

# Fukushima Daiichi Nuclear Disaster

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Cole M. Helmer

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## Abstract

**The Great East Japan Earthquake struck Japan on the date, March 11<sup>th</sup>, 2011. Earthquakes with large enough magnitudes are commonly known to be followed by a tsunami, which is exactly what happened here in Tohoku, Japan. This following tsunami had waves towering over 10 meters in height. The combination of effects from the earthquake and tsunami resulted in a large death toll, along with drastic devastation impacting large regions of north-eastern Japan. These natural disasters, in turn also caused great damage to the Fukushima Daiichi Nuclear Power Plant. These irreversible damages eventually led to the meltdown of the plant, leaving behind a radioactive wasteland for the inhabitants that remained after the accident. [6]**

## Introduction

On March 11<sup>th</sup>, 2011, at around 2:46 PM The Pacific Plate slides under The North American Plate at a subduction zone 130 kilometers east of Sendai, Japan.[4] The location of Sendai falls within the region known as the ‘*Ring of Fire*’, and would be located within the Japan trench on the provided graphic in Figure 1. Being located within this

‘*Ring of Fire*’ subjects the surrounding land masses to an increased risk of potential earthquakes. The magnitude of the earthquake that afternoon in Sendai, was initially recorded as 8.9 on the Richter Scale, but was later revised to be a 9.0. This earthquake ranks as the 5<sup>th</sup> largest earthquake ever recorded and later became known as the ‘*Great East Japan Earthquake*’.[4]

A common side effect from earthquakes is that of another natural disaster. Normally, when such a large earthquake occurs a tsunami follows shortly after. *The Great East Japan Earthquake* shifted the Earth off of its

axis and triggered the following tsunami, that occurred at around 3:27 PM (41 minutes post-earthquake), that pushed forward with waves standing over 10 meters high.[5] A man attempting to save his boat and crest the tsunami before it broke described them for a documentary about the incident, “they were like mountains... we went over three waves that came directly from the east... they were about fifteen meters high.”[5] Tsunami waves can travel at immense speeds, capable of reaching speeds up to as high as 800 kilometers per hour.[4] The wave headed towards Fukushima was traveling at over 160 kilometers per hour when they made landfall.[5] In just a few minutes after the initial wave reaches the shoreline, almost 2,000 kilometers of the Japanese shoreline is completely demolished. The proximity of the earthquake in comparison to the eastern coast of Japan, allowed minute amounts of time for civilian evacuation attempts, as entire towns and villages are wiped out.[4] The combined effects from both the tsunami and earthquake, led to an immense loss of life, killing over 18,000 people, along with prominent damage throughout north-eastern Japan, including the accident at Fukushima Daiichi Nuclear Power Plant.[2 & 6]

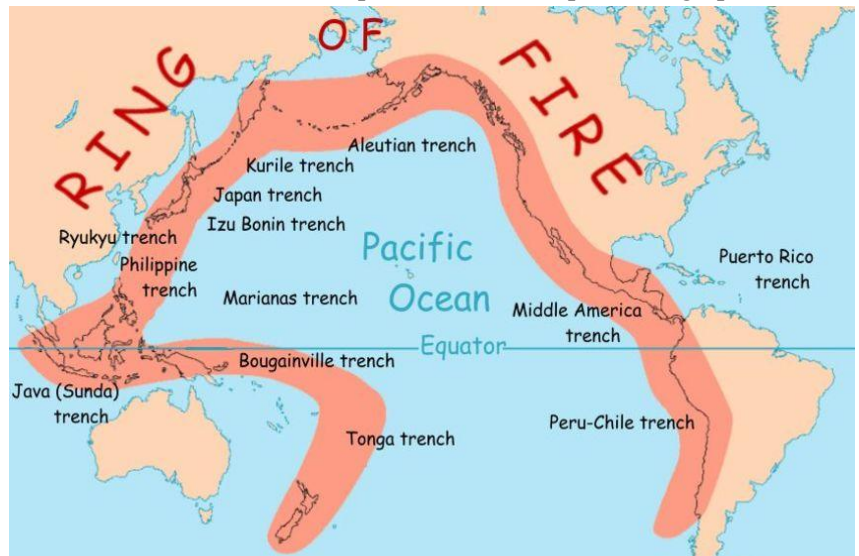


Figure 1. The graphic above highlights the Ring of Fire in red. This ring is formed by a string of volcanoes and is a region of high seismic activity. This region falls along the edges of the Pacific Ocean.[8]

