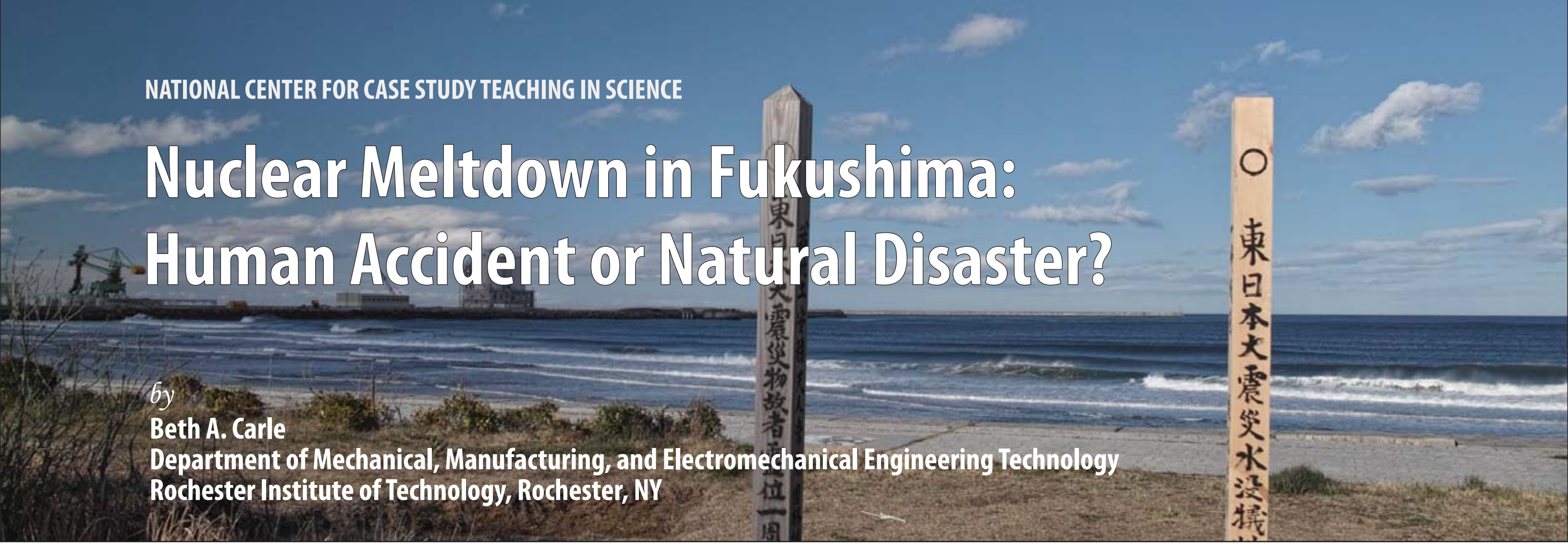

NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Nuclear Meltdown in Fukushima: Human Accident or Natural Disaster?

by
Beth A. Carle
Department of Mechanical, Manufacturing, and Electromechanical Engineering Technology
Rochester Institute of Technology, Rochester, NY

Part I – Nuclear Power Generation and Safety

Answer the following questions before reading any further.

Questions

1. What percentage of the world's energy is currently met by the different types of power generation supply?
2. On average, how many people are killed by the different types of electricity production per year?
3. What is the environmental damage caused by the different types of electricity production?

Background

World-wide electricity demand grew at an average annual rate of 3.4% from 1973 to 2010 and is projected to grow from 21,511 TWh (Tera-watt-hours) to 36,600 TWh from 2010 to 2035. Growth is expected to be even higher in Asia, averaging 4.7% per year to 2035.[1]

Nuclear power accounts for approximately 20% of U.S. electricity generation. Other sources of electricity generation in the U.S. in 2012 are fossil fuels, such as coal (37%) and natural gas (30%), hydroelectric (7%), wind (3%) and solar (<1%).[2] World-wide, nuclear generates 13% of all electricity; coal generates 40%, oil 5%, natural gas 22%, hydro 16%, and other 4%.[3] For contrast, France generates 75% of its electricity from nuclear and much of Europe and the former Soviet Union generate 40–50% from nuclear. Japan, prior to the Fukushima accident in 2011, received approximately 30% of its electricity from nuclear power. Japan is mineral and energy poor and relies on imports for 84% of its total energy requirements.[4]

In addition to being a carbon-free generation technology, nuclear power has fewer fatalities compared to other energy sources (Figure 1). Coal deaths are primarily related to mining and to handling the large volume of coal required for electricity generation. Hydroelectricity has had few accidents, but they have killed large numbers of people, up to 230,000.[5] Additionally thousands die due to air pollution from burning of coal and oil.

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1 World Nuclear Association, "World Energy Needs and Nuclear Power," http://www.world-nuclear.org/info/Current-and-Future-Generation/World-Energy-Needs-and-Nuclear-Power, accessed 31 May 2013.
2 U.S. Energy Information Association, "Electricity in the United States," http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states, accessed 31 May 2013.
3 World Nuclear Association, "World Energy Needs and Nuclear Power," http://www.world-nuclear.org/info/Current-and-Future-Generation/World-Energy-Needs-and-Nuclear-Power, accessed 31 May 2013.
4 World Nuclear Association, "Nuclear Power in Japan," http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan, accessed 10 June 2014.
5 World Nuclear Association, "Safety of Nuclear Power Reactors," http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Safety-of-Nuclear-Power-Reactors, accessed 31 May 2013.

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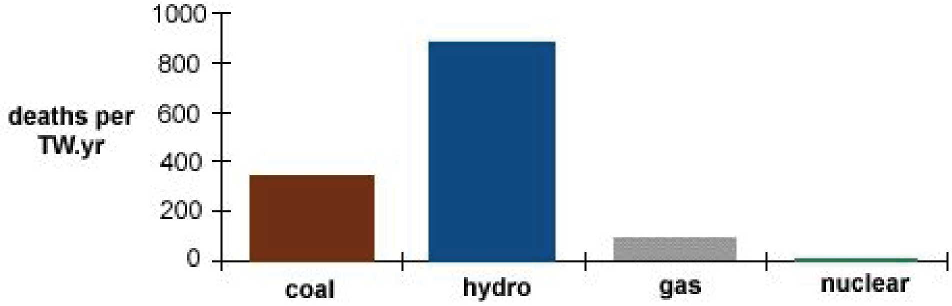

Figure 1. Deaths from energy-related accidents per unit of electricity. *Source:* Paul Scherrer Institut, 1998, considering 1943 accidents with more than five fatalities. One TW.yr is the amount of electricity used by the world in about five months.

The only nuclear power deaths came from the Chernobyl accident in 1986. Thirty-one people died initially, an additional 19 severely exposed workers and firemen died between 1987 and 2004, though not all from radiation-related causes. According to the UN Chernobyl Forum's Health Expert Group, "With the exception of thyroid cancer, direct radiation-epidemiological studies performed in Belarus, Russia and Ukraine since 1986 have not revealed any statistically significant increase in either cancer morbidity or mortality induced by radiation."[6]

There were no radiation-related deaths at Fukushima, compared to almost 20,000 from the tsunami. There were three deaths of workers due to flooding and being trapped in a crane. Of the 25,000 clean-up workers no deaths or acute radiation symptoms have been observed.[7] Future cancer deaths are expected to be undetectable in the general overall cancer rate.

All nuclear and fossil-fuel-burning power plants produce electricity in the same general fashion: water is heated to steam, which turns a turbine; the turbine then rotates a generator, which produces alternating-current electricity that is fed into the electrical power grid.

