The Great Tohouku Earthquake and the Fukushima Disaster: Incident Management from a Physical Control Standpoint

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Tohouku Earthquake

- 9.0 magnitude quake
- Occurred on March 11, 2011 at 2:46PM JST.
- Centered 8 miles off the city of Sendai, on the eastern coast of Honshu Island.
- Lasted approximately 6 minutes.
- Aftershocks: 9500 were recorded (up to 2013)
- Considered the largest earthquake in Japan's history.
- Earthquake was felt in places such as Russia, Taiwan, and Beijing, China.

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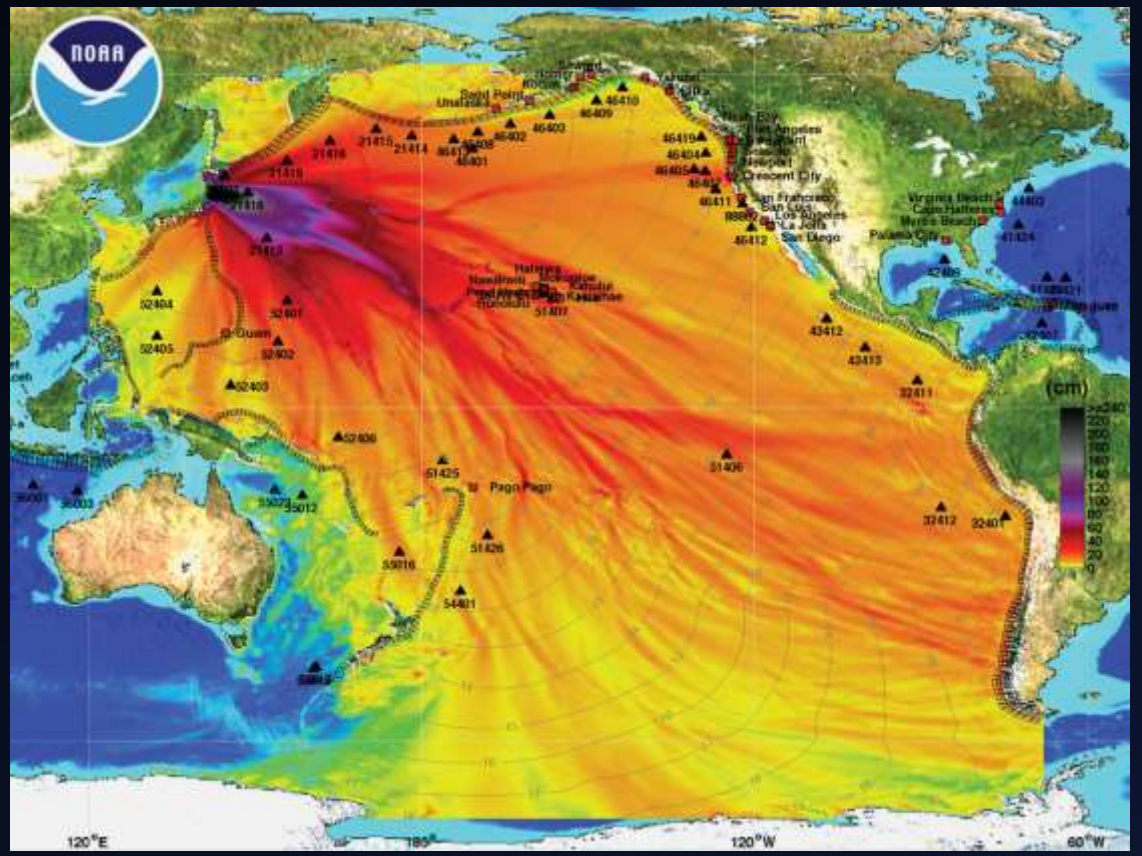
Tsunami

- Right after the earthquake, a tsunami warning was issued by the Pacific Tsunami Warning Center for the Pacific Ocean.
- A devastating tsunami attacked the Northern Pacific Coast of Japan with waves of up to 128ft.
- Total affected area of 155 square miles of land.
- Due to wide range of land penetrated by the waves, tons of debris were dragged out to the ocean along with the victims that had succumbed due to the flooding.
- Waves moved at a speed of 500 miles an hour.



