Section

I Natural Events

Case

1 The Great East Japan Earthquake of March 11, 2011

An example of the cascading crisis: earthquake, tsunami, with secondary nuclear reactor damage

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BACKGROUND

All disasters have multiple causes; there is never a disaster that has only one cause. On Friday, March 11, 2011, an earthquake that measured between 8.9 and 9.0 on the Richter scale rocked Japan. The epicenter of the earthquake was approximately 43 miles (69 kilometers) east of the Oshika Peninsula of Tohoku. It triggered a 32-foot (10-meter) tsunami that wiped out whole communities and caused explosions at two Japanese nuclear power facilities. The tsunami and subsequent radiation release devastated Japan, killing almost 16,000 people. This earthquake has been named the Tohoku earthquake, or the Great East Japan Earthquake.

Japan's social, technical, administrative, political, legal, healthcare, and economic systems were tested to their limits by the nature, degree, and extent of the socioeconomic impacts of the earthquake and tsunami, as well as by the possibility of a "nightmare nuclear disaster."[1]

THE SCIENCE OF EARTHQUAKES

The earth's outermost layer consists of the crust and upper mantle, known as the lithosphere. The lithosphere is divided into large rigid blocks, or plates, that are floating on semifluid rock. Japan lies approximately 250 miles from where these tectonic plates are colliding at their convergent borders, with one plate being dragged (subducted) beneath the other.[2] Japan, part of the volcanic belt known as the Pacific Ring of Fire, is particularly susceptible to subduction-zone earthquakes. This belt surrounds most of the Pacific Ocean and includes the western part of North and South America. The oceanic crust underlying the Pacific Ocean is spreading, and old crust is being subducted back into the earth's interior along the Ring of Fire. Because the oceanic crust rubs against the continental crust, most of the world's earthquakes happen in this setting.

On the day of the Tohoku earthquake, at 2:46 PM local time, at a point approximately 20 miles (32 kilometers) below sea level and 80 miles (129 kilometers) east of Sendai Japan, there was a slip in part of the subduction zone. The Philippine plate was subducted below the North American plate at an angle of about 15 degrees. This resulted in an earthquake, categorized as "great" on the Richter magnitude scale,[3] that ruptured a fault several hundred miles long, roughly parallel to the east coast of Japan.

THE SCIENCE OF TSUNAMIS

The word *tsunami* comes from the Japanese language and means "giant wave." It is a series of water waves caused by the displacement of a large volume of a body of water, which can be triggered by earthquakes, volcanic eruptions, and the like. The tsunami wavelength is much longer than normal sea waves, with a series of waves that can reach heights of 40 to 50 feet (12 to 15 meters) and be hundreds of miles long in large events.

Not all earthquakes generate a tsunami. To cause a tsunami, the precipitating event must result from an ocean-based earthquake and must also change the level of (raise or lower) the sea floor. If the level of the sea floor does not change, the earthquake will not generate a surface wave. If the level of the sea floor goes up or down, the earthquake generates a large water bulge, or water dimple, over the area where the sea floor has moved. When an earthquake generates a water bulge, the water moves outward in all directions—just like throwing a rock into a pond and watching it ripple. If this wave encounters shallow water, it will slow down and increase in amplitude, just as normal waves do at the shoreline. In other words, the wave will grow. The more shallow the water becomes, the higher the wave will be because all of the wave energy now builds wave height. With heights totaling 10 feet (3 meters) or more, a tsunami wave can overwhelm all low-lying structures when it strikes the coastline.

Following an earthquake, some buildings are already weakened or collapsed. Other buildings may be poorly constructed and are swept away when the waves hit. All of the debris—cars, pieces of buildings, shipping containers, boats, and the like—are carried along with the rushing water, smashing into anything in their path.[4]

How powerful was the tsunami that followed the earthquake in Japan? The tsunami following the Tohoku earthquake was 30 to 132 feet (10 to 40 meters) high. This wave was large and powerful enough to devastate miles of Japan's coast and inland.

