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Fukushima Daiichi: The Path to Nuclear Meltdown

LINDSEY GARRISON
SATCHIT BALSARI
JENNIFER LEANING

HARVARD FXB
CENTER FOR HEALTH & HUMAN RIGHTS

HARVARD T.H. CHAN
SCHOOL OF PUBLIC HEALTH

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On March 11, 2011, Japan suffered an unprecedented triple disaster. A 9.0 M earthquake occurred off the northeastern coast of Japan, triggering a large tsunami that rose to a height of over 30 meters, and traveled as far as 10 kilometers inland. The earthquake and tsunami damaged Japan's oldest nuclear power plant, setting off a chain of events culminating in a nuclear accident.

Japan is no stranger to earthquakes. Over the years Japan has instituted sweeping changes in its mitigation and response capacity. Buildings, bridges, and rail lines are designed to be earthquake resistant; communities regularly participate in disaster drills; and coastal populations are protected from tsunamis by high sea walls. Many of these were adopted after the Kobe earthquake in 1995, where over 90 percent of deaths were attributed to crush injuries from building destruction (1). In addition, the country's nuclear infrastructure was closely monitored by a collection of regulatory agencies and assumed to be safe.

Yet, the triple disaster resulted in over 15,000 deaths, explosions at the Fukushima Daiichi Nuclear Power Station (NPS), expulsion of radioactive material into the air, and release of contaminated water into the ocean. The investigations that followed unearthed regulatory lapses, counter-productive decision-making hierarchies, and a culture of complacence and collusion.

Your country is considering expanding its nuclear facilities to meet the demands of the new millennium. You have been asked to examine the Fukushima tragedy and make recommendations to the Energy Ministry to prevent such an event from happening in your country.

What errors (in design or in human decision-making) contributed to the nuclear meltdown?

Can you identify the problems with the decision-making process during the nuclear accident? Who were the different stakeholders? What were the obstacles to efficiency, reliability, and safety? How would you structure the response system differently?

How was information communicated to the public and to the rest of the world? Would you change anything? What would your recommendations be?

In light of the issues revealed by the Japanese nuclear disaster, what steps would you recommend to your Energy Ministry?

PART 1

Background

Japan is an archipelago of over 6,000 islands in East Asia with more than 29,000 kilometers of coastline. Due to its location on several fault lines, the country experiences approximately 1,500 annual seismic occurrences ranging from small tremors to massive earthquakes (2). Historically, earthquakes that produced massive tsunamis have taken place every 800 to 1,100 years in Japan. The Jogan earthquake in 869 AD resulted in the last large tsunami where sand deposits were found up to four kilometers inland in the Sendai region (3). The population of 127 million people is accustomed to the constant threat of natural disasters. In fact, since 1960, Japan has commemorated September 1, the anniversary of the 1923 Tokyo earthquake, as Disaster Prevention Day (4)[1]

To mitigate risk and prepare for these expected disasters, the government has adopted comprehensive disaster plans, instituted structural reinforcements, and implemented extensive training drills. Japan's GDP of USD 4.616 trillion has allowed it to invest significant resources in disaster mitigation and preparedness (4).

The Great East Japan Earthquake

On March 11, 2011 at 2:46 pm, a massive earthquake struck the northeast coast of Japan. It was the fourth largest earthquake since 1900, reaching a magnitude of 9.0, and lasting for six minutes (5).[2] The force of the earthquake moved Honshu, the largest island in Japan, 2.4 meters east and shifted the earth's axis by 17 centimeters (6) . The relatively shallow epicenter at a depth of only 24.4 kilometers was 130 kilometers east of Sendai City in the Tohuku coastal region and resulted in the massive tsunami waves that followed the earthquake. See Exhibit 1: Seismic intensity map of the GEJE.

Minutes after the earthquake ended, coastal residents received the first of several sequential tsunami warnings. Many Japanese towns have extensive loudspeaker systems and sirens to alert citizens to an impending disaster (7).The first tsunami warning issued by the Japan Meteorological Agency (JMA) was released less than five minutes after the earthquake, and about 20 to 25 minutes before the first wave reached shore.[3] Initially, the JMA predicted a wave height of three meters (8). The tsunami height warning was subsequently revised to over 10 meters, but only 12 minutes before the first wave arrived at the shore. The initial height estimates led residents to believe that the structural barriers would protect them from the tsunami

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[1] On September 1, 1923, the Great Kanto Earthquake (7.9 M) struck beneath Sagami Bay, 30 miles south of Tokyo. The earthquake was followed by a 13 meter tsunami and a series of devastating fires. The death toll quickly reached 140,000 people. In Tokyo, over 350,000 homes were destroyed and 60 percent of the population was rendered homeless. The situation was worse in Yokohama where 90 percent of the homes were damaged or destroyed (44,45).

[2] Six minutes is a very long duration for an earthquake. Earthquakes typically last between 10 and 30 seconds, with the duration of the quake largely dependent on the magnitude. The San Francisco Earthquake of 1906 lasted 40 seconds, and the Great Hanshin Earthquake of 1995 lasted about 20 seconds (46,47

[3] The system works by measuring seismic signals in the initial minutes of an earthquake to calculate potential tsunami heights. The wave heights are grouped into eight different categories, which range from 0.5 meters to over 10 meters (48). Warnings are updated as the JMA receives more information

waves, allowing them very little time to evacuate after the revised warnings.[4] See Exhibit 2: Japan's earthquake warning system.

The first tsunami wave hit the coastline at 3:27 pm, 40 minutes after the earthquake. V-shaped coastal bays allowed waves to travel deep inland, and amplified their height. Some waves reached over 35 meters - the height of a 12 story building (9). In some areas of Sendai the tsunami traveled 10 kilometers inland. The tsunami had the greatest effect on the Tohoku region of northeastern Japan with Iwate, Miyagi, and Fukushima prefectures suffering the most damage (10) . In spite of the early warnings, over 15,000 people were unable to escape the tsunami and lost their lives. There was wide variation in mortality across the coast. A study conducted in Yamada-machi and Ishinomaki-shi areas revealed that the audio quality of the broadcast messages was not clear; communities could not decipher the messages and did not appreciate the urgency in them. In spite of the prolonged nature of the earthquake, a majority of survivors interviewed in Ishinomaki did not think a large tsunami would follow (7).

Some neighborhoods like Sumoubama that regularly practiced drills managed to evacuate all residents (3). In Kamaishi, almost all 2,900 elementary and junior high students survived, likely due to a comprehensive disaster education program that began in 2005. This program extensively taught the concept of *tsunami tendenko*, an old tradition that implored people to "run for your life to the top of the hill and never mind others or even your family when the tsunami comes" (11). *Tendenko* literally translates as "go separately" and is an idea that has been prominent throughout the Sanriku region for several generations (11) . In contrast, in Okawa, where the primary school had never conducted evacuation drills and had no tsunami contingency plans, 74 of 108 children and 10 teachers lost their lives (3).

Years of outward migration in pursuit of employment had resulted in an aging rural population (12). The mean age of those that died was in the low 60s. Ninety -two percent of the victims died by drowning, and the rest succumbed to burn injuries, crush injuries, or of unknown causes. Evacuating the elderly was a particular challenge across many of the affected areas. Younger relatives returning home from work to check on their elders after the earthquake perished in the tsunami (13).

The scale of the disaster escalated further when it became clear that the tsunami had resulted in total power failure at the Tokyo Electric Power Company's (TEPCO) Fukushima Daiichi Nuclear Power Station (NPS). The plant's safety mechanisms had failed and the reactors were rapidly heading towards a nuclear meltdown. Speaking to PBS *Frontline* on December 29, 2011, Akio Komori, Managing Director of TEPCO's Nuclear Division, spoke of the complete station blackout,

> "*We were entering territory that exceeded what we had ever considered. My gut feeling was that our options for responding were going to be rather limited* "(14)[5]

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[4] The structural barriers along the coastline varied in height based on historical tsunami data for the region.

[5] While other countries, including the United States, began planning for station blackouts in the 1980s and 1990s, Japan did not. Satoshi Sato, a nuclear industry consultant from Tokyo, said "we [the Japanese government and nuclear industry] spent 10 times more money for PR campaigns than we did for real safety measures. It's a terrible thing" (33).

Questions

1. **What combination of planning, drills, and messaging might have reduced the large numbers of tsunami-related deaths that were observed in this disaster?**

2. **Comment on the communication channels used in the Japanese coastal towns to inform people about the tsunami. What other communication channels are used elsewhere in the world? Would those communication channels survive a power outage?**

3. ***Tsunami tendenko* has been criticized for being a selfish enterprise, counter-intuitive to the human impulse. Others state that it saves lives. Would you advise adopting the policy of *tendenko*? Explain your reasons.**

PART 2

The Fukushima Daiichi Nuclear Power Station Accident

In 2011, Japan had 54 nuclear reactors. The Fukushima Daiichi NPS, owned by TEPCO, contained six boiling water reactors (BWRs). Unit 1 was the oldest reactor in Japan and had already been in operation for 40 years (15).

There are mainly two types of nuclear reactors: Pressurized Water Reactors and Boiling Water Reactors (BWRs). All six at the Fukushima Daiichi NPS were BWRs, where nuclear energy is used to boil water to create steam, which, in turn, drives turbines to produce electricity. Water is boiled by heat generated from a nuclear fission reaction where a uranium atom is split into neutrons when it comes into contact with another neutron. The released neutrons split other uranium atoms and the chain reaction that ensues generates large amounts of heat. A one-inch pellet of uranium fuel generates as much energy as a ton of coal. The reaction is tightly modulated by raising or lowering cadmium (or boron) "control rods" into the nuclear fuel assembly in order to absorb the free released neutrons.

