entirely exposed to the air, which, obviously, led to the core damage. There was doubt regarding the sufficiency of water injection on account of a high value shown by the reactor pressure between the night of March 14 and 1 a.m. on March 15.

Unit 2 Vented

At Unit 2, efforts had been deployed to reduce the pressure and carry out venting. At 10:50 p.m. dry well pressure exceeded the allowed operation pressure of the rupture disk by 0.540 MPa[abs]. It was suspected that one of the two vent lines became usable around this time.

The dry well pressure did not stop increasing, and at 11:35 p.m. it reached 0.740 MPa[abs], whereas the pressure at the pressure control room went down. Accordingly, it was decided that venting be conducted by means of constructing a vent line from the dry well instead of from the pressure control room.

March 15

A Hydrogen Explosion Took Place at Unit 4

At 6:10 a.m., Unit 4 experienced what was suspected to be a hydrogen explosion. With the benefit of hindsight, it is now attributed to the flow into Unit 4 of the hydrogen generated at Unit 3. At the time of the explosion, however, hydrogen was deemed to have been generated at Unit 4 due to the spent fuel pool running out of water.

Pressure Diminished at Unit 2

At 6:10 a.m., around the same time that the explosion took place, the Unit 2 pressure control room gauge showed 0 MPa[abs]. It was suspected that the Unit 2 reactor building might have been damaged despite its external appearance, which led the operators to guess that the explosion might have occurred near the Unit 2 pressure control room. Analysis of seismograph records, however, eliminated such a possibility.

Operators Withdrawn from Fukushima Daiichi

At around 7 a.m., all operators except for plant guards and a minimum number of those needed for operations, 650 in total, took refuge in Fukushima Dai-ni. At 9:38 a.m., a fire broke out in Unit 4 near the northeast corner of the third floor, which was brought under control by 11 a.m.

March 16 and Onwards

A Helicopter Surveyed the Unit 4 Spent Fuel Pool and Water Was Dropped From the Air

In the afternoon of March 16, the Self Defense Force's helicopter reconnoitered Unit 4 from above and measured the radiation level. It visually confirmed that the spent fuel pool had water and that fuel rods were not exposed to the air.

On March 17, at 9:48 a.m., the Self Defense Force's helicopter dropped water from the air four times onto Unit 3, using a total of 30 tons of seawater.

Water Discharged to the Spent Fuel Pool from the Ground

On March 17, at 7:05 p.m., Tokyo Metropolitan Police Department's Riot Squad discharged water into the Unit 3 spent fuel pool using a high-pressure water cannon truck. It alternated with fire vehicles in the operation. The discharge of water was repeated between March 17 and March 25.

It was followed up by the injection of water using long-necked concrete pumps (the arms of which can reach approximately 58 meters). The first of such pumps was introduced on March 22 to cool Unit 4. Seawater was used at first, to be replaced by freshwater on March 30. On March 27, a new concrete pump was used for Unit 3, and on March 31 another was assigned to Unit 1. Unit 2 was cooled by connecting a fire hose to the cooling system of the spent fuel pool from March 20 onward.

The Central Control Room of Units 1 and 2 Regained Illumination

For the recovery of the power supply of Units 1 and 2, the power cable of Tohoku Electric, installed at the time of Fukushima Daiichi's construction, was used, which succeeded on March 20 in providing electricity to the Unit 2 power center. On March 23, the Unit 1 power center started to supply power to Unit 1. The lighting of the central control room of Units 1 and 2 was recovered on March 23.

Units 3 and 4 recovered lighting on March 22 thanks to the repair of the power line connected to the Shin Fukushima Substation, etc.

Unit 5 regained its power supply from Unit 6 (whose emergency diesel generator was in operation) on March 12 at 8:13 a.m. by use of an emergency power cable between Unit 5 and 6.

The Response of the *Kantei* (Prime Minister Kan[15] and His Cabinet)

March 11 and 12: The Unit 1 Vent

At the time of the earthquake, Deputy Chief Cabinet Secretary Tetsuro Fukuyama was at his office at the prime minister's official residence. He went to the Emergency Response Center

[15] Naoto Kan, born on October 10, 1946 in the Yamaguchi Prefecture. Graduated from Tokyo Institute of Technology's Department of Science, with a specialization in Applied Physics, according to his official website: http://n-kan.jp/about/, accessed on April 15, 2012.

located in the basement of the residence at 3 p.m. and was joined by Yukio Edano,[16] chief cabinet secretary. They were joined five minutes later by the prime minister, and others, who arrived from the Diet. (See Table 3a: Timeline of the Accident.)

Table 3a
Timeline of the Accident (March 11 - 12)