## **The Fukushima Daiichi Nuclear Power Plant**

The Fukushima Daiichi Nuclear Power Plant was located 461 miles north of Tokyo and was positioned along the Pacific Coast. The Plant contained a total of six boiling water reactors which drove electrical generators combining to a total power of 4.7 gigawatts.[6] The Plant was owned by The Tokyo Power & Electric Company, TEPCO, and these six reactors have been generating power at the facility since 1979. On that afternoon of March 11<sup>th</sup>, the tsunami flooded the Plant with sea water.[4]. A documentary on the case said, “At 3:35PM, the biggest of the waves struck. It was more than twice the height of the plant’s sea wall. It is now known that TEPCO had been warned by a government committee of scientists in 2009 that its tsunami defenses were inadequate.”[5] Ultimately, this wave towering over the sea wall flooded the plant. This flooding eventually led to complications deeper within the plant leading to the eventual meltdown within the reactors. This led to massive radiation leakage into the surrounding areas and is described in better detail in sections to come.

## **Results of the Tsunami**

With the situation at Fukushima Daiichi, it only added more drastic problems to Japan’s island, as if they did not have enough already with the 9.0 magnitude earthquake and ensuing tsunami claiming over 18,000 lives alone.[5] When the tsunami hit three out of the six reactors were already shut down for routine inspection. The three reactors that were running as usual, were immediately at an increased risk for a meltdown in result to the damage caused by the flooding. These reactors are designed to shut down in the event of an earthquake, while the backup diesel generators continuously pump coolant into the reactor to keep the fuel rods at a cool temperature. However, these generators fail, as they are greatly damaged from the immense power of the tsunami and the resulting flooding.[4] Without these generators, Fukushima is at an immediate risk of melting down. The only solution to save Fukushima Daiichi from melting down would be the cooling of the fuel rods by returning the flow of water to the reactor.

Engineers quickly understood that it was essential to get the generators back online fast or else the plant and surrounding area are at risk of being covered in radiation. A log kept by engineers in the control room on a white board, read the following, “1542: Nuclear Emergency Declared...1558: Loss of Water Level Reading...1636: Emergency Core Cooling System Malfunction- No water can be injected.”[5] At around 8:15 PM, the Japanese government, already with pertinent issues at hand, receive information about the issues being faced at the Fukushima Nuclear Plant. The Japanese government proceeded to release a statement, declaring a separate state of emergency in the Fukushima Prefecture. About 45 minutes after the declaration of emergency, an evacuation order is declared for anyone located within two miles of the Fukushima Plant. Many civilians did not have a place to evacuate to. Some decide to ride out the aftermath of natural disaster and oncoming nuclear storm within their households, or what remains of them, while the others who also were unable to evacuate were to be placed in emergency shelters.[4]

## **Catastrophe Leads to Catastrophe**

The nuclear plant without power and engineers with no tools or instruments to inform them on what exactly was happening within reactor core. The engineers working improvised, PBS interviewed an engineer working at the plant that day who said, “all of us who had a car, or a company car, were asked to

get the batteries to try and restore power.”[5] These car batteries would allow for essential monitoring instruments in the reactor one control room to be powered on again. Around midnight, workers restored powers to the pressure gauge, and what was revealed immediately inflicted panic amongst the engineers, as the pressure continues to rise and rise.[5] After the panic set in, “The engineers realized the rising heat of the fuel rods in the reactor core was creating massive amounts of radioactive steam and hydrogen. This resulting pressure meant that the workers could not get water onto the fuel rods. Even worse, it meant the containment vessel (for the reactor) might explode, a disaster that could leave parts of Japan uninhabitable for decades.”[5]