A loss of electric power would affect the operation of the control systems and shut down the water coolant pumping system. Typically, reactor vessels are kept at temperatures around 260°C. When the cooling mechanisms stop working, temperatures inside the vessels can soar to over 1,200°C. As temperatures rise, the zirconium alloy cladding on the fuel rods releases hydrogen. The water begins to boil and evaporate, filling the reactor with steam and hydrogen (16).

In these loss-of-coolant circumstances, the nuclear chain reaction continues to convert water to steam at increasing temperatures. As the water level drops, the nuclear fuel rods are exposed to air causing them to explode. The explosion would breach the containment vessel, releasing radioactive elements into the air and potentially culminating in a nuclear meltdown (17,18). See Exhibit 3: Boiling Water Reactor.

Of the six, Units 1-3 were operational at the time of the earthquake while Units 4-6 were shut down for routine maintenance (19). The earthquake triggered the automatic emergency shut down feature, or SCRAM, stopping the three operating reactors.[6] However, the tsunami damaged the plant's emergency diesel generators, resulting in a station blackout and loss of all electric power by 3:41 pm. See Exhibit 4: Tsunami damage at the Fukushima Daiichi NPS.

The loss of all electric power to the station meant that the cooling systems would fail. A back -up battery scheduled to last eight hours was also damaged (20). Another back-up transmission line provided by the Tohoku Electric Power Company failed to feed into Unit 1 due to a mismatched electrical socket.

The 9.0 M earthquake struck at 2:46 pm. By 3:42 pm, Site-Supervisor Yoshida filed the first nuclear emergency report, alerting his superiors and the government to an impending nuclear catastrophe. By 4:40 pm, Unit I began to experience a core meltdown. At 7:03 pm, March 11, the Prime

[6] When the sensors detect a seismic occurrence at the nuclear power station, all standard power supplies immediately shut down to prevent a nuclear accident from taking place. This is known as "SCRAM."

Minister's office declared a nuclear emergency, a first for Japan (21) . The first evacuation order was given at 9:23 pm for a three kilometer radius around the Fukushima Daiichi NPS. Those who lived between three and ten kilometers around the Fukushima Daiichi NPS were told to shelter in place. See Exhibit 5: Overview of the Nuclear Emergency Preparedness Act.

In a BWR, one of the ways to mitigate an impending nuclear chain reaction is to begin "venting" the reactors by releasing some of the built up steam pressure in the containment vessels. However, water in BWRs is exposed to radioisotopes and considered contaminated. Venting would entail releasing this radioisotope-laden "contaminated" steam into the air (22) . Plans to proceed with this venting include mandates that workers from the plant and citizens in the surrounding areas are notified and evacuated in a timely fashion to protect them from the release of radiation.

Without access to a source of electricity, as was the case at the Fukushima Daiichi NPS, venting had to be completed manually. Manual venting had not been considered within the realm of possibilities by TEPCO, leaving the Fukushima Daiichi NPS workers pouring over blueprints of Unit 1 in the midst of the total power failure (22). Venting finally began at 2:30pm on March 12, almost 20 hours after the earthquake – not in time to prevent the first hydrogen explosion in Unit 1, shortly thereafter, at 3:36pm.

The Prime Minister's Official Residence, the Kantei, ordered an extension of the evacuation zone to a 20 kilometer radius around the Fukushima Daiichi NPS on March 12 at 6:25 pm.[7] On March 14, Unit 3 exploded at 11:01 am. Unit 4 exploded at 7:00 am on March 15 and at 11:00 am the evacuation radius was extended to 30 kilometers by the Kantei. Large amounts of radioisotopes were dispersed into the air, soil, fresh water, and seawater across eastern Japan, contaminating an area of 800 km^2.

In a rare public address at a press conference on March 13, Prime Minister Naoto Kan stated:

> *"I consider this earthquake and tsunami, along with the current situation regarding the nuclear power plants, to be in some regards the most severe crisis in the 65 years since the end of the Second World War. I believe that whether or not we Japanese are able to overcome this crisis is something now being asked of all Japanese individually"* (23).

The Path to Failure

The Fukushima Daiichi NPS accident occurred in spite of the many agencies responsible for the safety of the nuclear reactors. The accident had huge implications on the environment, on human health and on the future of nuclear power in the country. The National Diet of Japan instituted an independent investigation into the nuclear

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[7] The Prime Minister's Official Residence is often referred to as the Kantei. In addition, many of the PM's advisors and administration work out of the Kantei on a daily basis. This was where the NERHQ was formed.

accident, as did several industry and academic institutions. Findings from these reports are summarized below. See Exhibit 6: Fukushima Daiichi NPS accident: sequence of events.

1. Limitations and Failures of the Regulatory Framework: the Japanese Mura

The nuclear regulatory framework in Japan included multiple organizations meant to provide checks and balances to maintain the safety of all nuclear energy operations. However, it was known to function as a village - or *mura* - of collaborators colluding to promote the nuclear power industry at the expense of public safety (24). These long-known allegations of collusion among Japan's regulatory bodies and the nuclear industry resurfaced during the investigations following the accident.

The nuclear power industry was a major donor to both political parties. Its mass media spending on public relations and advertising ran into millions of dollars annually; the nuclear industry spent close to three billion dollars on mass media between 1970 and 2011 (25). It also supported research work to showcase the advantages of nuclear energy. The number of technical experts available in the industry was limited and the same personnel rotated through jobs in the power companies and governmental regulatory authorities (26). The system was so institutionalized that the term *amakudari* or "descent from heaven" was applied to the move from government to industry, and *amaagari* or "ascent to heaven" to the reverse move from power companies to regulatory agencies.[8]

The regulatory framework included the following institutions:

<u>Ministry of Economy, Trade, and Industry (METI)</u>
METI was responsible for nuclear reactors and the facilities for all other activities regarding nuclear waste or energy. It was also responsible for promoting the nuclear power industry. At the time of the Fukushima Daiichi NPS accident, METI was responsible for all nuclear facilities except those used for testing and research (which were under the purview of MEXT).

<u>Agency for Natural Resources and Energy (ANRE)</u>
ANRE was responsible for all affairs that dealt with promoting nuclear energy (26).

<u>Nuclear and Industrial Safety Agency (NISA)</u>
NISA was a special entity of ANRE, and a subsidiary of METI. NISA could act independently without the guidance of the minister of METI or the involvement of ANRE (27). The organization was created in 2001 after a series of central government reforms, and it was responsible for conducting safety examinations.

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[8] One of the most glaring examples of the "nuclear village" or *mura* is the career of TEPCO's Tokio Kano. Mr. Kano joined TEPCO in 1957, and was in charge of the nuclear unit beginning in 1989. In 1998, he won a seat in the Japanese parliament representing Japan's largest business-lobbying group, Keidanren; TEPCO is one of the largest members of this group. Mr. Kano served two six-year terms in parliament until 2010, and led a campaign that reshaped Japan's energy policy. The new policy highlighted nuclear power and made it Japan's foremost investment for the country's future energy needs, as Japan formally adopted this policy in 2003. It was pushed through as a means to reduce greenhouse gases and achieve greater energy independence as Japan lacked its own natural energy resources. Nuclear safety was mentioned very briefly throughout this entire policy, despite the heavy national reliance on nuclear energy at the time. After his terms in parliament, Mr. Kano returned to TEPCO as an advisor in 2010 (24).

Japan Nuclear Energy Safety Organization (JNES)
In 2003, JNES was established as the technical support organization of NISA. JNES was responsible for conducting on-site safety assessments and inspections, as well as assisting engineers with the technical aspects of the safety reviews and assessing nuclear installations (26,27).

Ministry of Education, Culture, Sports, Science and Technology (MEXT)
MEXT was responsible for nuclear reactors that provide data for research and testing, and for monitoring environmental radiation levels and promoting nuclear energy (26,27).

Nuclear Safety Commission of Japan
The NSC functioned as a decision-making organization despite being positioned legally as a council. If the NSC made a decision, the Prime Minister was obligated to abide by it. If necessary, the NSC could make recommendations to the regulatory bodies through the Prime Minister (27).

As a third party, the NSC was responsible for supervising the safety regulations that NISA implemented and it routinely monitored the work of NISA and MEXT. (26). For instance, after NISA inspected the nuclear facilities for installment licenses, the NSC reviewed these inspections (conducted double-checks) per the Reactor Regulation Act and relayed this information to METI (27).

In actuality, the nuclear industry's interests trumped the enforcement of rigorous safety standards. The rising concerns around seismic and tsunami threats raised both by NISA and through investigations by TEPCO themselves, did not translate into necessary policy and site improvements.

A. The Known Seismic Risk

Seismic design and safety evaluation standards changed considerably since the Fukushima Daiichi NPS first went into operation 40 years prior to the 2011 disaster. Even the newest reactor at the Fukushima Daiichi NPS had been in operation for 31 years on the day of the accident.