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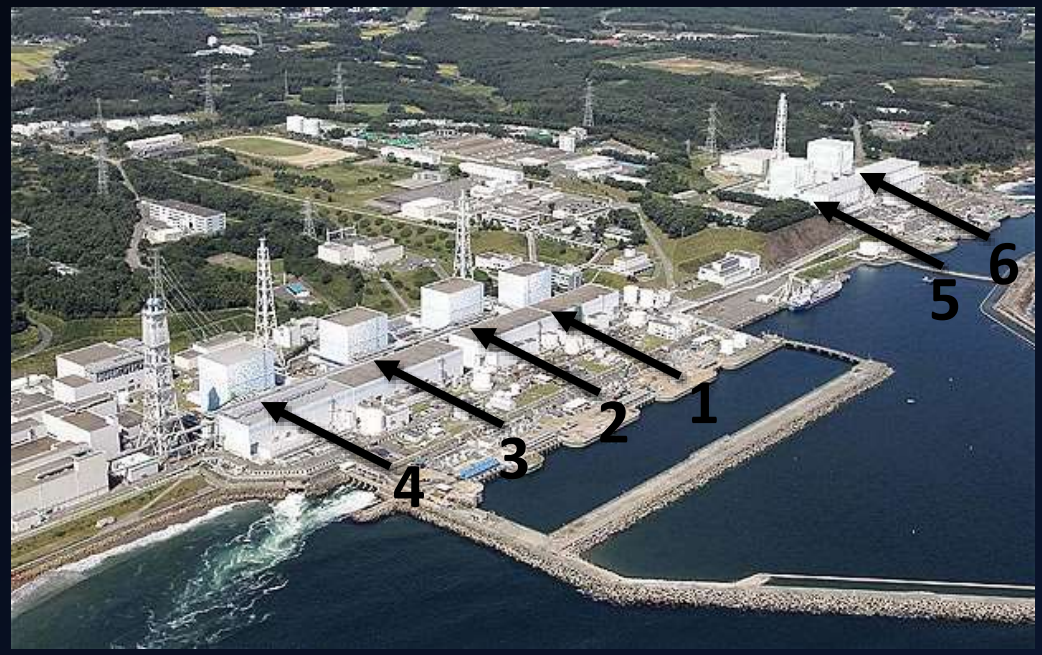
Retrieved from: http://www.nydailynews.com/news/world/amazing-photo-tsunami-waves-form-whirlpool-japan-article-1.121296

Retrieved from: http://www.theguardian.com/world/blog/2011/mar/12/japan-tsunami-earthquake-live-coverage

Fukushima Daiichi Nuclear Power Plant

- Located located between the towns of Futaba and Ohkuma, 155 miles north of Tokyo, Fukushima Daiichi is a Boiling Water Reactor Plant consisting of six Mark-I and Mark-II reactors over an area of 865 acres.
- Commissioned in 1971 by Tokyo Electric Power Company (TEPCO).
- The reactors had a combined capacity of 4696MW.



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Retrieved from: http://www.power-technology.com/projects/fukushima-daiichi/fukushima-daiichi3.html

Fukushima Daiichi Nuclear Disaster: March 11

- After the earthquake occurred, a SCRAM shutdown was ordered for reactors 1 thru 3 . Reactors 4, 5 and 6 had been shut down previously due to outages.
- Power is lost on-site due to earthquake damages. Emergency Diesel Generators (EDGs) are activated to provide power to the reactor core cooling systems.
- A 49 foot wave of the tsunami reached Tokyo Electric Power Company's Fukushima Daiichi Nuclear Plant, flooding the entire site. This caused the EDGs to stop operating.
- State of nuclear emergency was declared by the Government at 7:03 PM
- Alternative cooling systems used on reactor 3 were used on reactors 1 and 2 as well.

Fukushima Daiichi Nuclear Disaster: The Following Days

- The battery used as back-up supplies deplete and the pressure increases inside the reactor cores. Following that, the temperatures begin to rise and hydrogen explosions occur on reactors 1, 2 and 3, exposing the fuel rods.
- Reactor 4 sustains severe damage due to fires. Four days after the earthquake, meltdowns have already been detected on reactors 1,2,3 and 4.
- These explosions and fires released high levels of radiation.