With this information now understood, TEPCO was aware that they would now need to release radioactive gases into the air to prevent the nuclear reactor from exploding, but in order to do this they would need clearance from the Prime Minister of Japan himself. With the dropping of atomic bombs in **Hiroshima** and **Nagasaki** in 1945, Japan understood the extreme side effects that came with radiation poisoning/sickness, yet they understood it was essential in the big picture. The Prime Minister himself said, “Everyone agreed the venting had to happen. So, I said, ‘I understand. Let’s do it.’”[5] However TEPCO kept the Prime Minister in the dark about the fact that the company had never thought of the possibility of needing to vent a reactor, while the facility was without any electrical power and did not have any idea how to do it. These venting valves attached to the reactors were driven by motors, that being said, the valves simply will not open without electricity. It is possible in a way to open the valves manually, however, would prove to be very difficult. As engineers sit in the dark control room of reactor one poring over blueprints, trying to figure out a way to open the valves, radiation levels continue to increase at an alarming rate. This increase in radiation levels, was not only in the reactor, yet this was occurring in the control room itself too. As the engineers continue to search for a way to open the valves, the engineers began to suspect that nuclear meltdown had been set in motion.

The Prime Minister, who awaited news from TEPCO following his order to vent the reactors began to grow suspicious. After six hours of not hearing a response from TEPCO after giving the executive order, he felt as if TEPCO was hiding something. The Prime Minister decided he needed to go to Fukushima and see what was happening firsthand. The Prime Minister was confused as everyone had agreed that the reactors needed to be vented, yet nobody could explain why it was not happening, detailing that communications between the Plant and TEPCO felt like a game.[5] Masao Yoshida, plant manager, knew that the radiation levels near the vents, was at a potentially fatal level, yet claimed that he would send in a suicide squad if necessary.[5] Proving to be a hard decision the Prime Minister gives the go ahead to send people in to try and open the venting valves manually.

Once again, the venting gets delayed, as Fukushima is made aware that local evacuation efforts are not yet completed.[5] If the venting process had been started, these residents that remain in the area would be showered with dangerous potentially lethal amounts of radiation.[5] At around 9AM, on March 12<sup>th</sup>, 2011, the evacuation efforts had concluded and TEPCO ordered the venting team to go in.[5]. Plant logs show the first two volunteers went in at 9:04 AM.[5] These volunteers understood the dangers they were heading straight into, yet that was part of the mindset in Japanese culture. To sacrifice for the growth or betterment of the country was seen as very honorable. This is seen in past wars with Japan using kamikaze pilots and torpedo drivers, they took on their roles with great honor and pride and were looked onto by civilians as very honorable roles. Each worker was limited to 17 minutes inside the reactor building, after 9 minutes the workers had found the wheel for opening the vent. Inching it out and then pulling back when time was up.[5] When time ran out, four more workers would enter and repeat the process.[5]. Later that afternoon, a plume of gas from the venting tower, showed pressure within the

core was falling.[5] The bravery and courage from the venting team to walk straight into potentially lethal danger, saved northeastern Japan from a catastrophic explosion.[5] Many began to think the worst had passed and began to allow their nerves to calm, hoping the core would soon be stable. With venting completed, the focus shifted back to getting water into the reactor core.

The ground began to rumble at Fukushima, everybody unsure of what exactly it was at first. Engineers within the control center began to believe that the core of reactor one exploded, resulting in scattering radioactive fuel over the planet.[5] An engineer present for TEPCO stated that many within the control room started thinking of running to escape, yet running would only put you at an increased risk of radiation poisoning.[5] After about an hour, radiation levels stabilized and it was found out that leaking hydrogen had exploded in the roof of the reactor building(Figure 2), thankfully the core itself was still intact.[5]

“The radiation levels have not changed much since the explosion. Please remain calm. We see no damage to the containment vessel itself”, said the Prime Ministers Chief Cabinet, who was attempting to downplay the crisis back in Tokyo.[5] The Prime Minister, along with TEPCO were heavily criticized for the role in downplaying the crisis, which will be discussed more in later sections. Back at Fukushima, the explosion had stunted efforts of trying to get water into the core and was only a matter of time before meltdown occurred. A meltdown occurs when the fuel melts through into the open leaking out immense levels of radiation.