Over the years, TEPCO was found to have consistently resisted upgrading their equipment as advised (19,28). Between 1966 and 1971, when TEPCO submitted the installation licenses to install Units 4-6, there were no seismic design standards for nuclear facilities in Japan. However in 1981, the NSC established the "Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities." Even though the Fukushima Daiichi NPS was already operational at this time, the NSC decided that it too would have to meet these standards (19). These criteria were revised in 2006 by the NSC at NISA and METI's request, and TEPCO was instructed to evaluate the Fukushima Daiichi NPS to ensure that it met the updated standards.

TEPCO had a long history of substandard safety culture. In 2002, NISA reported that TEPCO had concealed numerous accidents at its plants, including 16 episodes that TEPCO President Tsunehisa Katsumata later described as "serious cases of inappropriate conduct" (26). These incidents were wide ranging and some included filing false safety inspection reports, destroying records to hide damage to equipment, and internally rescheduling safety deadlines set by NISA (26,28) . Many of TEPCO's leaders resigned as a consequence of this 2002 report. Yet the culture of collusion seemed to have changed little. Fukushima Daiichi NPS's Unit 1 was originally scheduled for decommissioning in 2011, at its 40 year mark. Instead, in 2010, TEPCO was given approval to extend its life for an additional 10 years (28).

In March 2008, TEPCO submitted an interim report on the seismic checks conducted for Unit 5, which NISA deemed acceptable despite the fact that TEPCO guaranteed safety checks in only seven of the numerous piping systems and installations of Unit 5. In 2009, TEPCO submitted additional reports on the remainder of the units, admitting to limited seismic safety in the event of a high magnitude earthquake (19). The deadline for the final report on seismic safety was June 2009, yet TEPCO made an internal decision to extend the deadline to January 2016.

A *Reuters* investigation that took place after the March 2011 disaster revealed that from 2004 to 2008 the Fukushima Daiichi NPS was rated as the most hazardous nuclear power station in Japan in terms of worker exposure to radiation, and one of the top five most hazardous throughout the world. The next set of evaluations and rankings was set to be released at the end of 2011 (28). *Reuters* discovered these rankings in a review of presentations and documents that were made at nuclear safety conferences over the past seven years. TEPCO had been privately tracking the rankings (28).

B. The Known Tsunami Risk

In 2002, the government's Headquarters for Earthquake Research Promotion (HERP) published a report warning of a 20 percent chance of an 8.0 M earthquake and tsunami along the Japan Trench within the following 30 years (19). The trench included the offshore area of the Fukushima Daiichi NPS.

In the same year, the Japan Society of Civil Engineers (JSCE) issued the Tsunami Assessment Method for Nuclear Power Plants. The JSCE stated that a tsunami at the Fukushima Daiichi NPS would not exceed O.P. +5.7m (19).[9]

Subsequent studies that included older tsunamis like the Jogan tsunami of 869 estimated tsunamis heights of OP +9.2m at the Fukushima Daiichi NPS (29). In 2006, NISA and JNES established the Spill Overtopping Study Group, "recognizing that events that exceeded postulates could occur with certain probabilities" (19) . The study warned that if an OP +10m tsunami occurred, the emergency seawater pump at the Fukushima Daiichi NPS would cease to function and core damage could occur; if an OP +14m tsunami occurred, there would be loss of all power supply (19).

The findings from the Spill Overtopping Study Group were conveyed to the Federation of Electric Power Companies of Japan. NISA issued "verbal communication" about the low margin of safety of the seawater pumps. Their warning was shared with TEPCO's executive vice president in charge of the nuclear power departments, but not with the president and chairman (19).

[9] Elevations are relative to the Onahama Peil (Onahama Port Construction Standard Surface), abbreviated O.P. for the Fukushima Daiichi and Daini plants; and mean sea level for Tokai Dainin plant, or 0.727m below the Tokyo-bay Mean Sea Level (49).

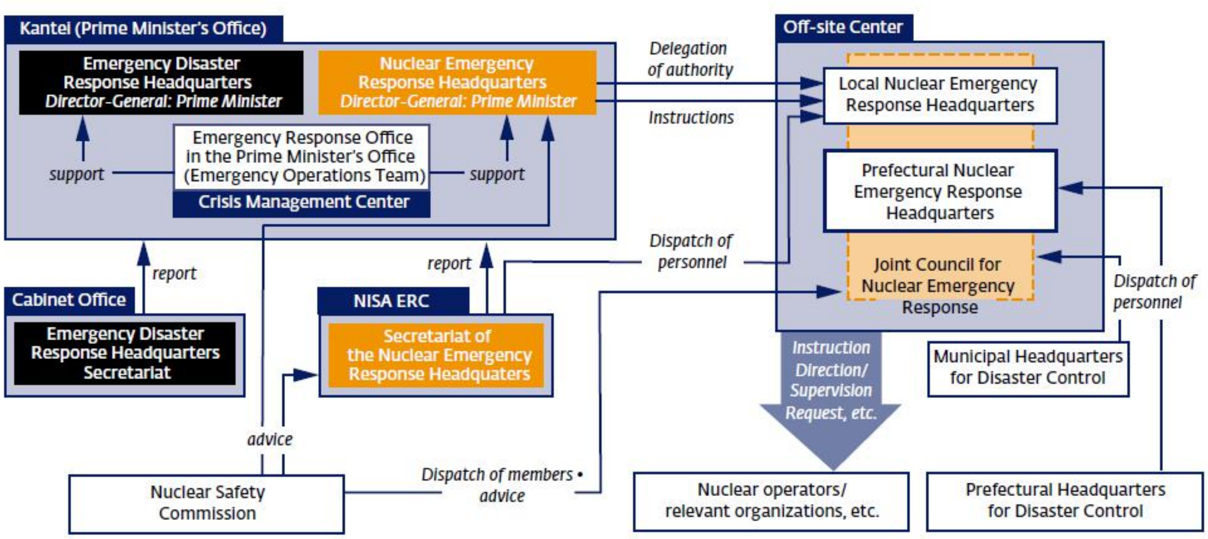
However, TEPCO concluded that the tsunami height determined by the JSCE methodology "is the maximum tsunami height that can be postulated from the perspective of building something" though JSCE had only considered tsunamis from the previous 400 years, excluding events like Jogan. The ¥183.78 million research funds for this JSCE assessment were provided by the nuclear power companies (29). Thirteen of the 30 members of the JSCE Tsunami Evaluation Subcommittee belonged to the Central Research Institute of the Electric Power Industry.

In October 2006, NSC issued a Regulatory Guide for Reviewing Seismic Design of Nuclear Power Facilities. Though it was released after the Spill Overtopping Study Group findings were made known, the NSC also concluded that "safety features of the [Fukushima Daiichi] facility shall not be significantly impaired by a tsunami" (19).

TEPCO continued to downplay the tsunami risk to the Fukushima Daiichi NPS, and NISA maintained a culture of oral instructions, leaving little to no trace of its communications. During the Diet's investigations in the months after the March 11 Great East Japan Earthquake, TEPCO reported that NISA communicated orally in October 2006 to the Federation of Electric Power Companies of Japan that "the evaluation by the JSCE Method is sufficient" (19).

2. The Obfuscation of Decision-Making

FIGURE 1: Outline of the Organizational Framework in the case of the Accident at the Fukushima Daiichi NPS



Source: The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, Chapter 3: Problems with the nuclear emergency response.

<u>A: The Prime Minister Goes to Daiichi</u>

Masao Yoshida was the Site Superintendent at the Fukushima Daiichi NPS during the Great East Japan Earthquake. Right after midnight, in the early hours of March 12, Site Superintendent Yoshida informed his workers that Unit 1 needed to be vented. Due to the power outage, in the absence of functional gauges, TEPCO employees could only estimate how quickly the water was evaporating within the pressure vessel (17).

A Fukushima Daiichi employee who spoke to *Frontline* on the condition of anonymity stated "I realized that the fuel had started to melt. We [Daiichi employees] got our masks and put them by our feet so we could escape at any time" (14). The situation at the plant was becoming dire and workers were willing to try anything, even risk their own lives, to prevent the Fukushima Daiichi NPS from becoming synonymous with Chernobyl. At 9:51 pm on March 11, managers had prohibited any Daiichi employees from entering the Unit 1 reactor building as radiation levels kept increasing. Workers were eventually allowed back into the building when venting became necessary (17).

At 1:30 am on March 12, the Prime Minister and Minister of METI Banri Kaieda approved venting the containment vessel to release the pressure, after receiving an explanation from TEPCO Fellow Ichiro Takekuro, NSC Chairman Haruki Madarame, and Vice-Director General of NISA Eiji Hiroaka. They planned to make a public announcement at 3:00 am explaining why venting was the only option and what radiation risks venting would entail (as compared to the even greater risks associated with an explosion from pressure buildup).

Back at the Fukushima Daiichi NPS, Yoshida and his team had no prior experience or training in venting the reactors manually and without power. The employee interviewed by *Frontline* described the Fukushima Daiichi NPS as "…not a place for humans. The temperature was 100 degrees plus. The surroundings were pitch black and there was condensation. The radiation was high" (14). He further noted:

> *"Kan was very angry. The government had given an order. What was TEPCO doing? But we were trying our best. The valves were hard to open. We were genuinely trying, we just hadn't managed it"* (14).