Fukushima Daiichi Nuclear Disaster: The Following Days

- Evacuations were ordered within the first fourteen days after the nuclear emergency started to unfold (this includes mandatory and voluntary evacuations). Approximately 300,000 people evacuated the exposed areas.
- The process of cooling down the reactors took 160 days.
- The nuclear accident was rated Level 7 on International Nuclear Events Scale, corresponding to “ Major Accident”. It can be compared to the events that occurred in Chernobyl.

Consequences and Losses

HEALTH

- Death Toll: 15,893 people
- Elevated levels of stress and anxiety in the locals of Iwate and Miyagi. Suicide rates increased.
- Children showed overweight, elevated levels of stress and anxiety; asthma among girls.
- Increase in cancer threat. Elevated signs of thyroid cysts and nodules on children.

ENVIRONMENT

- Radiation material released into the 12.5 miles of land surrounding Fukushima Daiichi.
- Contamination by radioactive cesium affected foods such as spinach, tea leaves, milk, beef, and even freshwater fish.
- 5 million tons of debris were swept into the sea.

Consequences and Losses

ECONOMY

- Costliest disaster in the history of the world. Estimated cost of 309 billion dollars.
- Supply chains of Toyota and Honda were affected by both the earthquake and the tsunami.
- Toyota had to stop production in four of their plants located in Hokkaido, Tohouku, Miyagi and Iwate.

Fukushima Daiichi Now

Retrieved from: http://abcnews.go.com/topics/news/fukushima-nuclear-power-plant.htm?mediatype=Image

Retrieved from: http://www.telegraph.co.uk/news/worldnews/asia/japan/11648535/Fukushimas-forbidden-ghost-towns-in-pictures.html?frame=3327941

Assessment of Fukushima Daiichi Accident

- After the accident occurred the IAEA prepared a report assessing the accident by taking into account several factors including human, technical, and organizational factors.
- They identified weaknesses in Fukushima Daiichi's plant design, emergency preparedness, and planning for management of large-scale accidents.
- In terms of physical controls: vulnerability to external events.

Assessment of Fukushima Daiichi Accident

- Original plant design included a conservative approach on its plant design, including hazards towards the eventuality of an earthquake of great magnitude.
- TEPCO failed to include tsunami hazards in their original plant design. Occurrence of tsunami of great scale was not considered credible to Japanese scientists.
- No reassessments of the design for the hazards had been performed.
- Plant operator performed trial calculations to modify tsunami hazard (2002). These calculations were never implemented.