Now, they begin to think of the spread from the accident. When the Prime Minister asked for a simulation to be run of the worst-case scenario, it would have advised to evacuate 120-190 miles around the planet.[5] Leading all of Japan to come to a static halt. With a plume of radioactive gas released from the explosion began was drifting across Japan, and they widened the evacuation zone to 12-miles.[5]

On the morning of March 15<sup>th</sup>, 2011, with efforts already slowed trying to get water into reactors one and two, now reactor three began to face potential meltdown warnings.[5] Fear of a hydrogen build up in reactor room three began to build and the building was presumed to explode at any moment. TEPCO needing help, had a specialist group of soldiers sent in with the plan to inject water directly into the core of reactor three.[5] “Just as we got out of the Jeep to connect the hose, it exploded.... Radioactive matter began to leak in through our masks. Our dosimeter alarms were ringing constantly.”, said one of the soldiers.[5] Thankfully, these soldiers were able to flee before anyone was fatally injured.

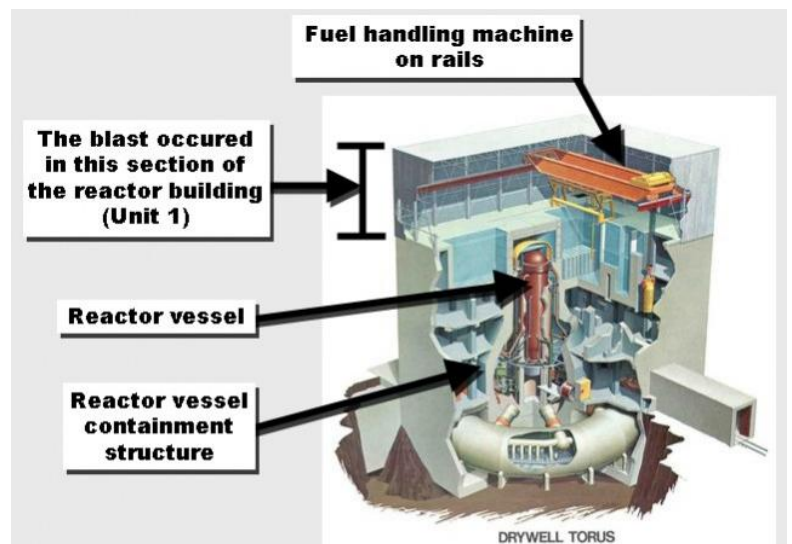


Figure 2. The above image shows where exactly the explosion happened in reactor room one.[1]



**Figure 3. The above image lays out Fukushima from an aerial view. Labeled are reactor rooms 1 & 3 with room 2 being the one in between still intact.[1]**

Parts of The Plant became entirely off limits to workers as radiation near one of the reactor buildings reached 1,000 millisieverts per hour, which after about an hour at these levels' radiation sickness would begin to set in, with a few hours meaning death.[5] At 3:00 AM on March 16<sup>th</sup>, the Prime Minister receives word that TEPCO planned to withdraw their workers from the plant, whereas the Prime Minister believed this was out of the question.[5] Abandonment would mean that 6 nuclear reactors along with 7 radioactive fuel pools would be left in chaos. If this were to occur, "Everything would meltdown.... Radiation tens of times worse than Chernobyl would be scattered.", said the Prime Minister in objection to the thought of employee withdraw.[5] At this point however, Yoshida had made his mind up and gathered his workers and had informed them of his plan to evacuate. He decided to send them home as he stated that he believed they could do no more. While this was happening at the plant, the Prime Minister went to TEPCO headquarters in Tokyo to try and put a stop to the total withdraw from the Plant.[5] The Prime Minister was able to stop a total withdraw but not too many remained, those few that did remain became known as 'The Fukushima Fifty'.[5]. At this point radiation levels were incredibly high, and the reactors were unmanned.