Prime Minister Kan was already distrustful of TEPCO. Receiving no explanation as to why the reactor was not being vented, at 6:15 am on March 12, the Prime Minister announced that he would visit the Fukushima Daiichi NPS himself (14).[10]

> "*Everyone agreed that we should vent but no one could explain why it wasn't happening. It was like a game of telephone with TEPCO headquarters in the middle*,"
>
> - Prime Minister Naoto Kan

The onsite personnel had to expend significant effort to respond to the Prime Minister's visit, including securing a landing site for the helicopter and arranging bus transportation from the landing site to the Seismic Isolation Building, in addition to

[10] As health minister of Japan in the mid-1990s, Kan was known for exposing the Ministry's use of HIV-infected blood, which had resulted in hundreds of hemophiliacs contracting HIV. He discovered that both pharmaceutical company officials and government bureaucrats had known about the contaminated blood. His suspicion of industry caused him to be equally wary of the nuclear energy industry given the strong linkages between the power companies and regulatory authorities (50).

addressing his questions on the venting progress. The two responsible for directing the emergency response at the site, Vice-President Muto and Site-Superintendent Yoshida, were forced to divert their attention from the reactors and focus on the Prime Minister (22). In defense of his visit, the Prime Minister noted,

> *"The driving force behind my visit to the plant on the morning of the twelfth was because no one could tell me why the venting operation was being delayed. So I was determined that it was necessary for me to talk to the person in charge at the plant"* (30).[11]

B: SPEEDI

The Three Mile Island nuclear accident (1979) in the United States resulted in significant changes in nuclear regulation around the world. The Japanese Government developed a System for Prediction of Environmental Emergency Dose Information (SPEEDI) in the 1980s to accurately predict radiation dispersion and help plan evacuation strategies to lead people away from radiation plumes (31).

SPEEDI was programmed to receive data from the Emergency Response Support System (ERSS) and the Japan Meteorological Agency. The ERSS continuously monitored reactor conditions and predicted the progression of an accident and the external release of radioactive material based on information transmitted from all nuclear plants. The JMA supplied SPEEDI with weather data to help predict rainfall, wind and dispersion patterns (32).

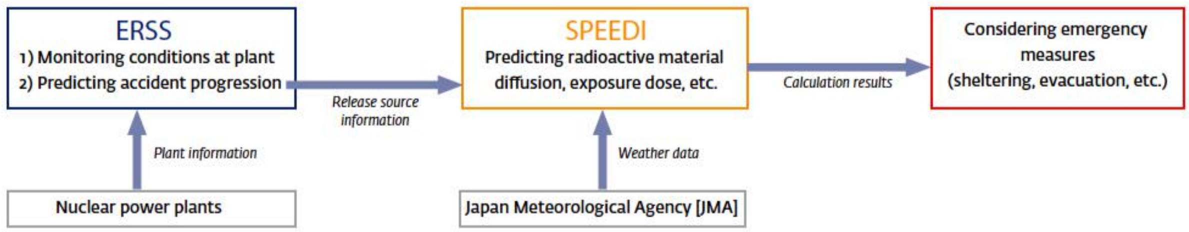
Factoring in potential communication failures during nuclear accidents, SPEEDI was also capable of generating models based on presumptive estimates allowing for disaster planning (and response). In the absence of real-time data, SPEEDI would use an emission rate of one Becquerel per hour (31). SPEEDI was also capable of providing reverse estimate calculation whereby radiation release at source could be estimated by measuring current radioactivity at a previously modeled site (32).

SPEEDI functioned in relative real-time with time from data input to map generation estimated at about fifteen minutes. The radiation maps generated by SPEEDI could be sent to computer terminals at the national and local Nuclear Emergency Response Headquarters (NERHQ), off-site centers, local governments, the NSC, MEXT, and METI via a secure network (31).

At the time of the Great East Japan Earthquake, SPEEDI was operated by the Nuclear Safety Technology Center (NUSTEC), which was commissioned by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) (31).

[11] It was later determined that TEPCO Fellow Takekuro Ichiro, who was among the advisors in NERHQ who were briefing the Prime Minister, was not actually in contact with personnel at the Fukushima Daiichi NPS but was instead relaying messages from TEPCO Headquarters located in Tokyo (21).

FIGURE 2: Outline of the Coordination between SPEEDI and the ERSS



Source: The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, Chapter 4: Overview of the damage and how it spread.

SPEEDI during the GEJE

The Nuclear Emergency Response Headquarters (NERHQ) was established at the Official Residence (of the Prime Minister), once the Prime Minister declared the Nuclear Emergency at 7:03 pm on March 11. Members of the NERHQ included:

- Prime Minister Naoto Kan,
- Minister of METI Banri Kaieda,
- Chief Cabinet Secretary Yukio Edano
- Deputy Chief Cabinet Secretary Tetsuro Fukuyama,
- Special Advisor to the Prime Minister Goshi Hosono,
- Director of NISA Nobuaki Terasaka, and
- Chair of the NSC Haruki Madarame (31).

The "local" NERHQ designated to play a key role in the disaster response coordination was established five kilometers away from the Fukushima Daiichi NPS. It was then relocated on March 15 to the Fukushima Prefectural Office. During this move, the NERHQ officials left behind files containing the radiation data they had been collecting since March 11.

A third hub, the Emergency Response Center (ERC) was set up by NISA on the third floor of METI, located 760 meters away from the Official Residence. The ERSS had not been able to collect real time data from Fukushima Daiichi NPS as all communication lines had broken down (32). Under instructions from MEXT, NUSTEC therefore began calculating SPEEDI predictions at 4:40 pm on March 11 using "unit release rate assumptions," and the results were distributed to NISA and other relevant organizations.

NISA was ordering its own SPEEDI estimations, in addition to those run on an hourly basis and reported to MEXT. The people in charge at NISA and the Secretariat of the NSC made predictive calculations assuming values other than unit release rate assumptions. These calculations, based on data from multiple sources, were likely to be more accurate (31). Though it took some time after March 16 to gather the atmospheric concentration data of radioactive nuclides necessary for reverse estimate calculation, the NSC also completed reverse estimation by the morning of the 23rd. Between March 11 and March 16, NISA collected 45 calculations from SPEEDI at the ERC, which they planned to use to assist in developing an evacuation strategy (31,32). However, these data were never used by NERHQ in formulating their evacuation plans.

The National Diet Independent Investigation Commission report concluded:

> The senior officials and the officials in charge at these relevant organizations decided that "the accident is not a situation where SPEEDI can be used" and reached the essential conclusion that SPEEDI would not be utilized. As a result, methods of using SPEEDI calculations were not systematically considered during the initial response, not only between these relevant organizations but also within the organizations themselves. The predictive calculations were partly used merely as reference material for deciding the measuring points of the emergency monitoring and determining orders of priority for screening. During the initial response to the accident, the results of SPEEDI were not transmitted to the politicians at the Prime Minister's office who were in effect considering protective action for the residents. The SPEEDI results had been sent by email to the Fukushima Prefecture Headquarters for Disaster Control from March 12 on but there was little will to systematically utilize the results, and 65 of the 86 emails received were deleted without sharing the information within the organization (32).

At 9:33 pm on March 11, Prime Minister Kan released the first of several evacuation announcements. He ordered those within a three-kilometer radius of the Fukushima Daiichi NPS to evacuate the area, and those within a 10-kilometer radius to shelter-in-place. These recommendations were developed without consulting the ERC for SPEEDI data. The evacuation zones were in concentric circles despite the fact that radiation spread is dependent dependent on weather factors and does not spread concentrically or uniformly (31).[12] An hour prior to the PM's orders, the prefectural officials, growing impatient with the delay in evacuation orders from the center, had announced a two-kilometer radius evacuation zone, causing significant confusion in the public's understanding of the evacuation guidelines (22).

On March 12 the evacuation orders from the NERHQ continued to change. At 5:44 am the evacuation zone was expanded to a 10-kilometer radius; at 6:25 pm, to 20 kilometers. On March 15 those between 20 and 30 kilometers from the Fukushima Daiichi NPS were under orders to shelter-in -place (22,31). While these evacuation zones kept changing the public were not informed of the reasons behind the changing zones nor were they informed of the health effects of the released radiation. These uncertainties eventually contributed to high anxiety among residents from the areas, who did not know whether the radiation levels they were exposed to were equivalent to one chest x-ray or to the high levels immediately in the near vicinity of Chernobyl.

Because the NERHQ (see page 12 for a listing of the members of the NERHQ) was not utilizing SPEEDI calculations they did not realize that radiation levels in the

[12] International Atomic Energy Agency guidelines recommend that concentric circles are used for evacuation measures, only if there are no complex radiation forecasting instruments, such as SPEEDI, available at the time (31).

northwest -- outside of the 20 kilometer evacuation zone -- were actually very high. The government evacuation orders in fact led people to evacuate right into these areas. For example, citizens of Namie, which is approximately eight kilometers outside of Daiichi, were told to evacuate to Tshuhima district, far outside of the 20 kilometer evacuation zone; yet this region had high atmospheric radiation content as shown by then available SPEEDI data (31).

Later investigations revealed that the SPEEDI terminal at the NSC was performing hourly calculations as ordered by MEXT. However, the NSC assumed that MEXT was forwarding these radiation dispersion maps to the NERHQ. Chair of the NSC, Madarame, believed it was NISA's responsibility to brief Prime Minister Kan on the SPEEDI data. The Director of NISA, Terasaka, believed that SPEEDI was MEXT's responsibility, and they should have worked to inform the Prime Minister. On March 16, MEXT had an internal meeting and decided that the NSC was responsible for interpreting and reporting SPEEDI results to assist in planning effective evacuations. MEXT's conclusion was verbally reported to the NSC, but the NSC claims that they never accepted responsibility for disregarding SPEEDI (31).