THE SCIENCE OF NUCLEAR POWER

The facility producing nuclear power is similar to a coal-fired power plant, except that the heat source is a nuclear fission reaction instead of coal. In both types of plants, you need to make steam. Steam passes

through a turbine and the turbine spins a generator, which makes electricity. Nuclear power plants are near bodies of water because they need a method of cooling, and the ocean is a very convenient source of large amounts of cool water.

How Nuclear Radiation Harms People

The type of nuclear radiation typically released from a damaged nuclear power reactor involves gamma radiation. Gamma rays have enough energy to break bonds between the nucleotides within human DNA when they strike them. During normal day-to-day living, our body can repair itself with enzymes that reattach the nucleotides that break loose. However, larger-scale damage overwhelms the repair mechanism, resulting in nucleotides being left out or added, or sections of DNA may be inappropriately joined. This may lead to altered protein synthesis and to the later development of various types of cancer.[5]

Types of Radioactivity Released from Damaged Reactors and Harm Caused

One common form of radioactivity released from damaged reactors is radioactive iodine. The human body then concentrates this radioactive iodine in the thyroid gland as it builds thyroid hormones. This concentration of radioactivity leads to more damage to the thyroid than to other areas of the body. Half of the radioactivity decays in 8 days, so the buildup does not last a long time. However, if a lot of radioactive iodine is released and blown over crops, humans or animals eating those crops will take in the iodine. Administering potassium iodide tablets helps block radioactive uptake.

Following the reactor damage at Chernobyl in 1986, the incidence of thyroid cancer rose up to 10 times in exposed children, the most susceptible group. The World Health Organization has estimated that up to 50,000 cases of thyroid cancer will be directly attributable to the Chernobyl radiation leak.[6] While it was believed that the damaged reactors in Japan would not release the amount of iodine that was released at Chernobyl, people living within several miles of the reactor site were evacuated as a precaution.

JAPAN'S NUCLEAR CONCERNS IMMEDIATELY FOLLOWING THE EARTHQUAKE

The Japanese nuclear power plants have backup generators to run the cooling water pumps when the electricity grid goes down. Those generators worked perfectly after the earthquake, but failed after the tsunami. The plants also had surge walls constructed in the ocean to protect the coastline in the event of a tsunami. However, the surge walls were insufficient because the tsunami was so large.

The tsunami flooded the generators and the backup pumps for the generators. When those backup pumps failed, pressure built up inside the reactors, and hydrogen was produced due to the high temperatures. The high hydrogen concentrations inside the reactors resulted in multiple explosions. On March 15, 2011, 4 days after the earthquake, there was a huge spike in radiation levels following a new explosion and fire at the Fukushima Daiichi plant in Okuma, Japan.

Fortunately, the problems surrounding the nuclear power plant did not result in a true disaster, as the entire plant remained intact following the massive earthquake. In a final measure to avert a crisis, the authorities flooded the problematic reactors with seawater. The effects of this last-ditch effort were twofold: a chance to avoid a nuclear meltdown and the destruction of the reactor. Flooding a plant disables the reactor, and it can never be used again. Although the authorities' goal was to keep enough seawater in the plant to avoid a meltdown, the end result was still uncertain. There were plenty of reasons for concern, and a disaster could have easily developed in the days, weeks, and months following the earthquake.

MEASURES OF EARTHQUAKE PREPAREDNESS

Japan has many measures in place to mitigate the damage caused by earthquakes, which spared the population from a far worse outcome following the Tohoku earthquake.[3] These preparations include the following:

- *Warning people, to minimize loss of life.* When an earthquake occurs, it initially sends out waves that travel through the earth, known as body waves. The fastest of these waves involve

compression and are called P-waves or primary waves. Slightly slower waves, known as S-waves or secondary waves, are very destructive because they shake things from side to side. Because there is a time difference in the arrival and detection of the P-waves and the S-waves, once P-waves are detected, a warning system sounds, escalators in Japan are stopped, trains come to a halt, gas main valves are shut off, and people are encouraged to seek protective cover. This warning sound provides as much as a minute of warning time—enough to stop the trains and allow people to protect themselves—before the more destructive secondary waves arrive. This warning system is reinforced with regular drills.