In a coal or gas plant the water is heated by burning fossil fuels and the combustion products are partially released through the vent stack, which can cause health issues in the area of the power plant and contributes to global warming. A typical 1000 MW coal-fired plant produces "125,000 tons of ash and 193,000 tons of sludge from the smokestack scrubber each year."[8] Combustion products contain various toxins such as heavy metals, dioxins, and radiation from the presence of radioactive elements naturally occurring in the coal. These combustion products lead to permanent storage needs. Coal combustion products are not currently regulated as hazardous wastes and are often stored without proper containment. The largest spill in U.S. history was December 2008 when a holding pond failed in Kingston, TN. "More than 5.4 million cubic yards of coal ash spilled from an on-site landfill, covering more than 300 acres of surrounding land and water."[9] Following the spill the EPA proposed in 2010 to regulate coal.[10] Industry groups have fought any additional regulations to date. A portion of these solid combustion products have reuse value as a component of building materials or when recycled with materials such as sand or gravel.

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6 United Nations Scientific Committee on the Effects of Atomic Radiation, "The Chernobyl Accident," http://www.unscear.org/unscear/en/chernobyl.html, accessed 5 June 2013.

7 United Nations, "No Immediate Health Risks from Fukushima Nuclear Accident says UN Expert Science Panel," http://www.unis.unvienna.org/unis/en/pressrels/2013/unisinf475.html, accessed 1 July 2013.

8 Union of Concerned Scientists, "Environmental impacts of coal power: wastes generated," http://www.ucsusa.org/clean_energy/coalvswind/c02d.html,, accessed 29 July 2014.

9 Tennessee Department of Environment and Conservation, "Ash Slide at TVA Kingston Fossil Plant," http://tn.gov/environment/kingston/, accessed 29 July 2014.

10 EPA, "Coal Combustion Residuals—Proposed Rule," http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ccr-rule/, accessed 29 July 2014.

In a nuclear plant the fission, or splitting, of a specific type of uranium atom, U-235, by a neutron releases energy that heats the water. When the uranium atom splits it forms two daughter products and neutrons that keep the reaction going. These daughter products are not stable and then radioactively decay, releasing more thermal energy and various amounts of radiation. It typically takes a number of decays before a stable atom is reached and no more decay heat is generated. This is the primary concern about nuclear waste—it takes a long time—high-level waste remains sufficiently radioactive to require storage for more than 100,000 years.[11]

Presently in the United States all spent fuel is stored on-site in casks. On a yearly basis a typical 1000 MWe nuclear power plant produces 20 m^3 of used fuel, weighing 22 tons. If this fuel is stored as-is the storage volume is 75 m^3 per year per plant. If the fuel is reprocessed, as is done in many other countries, the waste is reduced to 3 m^3 per plant per year and additional energy is extracted from the fuel.[12] Basically no radiation is released to the environment during normal reactor operation and no greenhouse gasses are produced.

Mining of uranium has similar issues to coal, but is on a much smaller scale due to the volume of uranium needed being significantly lower than the volumetric requirements of coal.

Two accidents, Chernobyl and Fukushima, have led to destruction of large areas. Chernobyl originally contaminated 150,000 square kilometers;[13] much of this land will remain uninhabitable for many years. And very low doses of radioactive fallout were distributed over much of the northern hemisphere. Fukushima will be discussed later in this case study.

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11 Nuclear Regulatory Commission, "High-Level Waste," http://www.nrc.gov/waste/high-level-waste.html, accessed 11 September 2014.

12 World Nuclear Association, "Radioactive Waste Management," November 2013, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/, accessed 29 July 2014.

13 International Atomic Energy Agency, "Frequently Asked Chernobyl Questions," http://www.iaea.org/newscenter/features/chernobyl-15/cherno-faq.shtml, accessed 29 July 2014.

Part II – Fukushima Accident Timeline

At 2:46 pm local time March 11, 2011 the Great East Japan Earthquake, with a magnitude of 9.0 on the Richter scale, struck in the Pacific Ocean about 80 km east of the city of Sendai. (Note that the Richter scale used to measure the strength of an earthquake is logarithmic; in other words, a 9.0 has ten times more motion than an 8.0 earthquake. In terms of energy release, a 9.0 releases about 30 times as much energy as an 8.0 earthquake.[1]) At this time 11 reactors at four nuclear power plants in Japan all shutdown automatically, including Units 1, 2, and 3 at TEPCO's Fukushima Daiichi Power Plant. Units 4, 5, and 6 at this plant were not in operation at the time. It is important to note that even though the reactors shut down and produced no new nuclear reactions, the radioactive products of prior fission events still produce very significant heat. This heat requires continuous cooling to prevent damage to the fuel and reactor structures.

While some reports state that there was no significant damage to the reactors from the earthquake, there is a reasonable possibility of a "loss of coolant accident"(LOCA) at Fukushima Daiichi Unit 1 based on a radiation alarm going off before the tsunami hit.[2] At Fukushima Daiichi all six external power supplies were damaged and the diesel generators started up as planned.

Approximately an hour later a 15-meter tsunami flooded the entire plant; the plant was under approximately five meters of water until it subsided. Significant physical damage to the plant occurred from the tsunami. Twelve of 13 backup diesel generators were disabled (one continued to operate for Unit 6). Heat exchangers for discharging waste heat and decay heat to sea water were disabled. Electrical switchgear was disabled. Seawater pumps and their motors, which provide the "ultimate heat sink" for heat from the reactor cores and generators, were completely destroyed. As a result, there was no ability to properly cool the reactors and to circulate water.

Units 1 through 3 lost core-cooling functioning over the next three days. This led to boiling of the water in the reactors, uncovering the fuel, and melting of the fuel cladding. The generation of the steam from boiling the water increased pressure and caused cracks, allowing radiation to escape. Radiation was also "vented" from the reactors in an attempt to bring the pressure down. The melting of the fuel cladding also generated highly flammable hydrogen gas. Because of the steam and hydrogen there were explosions at Units 1, 3, and 4. Note that Unit 4 is connected to Unit 3 by shared piping.

The explosion at Unit 4 led to a temperature rise at Unit 4's used-fuel storage pool; water was sprayed to bring the temperature down to the standard 55 C. The spent fuel pools store the fuel under water for at least a couple of years for the shorter term radioactive products to decay and hence release their energy. As time progresses there is less and less heat generated by the spent fuel and eventually it can be moved to dry, long-term storage caskets.

Seawater was used to douse the reactors, including by helicopter drops. This dropped the temperature to safe levels and further venting was no longer necessary. On 16 December 2011 all reactors reached cold shutdown, which means that the reactor temperature is below 100 C and no steam is generated.

The cores of Units 1, 2, and 3 of the reactors melted. Units 1, 2, and 3's containment structures were damaged.

As water is pumped into the reactors, water must also leave the reactors; it is contaminated. The highly radioactive water is being stored in tanks on site. However groundwater is leaking into the reactor basements and further exacerbating the amount of water needing to be stored.

Questions

1. What was the central problem in the accident?
2. Differentiate between the damage due to the earthquake and the damage due to the tsunami.

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1 U.S. Geological Survey, "Earthquake Facts and Statistics," http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php, accessed 29 July 2014.

2 Sydney Morning Herald, "Earthquake may have damaged reactor before tsunami," May 20, 2011, http://www.smh.com.au/environment/earthquake-may-have-damaged-reactor-before-tsunami-20110519-1ev1m.html, accessed 1 July 2013.

Part III – Effects on People and Food

The earthquake and resulting tsunami have had major effects on the local area: approximately 20,000 people were killed by the earthquake and tsunami and over 500,000 people were immediately homeless (many still are); over a million buildings were destroyed or damaged by the tsunami. The Japanese government estimates that it will take at least a decade for the hardest-hit areas to fully recover; some may never fully recover.[1]

The biggest fear with any nuclear incident is radiation, which is very poorly understood by most people.