C: Seawater Solution: Destroying the Reactor

Shortly after the venting around 2:30 pm on March 12, Superintendent Yoshida received more bad news about Unit 1 – his co- workers realized that the freshwater in the reactors was significantly depleted. Once the fuel rods were exposed to air, the reactor began to produce even more heat (22). It was critical that the rapid overheating be reversed immediately.

Fresh water injection had commenced at 4:00 am on March 12. Fire fighting vehicles on the premises were injecting 100 tons of water into the reactor, which was depleted by 2:53 pm on March 12. The 100 tons of water had initially been reserved for fighting fires but was repurposed when the overheating and gravity of the situation was recognized However, leakage of filtrate water in the wake of the earthquake and the limited amount of freshwater on the premises necessitated the simultaneous use of seawater (22). Superintendent Yoshida made an executive decision to begin preparing Unit 1 for seawater injection in an attempt to prevent a hydrogen explosion (and subsequent release of large amounts of radioactive material). All involved were aware that using seawater would cause irreparable damage to the reactor as the salt would leave a residue on the fuel rods rendering them unusable in the future (17). By 3:30 pm on March 12, the preparations for seawater injections were complete. Yoshida sent a fax to Minister Kaieda reporting that seawater injections had begun.

However, at 3:36 pm, a hydrogen explosion occurred in the reactor building of Unit 1 blowing off its roof and upper walls (21). The explosion damaged the seawater injection hose, further delaying the process. Seawater injection recommenced at 5:15 pm, and TEPCO notified NISA accordingly. But the Kantei had not yet consented to the use of seawater. Deliberately destroying the unit would require the eventual decommissioning of the entire plant, resulting in potential losses of billions of dollars in capital assets. TEPCO Fellow Takekuro asked Superintendent Yoshida to suspend the seawater injections.

Though Yoshida agreed to the suspension, he actually allowed the seawater injections to continue. At 7:55 pm, the Prime Minister gave his consent and at 8:20 pm Yoshida gave an "official order" for seawater injection to commence in Unit 1. See Exhibit 7: Reactor-wise sequence of events.

D: Abandoning the Fukushima Daiichi NPS

On the evening of March 14, TEPCO authorities in Tokyo began discussing the possibility of evacuating personnel from the Fukushima Daiichi NPS. About an hour later, at 8:16 pm, the Fukushima Daini plant began establishing a back-up emergency response office in the event that workers from the Fukushima Daiichi NPS needed to evacuate. TEPCO President Masataka Shimizu stated that they had not made a decision for final evacuation. They were "doing what should be done and conducting checks" (22).

Before dawn, on March 15, Shimizu confirmed that an evacuation of the Fukushima Daiichi NPS remained a possibility. This confirmation created concern at the Kantei where the Prime Minister, the Chairman of the NSC, and the Secretary for Crisis Management all felt that "withdrawal of all personnel was unacceptable" (22). Goshi Hosono, the Minister of Nuclear Disasters, asked Yoshida if he believed that it was necessary to evacuate the Fukushima Daiichi NPS. Yoshida responded with, "we can still hold on, but we need weapons, like a high-pressure water pump" (33).

At around 4:00 am on March 15, when the Prime Minister summoned TEPCO President Shimizu to the Kantei, Shimizu denied intending to evacuate all personnel. He stated that only the non-essential personnel would be asked to leave the Fukushima Daiichi NPS.

The Prime Minister, already wary of TEPCO, went to visit the TEPCO Emergency Response Center at 5:30 am and announced the establishment of a new integrated headquarters that he would direct. Through a video conference call, he spoke to the workers who remained at the Fukushima Daiichi NPS and said:

> *"This is a very tough situation. But you cannot abandon the plant. The fate of Japan hangs in the balance. All those over 60 should be prepared to lead the way in a dangerous place"* (30).

Unit 4 exploded at 6:12 am.

On March 15 at 11:00 am, the Prime Minister released this statement to the public,

> *I want to inform the people of Japan about the situation regarding the Fukushima Nuclear Power Stations. I urge you to please listen calmly to this information.*
>
> *As I explained previously, the reactor at the Fukushima Daiichi Nuclear Power Station was shut off following the earthquake and tsunami, but none of the diesel engines that would normally power the emergency cooling system are in a functioning state. We have been using every means at our disposal to cool the nuclear reactors. However, the concentration of radioactivity being leaked into the vicinity of the station has risen considerably following hydrogen explosions*

caused by hydrogen produced at the Unit 1 and Unit 3 reactors, and a fire in the Unit 4 reactor. There is a heightened risk of even further leakage of radioactive material.

Most residents have already evacuated beyond the 20 kilometer radius of the Fukushima Daiichi Nuclear Power Station, but let me reiterate the need for everyone living within that radius to evacuate to a point outside of it.

Moreover, in view of the developing situation, those who are outside the 20 kilometer radius but still within a 30 kilometer radius should remain indoors in their house, office, or other structure, and not go outside. Further, with regard to the Fukushima Daini Nuclear Power Station, most people have already evacuated beyond a 10 kilometer radius but we are calling for everyone who remains within that radius to fully evacuate to a point beyond it.

At present we are doing everything possible to prevent further explosions or leakage of radioactive material. At this moment, Tokyo Electric Power Company (TEPCO) workers in particular are taking great personal risks in their tireless efforts to supply water to the reactor. I realize that people in Japan are greatly concerned about the situation but I sincerely urge everyone to act in a calm manner, bearing in mind the tremendous efforts underway to prevent further radiation leaks.

This concludes my request to the people of Japan at this moment (34).

Questions

1. **What steps led to the containment breaches and meltdowns at the Fukushima Daiichi nuclear power plants? What were the underlying and precipitating causes of the nuclear accidents?**
2. **Were the interventions from the Kantei necessary or counterproductive?**
3. **Comment on the communication failures during this disaster response. How would you improve communication to or among the following groups:**
    a. **Fukushima Daiichi plant workers**
    b. **Japanese public**
    c. **Regulatory agencies**
    d. **Prime Minister's office**

4. **Based on this case, how would you suggest modifications in the design of the incident command structure in the event of a nuclear accident in Japan?**

PART 3

Long-Term Implications for Japan and the World

Cancer Risk

The World Health Organization (WHO) conducted a comprehensive health risk assessment based on preliminary radiation dose estimations collected between March and mid- September 2011, and released a report in 2013. The WHO report concluded that there was no observable increase in cancer rates when compared to the baseline (35) . However, there was an increased risk for certain types of cancers in specific subsets of people that would require long-term monitoring.

In analyzing data for those in the most contaminated areas of Fukushima Prefecture, the WHO predicted a higher lifetime cancer risk for those exposed as infants:

- A four percent increase in all solid cancers among females
- A six percent increase in breast cancer among females
- A seven percent increase in leukemia among males, and
- Up to a 70 percent increase in thyroid cancer among females (i.e.: an additional lifetime risk of 0.5 percent among exposed infants compared to the baseline risk of 0.75 percent) (35).

In addition, approximately one third of the emergency workers who responded to the disaster and were working inside the Fukushima Daiichi NPS were determined to have an increased lifetime risk of cancer (35). See Exhibit 8: Summary of radiation doses.

Psychosocial implications

Initial reports suggest that survivors have not sought mental health support owing to the cultural stigma associated with mental illness (36,37) . In Fukushima Prefecture, residents were primarily concerned about the radiation risks because they did not know what amounts they were exposed to. They were anxious about the safety of their family members, the loss of property, and the stigma associated with being an evacuee from Daiichi. This “radiation anxiety” has become part of everyday life (37). Health care professionals identified the following areas of interventions as high priority: addressing the fear of radiation; counteracting the reduction in mental health services; and attempting to rebuild a sense of community (37). The long-term implications of mental health issues as a result of the nuclear disaster are not yet known.

Regulatory Reform

In the months after the disaster at the Fukushima Daiichi NPS, the National Diet recognized the urgent need for nuclear regulatory reform. On June 27, 2012, the new “Act for Establishment of the Nuclear Regulation Authority” resulted in the creation of yet another regulatory body, the Nuclear Regulation Authority (NRA), under the Ministry of the Environment (MOE) (27). The Agency for Nuclear

Regulation (ANR) is now responsible for the administration of the NRA's activities.

The NRA will function independently from the MOE and other government organizations (27). The law also granted the NRA the power to make legally binding rules on matters that fall under its jurisdiction, freeing it from the influence of entities like METI that are charged with the promotion of the nuclear industry (27).

This new organization is led by a chairman and four commissioners appointed by the Prime Minister, with consent from members of the Diet. In an attempt to quell the culture of *amakudari* and *amaagari*, the disqualifying criteria for holding positions at the NRA include recent employment with a nuclear operator or a recent history of remuneration from a nuclear operator. (27).

In order to prevent people from moving between NISA, METI, and ANRE, the act also introduced a "no-return rule," which specifically prohibits personnel with the ANR from joining government organizations promoting nuclear power (27). The NSC's role was also curtailed. The NSC now reports to the NRA, and JNES acts as the NRA's technical support organization. See Exhibit 9: Reform of Japan's nuclear regulatory agencies.