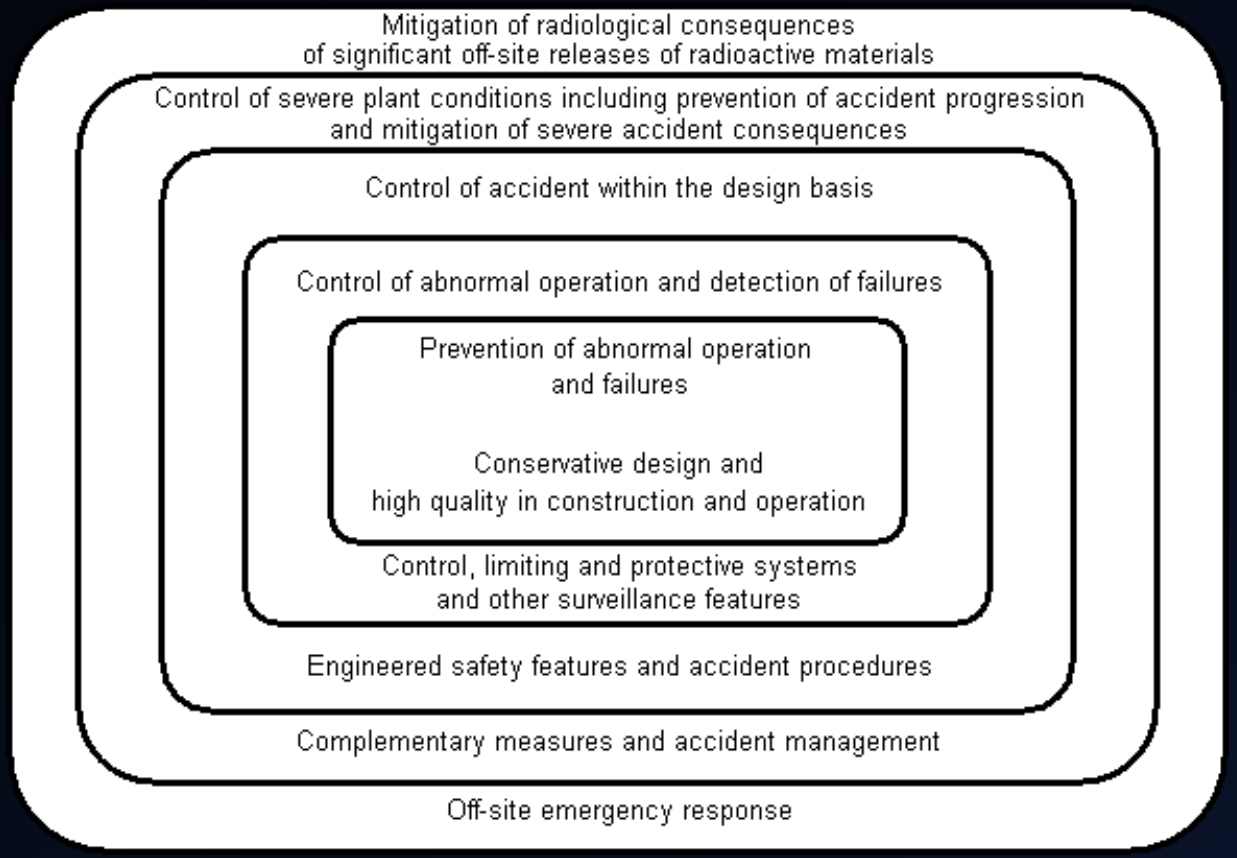
Assessment of Fukushima Daiichi Accident

- Assessment revealed that Fukushima Daiichi failed to comply with two of the three fundamental safety functions to ensure safety in nuclear plants.
  1. Control of reactivity in nuclear fuel.
  2. Heat removal from reactor core and spent fuel pool.
  3. Radioactive material confinement.
- Loss of electrical power led to failure of safety functions 2 and 3.
- Vulnerability to external events leads to defense in depth concept and how it was applied on Fukushima Daiichi.

Defense in depth

- According to IAEA, it is defined as “an approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials.”
- The concept consists in applying various levels of protection through the use of access controls, physical barriers, redundant safety functions, etc to meet the IAEA’s objectives, which are summarized as protecting the plant in order to avoid harm to the environment and the public.

Five Levels of Defense



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https://www.iaea.org/ns/tutorials/regcontrol/images/image025.gif

Defense in Depth at Fukushima Daiichi

- According to the IAEA, Fukushima Daiichi complied with the first three levels of defense with the systems and equipment installed on the site.
- Since the plant did not have any external hazards, the flooding from the tsunami compromised the three levels of defense which led to the emergency. Without the safety systems, the fourth level of defense could not be fulfilled either.

Recommendations by the IAEA

- Inclusion of conservative beyond design basis (external) hazards that take into account events that occur simultaneously and/or in succession.
- Periodic evaluation of nuclear plant safety in order to include advances in technology that could aid in the safety of the site.
- Implementation of five levels of defense and strengthening of them in order to respond to internal and external hazards.
- The instrumentation and control systems necessary to maintain the safety and operation of the nuclear plant must remain operational in the instance of an external hazard.
- Safety Analyses must be conducted to ensure the capability of the nuclear power plant to withstand external events.
- Performance training exercises, and drills should be conducted to make sure operators are prepared to take action in the event of a severe accident.