Evacuation was originally ordered for residents within a 2 km radius of the plant. As the situation deteriorated the evacuation zone increased to 10 km and then 20 km, with recommendations to shelter-in-place. The 20-km zone housed over 2000 hospital and nursing home patients who were evacuated to a screening site 26 km from the plant. Many had to wait more than 24 hours to reach admitting facilities. Over 50 people died from the transport. No significant contamination was found on any of the patients, even though they had been in the contaminated area for up to 48 hours.[2]

Fukushima prefecture radiation dose levels were too low to have any effect on fetal development. Therefore there are no expected increases in miscarriage or birth defects.[3]

The estimated effective radiation dose in the two locations evacuated several months into the accident ranged from 12-25 mSv; the rest of the Fukushima prefecture had exposures less than 10 mSv in the first year. UNSCEAR examined medical data from over 20,000 workers at the plant. Less than 165 people received more than 100 mSv and therefore face a slight increase in risk of developing cancer. Only 8 people exceeded the 250 mSv limit for front-line emergency workers; the two with the highest exposure had not taken potassium iodide tablets to prevent absorption of iodine-131.[4]

Using conservative methods intentionally chosen to avoid underestimation of risk there is a 7% increase over baseline in leukemia expected for males exposed as infants and a 6% increase over baseline for breast cancer for females exposed as infants. The highest increased risk is for thyroid cancer with an increased risk of 70% over baseline for females exposed as children. These are increases over baseline. For example, normal risk for a female without the exposure from Fukushima to develop thyroid cancer is 0.75%. A 70% increase to 0.75% only increases the risk to 1.25%.[5] Given that any person's risk of developing cancer in their lifetime is over 30%, a potential absolute increase of 0.5% is statistically undetectable. Even the workers receiving a dose greater than 100 mSv are unlikely to develop cancer at a rate that could be separated from the background cancer rate.

Electricity rationing is still an ongoing problem due to many reactors in Japan remaining closed pending safety inspections, possible upgrades, and more in-depth safety planning. This rationing leads to less heating, air-conditioning, lighting and even reduced mass transit. For those already on the edge due to health issues this can be devastating.[6] The loss of nuclear power has led to increased use of fossil fuel use which will also increase health risks due to known health effects of increased air pollution.

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1 The Seattle Times, "Recovery isn't in sight 3 years after Japan's tsunami," *The Seattle Times*, 8 March 2014, http://seattletimes.com/html/local-news/2023084236_japanrecoveryxml.html, accessed 24 June 2014.

2 Koichi Tanigawa, et al. "Loss of life after evacuation: lessons learned from the Fukushima accident," *The Lancet*, Volume 379, Issue 9819, Pages 889–891, 10 March 2012. http://www.thelancet.com/journals/lancet/article/PIIS0140-6736%2812%2960384-5/fulltext, accessed 17 June 2013.

3 World Health Organization, "Health Risk Assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami based on preliminary dose estimation," 2013.

4 Brumfiel, G. "Fukushima's doses tallied," *Nature*, 23 May 2012 http://www.nature.com/news/fukushima-s-doses-tallied-1.10686, accessed 20 November 2014.

5 World Health Organization, "Health Risk Assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami based on preliminary dose estimation," 2013.

6 Harmon, Katherine, "Japan's Post-Fukushima Earthquake Health Woes Go Beyond Radiation Effects," *Scientific American*. March 2, 2012 http://www.scientificamerican.com/article.cfm?id=japans-post-fukushima-earthquake-health-woes-beyond-radiation&page=2, accessed 17 June 2013.

Due to concerns about radiation, foods from the Fukushima prefecture were immediately pulled from distribution. Adding food shortages and food fears greatly increased the stresses on residents. In retrospect, two years later it is likely that the food radiation contamination was overblown. Radiation would be readily detectable. Contamination by iodine is short-lived due to its eight day half-life and contamination by cesium, while more problematic due to a longer half-life, is harder to get into the food supply.[7]

One of the real challenges is figuring out what levels of radiation really exist and what is safe. Radiation was spread unevenly so testing had to be carried out almost on a farm-by-farm basis and different food groups were differently affected. The government has tested rice from 4975 farms and while ~20% showed cesium contamination, only 300 (~6%) have levels that would exceed the new tougher standards adopted in April 2012. Add to that the lack of understanding of the risks of low-level contamination and there is wide-spread confusion and distrust.[8]

The common unit of contamination in food is Becquerel per kilogram. Of the radioisotopes that can contaminate food cesium is of great concern due to its relatively long decay time. Table 2 shows how the standards for acceptable levels of cesium contamination vary throughout the world. Japan's limits before Fukushima were already the most restrictive in the world. In response to the fear of the public, in April 2012 Japan further reduced its acceptable limits. Some cities went ever further in what they considered safe. Table 3 shows the percentage of food tested in the 10 prefectures that had the highest percentage of foods sampled above the stated limits. It is important to note that the 2012 data were before the acceptable limits were reduced. These tables highlight the challenges on the Japanese government to show that the food is safe. While a larger percentage of foods were found to be somewhat radioactive, only a very few were actually high enough to have any statistical likelihood of causing harm when compared to the most restrictive standards in the world.

Table 2: Japanese and overseas limits on radioactive cesium in food. Unit: Bq/kg [9]

	Drinking Water	*Milk*	*General foodstuffs*	*Food items for babies*
Japan (New limits from April 1, 2012)	10	50	100 (Including dairy products)	50
Japan (Provisional limits from March, 2011)	200	200 (Including dairy products)	500	200
United States	1,200	1,200	1,200	1,200
European Union	1,000	1,000	1,250	400

Table 3 Percentage of food tested in Japan that exceeded Japanese government limits on radiation during the first year[10] after Fukushima and 2014[11]

	2012	*2014*
Fukushima	3.33%	0.62%
Miyagi	0.43%	0.23%
Tochigi	0.61%	0.16%
Gumma	0.21%	0.11%
Chiba	0.91%	0.08%
Iwate	0.35%	0.04%
Ibaraki	0.64%	0.04%
Saitama	3.64%	0.00%
Kangawa	1.98%	0.00%
Tokyo	1.42%	0.00%

7 Ibid.

8 Fackler, Martin, "Japanese Struggle to Protect Their Food Supply," *The New York Times*, 22 January 2012, http://www.nytimes.com/2012/01/22/world/asia/wary-japanese-take-food-safety-into-their-own-hands.html?pagewanted=all&_r=0 Accessed. 17 June 2013.

9 Frid, Martin J., "Food Safety in Japan: One Year after the Nuclear Disaster," *The Asia-Pacific Journal*, Vol 10, Issue 12, No 1, March 19, 2012. http://www.japanfocus.org/-Martin_J_-Frid/3722, accessed 17 June 2013.

10 Ministry of Health, Labour and Welfare, "Sum up of test result of food sampled until 31 March 2012," 1 April 2013, http://www.mhlw.go.jp/english/topics/2011eq/dl/01Apr2013_Sum_up_until_31Mar2012.pdf, accessed 30 July 2014.

11 Ministry of Health, Labour and Welfare, "Sum up of radionuclide test results reported in FY2014," 29 June 2014, http://www.mhlw.go.jp/english/topics/2011eq/dl/Sum_up_of_radionuclide_test_results_FY2014.pdf, accessed 30 July 2014.