Global Response

After the accident at the Fukushima Daiichi NPS, several countries revised their plans for the expansion of nuclear power and undertook a review of their safety protocols. In addition, public support for nuclear power decreased dramatically in France, Germany, Sweden, and the UK (38). Germany opted to close all of its operating facilities by 2022 (39).

A 2011 study conducted by HSBC Bank notes the following global changes as a result of the accident:

- Safety reviews of reactors in countries such as Germany, the United States, and Switzerland, among others;
- Immediate shutting down of older reactors in Germany;
- Revision of policies to prevent extension of power plant lifetimes in Germany, the United States, and the UK;
- Suspension of new plant approvals, including in China;
- Review of reactors and subsequent safety measures on reactors under construction in areas of seismic activity; and
- Revision or review of energy policies in many nuclear countries that place greater emphasis on energy efficient measures, renewable installations, and natural gas (38).

Endnote

By April 12, 2011, the International Atomic Energy Agency (IAEA) had declared the accident at the Fukushima Daiichi NPS a Level 7 event on the International Nuclear and Radiological Event Scale (INES). This is the highest rating on the scale and had only been used previously to classify the incident at Chernobyl in

1986 (40). The estimated radioactive material released into the atmosphere in Japan was approximately 10 percent of that in the atmosphere after Chernobyl. The total amount of contaminated material and soil from Fukushima Prefecture is estimated to have reached 22 million cubic meters. The decontamination efforts are likely to last until 2017 and cost ¥1,300 billion (USD 10 billion) (41).

In the two year time period after the Great East Japan Earthquake, Japan took all 54 of its nuclear reactors offline to undertake rigorous safety inspections. However, Japan had to begin importing greater amounts of coal, oil, and natural gas from foreign sources, resulting in a substantial increase in their carbon emissions (42). This increase provides a large incentive, both financial and environmental, for the country to bring its 43 viable nuclear reactors back online. According to the new regulations, both the NRA and the local government are required to approve each reactor scheduled to go back online (42).

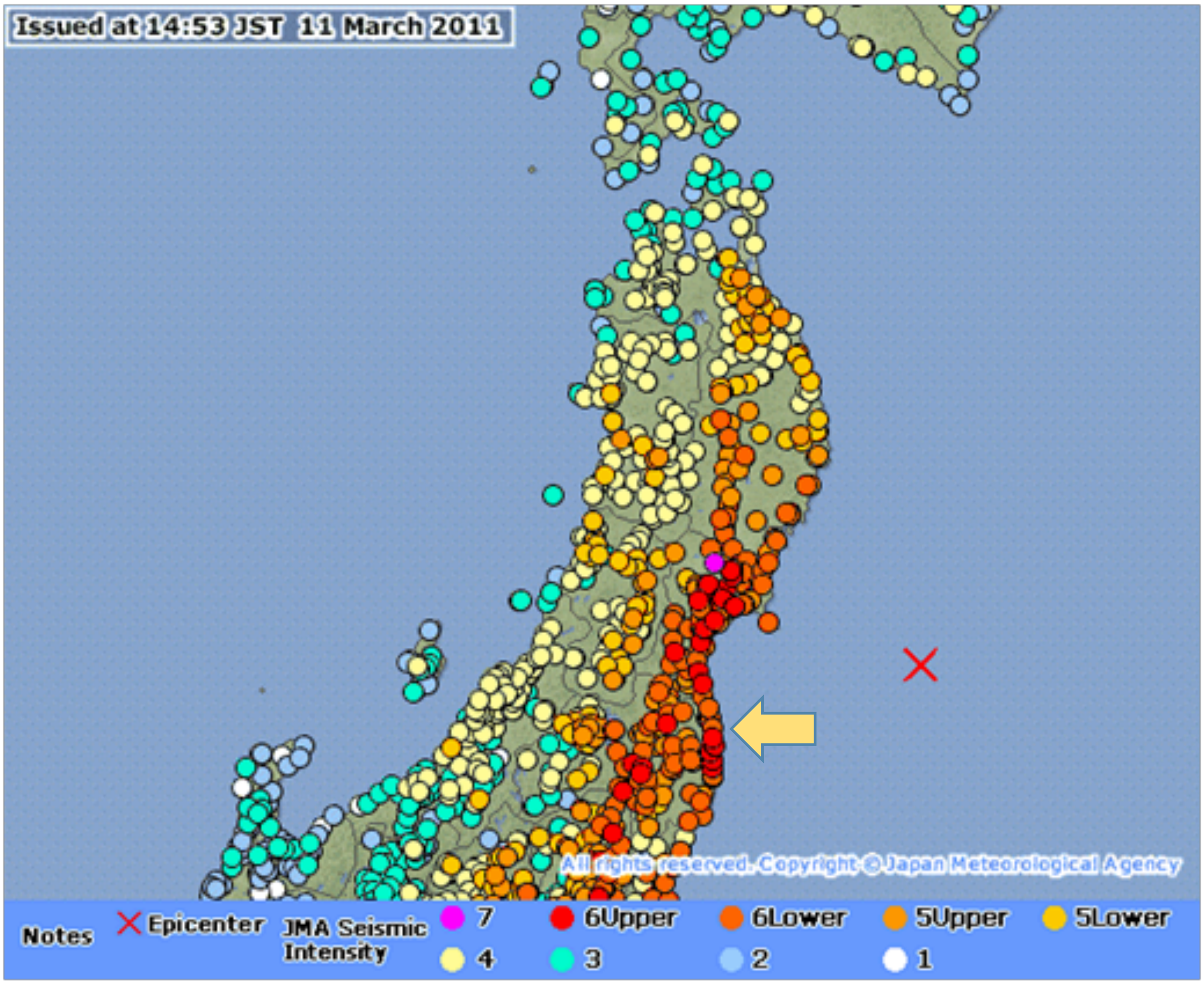
On August 11 2015, Kyushu Electric Company restarted the Sendai 1 nuclear facility. Sendai 2 was restarted on October 15, 2015 (43).

Questions

1. **How do incident command systems work in your country? What lessons can you learn from the Fukushima Daiichi NPS accident?**

2. **Are there other high-risk nuclear plants in the world? What agencies are responsible for maintaining their safety?**

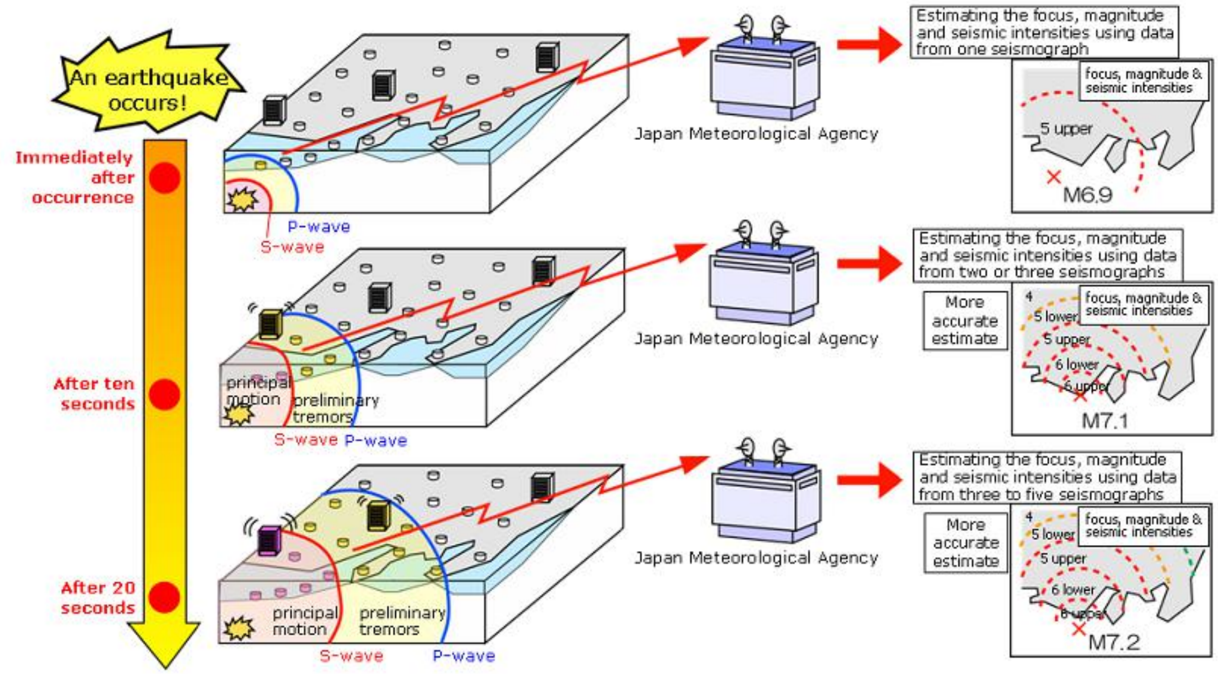
EXHIBIT 1: Seismic Intensity Map of the Great East Japan Earthquake. Recorded at 2:53pm JST, March 11, 2011.