- *Emergency drills.* From a young age, children are taught how to protect themselves if an earthquake occurs so they are prepared to take cover.
- *Emergency rations*. The Japanese people store emergency rations in their homes, enough for a couple of days in the event that they are without food or water for a period of time.
- *Building codes.* Houses and buildings are designed and built to sway with the back-and-forth motion of earthquake waves. The idea is to build things so that if the earthquake is very severe, rather than the building collapsing (as it would if it were made of brick or concrete), it will sway without breaking; if it sways too much, it will deform and bend, but still give people time to get out.

PROTECTION AGAINST TSUNAMIS

Advance warning and vertical evacuation are the keys to surviving a tsunami. Important life-saving principles include the following:

- Monitoring technologies and warning systems
- Knowing where, when, and why a tsunami occurs in order to notify populations to evacuate
- Knowing when to evacuate and where to go before a tsunami wave arrives

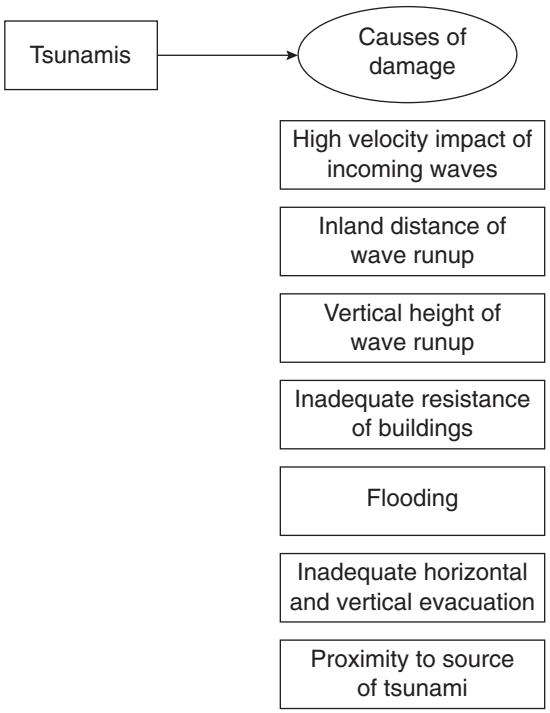
Japan has an extensive system of coastal barriers designed to prevent high waves from flooding areas where large populations live. Following the Tohoku earthquake, the resulting waves were higher than the Japanese had expected, and water poured over the barriers. As part of Japan's early warning system, when a big earthquake

occurs, officials determine whether it might cause a tsunami. If they think it will, they quickly alert the population. However, people have to then be able to go somewhere safe (e.g., higher ground if they are on land in low-lying areas; out to deeper water if they are in a boat). If the warning time is too short, people will not have time to evacuate to a safer area.

Evacuation for a tsunami is complicated both by the short time between the earthquake and the arrival of the tsunami wave, and by the damage and loss of function to buildings and infrastructure caused by the earthquake and its aftershock sequence (see **Figure 1-1**). For those who choose not to evacuate or are unable to evacuate, the odds for survival are lower. It is nearly impossible to outrun or divert a 32-foot-high, debris-laden, ocean wave that arrives with a high velocity (i.e., 20 miles per hour or faster) and moves rapidly inland, covering 1 mile or more of land.

Figure 1-1

Causes of damage from a tsunami.



IMPACT OF CULTURE

The Japanese are an amazingly stoic and disciplined people. Japanese culture has always emphasized the importance of *gaman*, which means the ability to endure hardship with patience and without complaint. Furthermore, the Japanese are well aware that they live in a country subject to frequent earthquakes and tsunamis. Each community in Japan has developed emergency procedures to follow in the event of a serious tremor or a tsunami. There are periodic drills for people to practice how best to protect themselves in the event of a major earthquake or tsunami.

The Japanese are known as a people who are among the most disciplined and hard working in the world. They are used to rebuilding their homes and communities, whether after earthquakes, tsunamis, or the dropping of atomic bombs. The great earthquake in the Tokyo area in 1923 claimed the lives of nearly 130,000 people. In Yokohama, 90% of all homes were damaged or destroyed, while 350,000 homes in Tokyo met the same fate, leaving 60% of the city's population homeless. And the Japanese rebuilt. Because of their core values and history, the Japanese people met this unbelievable catastrophe with a calm, disciplined response.