It is important to note that all food and water everywhere contains a certain amount of radioactivity. Bananas, Brazil nuts, carrots, white potatoes, red meat, lima beans, and sodium-free salt have the highest amounts. Even beer contains measureable amounts of radiation. Most of this radiation is from potassium. It is interesting to note that the decay energy from the potassium found in the above foods is actually slightly higher than the energy coming from the cesium released at Fukushima (1.31 MeV/decay potassium-40 vs. 1.17 MeV/decay for cesium-137); both release a beta particle as well. All ground water also contains naturally occurring radiation from radioactive elements in the soil (Uranium and its decay products, particularly Radon).

Complicating all the radiation discussion is the potential effect, or lack thereof, of very low doses of radiation. While the Linear Non-Threshold (LNT) model assumes that all radiation, even in very low doses is dangerous, others contend that we live with radiation all the time from cosmic sources, background radon, medical X-rays and the like with no effect. Since the beneficial versus harmful effects of very low doses are hard to sort out it is likely that the response, good or bad, is very weak and the statistics don't warrant spreading fear.

Disruption of normal life also causes significant stress and health effects. As of September 2014, more people have died in certain exposed prefectures from stress-related illnesses than injuries directly linked to the earthquake and tsunami;[12] this number is expected to continue to increase. Many families were torn apart and the usual structure of multiple generations living together has been shattered. The population in the Fukushima prefecture is quite elderly and the disruption of the prior health system has caused significant problems and deaths, in spite of volunteer teams from other locations helping to meet the displaced people's medical needs. Housing and other services have been provided for these elderly adults. However, as was noted after the 1995 Kobe earthquake, "the government can't buy you a new family."[13]

Questions

1. Comparing scientific knowledge of radiation hazards with the response, has the toll on the residents been justified?
2. Based on knowledge of the linear non-threshold (LNT) model for assessing the risk associated with low levels of radiation, are the actions by the Japanese in 2012 to further reduce the acceptable levels of radiation in food justifiable?

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12 Smith, Alexander, "Fukushima evacuation has killed more than earthquake and tsunami, survey says," *NBC News*, 10 September, 2013. http://www.nbcnews.com/news/other/fukushima-evacuation-has-killed-more-earthquake-tsunami-survey-says-f8C11120007, accessed 24 June 2014.

13 Ibid.

Part IV – Cleanup

Cleanup involves two key components: the nuclear power plant and the surrounding areas so people can move home and return to farming and fishing.

Cleanup of the Damaged Fukushima Power Plant

An ongoing serious problem is the storage and eventual treatment of all the contaminated water. As of September 2013, 300 tons of contaminated water has leaked to the Pacific Ocean due to leaks at the water holding facilities at Fukushima Daiichi.

Water comes from 300 tons of water a day being used to cool the reactors and 400 tons of groundwater flowing into basements and mixing with the contaminated water. It is likely that most of the 330,000+ tons of contaminated water will eventually be released to the Pacific Ocean after being scrubbed to remove radioactivity to below internationally established limits. Cesium has already been removed, but other elements, such as strontium, still need to be removed. Adding to the challenges is the filtering unit being operationally off-line, just months after starting, due to corrosion issues.[1]

This groundwater issue was identified in 2011 but its importance was downplayed by TEPCO and was not pursued by the Trade Ministry. "We were so focused on the fuel rods and melted reactor cores that we underestimated the water problem," said Tatsujiro Suzuki, vice chairman of the Japan Atomic Energy Commission, a government body that helped draw up TEPCO's original cleanup plan. "Someone from outside the industry might have foreseen the water problem."[2] Stopping the groundwater is a priority since it would reduce the amount of contaminated water that needs to be cleaned for release.

Additionally, as of September 2013, radiation levels near at least one water storage tank were 1800 mSv/hr, a fatal level in 4 hours of unprotected exposure. The 1800 mSv/hr reading was 5 cm from the tank, and dropped to 15 mSv/hr by 50 cm from the tank.[3] Previously the level was measured to be 100 mSv/hr. However, that was the limit of the device at the time used so the actual prior level is unknown.[4]

The problems continue. March 28, 2014 a worker was killed while digging a ditch.[5] Working conditions have long been an issue that TEPCO has promised to address.[6]

While TEPCO has long resisted aid from the international community, there are signs that nuclear remediation experts from the Britain, France, and Russia could provide assistance to the cleanup efforts.[7]

Another critical activity is focused on removing the spent fuel from the pool in the damaged reactor buildings and then removing the cores and dismantling the reactors. TEPCO is estimating that this process will take 30–40 years. However, the International Atomic Energy Agency stated that TEPCO will likely not be able to complete decommissioning of the Fukushima Daiichi reactors in TEPCO's projected 30–40 year timeline.[8] Significant

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1 Adelman, Jacob, Takashi Hirokawa and Yuriy Humber, "Japan's Nuclear Watchdog Seas Ocean Dump for Fukushima Water," Bloomberg, September 2, 2013. http://www.bloomberg.com/news/2013-09-01/TEPCO-should-use-welded-tanks-to-stem-toxic-tide-academic-says.html,, accessed 2 September 2013.
2 Fackler, Martin, "Flow of Tainted Water Is Latest Crisis at Japan Nuclear Plant," *The New York Times* 29 April 2013.
3 Adelman, Jacob, Takashi Hirokawa and Yuriy Humber, "Japan's Nuclear Watchdog Seas Ocean Dump for Fukushima Water," *Bloomberg*, September 2, 2013.
4 McCurry, Justin, "Fukushima: Japan promises swift action on nuclear cleanup," *The Guardian*, http://www.theguardian.com/environment/2013/sep/02/fukushima-japan-action-nuclear-cleanup, accessed September 2, 2013.
5 Saito, Mari, "Fukushima worker killed in accident, cleanup halted," March 28, 2014, http://ajw.asahi.com/article/0311disaster/fukushima/AJ201310210100, accessed 11 June 2014.
6 Reuters, "Low pay, high risks and gangster activity mar cleanup efforts at Fukushima site," *Daily News*, October 25, 2013, http://www.nydailynews.com/news/world/fukushima-cleanup-pay-high-risks-gangsters-article-1.1496584, accessed 10 June 2014.
7 Associated Press, "Japan seeks international help on Fukushima leaks," reported on *CBSNews*, October 7, 2013.
8 Yamaguchi, Mari, "Fukushima Cleanup: IAEA Says Japan Nuclear Cleanup May Take More Than 40 Years," *Huffington Post,* June 17, 2013, http://www.huffingtonpost.com/2013/04/22/fukushima-cleanup-japan-nuclear-40-years_n_3130891.html, accessed 17 June 2013.

challenges remain in developing the technology and equipment required to dismantle the melted cores while working in extremely high radiation levels.

Cleanup of the Surrounding Areas

Cleanup of the surrounding areas is progressing, as evidenced by Figure 3 and Figure 4, with a goal of achieving less than 20 mSv/yr. Decontamination crews have been removing the top few centimeters of topsoil and washing buildings. However cleanup efforts have been riddled with problems. There is no place to put the contaminated materials, expected to exceed 29 million cubic meters. The government has assumed control over all cleanup activities, funneling nearly 1 trillion yen ($10B) to big construction companies with little or no experience in radioactive cleanup. Charges abound of mismanaged and even dangerous remediation efforts with contaminants being dumped in rivers and areas away from measurement sites.[9,10] The original plan of having much of the cleanup for 6 of the 11 municipalities in the exclusion zone completed by March of 2014 have now been extended by up to three years.[11]