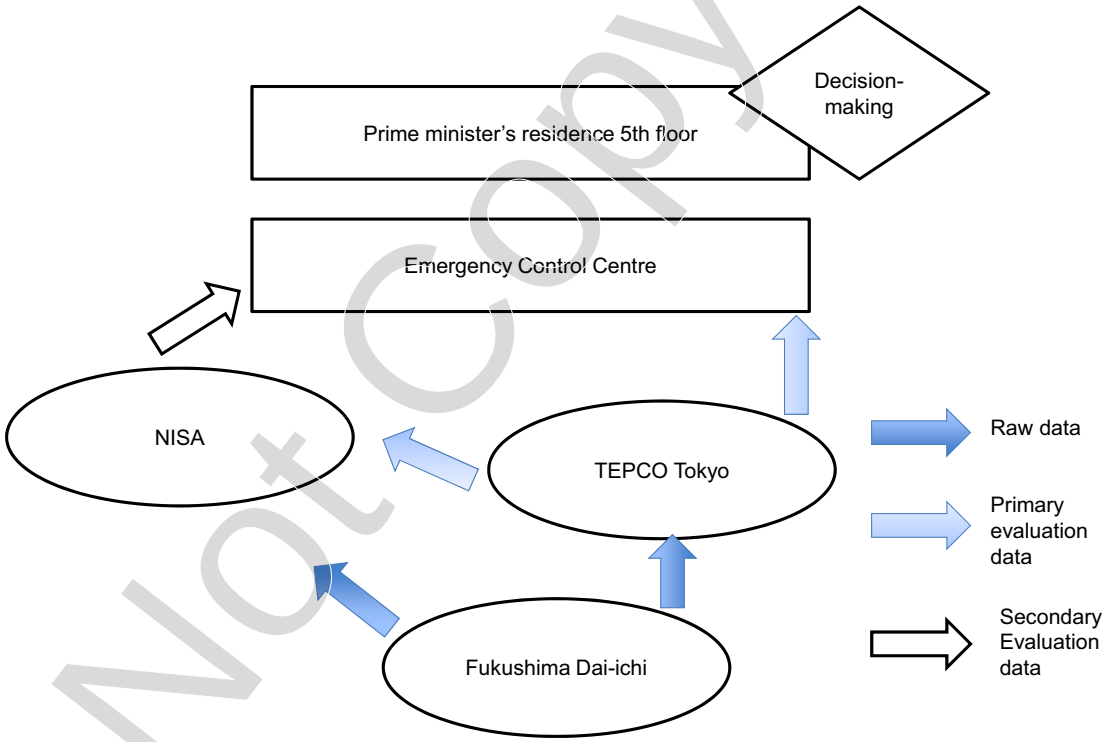
Date	Time	Event
March 11	2:46 p.m.	The earthquake
	3 p.m. (approx.)	PM's arrival at the Emergency Control Center in the basement of the PM's residence
	3:14 p.m.	The Headquarters for Disaster Control (HDC) constituted
	3:37 p.m.	The first meeting of the HDC
	3:42 p.m.	The warning issued according to Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness
	4:45 p.m.	The warning issued according to Article 15 of the Act
	Evening	The second floor of the Residence was ready for accommodating the emergency committee to discuss the issues
	9:23 p.m.	Evacuation warning for the 3 km radius of Fukushima Daiichi
March 12	12:05 a.m.	Warning issued according to Article 15 of the Act
	1:30 a.m. (approx.)	PM's Office accepted TEPCO's request to carry out venting
	3:06 a.m.	The Press meeting of Kaieda (METI) and TEPCO
	5:44 a.m.	The evacuation zone amplified to a 10 km radius on account of the vent not being put into place
	6:14 a.m.	PM Kan travelled to Fukushima by helicopter
	6:50 a.m.	Kaieda ordered TEPCO to carry out venting by virtue of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors
	8:03 a.m.	Director Yoshida ordered the venting
	8:04 a.m.	PM Kan left Fukushima Daiichi
	8:27 a.m.	TEPCO learned that part of Okuma-machi inhabitants not yet evacuated
	9:02 a.m.	The evacuation of Okuma-machi confirmed
	9:04 a.m.	Operators started the vent
	2:53 p.m.	80,000 tons of water injected to Unit 1 from fire vehicles
	3:36 p.m.	Unit 1 hydrogen explosion
	5:39 p.m.	Evacuation ordered for the 10 km radius of Fukushima Dai-ni
	5:45 p.m.	Chief cabinet secretary's press conference recognizing some kind of explosion having taken place
	5:55 p.m.	Kaieda (METI) ordered the filling of RPV with seawater by virtue of Clause 3, Article 64 of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors
	6:25 p.m.	Evacuation ordered within a 20 km radius
	7:04 p.m.	Seawater injection of nuclear reactors started
	8:32 p.m.	PM Kan's message explaining the 20 km-radius evacuation
	8:41 p.m.	The chief cabinet secretary held a press meeting and said: "The explosion was not inside the reactor container. [...] No drastic change in the radiation level expected compared with that before the explosion."

Source: Independent Panel (2012), pp. 75, 80.

[16] Yukio Edano, born May 31, 1964. Graduated from Tohoku University, Faculty of Law. Lawyer according to his official website: http://www.edano.gr.jp/profile.html, accessed on April 15, 2012.

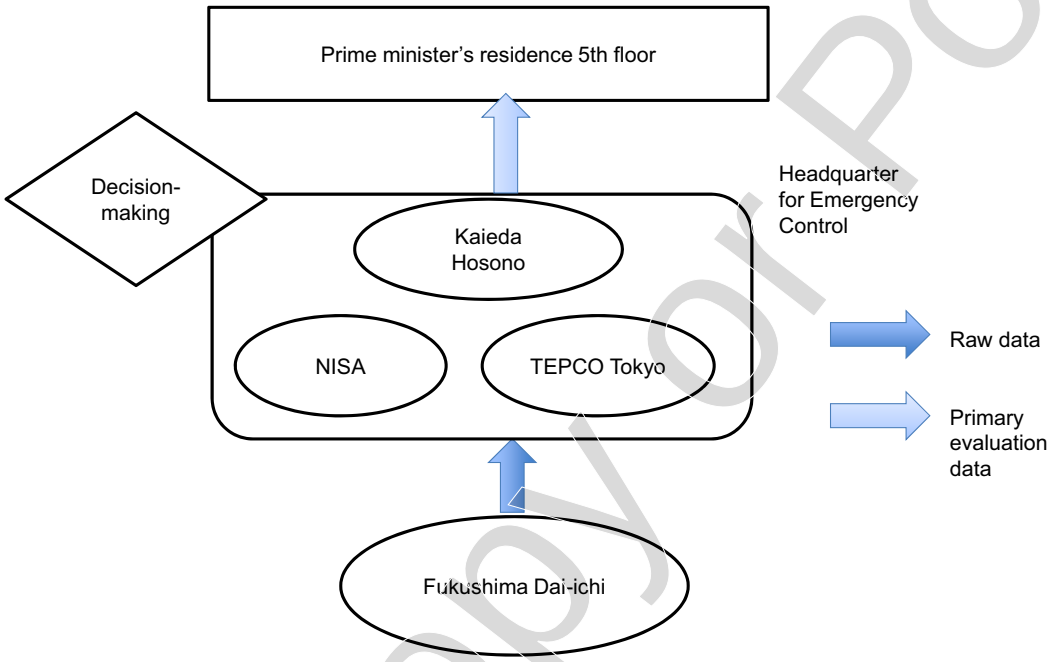
At the center, news from the Defense Ministry and TV stations were displayed on 10 monitors. At a round table, 20 high-ranking officials from different ministries sat amidst this hubbub. A total of 100 strong people were going in and out of the center immersing it in utter uproar, which impeded in-depth discussion of the situation. However, Kan, Edano and Fukushima dealt with urgent issues for the first 15 minutes and, by virtue of the Disaster Countermeasures Basic Act, the Headquarters for Emergency Disaster Control was established at 3:14 p.m. It could have been organized as soon as these three politicians met at the center, but they judged it better to postpone it until they had more precise information on the situation and had gathered the cabinet members. The first meeting of the headquarters was held at 3:37 p.m., after each minister had met with his ministry officials to gather more information. (See Graphs 1 and 2 for the information flow before and after the constitution of the Headquarters for Disaster Control.)

Graph 1
Information Flow Immediately After the Earthquake



Source: Independent Panel (2012), pp. 104, 106.

Graph 2
Information Flow After the HQ for Emergency Control Was Established (March 15 Onward)



Source: Independent Panel (2012), pp. 104, 106.

At 3:35 p.m., Fukushima Daiichi's AC power supply sources were lost due to the second tsunami, putting Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness into motion, which was officially communicated by TEPCO to the Minister of Economy, Trade and Industry, Nuclear and Industrial Safety Agency (NISA[17]) and incumbent autonomous governments.