Incident Management: Points to Evaluate

- In order to create an effective incident response, a number of aspects have to be evaluated:
  1. Localization
  2. Geographical conditions
  3. Regional climatic conditions
- Taking these factors into account a list of recommendations are proposed to avoid a series of events, either in succession or simultaneously, that endanger the safety and operation of the nuclear reactors

Incident Management: Plant Design

- Elevation of the terrain where the plant is located to reduce the risk of flooding.
- Installation of a sea-wall around the site with an appropriate height, taking into consideration the worst possible scenario. For instance, if a sea wall were to be built in a new nuclear plant in a similar location, then it would have to exceed 49 feet in height, since the wave that flooded Fukushima Daiichi had that height.
- Design an efficient site drainage system, prioritizing areas where safety and/or backup systems are located.
- Installation of watertight doors where essential equipment is kept, and where backup systems are located to ensure their operation in an emergency.

Incident management: Emergency Backup Systems

- EDGs should be located in an elevated area of the site, protected by watertight doors in order to protect them from flooding.
- The EDG system should be redundant, meaning there should be an additional group of EDGs in the event that the first group fails. This second group of EDGs should be located in a different area than the first, but equally secured.
- Cooling system should be robust (able to operate properly under certain parameters or disturbances), and should have a backup. It should also be secured by watertight doors in an area where they are not in risk of flooding.

Incident Management: Control Systems, Instrumentation, and Equipment

- Installation of a seismic sensor, such as an automated accelerograph, near the reactor containment vessel, in order to detect earthquakes. Once the operator detects movement, the information shall be confirmed with the Japan Meteorological Agency to begin emergency shutdown procedures.
- Installation of a water-level sensor in the spent fuel pool, with levels indicating: “normal water level”, “above normal water level”, and “below normal water level”. This will ensure, in the event of an emergency, that there is no release or exposure of nuclear material to the environment.
- Installation of a gas detector sensor at the reactor containment vessel to detect and monitor potential hydrogen releases.
- Mark-I and Mark-II, reactors shall contain a hardened venting system inside the containment vessel to avoid rise of temperature and pressure in the event the cooling system fails.

References

- United States Geological Survey (2011, March 11). *Magnitude 9.0-Near the Coast of Honshu, Japan.* Retrieved from: http://earthquake.usgs.gov/earthquakes/eqinthenews/2011/usc0001xgp/#details
- Oskin, B. (2015, May 7). Japan Earthquake and Tsunami of 2011: Facts and Information. *LiveScience*. Retrieved from: http://www.livescience.com/39110-japan-2011-earthquake-tsunami-facts.html
- PBS Nova (2011, March 30). *Japan's Killer Quake*. Retrieved from: https://www.youtube.com/watch?v=_HY18qrkNxY
- Rafferty, J.P. Japan Earthquake and Tsunami of 2011. *Encyclopedia Britannica*. Retrieved from: http://www.britannica.com/event/Japan-earthquake-and-tsunami-of-2011
- The Japan Times. (2012, March 13). More than 9,500 Aftershocks logged since Mega-Quake. *The Japan Times RSS*. Retrieved from: http://www.japantimes.co.jp/news/2013/03/12/national/more-than-9500-aftershocks-logged-since-mega-quake/#.VnmIJvkrK71
- Mustain, A. (2012, May 23). Japan Aftershock Tally Exceeds 5000. *LiveScience*. Retrieved from: http://www.livescience.com/20519-japan-earthquake-aftershocks.html
- Mori, N., & Tomoyuki, T. (2012). Nationwide Post Event Survey and Analysis of the 2011 Tohoku Earthquake Tsunami. *Coastal Engineering Journal,* 54(1).
- Tokyo Electrical Power Company. *Nuclear/TEPCO-Power Plants.* Retrieved from: http://www.tepco.co.jp/en/challenge/energy/nuclear/plants-e.html