Eventually a team of American nuclear specialists, who had just arrived in Japan, feared that they had run out of options.[5] They believed that the number of people on-site simply would not be enough for what had to be done.[5] The American scientists decided to fly a drone over the Fukushima plant to see what exactly they were dealing with. They found that a third hydrogen explosion had exposed pools of discarded radioactive fuel to the open atmosphere, these spent rods were still incredibly radioactive. If these pools happened to boil dry, these spent rods could ignite causing immense radioactive contamination, worse than that in the event of just a meltdown.[5] They could see that there was obviously fuel damage occurring in the spent fuel pools from the lack of coolant, with protection of the citizens being the utmost priority, they figured they needed to get water in there to cool it down to a controllable temperature.[5]

The morning of March 18<sup>th</sup>, the Prime Minister made the order to dump water on the spent fuel pools from the air.[5] These pilots, like many of the honorable people mentioned above, knew the pilots who performed a similar tactic at Chernobyl died following the event as a result of cancer from the operation.[5] They had bolted tungsten plates to the choppers, in order to protect the soldiers from lethal gamma rays. They had to keep moving and drop the water from 300 feet, higher and they would miss, lower and they would be in immense danger.[5] The soldiers had successfully hit the pools with water, yet the following missions missed. The Americans then began to develop an evacuation plan for 90,000 Americans from Japan and advised all of its citizens to stay at least 50 miles from the plant, while the Japan evacuation zone, still remained at 12 miles.[5]

In the evening of March 19<sup>th</sup>, the Japanese government ordered a team of firefighters to get water into the fuel pools by any means necessary.[5] First, one man went in alone to plot a route for his men to take to get to the pools themselves, however he would not be able to go back in with his men after his plotting trip. The plan was to drive a truck up to the sea line, put a hose into the sea to suck up water and then lay over 800 yards of hose to leave it spray into the fuel pools.[5] After about an hour on-site, the hoses were finally connected and the water had begun to spray and the firefighters started their withdraw. Now, March 20<sup>th</sup>, radiation levels begin to lower and TEPCO brings in their employees to lay miles of pipes to channel constant water flow into the cores. After the pipes were put in place, finally a steady flow of water was directed to the reactors. Finally, the system was turned back to a controllable state and the process of cleanup began.

### Aftermath

The Prime Minister was forced to resign shortly following the accident that occurred at Fukushima Daiichi. He was often accused for his mishandling of the situation, many claimed that him going to TEPCO while they were trying to figure out what was happening, interfered with their work.[5] TEPCO instantly faced having to pay out tens of billions of dollars in damages as the company is on the verge of bankruptcy.[5] While all of the workers who risked their own lives attempting to save thousands, faced an uncertain future. As they were exposed to dangerous levels of radiation, it was not sure what type of side effects lay ahead for them, thankfully none of them have died directly from their exposure to radiation.[5]

The radiation released from the meltdowns at Fukushima, contaminated hundreds of square miles in eastern Japan. Leading to more than 100,000 people fleeing the nuclear fallout. An exclusion zone is still active for 12-miles around the plant.[5] Inside the exclusion zone, there are many not-so pretty sites that are discovered. Farm animals left behind by fleeing owners, have starved to death, while some roam around wild. Many districts around Fukushima have been so badly contaminated that they will be uninhabitable for years. “Authorities believe it will take up to 40 years to finish the work of decontamination, which has already cost Japan trillions of yen.”, said a recent BBC article following up on the Plant and its surrounding