After 4 p.m., the second meeting of the Headquarters for Emergency Disaster Control took place to discuss the earthquake, the tsunami and the nuclear power station. As Edano was busy communicating with the affected prefectural governments and autonomous bodies, Fukuyama took charge of the nuclear accident.

Minister Kaieda[18] (METI) was at the Budget Committee at the time of the earthquake. He was informed that the nuclear power station had come to an emergency halt thanks to the control rods. But he learned of the seriousness of the accident at Fukushima Daiichi only when he went back to his office after an emergency meeting to deal with a fire declared in the Chiba chemical complex.

In the evening of March 11, a small meeting was held in a tiny meeting room on the second floor of the residence beside the Crisis Management Center. Its members comprised Prime

[17] NISA was "established on January 6, 2001 as part of a reorganization of central government ministries. Our mission is to ensure the safety of the people's livelihoods through the regulation of the energy industry and related industries." http://www.nisa.meti.go.jp/english/aboutnisa/mission.html, accessed on April 16, 2012.

[18] Banri Kaieda, born on February 26, 1949. Graduated from Keio University's Faculty of Law.

Minister Kan, Edano, Kaieda, Fukuyama, Terada and Hosono (aides of the PM), all of whom are politicians, and NISA's Nobuaki Terasaka. At around 9 p.m. or 10 p.m., they were joined by Haruki Madarame from the Nuclear Safety Commission,[19] TEPCO's Ichiro Takeguro, and NISA's Eiji Hiraoka, who replaced Terasaka.

The first measure adopted at the meeting was the supply of power-generating vehicles to make up for the loss of power-supply sources. It was later reported that TEPCO could not find power cords to connect to power-generating vehicles, which, according to Edano, was the beginning of the distrust felt by the government towards TEPCO.

Madarame, when he arrived at the prime minister's residence, expected NISA to take charge of the situation, but, to his surprise, he found that NISA was too busy gathering information on the power station and that it was he himself who had to answer the questions formulated by the prime minister. He advised in favor of putting a vent in place to release heat outside reactors in view of the impossibility of using high-pressure pumps to inject water due to the power-source loss. Thus, at that time, the need to create a vent was commonly agreed upon by the meeting members.

At 9:23 p.m., Kan ordered the evacuation of the area within a 3 km radius from Fukushima Daiichi in light of the need to operate the vent. At around 10 p.m., NISA predicted a meltdown at Unit 2. At around 11 p.m., Takeguro urged TEPCO over the phone to make its decision to move ahead with the vent. But the vent was not conducted, causing the pressure inside the reactor container to continue increasing, and, at 12:55 a.m. on March 12, the abnormal increase in Unit 2's container pressure was reported by virtue of Article 15 of the Act on Special Measures Concerning Nuclear Emergency Preparedness. At around 1:30 a.m., Takeguro proposed venting to Kan, and Akio Komori, TEPCO's managing director, did the same to Kaieda, both of whom agreed. Kaieda suggested that the vent be conducted after the press conference at 3 a.m.

At 3:06 a.m., a joint press meeting was held between Minister Kaieda, TEPCO and NISA to announce the carrying out of the venting. At 3:12 a.m., Edano also held a press conference and announced the conducting of the vent. But the venting was not carried out. When Kaieda asked Takeguro about the reason for the delay, he only said that he did not know and, as a consequence, Kaieda began to think about the need of forcing TEPCO to act under the Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors (Nuclear Reactor Regulation Law).

The lack of dissemination among the minister, NISA, and TEPCO's Tokyo headquarters regarding the news that Unit 2 was running RCIC gave rise to some confusion about which Unit would need the vent.

Based on Madarame's explanation that even in Chernobyl evacuation was not carried out in more than a 30 km radius, and in the belief that the vent in question was a wet vent that would not disperse the radiation fallout in a wide range, the *Kantei* did not see the need to extend the evacuation area to more than a 3 km range.

[19] "In a conventional nuclear emergency, the NSC Japan shall convene the 'Technical Advisory Organization in an Emergency' that is composed of the Commissioners and the Advisors for Emergency Response and shall give technical advice to the prime minister." http://www.nsc.go.jp/NSCenglish/index.htm, accessed on April 16, 2012.

However, TEPCO Tokyo HQ formed an estimate of the radiation exposure after the vent, which it shared with Fukushima Daiichi management. The estimate took into consideration the need to conduct dry venting on Unit 1 and reckoned that at a point 4.29 km south of the power station, the level of radiation would shoot up to 28 mSv after three hours. This estimate was related to NISA by Fukushima Daiichi, but was not forwarded to the PM's office. Madarame later stated that he had been ignorant of the dry venting, which, if carried out, would make the 3 km radius evacuation insufficient, with 10 km being the adequate number.

Fukuyama returned from a meeting to deal with the earthquake in Nagano that took place at 3:59 a.m. and was surprised to find that the venting had not yet been carried out. At around 5 p.m., Kan also became aware that the venting had not yet been conducted, and asked Takeguro, from TEPCO, for the reason, whose response pointed to the blackout. With the venting not having been started and the pressure of Unit 1 having increased, the evacuation range was extended to a 10 km radius for fear of an explosion.

At 6:14 p.m., Kan headed for Fukushima Daiichi in the Self Defense Force's helicopter, a plan which Edano had opposed on the grounds that it might provoke political criticism. Kan was adamant in his belief that getting the nuclear power station under control was more important than him being politically criticized or not. Edano still did not consider a politician's visit to the site indispensable.

Even after the departure of Kan to Fukushima, the venting was not conducted. Minister Kaieda then took it upon himself, and verbally ordered the carrying out of the venting at 6:50 a.m. based on Clause 3 of Article 64 of the Nuclear Reactor Regulation Law. No specification was made about which units were involved, but NISA understood it to refer to Units 1 and 2. Director Yoshida, however, deemed that Unit 1 was the priority. It was witnessed that Director Yoshida was strongly against the visit of PM Kan to the site.

On their way to Fukushima, Madarame wanted to express his concern regarding a wide gamut of issues, but Kan insisted on the former's response to his questions only. One of the questions raised by Kan was whether a hydrogen explosion might occur or not, to which Madarame responded negatively on the grounds that, in the reactor container, hydrogen would have been replaced by nitrogen, and explosions therefore would not take place. When the hydrogen explosion of Unit 1 took place, Kan rapidly withdrew his trust in Madarame.

At 7:11 a.m., Prime Minister Kan arrived at Fukushima Daiichi. On his way to the site, Kan demanded an explanation from TEPCO's Vice President Muto as to why the venting had not been carried out. He barked at Muto when the latter insisted on the lack of power supply.