Source: Japan Meteorological Agency, Information on the 2011 off the Pacific Coast of Tohoku Earthquake. 2011. http://www.jma.go.jp/jma/en/2011_Earthquake/Information_on_2011_Earthquake.html Accessed January 5, 2016

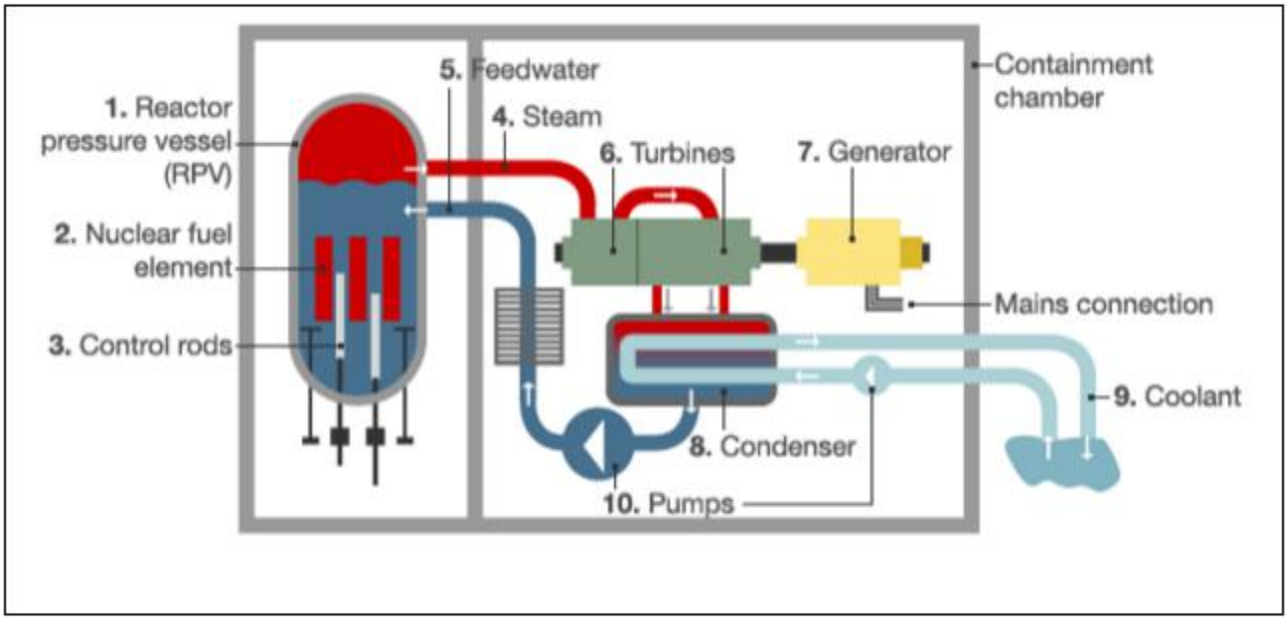
Note: The arrow (added by authors) indicates the location of the Fukushima Daiichi NPS

EXHIBIT 2: Diagram of Japan's Earthquake Warning System



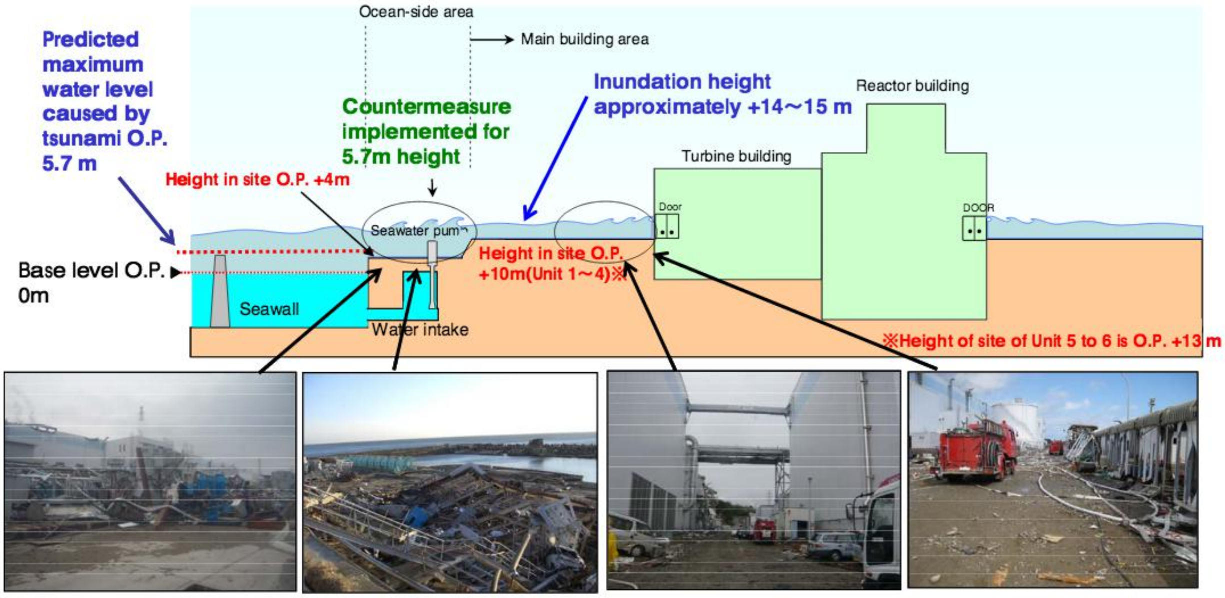
Source: Japan Meteorological Agency, What is an Earthquake Early Warning? 2007.
http://www.jma.go.jp/jma/en/Activities/eew1.html Accessed January 5, 2016

EXHIBIT 3: Boiling Water Reactor



Source: Black R. Choppers bring no nuclear relief - but current might. BBC 2001. http://www.bbc.co.uk/news/science-environment-12773350 Accessed January 5, 2016.

EXHIBIT 4: Tsunami Damage at the Fukushima Daiichi NPS



Source: Fukushima Nuclear Accident Independent Investigation Committee, Result of the Investigation on Tsunami at Fukushima Daiichi Nuclear Power Station. 2012.
https://www.nirs.org/**fukushima**/naiic_report.pdf Accessed January 5, 2016.

EXHIBIT 5: Overview of the Japan Nuclear Emergency Preparedness Act, 1999

In the event of a nuclear emergency, the Nuclear Emergency Preparedness Act clearly delineates the organizational structure and responsibilities of both the nuclear operator and the relevant government agencies. Interestingly enough, this law did not stipulate what to do if a nuclear disaster happened simultaneously with an earthquake, tsunami, or both (21).

- Once the operator determines that an emergency has occurred, he or she is required to report it to METI and the heads of the local government affected, if an event in Article 10 occurs.
- METI than takes all necessary measures as stipulated by law. The Senior Specialists of Nuclear Emergency Preparedness are assigned to work on the site of the affected nuclear power plant to collect information and perform necessary duties to prevent the Specific Event from escalating.
- If the Minister of METI feels that the situation has escalated from a Specific Event to a nuclear emergency situation, they alert the Prime Minister, as described in Article 15.
- The Prime Minister then declares a Nuclear Emergency Situation and provides orders to the affected local governments to take the necessary emergency response measures such as sheltering in place, widespread evacuation, or distribution of potassium iodide[13]
- In Tokyo, the Prime Minister establishes a Nuclear Emergency Response Headquarters (NERHQ).
- The NSC convenes the Technical Advisory Organization in an Emergency. This group is composed of the Advisors and Commissioners for Emergency Response, and their role is to provide the Prime Minister with technical advice on the developing nuclear emergency (24).

Article 10 of the Special Law of Emergency Preparedness for Nuclear Disaster, National Diet of Japan

When the management personnel for nuclear disaster prevention detect or are notified of the detection, by means of the methods designated by government ordinance, of radiation doses exceeding the level designated by government ordinance, or of other events designated by government ordinance near the boundary of the area of the establishment of nuclear enterprise, they shall immediately report the finding to the competent Minister, competent governor of prefecture, competent mayor of the municipality, and governors of the related neighboring local governments (or if the event occurs during transportation outside an establishment, to the competent Minister and to the governor of the prefecture and mayor of the municipality who have jurisdiction over the area in which the event occurred, as stipulated by the order of the competent Ministry and the disaster prevention plan of nuclear business operators. Upon being so notified, the competent governor of prefecture and governors of the related neighboring local governments shall report the event to the mayors of the related surrounding municipalities.

Article 15 of the Special Law of Emergency Preparedness for Nuclear Disaster, National Diet of Japan

1. When a nuclear emergency situation is prescribed in the succeeding paragraphs is deemed to have occurred, the competent Minister shall immediately submit to

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[13] When taken on the advice of public health or emergency management officials, potassium iodine helps block the absorption of radioactive iodine from being absorbed by the thyroid gland. As the thyroid gland is most sensitive to radioactive iodine, this can help protect it from radioactive injury

the Prime Minister both drafts of notification as prescribed in the succeeding Paragraph and instructions as per the provisions of Paragraph 3, in addition to provide necessary information on the situation.