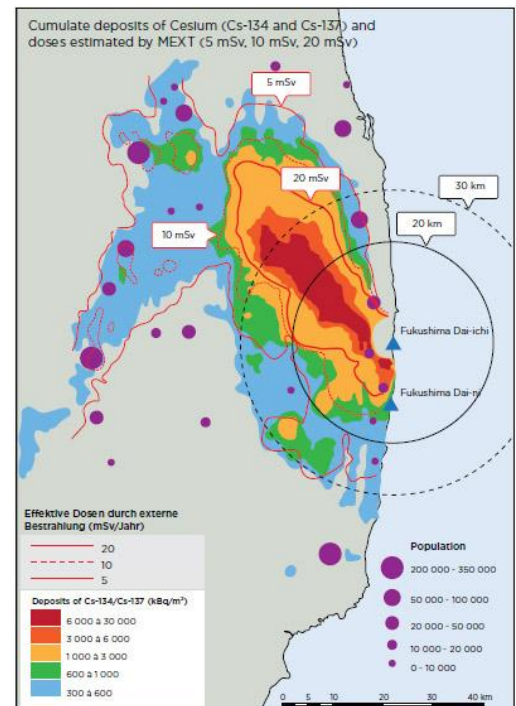


Figure 3. The above, pictures a map showing the contamination as a result from the meltdowns at Fukushima.[1]

area.[2] This event was classified as a level 7 by the International Atomic Agency, this is the only event to meet this classification since the disaster that occurred in *1986 at Chernobyl in Russia*. [5]

### **Design Flaws**

The cause of the disaster at the Fukushima Daiichi Nuclear Power Plant, could mainly be attributed to the design and placement of the facility. Firstly, with the location of Fukushima Daiichi being situated within the Ring of Fire, found in Figure 1, the event of earthquake and resulting tsunami should have been accounted for when designing and constructing this facility. In terms of safety standards, simply protecting the facility from these common natural disasters, it was equipped with a sea wall. This was to block rogue waves and tsunamis as such from making their way into the plant causing damage. If this is the case how did the tsunami hit? Because the sea wall was nowhere the height that it needed to be. It was said that when the tsunami made landfall, it was at least double the height of this sea wall. This would render the sea wall practically obsolete in defense to the tsunami.

Previously mentioned, the diesel backup generators at Fukushima Daiichi were situated in the basement of the turbine building at the Plant. This meant these generators were positioned at a level close to sea level, rendering them obsolete in result of a flood. The event of tsunamis should have been accounted for in the design of the plant, placing these generators close to sea level was a catastrophic design flaw.[10] When dealing with a nuclear power plant, everything that revolves around safety must be stepped up a notch, as you are dealing with machines and instruments that could potentially leave an impact on the entire world. With that being said, these backup generators were the key safety component to prevent catastrophe at Fukushima and were known to be taken out by water. Yet these generators are stored near sea-level, with the plant already being placed on the coast of Japan? Beach house owners most of the time do not even build a basement because of flood risk, yet nuclear engineers at one of the top facilities deemed it okay to store these essential generators in the basement. This crucial design flaw, led to days on days of scrambling for solutions that were nowhere to be found.

### **NSPE Ethical Analysis**

The *National Society of Professional Engineers*, or the NSPE, is an organization created in 1934 with one crucial goal. The overall goal of the NSPE taken directly from their website is to, “create an inclusive, nontechnical organization dedicated to the interests of licensed professional engineers, regardless of practice area, that would protect engineers (and the public) from unqualified practitioners, build public recognition for the profession, and stand against unethical practices and inadequate compensation.”[9] With that being said, the NSPE has come together to set up a list of rules/guidelines to uphold the morals and ethics within the engineering world.

There were many criticisms directed towards TEPCO and the Japanese Prime Minister following the events at Fukushima Daiichi. Many claimed they did not handle the situation properly, which eventually forced the Prime Minister into resigning. TEPCO immediately had broken fundamental canons 1,2,4,5,6, all but canon two which is ‘perform services only in areas of their competence’, which these engineers knew what they were working with, yet it was the blatant disregard for these natural disasters in designing the plant that was the ultimate flaw.[9] However, when the engineers did not account for these disasters, they did not hold the safety of the public as their number one priority, along with issuing public statements that were not entirely truthful. TEPCO, playing ‘phone-games’ as the Prime Minister described it, seemed to be performing deceptive acts in order to give a sense that they had it under control, when they in fact did not have anything under control at Fukushima at all. The Prime