Despite these strengths, there were cultural stumbling blocks that impaired acting decisively after the Tohoku earthquake. Japan's own preliminary investigation showed disagreement and confusion over who should be making the final decisions. As evidenced following the Kobe earthquake in 1995, this was partly cultural. The Japanese decision-making process, which emphasizes group rather than individual decision making, might have been a hindrance for dealing with an emergency situation. It is difficult to quantify, but it seems that making multi-billion-dollar decisions such as these is more difficult to do promptly in the Japanese culture than, for example, in the United States.[7]

EVENTS IN JAPAN

On March 11, 2011, a 9.0 earthquake with an epicenter approximately 80 miles east of Sendai, Japan, generated a tsunami that reached heights of up to 132 feet (40 meters) and, in the Sendai area, traveled up to 6 miles (9 kilometers) inland (see **Figure 1-2**). It was the fourth-largest recorded quake.[8]

The earthquake and tsunami destroyed or damaged over 125,000 buildings, with almost 20,000 individuals killed or injured. In addition, the events caused several nuclear accidents, including the

Figure 1-2

Map of Japan and epicenter of earthquake.

Source: Adapted from http://sertit.u-strasbg.fr/SITE_RMS/2011/05_rms_japan_2011/05_rms_japan_ 2011.html

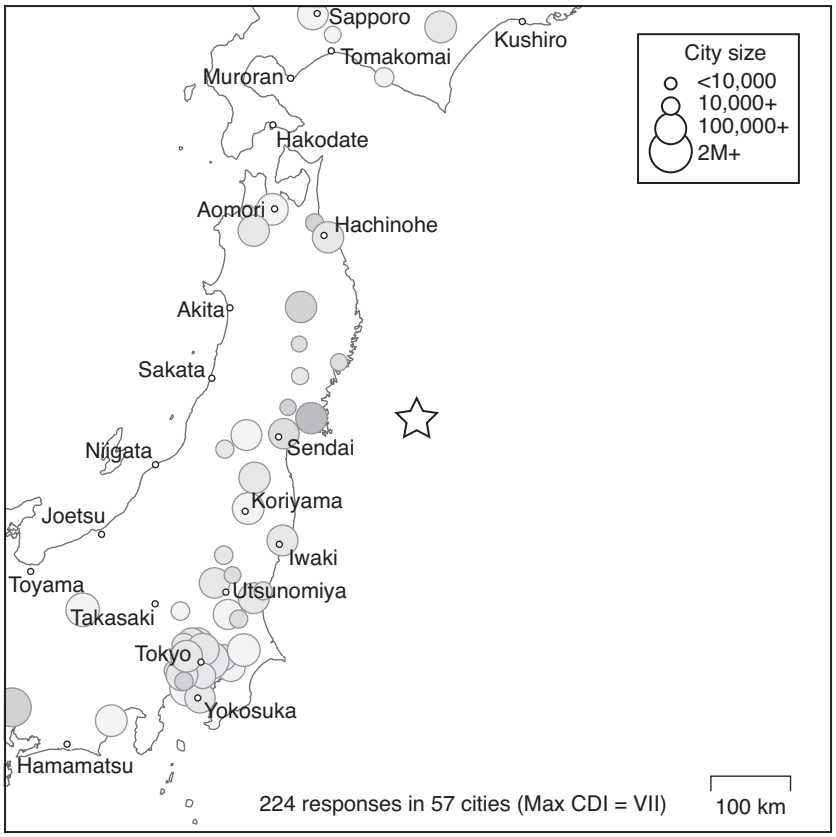
ongoing level 7 meltdowns at the Fukushima nuclear power plant complex. The earthquake and tsunami caused damage to much of Japan's infrastructure—destroying roads and railways, triggering numerous fires, and collapsing a dam. Over 4 million households were left without electricity, and 1.5 million were left without water. The earthquake moved the city of Honshu 1.4 miles to the east and shifted the earth on its axis by approximately 7 inches.[9]