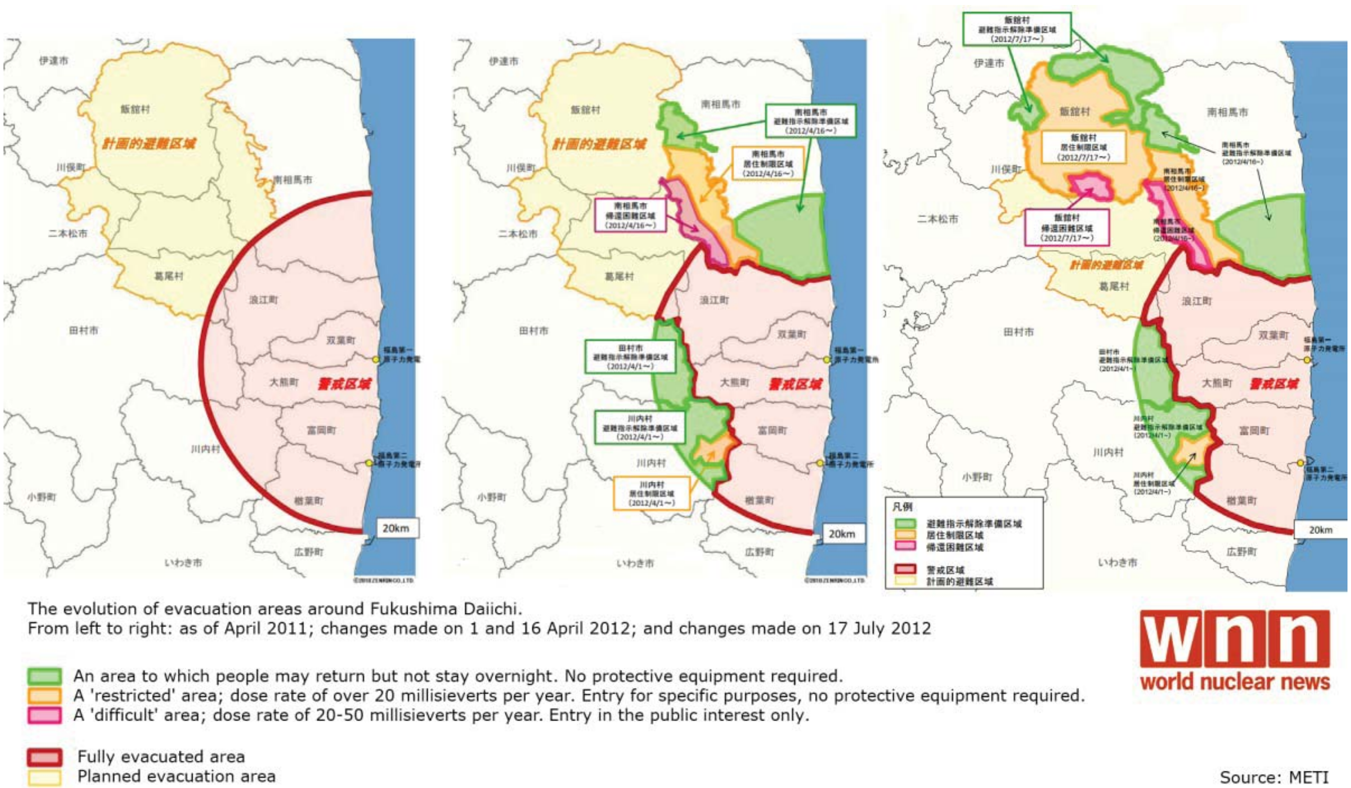

Figure 3. The evolution of evacuation areas: April 2011, April 2012 and July 2012.[12]

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9 The Asahi Shimbun, "Crooked Cleanup (1): Radioactive waste dumped into rivers during decontamination work in Fukushima," 4 January 2013, http://ajw.asahi.com/article/0311disaster/fukushima/AJ201301040058, accessed 1 July 2013.

10 Tabuchi, Hiroko, "In Japan, a Painfully Slow Sweep," *The New York Times*, 7 January 2013, http://www.nytimes.com/2013/01/08/business/japans-cleanup-after-a-nuclear-accident-is-denounced.html?pagewanted=all&_r=0, accessed 1 July 2013.

11 The Asahi Shimbun, "Japan delaying cleanup of towns near nuclear plant," October 21, 2013, http://ajw.asahi.com/article/0311disaster/fukushima/AJ201310210100, accessed 11 June 2014.

12 World Nuclear News, "Iitate evacuation relaxed," http://www.world-nuclear-news.org/RS_Iitate_evacuation_relaxed_1607121.html, accessed 1 July 2013.

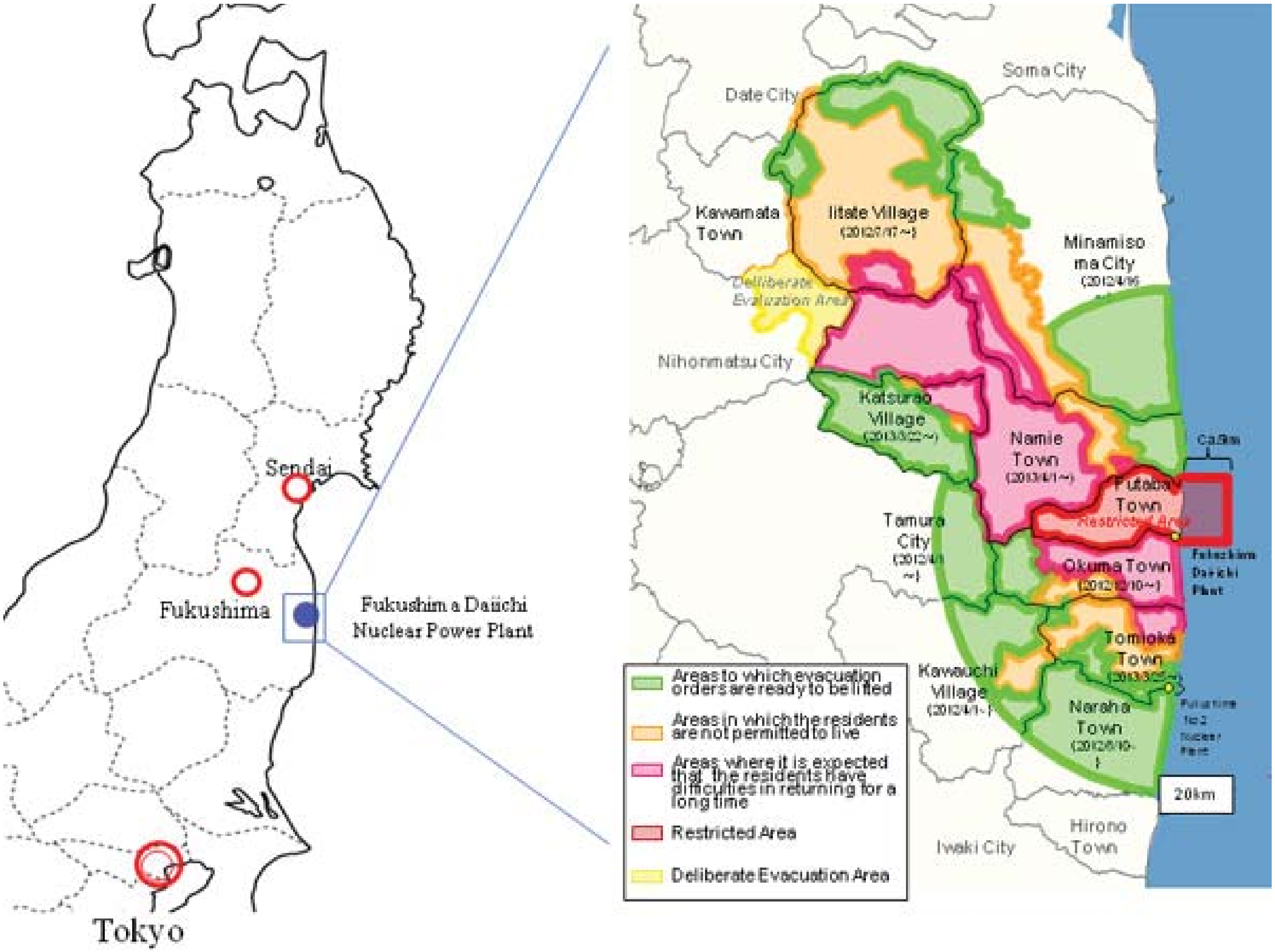

Figure 4. Evacuation zones as of March 2013.[13]