At the isolated-base building, Director Yoshida[20] stressed his determination to face the crisis, even organizing a death squad, which met with the prime minister's approval. At 8:03 a.m., Director Yoshida instructed the venting to be carried out at 9 a.m., and Prime Minister Kan departed for Tokyo at 8:04 a.m. convinced of the capability of Director Yoshida.

At 8:27 a.m., TEPCO learned that some of the inhabitants of Okuma-machi had not evacuated yet, wherefore TEPCO and the Fukushima Prefecture agreed on not carrying out the venting until a 10 km radius had been evacuated. (Edano could not conceal his annoyance at

[20] Masao Yoshida, born on February 17, 1955. Graduated from Tokyo Institute Technology's Department of Engineering in 1977.

discovering some months later that he had not been informed of the existence of such an agreement.) At 9:02 a.m. the evacuation of Okuma-machi was confirmed, and at 9:04 a.m. vent operators headed to the site. At 9:15 a.m. the vent valve was manually opened at the reactor container and at 10:17 a.m. the opening operation was attempted from the central control room and the success of the vent was confirmed.

March 12: A Hydrogen Explosion at, and the Injection of Seawater Into, Unit 1

On March 12 at 3:36 p.m., Prime Minister Kan was in the middle of a meeting with the heads of the opposition parties. Upon his arrival to his office on the fifth floor of the residence, a report was communicated to him that Unit 1 had been emitting a white column. Madarame's interpretation pointed to the ignition of some volatile materials. One hour later, TV channels broadcasted images of a destroyed building with a large quantity of white smoke. Kan frowned at them and reprimanded Madarame for his erroneous interpretation.

Kan ordered the confirmation of facts from NISA and TEPCO. The latter reported that one of its staff was heading to the site to carry out a visual inspection. Fukuyama asked if the explosion was of the same nature as that at Three Mile Island and Chernobyl. Aware of his error, Madarame did not dare to answer him directly, though he immediately realized that it had been a hydrogen explosion.

Kan tried to obtain an accurate perspective of the situation by consulting various experts, but at the time of his preparing for a press interview to be held at 5:45 p.m., the real picture of the explosion had not yet been established. Against Fukuyama's opinion that until they were informed of the situation in which the reactor container and reactor vessel were left the press conference should be postponed, Edano decided to go ahead with it, in the belief that if after two hours of the accident the conference was to be put off, the public would become nervous.

Edano's only information was that the radiation dose had not increased at the entrance of Fukushima Daiichi. He stuck to it and asserted that, while recognizing that some explosive phenomenon had taken place, people must remain calm. The journalists, aware of Edano's ambiguous explanation, pressed for assurance about the safety of the nuclear reactor and the sufficiency of the 10 km evacuation radius. Edano recalled this press conference as having been very trying for him.

Two hours after the press conference, at 7:40 p.m., Hosono entered the prime minister's office and reported that it had been a hydrogen explosion judging from the decrease in the radiation dose in a neighboring area of the site. Terasaka from NISA later admitted their delay in informing the prime minister correctly, owning to their conviction that the success in the venting must have nullified the possibility of a hydrogen explosion, hence it took time before they could reach an accurate conclusion.

In the meantime, at 5:26 p.m., Edano asked NISA to conduct a simulation on the need of evacuating the area within a 20 km radius, on the assumption that both Fukushima Daiichi and Fukushima Daini were affected. At 5:39 p.m., Prime Minister Kan ordered that the area within a 10 km radius be evacuated, which was extended to 20 km at 6:25 p.m.

In the afternoon of March 12, the *Kantei* held meetings to see if it was necessary to inject water into the Unit 1 reactor core; and if it could be seawater should freshwater not be available. Even at the time of Edano's press meeting at 5:45 p.m, Kaieda, Hosono, Madarame, etc., discussed the issue and consequently, at 5:55 p.m., Minister Kaieda verbally issued an order that seawater be injected to the Unit 1 reactor by virtue of Article 63, Clause 3 of the Nuclear Reactor Regulation Law.

At 6 p.m., Prime Minister Kan joined the meeting, and upon being informed of the seawater injection, demanded an explanation regarding the negative effects of using seawater. Madarame explained the possibility of the pipes being obstructed by salt and the risk of them being oxidized.

Kan further insisted on an explanation of recriticality.[21] Madarame did not fully deny the possibility of it taking place, regarding which Kan expressed his concern. Takeguro called his attention to the fact that it might take one and a half hours to prepare the seawater injection on account of the damage caused to the hoses. The meeting was divided.

The meeting's attendees, concerned that the seawater injection might be postponed in light of Madarame's comment and Kan's reaction to it, met again in a small room beside the prime minister's assistants' offices. METI's Tadao Yanase, Madarame, Yutaka Kukita (Madarame's No. 2), Takeguro, and the prime minister's secretary considered Madarame's comment. Regardless of Madarame's protest that he could not have said otherwise, being questioned by the prime minister, a consensus was reached that the seawater injection was peremptory. At the suggestion of Yanase, they rehearsed what they would tell Kan in order to avoid a situation in which the prime minister might raise doubts about the viability of seawater injection. Madarame requested that Kukita give an explanation on criticality resumption.

At 7:40 p.m., the meeting was renewed, with the participation of the prime minister. Takeguro, as TEPCO's representative, following the previously established consensus, requested the seawater injection. Kukita then stressed that unlike Madarame's comment, the possibility of recriticality taking place was remote and the need to inject seawater was very high. Hosono reported that the hoses were ready for the seawater injection. Vis-à-vis these explanations, Kan expressed his approval, and at 7:55 p.m. instructed Kaieda to move forward with the seawater injection. Madarame did not participate in this meeting.

At TEPCO at 6:05 p.m., its management meeting reported Kaieda's order and gave its authorization for the seawater injection at 7:04 p.m. However, immediately afterwards, Takeguro phoned Director Yoshida to advise him that the prime minister's approval was yet to be obtained and therefore the seawater injection should be suspended. Director Yoshida,

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[21] "Criticality is a nuclear term that refers to the balance of neutrons in the system. 'Subcritical' refers to a system where the loss rate of neutrons is greater than the production rate of neutrons and therefore the neutron population (or number of neutrons) decreases as time goes on. [...] The criticality of a system can be calculated by comparing the rate at which neutrons are produced, from fission and other sources, to the rate at which they are lost through absorption and leakage out of the reactor core. A nuclear reactor is a system that controls this criticality or balance of neutrons. [...] A reactor is maintained critical during normal power operations. In other systems, such as a spent fuel pool, mechanisms are in place to prevent criticality. If such a system still achieves criticality, it is called "re-criticality". [...] Most types of light water reactors (like the BWRs in Japan) use water to not only cool the reactor, but to also slow down neutrons. [...] Therefore, if the water boils off, neutrons will not slow down as much and the probability of fission reactions and power decreases, thus putting the nuclear system in a subcritical state. [...] If water heats up and vaporizes in a BWR reactor or spent fuel pool without cooling, the temperature increase of the water and eventual vaporization of water will tend to place the system in a subcritical condition." http://mitnse.com/2011/03/18/what-is-criticality/, accessed on April 16, 2012.

nonetheless, made the decision on his own. He reported back to the headquarters that the injection had been suspended, but instructed his subordinates to continue with it.