During the initial response, Japan's Meteorological Agency issued earthquake and tsunami warnings. It only took seconds for the earthquake's P- and S-waves to do their damage. The tsunami reached Sendai only 15 minutes following the earthquake. Devastation was

widespread. The aftermath included a 300-second shaking from the main shock and hundreds of powerful aftershocks, many at the magnitude of a strong earthquake (see **Figure 1-3**). The magnitude of this earthquake can be compared to the 1994 Northridge, California earthquake or the 1995 Kobe, Japan earthquake, which each had about 10 to 20 seconds of ground shaking. Coupled with the

Figure 1-3

Map showing intensity of shaking from earthquake on March 11, 2011.



Intensity	I	II–III	IV	V	VI	VII	VII	VII	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Damage	None	None	None	Very light	Light	Moderate	Moderate/ heavy	Heavy	Very heavy

Source: http://earthquake.usgs.gov/earthquakes/dyfi/events/us/b0001r57/us/index.html

Figure 1-4

Aerial view of damage to Sukuiso, Japan.

Source: McCord D., U.S. Navy from the National Geophysical Data Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Available at: http://www.ngdc.noaa.gov/.

tsunami, there was widespread damage to homes, buildings, essential facilities, nuclear facilities, and critical lifelines (e.g., transportation infrastructure). Together, the ground shaking and subsequent wave caused major damage in northern Japan (see **Figure 1-4**).

The earthquake and the aftershocks triggered widespread fires, including massive blazes at oil refineries. Four million households were left without electricity. The subways and trains shut down for almost 2 months.[4] This was all complicated by the damage to nuclear power plants, the effects of which continued well into the recovery phase.

Some of the nuclear power plants in the region shut down automatically, leading to an evacuation of several thousand people. All search, rescue, and relief operations; evacuations; and international humanitarian assistance efforts were conducted within the framework of possible significant radiation release and nuclear meltdown resulting from the fires and explosions at the Fukushima Daiichi nuclear facility. A week after the earthquake and tsunami, Japanese efforts focused on the pools used to store spent nuclear fuel, now dry or nearly so, because the

consensus was that the dry rods could heat up and spew intense radiation. Subsequently, radioactive contamination of soil, coastal waters, and groundwater was detected, with radiation levels as high as 10,000 times the maximum government standards.

As a result of these developments, the U.S. Centers for Disease Control and Prevention (CDC), Food and Drug Administration (FDA), Environmental Protection Agency (EPA), and Customs and Border Protection (CBP) issued informational updates in the following areas:

- Screening procedures for elevated radiation levels for individuals returning from Japan
- Travel guidance for humanitarian volunteers
- Screening procedures for food products from Japan
- Environmental monitoring/potassium iodide
- Monitoring maritime and air traffic from Japan

RESPONSE

The major goal of the response was containment, especially to prevent a meltdown at the Fukushima nuclear facility, where the normal cooling system was compromised by the earthquake and tsunami. To that end, emergency workers tried helicopter water drops, heavy-duty fire trucks, and water cannons to cool down Japan's dangerously overheated nuclear reactors and spent fuel pools.

Coordination at the National Level

Immediately after the earthquake and tsunami, the Japanese government began implementing its postdisaster response plans in a highly charged environment with the constant threat of the possibility of significant radiation release and a nuclear meltdown. The fires and explosions in the Fukushima Daiichi nuclear facility and radiation levels that were 1,000 times the normal levels created a nightmare disaster response scenario for the government of Japan. Approximately 140,000 people living within a 20-mile radius of the plant were evacuated. The increased risk from radiation stymied search and rescue operations, which were already operating beyond the "golden window" where most lives can be saved, and slowed humanitarian assistance.

Search and rescue operations—an international effort—were organized within hours and continued for months. Approximately 50,000 members of Japan's Self Defense Forces were mobilized immediately to the hardest-hit areas. Tokushu Kyuunan Tai, the search and rescue unit of the Japan Coast Guard, was dispatched to accelerate search and rescue operations. The Japanese Red Cross dispatched 62 response teams within 24 hours of the earthquake.[3] The teams were primarily for medical relief and included 400 personnel—doctors, nurses, and support staff—who worked from mobile medical clinics.