Foreign companies with proven expertise have been shunned, as have local R&D efforts. "Even if a method works overseas, the soil in Japan is different, for example," said Hidehiko Nishiyama, deputy director at the environment ministry, who is in charge of the Fukushima cleanup. "And if we have foreigners roaming around Fukushima, they might scare the old grandmas and granddads there."[14]

Questions

1. How is the groundwater problem indicative of the problems in the cleanup of the Fukushima reactors?
2. For an area to be reopened the radiation level has to be below 20 mSv/yr and the target is to reduce the exposure to 1 mSv/yr above normal background levels of ~3 mSv/yr (not including any medical or diagnostic procedures involving radiation). How does this correspond to the approximate radiation dose you received this past year? (Refer to background information on ionizing radiation and its units as necessary.)

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13 Reconstruction Agency, "Progress to Date: the Status in Fukushima," http://www.reconstruction.go.jp/english/topics/2013/03/the-status-in-fukushima.html, accessed 1 July 2013.

14 Ibid.

Part V – Planning

Planning for potential disasters is crucial in the design and operation of any nuclear power plant. The required planning falls into two categories: designing to prevent an accident, and developing and practicing operating procedures to deal with any possible problem that does arise.

Designing to Prevent an Accident

A governing principle in the design and operation of a nuclear power plant is "defense in depth." This approach involves multiple layers of independent and redundant layers to handle occasional failures of human and mechanical systems. No one layer is counted on for complete protection; all layers contribute providing multiple levels of protection.

All reactors are designed to withstand "worst case" predictions known as "design basis" accidents (DBA). In the United States nuclear power plants are designed against natural phenomena that have occurred, or are thought to have occurred, in the last 10,000 years. Other design basis events considered in the design of nuclear power plants include mechanical and electrical break downs, such as a break in a coolant line or loss of station power.

The Fukushima Daiichi design was focused on seismic events, and did not include tsunamis happening on the 1000+ year time scale. The maximum response acceleration exceeded the design basis ground motion in the east-west horizontal direction for Units 2, 3, and 5 by up to 25%. All other seismic accelerations (N-S, E-W, and vertical) were below design basis. Prior experience at another Japanese nuclear power plant and other probabilistic risk assessment studies indicate that the ground acceleration should not have been significant.[1] However, there is a reasonable probability that Unit 1 suffered a Loss of Cooling Accident (LOCA) resulting from the earthquake. When a Japanese commission looked into whether the earthquake damaged the emergency cooling system leading to a LOCA, TEPCO admitted to denying damage and lying about actual conditions to keep inspectors out. The intent of the deception was to reduce the requirement for tougher quake-resistant standards, which would be required if the cooling system had been damaged.[2]

Japan has a history of tsunamis, yet their assessment of tsunami risks were not to international standards. The 2006 seismic safety guidelines did not include tsunami experts in developing the tsunami related clauses. The Japanese culture also played a role; there is limited discussion of worst-case scenarios. Discussions of earthquakes are commonplace, but tsunamis are much less discussed.[3]

The observed tsunami levels at the Fukushima Daiichi nuclear power plant significantly exceeded design basis. Based on the permit, the design basis was 5.7 m while the actual maximum tsunami level was 14–15 m.[4]

After 9/11 all U.S. power plants increased plants' abilities to "maintain or restore core cooling, containment and spent fuel pool cooling capabilities. At the time of the accident, Japanese utilities had not developed and implemented extensive damages guidelines. (There was) no guidance on tsunamis and design basis flood."[5]

The Japanese also had no planning for station blackout. According to Japanese Guidelines "no particular considerations are necessary against a long-term total AC power loss because the repair of troubled power transmission

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1 American Nuclear Society "Appendix E: Comparison of the Eathquake and Tsunami to the Design Basis in Japan," http://fukushima.ans.org/inc/Fukushima_Appendix_E.pdf, accessed 22 July 2013.
2 RT, "Fukushima survivors to file class action lawsuit against Japanese govt, plant operator," February 2013, http://rt.com/news/fukushima-lawsuit-tepco-government-747/, accessed 20 December 2014.
3 Acton, James M. and Mark Hibbs, "Why Fukushima Was Preventable," Nuclear Policy, March 2012 http://carnegieendowment.org/files/fukushima.pdf, accessed 4 July 2013.
4 RT, "Fukushima survivors to file class action lawsuit against Japanese govt, plant operator," February 2013, http://rt.com/news/fukushima-lawsuit-tepco-government-747/, accessed 20 December 2014.
5 U.S. Nuclear Regulatory Commission, "A comparison of U.S. and Japanese regulatory requirements in effect at the time of the Fukushima accident," November 2013, http://pbadupws.nrc.gov/docs/ML1332/ML13326A991.pdf, accessed 20 December 2014.

line or emergency AC power system can be expected in such a case."[6] Because of this no provisions were made to operate the valves manually. Workers used car batteries to open valves to try to depressurize the reactors.

Containment venting is different in the U.S. and Japan. In the U.S. venting is required before reaching the containment design pressure. The decision to vent is based on hydrogen concentrations and the potential for explosions. The decision is made by the shift manager with outside consultation.

In contrast, Japanese venting contains rupture disks which are designed to not fail, or burst, until maximum operating pressure is reached. At Fukushima venting was not to take place until pressure exceeded twice the maximum operating pressure if fuel damage had occurred. The approval to vent also has to come from a higher authority, site superintendent, than in the U.S. The Japanese goal was to minimize any potential release of radioactivity, but did not consider hydrogen leakage at high pressure nor how low-pressure injection would behave during accident conditions.[7]

"Prior to the Fukushima accident, both Japanese regulators and industry publicly stated that the possibility of severe accidents was sufficiently low, to the extent that a severe accident could not occur from an engineering viewpoint."[8]

In October 2012 TEPCO admitted "When looking back on the accident, the problem was that preparations were not made in advance… ."[9]

Had proper risk assessment been completed various design modifications could have been made:

- Sealing the diesel generators in water-tight bunkers and placing them at higher elevations. The only generator that remained working after the tsunami was above the waterline and provided power to units 5 and 6.
- Sealing connections to seawater pumps.
- Watertight connections from emergency power supplies.
- Building higher seawalls.
- On-site back-up power sources to run instrumentation.

Improvements to the ability to communicate with the operators would also have been helpful. The communication to the emergency control center was a single wired line. The off-site response center was evacuated as it was not designed to handle the high radiation levels it experienced.

Operation of a Nuclear Power Plant

There are many aspects of defense in depth that apply to the routine and non-routine operation of a nuclear power plant:

- A safety culture focusing on safety over production.
- Conservative decision making.
- On-going training, including emergency response.
- Monitoring safety related systems.
- Detecting failures and taking corrective actions.
- Operating procedures and emergency response procedures.

Emergency Operating Procedures (EOPs) outline how operators are to respond to a broad spectrum of issues and accidents. A key goal is to maintain or restore core cooling and other critical safety functions. Many EOPs were in place in Japanese nuclear power plants.

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6 Nuclear Safety Commission of Japan, "NSCRG: L-DS-1.0 Regulatory Guide for Reviewing Safety Design of Light Water Nuclear Power Reactor Facilities," August 1990, http://www.nsr.go.jp/archive/nsc/NSCenglish/guides/lwr/L-DS-I_0.pdf.