March 14 and 15: The Government-TEPCO

At around the stroke of midnight on March 14, Minister Kaieda received a phone call from TEPCO's president, Shimizu, stating that due to the high possibility of explosions in Unit 2, they wanted to withdraw all of their staff and move them to Fukushima Daini. Director Yoshida, too, had been preparing to pull out staff, leaving only a minimum required number on the site for fear of a China Syndrome-type of accident.[22] Kaieda interpreted Shimizu's request as that of the withdrawal of all staff and flatly refused in order to avoid the total loss of control. He felt a chill running down his spine. (See Table 3b: Timeline of the Accident.)

Table 3b
Timeline of the Accident (March 14 - 24)

Date	Hour	Event
March 14	11:01 a.m.	Unit 3 Reactor building destroyed by a hydrogen explosion
	06:22 p.m.	Unit 2 fuel rods exposed to the air due to the scarcity of cooling water
March 15	Around 3 a.m.	TEPCO President Shimizu's request to Minister Kaieda for the withdrawal of their operators from Fukushima Daiichi
	Around 3 a.m.	Shimizu's request to Chief Cabinet Secretary Edano for the withdrawal of their operators
	04:17 a.m.	TEPCO's Shimizu arrived at PM's residence
	05:26 a.m.	Government-TEPCO Headquarters for Disaster Control established
	05:40 a.m.	PM Kan visited TEPCO's headquarters
	06:00 a.m.	A sudden loud blow near Unit 2 pressure control room; Unit 4 building damaged
	07:00 a.m.	650 operators withdrawn and moved to Fukushima Daini
	11:00 a.m.	Evacuation ordered of the area within a 20 - 30 km radius of Fukushima Daiichi
March 16	05:45 a.m.	Fire started in the northeast corner of Unit 4's fourth floor
	08:34 a.m.	White fumes coming from Unit 3
March 17	09:48 a.m.	Water discharged to Unit 3 spent fuel pool from a helicopter
	10:22 a.m.	PM Kan and President Obama talked over the phone; the latter informed of the United States' intention to order the withdrawal of its citizens living in Tokyo Metropolitan area
	02:15 p.m.	The U.S. government recommended that its citizens leave Japan
	07:00 p.m.	Police and the Self Defense Force started to discharge water into Unit 3 spent fuel pool
March 18	02:42 p.m.	Water discharged to Unit 3 spent fuel pool by the Self Defense Force and U.S. Army
March 19		Emergency Fire Response Team discharged water into Unit 3 spent fuel pool
March 20	05:17 p.m.	Water discharge to Unit 4 spent fuel pool; started using concrete pump vehicles
March 24		Power supply and cooling pumps for spent fuel pools of several units recovered using external power sources

Source: Independent Panel (2012), pp. 84, 87.

[22] "The accidental melting of a nuclear reactor core so that its contents sink through the bottom of its container and into the earth." (American Heritage Dictionary).

Edano was called to the prime minister's drawing room and Kaieda explained Shimizu's request to him. Both of them agreed on the need to dissuade TEPCO. At that moment, Shimizu rang Edano to reiterate the request, alleging that their staff in the power station were at the limit of their capability, to which Edano responded that it was beyond his authority to make that decision. Hosono then tried to confirm the situation with Yoshida, who commented that they would still deal with it but that they would need equipment and the required materials, including pumps to inject water under the high-pressure environment. Madarame and the others opined that the cooling and water-injection operations would suffer if staff were to be withdrawn, though Madarame could not give any concrete suggestions to circumvent the difficulties. The people gathered in the drawing room, albeit against the withdrawal of TEPCO's staff, started to feel very pessimistic.

At around 3:20 a.m., Edano woke up the prime minister to discuss the issue at the PM's office with Kan, Edano, Kaieda, Fukuyama, Hosono and Terada. Kan expressed his strong feelings against TEPCO's request.

Kan moved into the drawing room and summoned Fujii (deputy chief cabinet secretary) and Matsumoto (minister in charge of disaster prevention). Madarame and NISA officials were also present. All agreed on the refusal of TEPCO's request. Kan reportedly expressed his fear about Units 1 - 3 and the treatment of the spent fuel pool in Unit 4, as well as his concern about the destiny of eastern Japan if radiation were not put under control.

Those present likewise called into question a good flow of communication between the *Kantei* and TEPCO. Kan ordered Hosono to move to TEPCO's headquarters and asked his assistant if there were any legal impediments in carrying out the order. Kan also decided to talk directly to Shimizu and summoned him to his office at 4 a.m. (TEPCO's official communication denies the request to withdraw its entire staff. NISA's Terasaka, referring to Shimizu's phone call to him on the night of March 14, did not remember if total withdrawal was mentioned. Circumstantial evidence does not seem to support TEPCO's denial.)

At 4:17 a.m., Shimizu arrived at the prime minister's residence. Kan stressed that withdrawal from Fukushima Daiichi would be out of the question, to which Shimizu responded by renouncing his request; and upon Kan's insistence on this point, Shimizu, in a faint voice, confirmed his renunciation.