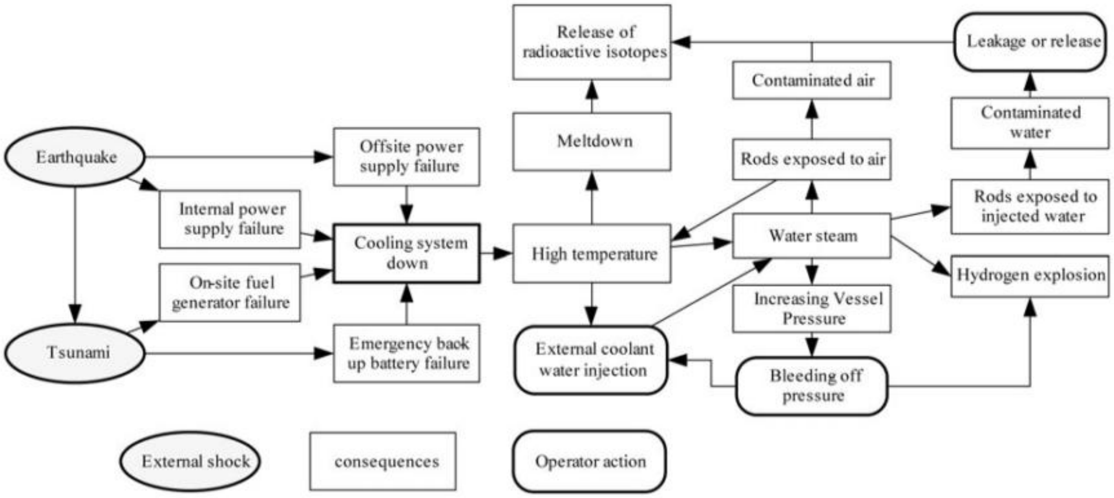
i. The radiation dose reported to the competent Minister in accordance with the former part of the provisions of Article 10, Paragraph 1 or the radiation dose detected by the methods and radiation-measuring devices designated in the government ordinance exceeds the threshold for radiation doses in abnormal level designated in the government ordinance.
ii. An event designated in the government ordinance as indicating the occurrence of a nuclear emergency situation, in addition to the events prescribed in the preceding Clause.

2. Upon receipt of the report and drafts prescribed in the preceding Paragraph, the Prime Minister shall immediately issue an official announcement (hereinafter referred to as ‘Notification of Activating Nuclear Emergency Organization’) concerning a notification of a nuclear emergency situation and the items outlined in the succeeding clauses.

i. Areas where immediate emergency countermeasures should be taken
ii. Summary of the nuclear emergency situation
iii. Issues exhaustively notified to residents, visitors, and public and private groups in the areas designated in Clause (a) (hereinafter referred to as ‘residents’), in addition to the information in the preceding Clause (1) and Clause (2)

3. Upon receipt of the information and drafts in Paragraph 1, the Prime Minister shall immediately provide instructions and/or recommendations of refuge by evacuation or sheltering to the mayors of municipalities and governors of prefectures who have jurisdiction over the areas designated in Clause (1) of the preceding Paragraph, in accordance with the provisions of Article 60 Paragraphs 1 and 5 of the Basic Law on Disaster Countermeasures, as applicable after being amended as per the provisions of Article 28, Paragraph 2, and provide instructions of other measures related to immediate emergency countermeasures.
Once immediate countermeasures to prevent the propagation of a nuclear disaster are deemed no longer necessary, the Prime Minister shall immediately consult the Nuclear Safety Commission and issue an official announcement to cancel the nuclear emergency situation (hereinafter referred to as ‘a Notification of Deactivating Nuclear Emergency Organization’). (Establishment of Nuclear Disaster Countermeasures Headquarters)

EXHIBIT 6: Fukushima Daiichi NPS Accident: Sequence of Events.



Source: Norio, et al., The 2011 Eastern Japan Great Earthquake Disaster. Int. J. Disaster Risk Sci. 2011, 2 (1): 34–42 doi:10.1007/s13753-011-0004-9

EXHIBIT 7: Sequence of Events by Reactor March 11-15, 2011

	Unit 1	Unit 2	Unit 3	Unit 4
March 11		Operated at standard output		Under routine inspection
		Earthquake strikes 14:46 - Scram		
		Automatic activation of emergency diesel generators		
		Start of Reactor Core Cooling Isolation (RCIC) System		
		First tsunami hits 15:42, second hits at 15:50		
		Station Blackout		
	18:10: Start of reactor core exposure			
	18:50: Start of reactor core damage			
March 12	5:46: Start of freshwater injection		11:36: Shutdown of RCIC	
	14:30: Venting		12:35: Start of high-pressure coolant injection (HPCI)	
	15:36: Hydrogen explosion at reactor building			
	19:04: Start of seawater injection			
March 13			2:42: Shutdown of HCPI	
			9:10: Start of reactor core exposure	
			9:20: Venting	
			9:25: Start of freshwater injection	
			10:40: Start of reactor core damage	
			13:12: Start of seawater injection	Backward flow of hydrogen from Unit 3 via Standby Gas Treatment System (SGTS)
March 14		Interference with recovery operation	11:00: Hydrogen explosion at reactor building	
		13:25: Diagnosis of RCIC shutdown		
		17:00: Start of reactor core exposure		
		19:20: Start of reactor core damage		
		19:54: Start of seawater injection		
March 15		6:00: Damage to Suppression Chamber (S/C) – massive discharge of radioactive material		6:00: Hydrogen explosion at reactor building

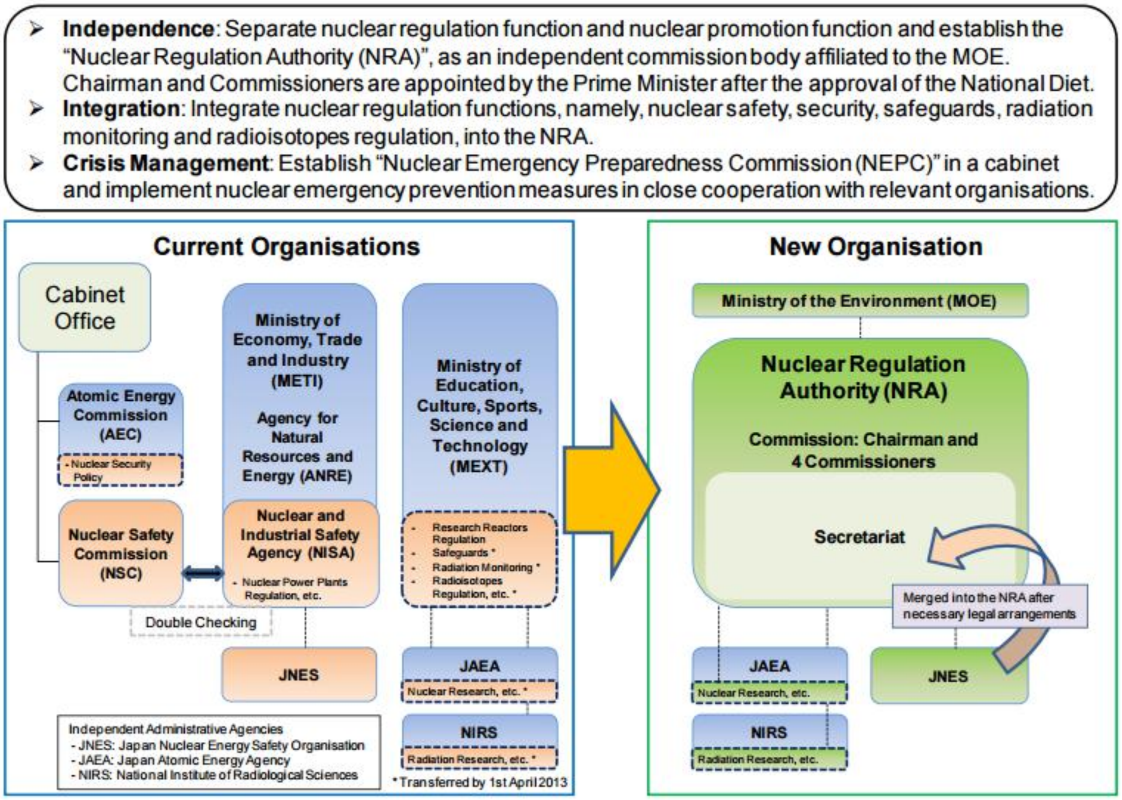
Source: Fukushima Nuclear Accident Independent Investigation Committee. Chapter 3: Problems with the nuclear emergency response. 2012.

EXHIBIT 8: Summary of Radiation Doses

Event	Radiation in millisievert (mSv)	Radiation in millirem (mrem)
Single dose, fatal within a few weeks	10,000.00	1,000,000
Standard dose recorded among Chernobyl workers that died within a month of exposure	6,000.00	600,000
Single dose that would cause radiation sickness but would not be fatal	1,000.00	100,000
Maximum radiation levels recorded at Fukushima Daiichi on March 14, 2011 (per hour)	350.00	35,000
Recommended exposure limit for radiation workers every five years	100.00	10,000
Full-body CT scan	10.00	1000
Natural radiation exposed to in one year	2.00	200
Radiation detected at Fukushima Daiichi on March 12, 2011 (per hour)	**1.02**	**102**
Dental x-ray	0.01	1

Source: Adapted from Rogers S. Radiation exposure: a quick guide to what each level means. 2011. (Radiation dose in millirem added for reference) http://www.theguardian.com/news/datablog/2011/mar/15/radiation-exposure-levels-guide Accessed January 5, 2016

EXHIBIT 9: Reform of Japan's Nuclear Regulatory Agencies as of July 2012



Source: Government of Japan, Convention on Nuclear Safety, National Report of Japan for the Second Extraordinary Meeting. 2012. http://www.meti.go.jp/english/press/2012/pdf/0705_01b.pdf Accessed January 5, 2016

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17. Strickland E. 24 Hours at Fukushima: A blow-by-blow account of the worst nuclear accident since Chernobyl [Internet]. IEEE Spectrum. 2011 [cited 2015 Sep 21]. Available from: http://spectrum.ieee.org/energy/nuclear/24-hours-at-fukushima

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