7 U.S. Nuclear Regulatory Commission, "A comparison of U.S. and Japanese regulatory requirements in effect at the time of the Fukushima accident," November 2013, http://pbadupws.nrc.gov/docs/ML1332/ML13326A991.pdf, accessed 20 December 2014.

8 U.S. Nuclear Regulatory Commission, "A comparison of U.S. and Japanese regulatory requirements in effect at the time of the Fukushima accident," November 2013, http://pbadupws.nrc.gov/docs/ML1332/ML13326A991.pdf, accessed 20 December 2014.

9 RT, "Fukushima survivors to file class action lawsuit against Japanese govt, plant operator," February 2013, http://rt.com/news/fukushima-lawsuit-tepco-government-747/, accessed 20 December 2014.

Another set of procedures are Severe Accident Management Guidelines (SAMGs). SAMGs were voluntarily developed in response to the 1986 Chernobyl accident. SAMGs are designed for severe, and very unlikely, problems resulting from a combination of problems; for example a design basis accident occurring simultaneous with a different equipment failure.

The criteria for using SAMGs is when part of the fuel rods are uncovered, resulting in temperatures that compromise the fuel cladding and gaseous hydrogen is created. The focus of SAMGs is maintaining containment and minimizing radiation releases outside the plant. SAMGs are very specific to the design of an individual plant. Globally, SAMGs have continued to evolve to include responses to beyond design basis accidents resulting from natural events such as earthquakes, floods, and tornadoes as well as man-made events such as aircraft impacts and other acts of terrorism.[10]

Japanese SAMGs deviated from those in the U.S. starting in the 1990s. Japanese SAMGs assume that all station power is available for instrumentation and lighting. It is also assumed that radiation levels will not be high enough to prevent operators from taking manual actions. Probabilistic safety assessments (PSAs) were not required for external events, such as earthquakes and tsunamis. Level 2 PSA, which deal with accident progression and how to deal with core damage, did not exist.[11]

In dealing with the accident there were serious problems in the preparedness of the plant operators. "Plant staff was not prepared with detailed emergency procedures, and specifically was not prepared for a loss of plant power situation. Staff also was not prepared for loss of cooling water and took some actions initially that made things worse rather than better."[12]

The lack of station power compounded efforts of the operators to assess the situation. They had no ability to use instrumentation to determine the status of anything in the plants. The operators did scavenge car batteries to be able to read some instrumentation. Unfortunately, when the operators did have instrument readings, they were sometimes found later to have been erroneous. This contributed to delays in making efforts to use sea water to cool the reactors.

Unit 1's isolation condenser, a backup cooling system that does not require electricity to run, started automatically after the earthquake. This possibly indicated some sort of failure in the cooling system. However, the isolation condenser was cooling the system too quickly and the operators followed procedures and shut the IC down. Once the tsunami hit all power was lost, including that necessary to read instrumentation and open and shut valves. The IC could have helped maintain cooling as it uses gravity and convection, not electricity, but it was not able to be restarted in time to help with the rapidly deteriorating situation.[13]

The operators had received no training on how to handle the complex situation that was developing at the Fukushima reactors. Japanese operator training is much less than for U.S. workers. U.S. workers spend significant time in simulators designed to match their exact reactor and control room. This is not the case in Japan where the simulators are more generic and training time is much shorter. To have any success with handling such a severe crisis, operators would have needed extensive training on how to respond using only what was on-hand at that time with little communication to the outside world.

There was also no clear command chain. Then-prime minster Kan interfered with TEPCO's attempts at managing the complex situation and issued contradictory orders. Japanese regulations and culture tied the operators' hands by making them wait for high-level approval before taking actions such as venting. It wasn't until a few days after the accident started that the government and TEPCO started working together.

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10 Argonne National Laboratory, "Design Basis and Severe Accidents," April 2011. http://www.ne.anl.gov/pdfs/nuclear/design_basis_and_severe_accidents_sienicki.pdf, accessed 20 December 2014.

11 U.S. Nuclear Regulatory Commission, "A comparison of U.S. and Japanese regulatory requirements in effect at the time of the Fukushima accident," November 2013, http://pbadupws.nrc.gov/docs/ML1332/ML13326A991.pdf, accessed 20 December 2014.

12 Sweet, Bill. "Management Failures Were Critical in Fukushima Nuclear Catastrophe," 9 January 2012, http://spectrum.ieee.org/energywise/energy/policy/management-failures-were-critical-in-fukushima-nuclear-catastrophe.

13 Strickland, E. "24 Hours at Fukushima," IEEE Spectrum, 31 October 2011, http://spectrum.ieee.org/energy/nuclear/24-hours-at-fukushima, accessed 20 December 2014.

Lessons Learned

Following the nuclear accident in Fukushima, the European Commission and the European Nuclear Safety Regulators' Group (ENSREG) agreed on 25 May 2011 on voluntary tests for the EU's 143 nuclear power reactors—"stress tests." These tests were based on a common methodology and assess both natural and man-made hazards (i.e., effects of airplane crashes and terrorist attacks). The assessments were conducted by independent national authorities and through peer review. The tests started on 1 June 2011. All national reports and peer reviews are or will be public as they are finalized at www.ensreg.eu.

One result in the U.S. following analysis of the Fukushima reactors was to order plants to upgrade the ventilation systems at the 31 reactors of similar design to the Fukushima reactors. The order "stops short of requiring filtered vents, as some safety advocates and NRC's staff had urged."[14] The goal was to minimize radioactive particles from leaving the plant during a venting operation. The nuclear industry opposed the order citing cost and that the filtered vents may not remove radiation in all accident scenarios.

Another major improvement was to provide for extended station blackouts. Recommendations included on-site battery backup for at least eight hours and methods of keeping the reactors and spent fuel pools cool for at least three days, allowing time to get external power if necessary. Safety plans also needed to be updated to deal with extended station blackouts and multiple-reactor emergencies.

As is typical in the nuclear industry, information was shared between plants, regulatory bodies, and made public in almost all countries. Unlike most businesses who view others as competition, the nuclear industry realizes that for nuclear power to succeed globally everyone must work together and share information to improve all reactors world-wide.

Questions

1. Would safety plans including events like the Great East Japan Earthquake and resulting tsunami have been sufficient to prevent this disaster?

14 CBSNews, "U.S.: Nuke plants with Fukushima-like vents must upgrade," March 20, 2013, http://www.cbsnews.com/news/us-nuke-plants-with-fukushima-like-vents-must-upgrade/. Accessed10 June 2014.

Part VI – Response of Japan's Government and TEPCO

The communication from TEPCO and the Japanese government to the populace during the evolving crisis revealed serious problems.

TEPCO failed to communicate properly with the government and the people. Japan's prime minister learned from the television that Unit 1 had exploded; TEPCO did not inform the prime minister. TEPCO's communication with the populace "provided vague and delayed information and preferr[ed] to apologize for 'causing inconvenience' instead of keeping the people truly appraised of developments."[1] The government's response was equally vague and sometimes contradictory.

The Emergency Response Support System (ERSS) is supposed to monitor reactor status following a nuclear accident and predict the progress of the accident. However data transmission errors started occurring right after the accident. The System for Prediction of Environmental Emergency Dose Information (SPEEDI) is used to predict radiation dose and concentration of radioactive nuclides in the atmosphere. However the necessary information from ERSS was unavailable.[2] Because of this lack of communication evacuees were moved from areas of lower radioactivity to areas of higher radioactivity. Evacuation orders were also changed frequently without clear explanations. Many people were moved more than once.