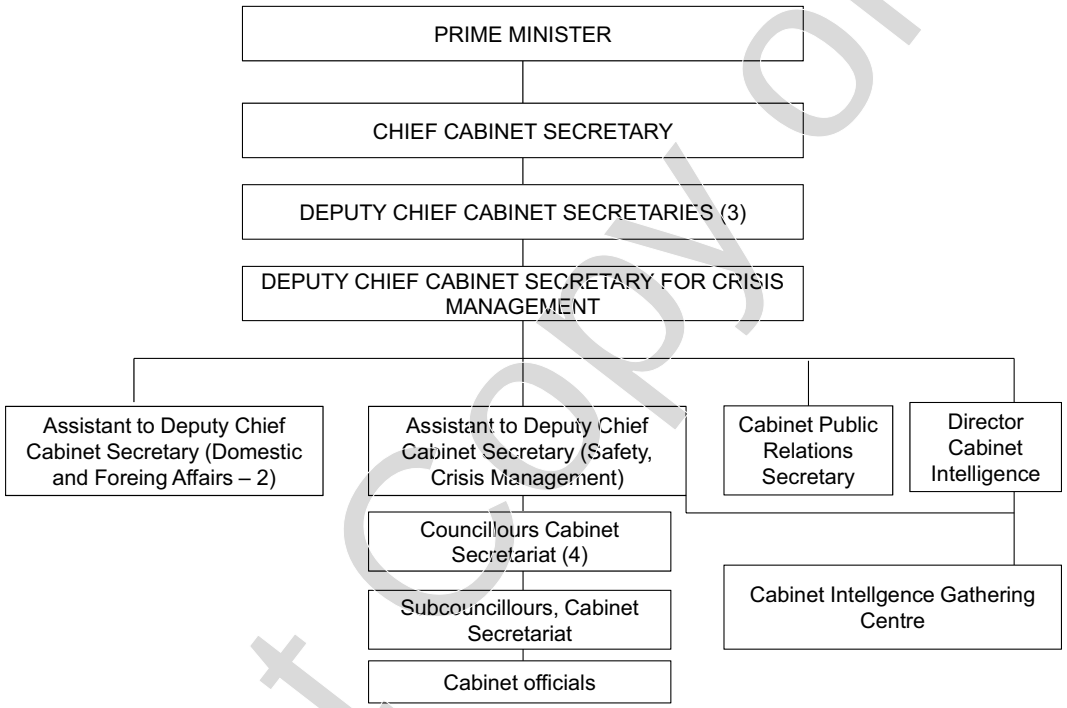
Kan revealed to Shimizu his intention to send Hosono to TEPCO's headquarters and informed him of his plan to visit TEPCO's office himself. Shimizu asked him to wait for one or two hours to allow preparations to be made, but Kan imposed his will to visit TEPCO in half an hour's time.

At 5:26 a.m., Kan, Kaieda, Hosono and Terada went to TEPCO by car, accompanied by a group of journalists. In the operation room, equipped with several gigantic monitor screens connected to Fukushima Daiichi, Kan appealed to TEPCO's management and employees saying that withdrawal was out of the question, and that if it were to be carried out, TEPCO would be swept off the face of the earth. At 6 a.m., an explosion was heard near the pressure control room in Unit 2, which made it necessary to withdraw 650 operators from Fukushima Daiichi, leaving only 50 in charge. (See **Exhibit 2** regarding the limited involvement of the bureaucratic machine during the nuclear power station crisis.)

Evaluation of the *Kantei* 's Intervention

In the Measures Concerning Nuclear Emergency Preparedness Manual produced by the government, the role of the *Kantei* is set out as: (1) the publication of the nuclear emergency and communications with related organizations; (2) the provision of information to the public; (3) giving instructions to the relevant autonomous bodies, information diffusion, etc. (See Graph 3 for the organization of the cabinet secretariat in the event of an emergency.)

Graph 3
Cabinet Secretariat Organization in the Event of an Emergency



Source: Independent Panel (2012), p. 114.

Contrary to this definition of their role, the prime minister and his staff actively intervened in the accident management, including the dispatch of power generating vehicles, instructions about the vent, on-site inspection by the prime minister, orders to inject seawater, etc.

The main players in such an intervention were Prime Minister Kan, METI's Kaieda, Chief Cabinet Secretary Hosono, Deputy Chief Cabinet Secretary Fukuyama, the Prime Minister's aides Terada and Hoson, assisted by Nuclear Safety Commission's Madarame, TEPCO's Takeguro, and NISA's specialists.[23]

[23] The government was severely criticized by the media, inside and outside Japan, for not using SPEEDI (system for prediction of environmental emergency dose information) data. However, it was verified that the top politicians in Kan's government had not been informed of its existence, nor was the data from it communicated to them. Kaieda stressed that neither NISA nor the Nuclear Safety Commission directors brought its existence to their notice during the crisis. Independent Investigation Commission on the Fukushima Daiichi Nuclear Accident (2012), p. 174.

After the Headquarters for Disaster Control were established on March 15, it was divided between Minister Kaieda, stationed at TEPCO, on the one hand, and PM Kan, Edano and Fukuyama, based in the prime minister's residence. By then, Kan had appointed several advisers to gather second and third opinions.

Chief Examples of the *Kantei*'s Intervention and Their Impact

(1) Power-generating vehicles (night of March 11)

Upon hearing the news that Fukushima Daiichi had lost all power supplies, the PM's office prepared 40 vehicles. They were not of much use after their arrival, due to the difference in the connection types, and could not be used.

(2) Vent on Unit 1 (night of March 11 to morning of March 12)

Madarame insisted on the need for this on the night of March 11. Yoshida made the decision to prepare for it himself, without waiting for any instructions, in light of the pressure increase in Unit 1 on March 12 at 12:06 a.m. TEPCO proposed this measure to the PM's office at 1:30 a.m. At 6:50 a.m., Kaieda forced this by virtue of a law, in view of the TEPCO's delay in carrying it out. At 7:12 a.m., upon his arrival at Fukushima Daiichi, Kan requested the measure again. It was conducted at 9:04 a.m. There was considerable evidence that the decision of the PM's office or Minister Kaieda's, and PM Kan's pressure, prompted it.

(3) Seawater injection (night of March 12)

Yoshida instructed the seawater injection into Unit 1 by aligning three fire vehicles in series at 12:54 p.m. on March 12. A hydrogen explosion occurred at Unit 1 at 3:36 p.m. At 5:55 p.m., Kaieda instructed the implementation of the seawater injection; but with Kan suspecting recriticaliy, it did not go through. At Fukushima Daiichi, however, they restarted the injection of seawater at 7:04 p.m. Yoshida was contacted by Takeguro, who, upon learning that the injection had been carried out, asked for it to be suspended. TEPCO Tokyo suggested the same to Yoshida, who, for fear of the worsening of the situation, ignored it. If the decision – or non-decision – of the PM's office had been undertaken, the operation would have been jeopardized, increasing the danger level.

(4) Unit 3 water injection (March 13)

At 2:42 a.m., on March 13, the operators in charge of Units 3 and 4 manually stopped HPCI for fear of it breaking down. At 3:55 a.m., Yoshida, as soon as he learned of it, ordered the injection of seawater; and by 7 a.m., the hoses were ready. Around the same time, the PM's office thought it better to use freshwater instead of seawater and instructed Yoshida to that effect through TEPCO's headquarters. Yoshida switched to freshwater and started the injection at 9:25 a.m., but, after three hours, the freshwater ran out and they had to switch to seawater. It is suspected that the switch to seawater from freshwater led to the unnecessary exposure of the operators to radiation, in addition to the possibility of the water injection operation risking failure.