Minister on the other hand was heavily criticized for showing up at the plant and right so, he breaks rule 2 immediately, which reads ‘Engineers shall perform services only in areas of their competence.’[9] The Prime Minister himself was no expert in nuclear radiation, so him putting his boots on the ground there does not do much other than add to the stress levels placed on engineers. On the other hand, however, TEPCO was acting suspiciously towards the Prime Minister, and he deemed it essential to find out what exactly they were dealing with. Without this, nobody knows how far TEPCO would have gone to cover the severity of what they had allowed to happen on their watch. The Prime Minister could also be under heavy fire for not extending his evacuation zones enough and downplaying the situation to his citizens. As stated, America issued statements to evacuate everyone within 50 miles of the plant, while Japan only had an evacuation zone of 12 miles, making the American evacuation zone almost more than 4 times the size.

### **Recommendations**

The blatant disregard to establishing an effective yet safe work environment for where the plant was geographically located is also a key issue that should have been addressed. A TEPCO managing director of the nuclear division, claimed that, “The company had never imagined that one of its plants could lose all power.”[5]. This seems as though it is blatant negligence, especially when looking at the location of Fukushima Daiichi in a geographical aspect. The plant is situated on the coast of Japan, a country located in the heart of the *Ring of Fire*, found in Figure 1. Placing it in a hotbed of seismic activity, or earthquakes, which commonly are followed by tsunamis. The fisherman referred to in the *Introduction* section mentioned how the everybody around the coast of Japan knows the tsunami follows the earthquake, hence why the fisherman rushed to save his boat. It is unbelievable that a managing director at one of the world’s top nuclear facilities could not piece this together as a thought of concern before the catastrophic event unfolded.

Had the plant been designed with these types of natural disasters in mind, since it is located in a hotbed for natural disasters as such, it could potentially have changed the overall design of the plant. This potentially would have also raised the generators out of the basement, which is another change that should have been made and is discussed below, preventing them from being rendered obsolete from flooding. Mentioned in *The Plant* section, the wave that hit Fukushima was twice the height of the sea wall, rendering this sea wall useless and leading to tons of flooding throughout the plant. Potentially the plant, realistically still suffers some severe damage, yet in an event like this there is still enough control to prevent it from becoming even more of a disaster. The sea wall being raised potentially blocking out all flooding would have meant these diesel backup generators never become damaged and proceed to do their job cooling down the reactors. It is also unbelievable that this route was not taken when thinking about what operations were carried out at the Fukushima Daiichi Plant. When harnessing nuclear energy, it is known, not entirely but for the most part what the effects are of radiation. The fact that something like this was not more of a concern for the staff dealing with safety at the Plant, is somewhat more concerning.

The placement of the diesel backup generators also should have been in a better suited location. The position at the time of the accident rendered them as obsolete in result of a flood. The tsunami knocking out these generators prevented the flow of coolant into the reactors allowing their temperatures and reactions to rise immensely leading to the eventual meltdown. If these generators were situated in a better location, perhaps somewhere way above sea level, the flow of coolant into the reactors is unaffected. This would allow for the controlling of temperature and reaction rate within the reactors.

This amount of control potentially could have saved Fukushima Daiichi; however, these reactors were rendered obsolete, and The Plant was destroyed.

### **Conclusion**

The tragedy that took place on March 11<sup>th</sup>, 2011, will forever be remembered. Not only for the nuclear disaster that occurred, but for the over 18,000 lives lost as a result to the natural disaster. Many civilians lost their homes or were simply forced out. On top of that, now you add the tragic occurrence at Fukushima, it truly was a never-ending day of disaster after disaster. Thankfully, no lives were lost as a direct result of Fukushima, however many received dangerous amounts of radiation poisoning and will continue in life with an uncertain future. Many Japanese engineers and soldiers valiantly stood their ground at the plant and risked their lives to save the majority. Ultimately, they were successful in preventing the worst of the worst, however meltdown did still occur in Fukushima, leading to mass amounts of radiation leakage, contaminating the area for what experts expect to be around 40 years before humans are able to return safely. This event signifies the importance in the details within engineering. In class right now, we work on a smaller scale, these are things that must be kept in mind along with holding the NSPE code of ethics for engineer's paramount while you carry out your daily duties.

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