Local media captured video of the reactors exploding, but there was no communication from TEPCO or the Japanese government about what had happened. Only by reporters reaching out internationally was it revealed to the public that the explosions were likely hydrogen explosions resulting from meltdown of the cores. "But when we reported this, we had so much criticism from the Japanese side for using the word 'meltdown,' " [Fackler] said. "There was this amazing denial."[3] The lack of communication also led to both inaccurate reporting of the actual versus perceived hazard of radiation and, in many cases, simply parroting the official line, which downplayed the risks.

Government officials denied that meltdowns were taking place, even though telltale radioactive elements such as tellurium-132 were found within a day of the tsunami. They did not reveal the presence of tellurium-132 for three months after the accident started.[4]

One concern was how slowly TEPCO started cooling the reactors and spent fuel pools with seawater. Seawater is corrosive and would destroy the large investment TEPCO had made on the reactors. Kuni Yogo, a former atomic energy policy planner in Japan's Science and Technology Agency, said he believed that the executives at TEPCO did not recognize the risks soon enough. "They failed to cool the reactors on the day of the earthquake, March 11, and even after a hydrogen explosion the following day, they waited more than four hours to start dousing the reactors with seawater. They did not even try to put water into the spent fuel pools for several days."[5]

"Transmission and public announcement of information on urgent matters was delayed, press releases were withheld and explanations were kept ambiguous… Whatever the reasons, such tendency was hardly appropriate, in view of communication in an emergency."[6]

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1 Kaufmann, D and V. Penciakova, "Japan's triple disaster: governance and the earthquake, tsunami and nuclear crises," Brookings, 16 March 2011, http://www.brookings.edu/research/opinions/2011/03/16-japan-disaster-kaufmann, accessed 21 December 2014.

2 Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, "The Accident at TEPCO's Fukushima Nuclear Power Station," http://www.kantei.go.jp/foreign/kan/topics/201106/pdf/chapter_v.pdf, accessed 18 August 2013.

3 Pacchioli, D., "Communication in the Fukushima Crisis," *Oceanus Magazine*, 9 May 2013, http://www.whoi.edu/oceanus/viewArticle.do?id=168269, accessed 27 December 2014.

4 Onishi, Norimitsu, "Japan Held Nuclear Data, Leaving Evacuees in Peril," *The New York Times,* August 8, 2011.

5 Belson, Ken, Keith Bradsher and Matthew l. Wald, "Executives May Have Lost Valuable Time at Damaged Nuclear Plant," *The New York Times,* March 19, 2011.

6 Smith, M. and Y Wakatsuki, "Japan's nuclear response filled with errors, report says," *CNN,* 26 December 2011, http://www.cnn.com/2011/12/26/world/asia/japan-nuclear/, accessed 28 December 2014.

The continued lack of clear communication has significantly eroded public trust in TEPCO and the government. “The conclusion I come away with is that scientists and the government, faced with communicating this disaster, were very concerned with protecting the public. They didn’t want to cause a panic, they didn’t want to spread fear—but in trying to avoid doing so, they withheld information, and this spread more fear than anything else they probably could have done.[7]

Questions

1. How do you think the media helped or hurt the response to the Fukushima disaster?
2. How could technically accurate information have been provided to help people understand the effects of their radiation exposure both during the initial crisis and now as long-term cleanup is underway?

7 Pacchioli, D., “Communication in the Fukushima Crisis,” *Oceanus Magazine*, 9 May 2013, http://www.whoi.edu/oceanus/viewArticle.do?id=168269, accessed 27 December 2014.

Part VII – Was Fukushima Preventable?

According to the Fukushima Nuclear Accident Independent Investigation Commission, "The TEPCO (Tokyo Electric Power Company) Fukushima Nuclear Power Plant accident was the result of collusion between the government, the regulators and TEPCO, and the lack of governance by said parties. They effectively betrayed the nation's right to be safe from nuclear accidents. Therefore, we conclude that the accident was clearly manmade."[1]

Even before the Fukushima incident there were concerns about the lack of independence in the regulatory structure of Japan's nuclear reactors. The Nuclear and Industrial Safety Agency (NISA), which is the Japanese agency to oversee Japan's nuclear reactors, is part of the Ministry of Economy, Trade and Industry's Agency for Natural Resources and Energy (METI). One of METI's roles is to promote nuclear energy, creating a conflict of interest. There was also frequent movement of key personnel between NISA and the nuclear power companies.

In an attempt to restore public confidence in Japan's nuclear regulatory system the new Nuclear Regulatory Authority (NRA) was formed under the Ministry of Environment in September 2012. The NRA is supposed to be independent of the nuclear industry.[2] A new Nuclear Safety Investigation Committee (NSIC) has also been formed to investigate any nuclear accidents and determine the effectiveness of the NRA.

According to the Carnegie Report by Acton and Hibbs, "The methods used by TEPCO and NISA (Nuclear and Industrial Safety Agency, Japan's regulatory body) to assess the risk from tsunamis lagged behind international standards."[3] There was evidence of very large tsunamis inundating Japan on the order of every thousand years. Simulations conducted in 2008 showed that the plant was not sufficiently protected. Ironically, the results were communicated to TEPCO only 4 days before the Great East Japan Earthquake and resultant tsunami occurred. TEPCO in 2006 knew that station blackout and loss of ultimate heat sink could occur if a tsunami greater than 5.7m occurred. "However, NISA gave no instruction to the company to prepare for severe flooding, and even told all nuclear operators that it was not necessary to plan for station blackout."[4]

American and European reactors have significantly upgraded their reactors to deal with extreme external events in the last couple of decades. Rooms housing diesel generators have been made watertight; key connections have been made watertight. Pumps to transfer heat from the reactors and diesel generators to the ultimate heat sink have been improved and back-up systems installed. TEPCO was aware of the safety improvements being made elsewhere throughout the world and chose not to apply them to their reactors.

Many potential reasons for TEPCO and NISA's failure to follow international best practices have been identified:

- Lack of independence of regulators from the nuclear industry.
- Primarily focusing on earthquake risks, often ignoring other known or predictable hazards.
- Mistaken belief that a severe accident was simply impossible.
- Nuclear professionals isolating themselves from external advice.

"In the final analysis, the Fukushima accident does not reveal a previously unknown fatal flaw associated with nuclear power. Rather, it underscores the importance of periodically reevaluating plant safety in light of dynamic external threats and of evolving best practices, as well as the need for an effective regulator to oversee this process."[5]

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1 National Diet of Japan, "The Fukushima Nuclear Accident Independent Investigation Commission," 2013, http://www.nirs.org/fukushima/naiic_report.pdf, accessed 14 June 2013.

2 The Guardian, "Japan to fire top nuclear officials over Fukushima crisis," August 4, 2011, http://www.theguardian.com/world/2011/aug/04/japan-fire-nuclear-officials-fukushima, accessed 2 September 2013.

3 Acton, James M. and Mark Hibbs, "Why Fukushima Was Preventable," Nuclear Policy, March 2012, http://carnegieendowment.org/files/fukushima.pdf, accessed 4 July 2013.

4 World Nuclear News, "Fukushima a disaster 'Made in Japan,'" 5 July 2012, http://www.world-nuclear-news.org/RS_Fukushima_a_disaster_Made_in_Japan_0506121.html, accessed 2 September 2013.

5 Acton, James M. and Mark Hibbs, "Why Fukushima Was Preventable."

Questions

1. Was the Fukushima disaster primarily a natural disaster exacerbated by human actions, or was it primarily a human accident precipitated by a natural disaster?
2. Do some of the same issues of ties between industry and government regulatory concerns exist in the U.S. in both nuclear and non-nuclear industries? If these issues exist in the U.S., what are their implications for safety in other industries?

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