(5) TEPCO's plan to withdraw (night of March 14 and morning of March 15)

In view of the increasing danger of explosion in Unit 2 on March 14, Yoshida thought about the withdrawal of his operators, leaving only the minimum number necessary. TEPCO HQ proposed the total withdrawal. Kaieda, Edano and Hosono, who talked with TEPCO's Shimizu, understood that the request concerned the withdrawal of all operators. Kan summoned Shimizu to his office and refused the request. Yoshida expressed his opinion that they would be able to cope with the situation given the success of injecting water into Unit 2. At 6 a.m., however, Unit 2 suffered an explosion, forcing 650 operators to seek refuge. Kan insisted on keeping the water injection team on-site. Kan's refusal of Shimizu's request was based not on a concrete idea about the Unit 2 problem, but rather on the feeling that the withdrawal signified the worst-case scenario. Nonetheless, the refusal forced TEPCO to awaken to the need to deal with the crisis; in that sense this was the turning point of the crisis.

(6) Water injection to the spent fuel pool (March 17 onward)

From March 15 onward, the emergency headquarters were in charge of measures related to the operations. Minister Kaieda coordinated globally, assisted by Hosono as Kan's representative. Thanks to this coordination, the injection of water by the Self Defense Force and the fire brigade went smoothly.

The *Kantei*'s Distrust of TEPCO and NISA[24]

(1) TEPCO[25]

Witnesses revealed that the prime minister's team started to harbor distrust towards TEPCO as early as the night of March 11. Despite the preparation of power-generating vehicles on this night, the PM's office did not receive explanation from TEPCO as to why the power station's power supply continued to be cut. On March 12 at 1:30 a.m., the vent was approved in Unit 1; but at 4:30 a.m. on the same day, Fukuyama found that it had not been carried out and demanded an explanation from TEPCO's Takeguro. At 5 a.m., they reiterated the question to Takeguro, who was incapable of providing any satisfactory explanation. Kaieda's anger was witnessed. At 6:50 a.m., Kaieda issued the order to carry out the vent, because of the mistrust felt towards TEPCO.

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[24] Hasegawa (2011) points out the "vested interest structure" related to the nuclear power industry, figuratively forming a "nuclear power village" comprising politicians, bureaucrats, business people, academics and the media; representing ¥2 trillion in spending per year for its maintenance among nine electric power companies in Japan, involving 400 strong first-ranking companies, supported by the governmental budget for ¥456 billion a year. Hasegawa (2011) cites the Liberal Democratic Party's Taro Kono as denouncing the "safety myth" created by the nuclear village to protect their interests. Hasegawa (2011) further informs that 48 MPs from the Democratic Party of Japan were endorsed by the Federation of Electric Power's related Industry Workers Unions of Japan in the upper house election in 2010; that the Liberal Democratic Party of Japan, on its part, received donations from TEPCO's executives for the amount of ¥20 million in the period between 2007 and 2009; and that at present, TEPCO employs four high-ranking former METI officials as its staff.

[25] Genshiryoku Shiryo Johoshitsu (n.d.) reports the discovery of 29 cases of problems between the late '80s and the '90s that TEPCO hid in relation to its 17 reactors in operation, 13 of which were denounced as suffering some kind of trouble by an anonymous insider informant, who sent a letter to MITI in July 2000.

(2) NISA

According to the Nuclear Emergency manual, it was foreseen that the Headquarters for Nuclear Disaster would be installed at METI's Emergency Response Center (ERC) with the head of NISA working as the central figure, coordinating communications with the prime minister and government officials. As a result of NISA's Terasaka and his staff being based in the prime minister's office as of March 11, the administrative function of the headquarters was split between the PM's office and the ERC. This might have affected NISA's capacity to handle and analyze data in order to make decisions. It was also suspected that putting the headquarters at METI might have been a non-starter vis-à-vis the need to coordinate various ministries. The fact that all eight NISA inspectors stationed at Fukushima Daiichi abandoned the site made it impossible for NISA to gather any first-hand information. Consequently, NISA's information depended on TEPCO. There is no evidence that NISA's Terasaka and Hiraoka took any initiative in proposals and data gathering at the PM's office, which made the politicians doubt their capability.

(3) Multiple hierarchical and communication layers generating distrust and confusion

With the prime minister's office intervening directly in the handling of the crisis, the response to the disaster greatly differed from the scheme described in the Nuclear Emergency Response Manual. The instructions issued from the PM's office, which was far removed from the actual accident site, made communication routes complex, causing the delay in the gathering of data and distrust among the people concerned.

Between the evening of March 11 and the morning of March 12, the Emergency Response Center held a meeting on the second floor of the PM's residence. But after midday on March 12, the decision-making function moved to the prime minister's office and his drawing room on the fifth floor.

Data gathering and communication became complex as a result of this. For example, the seawater injection into Unit 1 on March 12 was started at 7:04 p.m., which was communicated to the ERC by NISA, but not to the fifth floor meeting.

One of the reasons for moving to the fifth floor was that the use of mobile phones was banned at the ERC (which only had two fixed telephone lines).

Prime Minister Kan's Management Style

(1) Top down style

Kan prefers to gather information and make decisions personally. His decisions comprised a wide range of issues, from strategically important issues, such as the refusal of TEPCO's request to withdraw, to operational issues such as the supply of power-generating vehicles. Some of the staff appreciated this quick decision-making by the prime minister. Hosono speculated that Kan's personal intervention style intensified after his visit to Fukushima Daiichi on the early morning of March 12.

Criticism leveled against Kan considers his style as being too much like micro-management. For example, Kan was very interested in being kept posted about the use of power-generating vehicles and giving very concrete instructions.

His strong intervention, more often than not, forced his staff to interrupt their work to prepare the information demanded by Kan.

(2) Strong personality

Kan's style was characterized by his insistence on his opinion. One of the people who accompanied him to Fukushima Daiichi recalled Kan yelling at his entourage, whose attention was deviated from gathering information. Madarame tried to explain the technical matters to Kan on their way to Fukushima, but the prime minister told him not to, and to limit himself to responding to his questions, which was frustrating for him.

The visit to Fukushima was not first approved by Edano, Kaieda, Fukuyama, etc., but ultimately Kan got his own way.

Some people, such as Hosono, insisted that opposing opinions could be explained to Kan without any problem, but others doubted the possibility of daring to contradict an irate prime minister.

(3) Mistrust of "official" information, and trust in his staff

Kan was well-known for not trusting information coming from the organizational route, such as from Kasumigaseki (i.e., Japanese Whitehall) and from TEPCO. He was always critical of officialdom and bureaucratic organization in the belief that public servants only released the data and information that did not run counter to their interests.

Kan, on the other hand, put a considerable amount of trust in his staff. Hosono and Terada could therefore intervene in issues that were not suited to their competencies. Kan also appointed a host of advisers by March 29, which Edano advised against. Kan tended to gather information from his personal conversations via mobile phone, which prevented even Kan's personal aides to keep abreast with his thinking.