References

- Brook, B. (2011, March 15). Fukushima Nuclear Accident-a Simple and Accurate Explanation. *The Energy Collective RSS.* Retrieved from: http://www.theenergycollective.com/barrybrook/53461/fukushima-nuclear-accident-simple-and-accurate-explanation
- Nuclear Energy Agency. Fukushima Press Kit. *OECD NEA*. Retrieved from: http://www.oecd-nea.org/press/press-kits/fukushima.html
- Nuclear Energy Agency. Timeline for the Fukushima Daiichi Nuclear Power Plant Accident. *OECD NEA*. Retrieved from: http://www.oecd-nea.org/press/press-kits/fukushima-timeline.html
- National Geographic. (2014). *Mega Disasters 2014 Fukushima Nuclear Disaster*. Retrieved from: https://www.youtube.com/watch?v=gBkky3VHrkA
- National Police Agency of Japan. (2015, September 10). *Damage Situation and Police Countermeasures associated with 2011 Tohouku District-off the Pacific Ocean Earthquake*. Retrieved from: http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf
- The Japan Times. (2011, April 21). 90% of Disaster Casualties Drowned. *The Japan Times RSS*. Retrieved from: http://www.japantimes.co.jp/news/2011/04/21/national/90-of-disaster-casualties-drowned/#.Vnrj7_krK70
- Talesnik, D. (2015, January 16). Assessing Health Effects of Japan's Quake, Tsunami, Nuclear Accident. *NIH Record*. Retrieved from: https://nihrecord.nih.gov/newsletters/2015/01_16_2015/story2.htm

References

- Cable News Network. (2015, October 22). 2011 Japan Earthquake-Tsunami Fast Facts. *CNN*. Retrieved from: http://edition.cnn.com/2013/07/17/world/asia/japan-earthquake---tsunami-fast-facts/
- World Nuclear Association. (2015, October). *Fukushima Accident*. Retrieved from: http://www.world-nuclear.org/info/safety-and-security/safety-of-plants/fukushima-accident/
- Starr, S. Costs and Consequences of the Fukushima Daiichi Disaster. *Physicians for Social Responsibility*. Retrieved from: http://www.psr.org/environment-and-health/environmental-health-policy-institute/responses/costs-and-consequences-of-fukushima.html?referrer=https://www.google.com.pr/?referrer=http://www.psr.org/environment-and-health/environmental-health-policy-institute/responses/costs-and-consequences-of-fukushima.html
- Lah, K. (2013, March 11). Japanese Tsunami Debris Makes its Way into Hawaiian Birds. *CNN*. Retrieved from: http://edition.cnn.com/2013/03/11/us/hawaii-japan-tsunami-debris/index.html
- Iboshi, K. (2015, March 16). 1 Million Tons of Tsunami Debris Still Floating in Pacific. *KGW*. Retrieved from: http://legacy.kgw.com/story/news/investigations/2015/03/16/1-million-tons-of-tsunami-debris-still-floating-in-pacific/24868579/
- Censky, A. (2011, March 23). Japan Earthquake could cost $309 billion. *CNN Money*. Retrieved from: http://money.cnn.com/2011/03/23/news/international/japan_earthquake_cost/index.htm
- Tefris Team. (2011, April 8). Japan Quake, Tsunami Take Heavy Toll on Toyota. *Forbes*. Retrieved from: http://www.forbes.com/sites/greatspeculations/2011/04/08/japan-quake-tsunami-take-heavy-toll-on-toyota/
- World Nuclear Association. *The Situation at Fukushima*. Retrieved from: http://www.world-nuclear.org/Features/Fukushima/Situation-at-Fukushima/

References

- Fackler, M. (2015, August 8). 4 Years after Fukushima Nuclear Calamity, Japanese Divided on Whether to Return. *The New York Times*. Retrieved from: http://www.nytimes.com/2015/08/09/world/asia/japan-fukushima-nuclear-disaster-iitate-return-plan.html
- Amano, Y. (2015). *The Fukushima Daiichi Accident. A Report by the Director General.* Retrieved from: http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1710-ReportByTheDG-Web.pdf
- Nuclear Regulatory Commission. (2015, December 17). *Defense in Depth*. Retrieved from: http://www.nrc.gov/reading-rm/basic-ref/glossary/defense-in-depth.html
- International Atomic Energy Agency. *3.2.1.3 Defence in Depth Concept*. Retrieved from: https://www.iaea.org/ns/tutorials/regcontrol/assess/assess3213.htm
- Nuclear Regulatory Commission. (2015, April 17) *What Are the Lessons Learned from Fukushima?*. Retrieved from: http://www.nrc.gov/reactors/operating/ops-experience/japan-dashboard/priorities.html

Questions?

THANK YOU