Concluding Remarks

The Fukushima Daiichi Nuclear Power Station accident uncovered many shortcomings in the Japanese organizational system in coping with such a world-scale, unheard-of disaster. A member of the Independent Panel wonders if there were real leadership figures at the government or at TEPCO; if the communication between the Emergency Control Center, in the basement of the prime minister's residence, and the prime minister, on the fifth floor, were sufficient; if there were too much micro-management on the part of the prime minister; if the prime minister and his entourage were capable of establishing what Churchill called "War Room," that integrated the wisdom and expertise of all the parties involved; and if the TEPCO management in Tokyo was best suited to cope with the crisis, when considering the fact that the majority of its top executives were strategic planners or from the procurement department, good at keeping good relations with Kasumigaseki, but entirely lacking in the practical wisdom needed to face the crisis, etc. (See **Exhibit 3** for the analysis of the causes of the accident by a team headed by Ken'ichi Ohmae.)

Exhibit 1

Worst-Case Scenario Analysis

Vis-à-vis the worsening situation at Unit 2 as well as at Unit 4's spent fuel pool between March 14 and March 15, Prime Minister Kan felt the acute need to conduct a worst-case scenario analysis. Edano reminisced about their fear that Tokyo might have to be evacuated if Fukushima Daiichi escaped out of control affecting the operation at Fukushima Dai-ni, which might result in Tokai Nuclear Power Station being severely affected, etc.

The Nuclear Safety Commission's advice would be sought for this kind of analysis and Madarame and his staff would be charged to carry it out; however, Kan did not hold Madarame's opinion in high esteem anymore on account of his failed prediction that Unit 1 would not suffer a hydrogen explosion.

Accordingly, Shunsuke Kondo, the chairman of the Atomic Energy Commission, was contacted for the task as per Hosono's advice. On March 22, Kan invited Madarame (Nuclear Safety Commission), Kondo and Terasaka (NISA) to his office and requested the preparation of the worst-case scenario report. Edano, Fukuyama, Hosono and Terada were present in the meeting. Kan asked for the report to be ready in three days' time.

Between March 22 and March 25, Kondo worked out the analysis with the help of Akira Omoto (Tokyo University), NISA, JNES (Japan Nuclear Energy Safety Organization), and JAEA (Japan Atomic Energy Agency). A computer analysis was conducted.

Its result was:

(1) It was not necessary to extend the 20 km-radius evacuation zone even in the case that hydrogen explosions might have increased the radiation level, followed by the radiation from other units, according to the analysis of the radiation dose;

(2) It would not be advisable that inhabitants near the power station seek refuge inside their homes in light of possible radiation due to Unit 4 spent fuel pool destruction and the interaction in the core concrete. Instead, they should be ordered to move beyond a 50 km radius within 14 days;

(3) Within the radius of the 70 km zone beyond 50 km, taking refuge inside buildings might be feasible; however, even in the radius of 110 km, there could be spots from which inhabitants must be moved if their soil were found to be highly radiation-contaminated;

(4) It might be possible that in other units' spent fuel pools, fuel destruction might take place, which could result in the interaction in the core concrete with a large amount of radiation emission. As a consequence, the evacuation zone might become extended to 170 km and over; and if the annual radiation dose largely exceeded the natural radiation level, the evacuation might be extended to a 250 km-radius area;

(5) The radiation level of 170 km and 250 km-radius areas would need several decades before their natural radiation level would reduce to a normal level.

Exhibit 2

Bureaucratic Machine's Scarce Involvement

Throughout the Fukushima Daiichi crisis, the response of the Kasumigaseki bureaucratic machine, including NISA, was characterized by its passiveness and ex-post reactions. It was a reflection on human limitations in view of complex and compounded disasters as well as of the dearth of appropriate human resources capable of facing such a large-scale crisis.

Legally, the responsibility for the accidents such as nuclear power station troubles falls on (1) the deputy chief cabinet secretary, (2) the deputy chief cabinet secretary for crisis management, and (3) the deputy chief cabinet secretary for safety, the second of whom is to take charge of issues concerning crises affecting the lives and safety of Japanese nationals, except for those directly related to the self-defense of the country.

Therefore, from the viewpoint of the legal scheme, the deputy chief cabinet secretaries for crisis management and for safety were expected to integrate and coordinate the ministries and governmental bodies.

However, the present crisis being by far more complicated due to the combination of the earthquake, tsunami and nuclear power station accident, Ito (the deputy chief cabinet secretary for crisis management) was assigned to the Fukushima issue, whereas Takino (the deputy chief cabinet secretary) and Nishikawa, his number two, were appointed to deal with the earthquake and tsunami disasters.

Ito, even being in charge of the Fukushima accident, only partially intervened in the decision-making meeting held on the fifth floor of the prime minister's residence. Ito instead centered his effort on the withdrawal of inhabitants and the search for their relocations, coordination, etc.

The government official's appraisal of NISA (working theoretically as the secretariat of the nuclear emergency response headquarters) was low. Above all, Terasaka (general secretary) and Hiraoka (deputy director) were not held in high esteem on account of them not being nuclear specialists. PM office officials testified that no concrete proposal had been put forward by them and denied their competence as crisis managers. As a remedy, on March 13 NISA appointed Masaya Yasui, seconded at NISA from METI, as NISA's representative at the PM's residence. Edano appreciated Yasui's contribution and thought it eased to some extent the tension between NISA and the PM's residence.

Prime Minister Kan did not micro-manage the appointment of representatives from ministries and NISA, and insisted on his need to have people capable of providing appropriate explanations available. Edano opined that adequate appointments for the time of crisis had not been made.

Exhibit 3

The Analysis of the Accident and its Causes

Team H20 Project's (2011) interim report dated October 28, 2011 analyzes the accident and its causes as follows:

1. The cold shutdown would have been feasible if one of the power supply sources had survived the earthquake and tsunami;
2. The core meltdown did not take too much time to take place owing to the loss of the cooling system (perhaps two or three hours after the tsunami);
3. At Fukushima Daiichi, important devices were flooded (emergency AC power generators and DC batteries);
4. Water was not available to feed water-cooling emergency power generators;
5. The main cooling motors and pumps at the seaside were damaged by the tsunami; out of 13 generators at Fukushima Daiichi all except one broke down;
6. The power panels at Units 1 to 4 were flooded and made the power supply from the outside impossible, and consequently the cooling function ceased to work;
7. The vent was not operated from the outside; its preparation took time, making it impossible to carry it out on time;
8. Loss of power supply and therefore the cooling function led to the core meltdown that caused the generation of a massive quantity of hydrogen inside the reactor due to the oxidation of the zirconium cladding tube;
9. At Units 1 and 3 hydrogen accumulated and flowed from the reactor containers to reactor buildings and exploded; at Unit 4, hydrogen from Unit 3 flowed from the vent shared between the two units and accumulated and exploded;
10. The reactor buildings lacked any mechanism or system to detect hydrogen or any outlet to let it escape outside.

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