During the crisis, between 300,000 and 350,000 people were evacuated. The tsunami and earthquake knocked out power supplies in addition to those supplied from the Fukushima power plant. Because the tsunami hit in the winter months, there was an immediate need to provide shelter against the cold and a need for clean water. There was difficulty with the evacuations and difficulty finding food, shelter, and especially water for those needing temporary housing (see **Figure 1-5**). Shortages, closed roads, and lack of fuel made it nearly impossible to meet survivors' basic needs. The aid needed most was provided by organizations such as the International Red Cross and the International Medical Corps. They supplied food, clean water, blankets, fuel, and medical supplies.[10]

During the response phase, responders worked to reduce secondary damage such as fires from broken gas lines and water contamination from broken water lines. Teams were organized to inspect the infrastructure of buildings and utilities. Through all of this, first responders were tasked with utilizing critical information to make rapid decisions in order to provide emergency assistance for victims of the earthquake. As soon as people were available to assist the first responders, the assignment of these personnel to various tasks, such as search and rescue teams, began. Utilizing geographic information systems (GIS), grid maps of collapsed buildings were produced. Mapping data allowed emergency responders to identify severely damaged areas; prioritize medical needs; map out areas that would be suitable for the distribution of food, water, and supplies; and locate emergency medical centers and emergency shelters.

International Humanitarian Assistance

In the recovery phase, Japan needed support in managing the incoming offers of assistance and donations. The entire international community participated in these efforts. Humanitarian assistance was pledged or dispatched to Japan by many countries to mitigate the

Figure 1-5

Rescuer following the earthquake/tsunami.

Source: NOAA/NGDC, Patrick Fuller, IFRC.

possibility of thousands of deaths and to provide specialized health care in light of possible waterborne diseases, the effects of high radiation levels, and a possible nuclear meltdown. Japan received offers of assistance from 116 countries and 28 international organizations.[11] Japan requested specific assistance from the United States, United Kingdom, Australia, and New Zealand, in addition to requesting the activation of the International Charter on Space and Major Disasters for readily available use of satellite imagery of affected areas.

The U.S. Agency for International Development deployed search and rescue missions at the request of the Japanese government. Ninety medical teams from Médecins Sans Frontières arrived on Sunday, March 14, and were deployed in the Miyagi prefecture. The USS Ronald Reagan was dispatched immediately to Japan and, at the request of the Japanese government, made helicopters available and began assisting in urgent search and rescue missions. U.S. marines were already stationed in the area and assisted in local search and

rescue missions. Teams from Germany and China also arrived that Sunday to assist Japan's recovery.

THE FUTURE

This case study on the Great East Japan Earthquake of March 11, 2011 focused on appropriate leadership knowledge and skills required for effective performance during rapidly changing situations and crisis events within and external to most organizations. Despite best-laid plans, actual crises often require the ability to deal with the unexpected. Crisis events not only require flexibility, but also depend heavily on effective delegation and well-planned resource logistics. Health professionals planning or preparing for deployment to situations that are experiencing rapid change or crisis events need to be especially careful when considering what skills they require.

Long-term recovery from this disaster will take many years. Stakeholders must recognize the difference between meaningful short-term recovery and the ultimate long-term goal. Long-term recovery plans must consider the constraints of the predisaster social situation, including baseline economic characteristics and political conflicts that require the involvement of local people and political structure as the key central stakeholders. Major effort will be needed to rebuild schools, homes, hospitals, and roads; reestablish the sanitation infrastructure; recover from environmental damage; address long-term healthcare needs; and provide preventive care.

The recovery phase may also be an opportunity for the growth of policies that address pre-tsunami preparedness, such as enhancing the art and science of knowing when to evacuate and where to go before a tsunami wave arrives. Key stakeholders in the recovery include the people who are still homeless as a result of the earthquake and tsunami, the Japanese government, the organizations that were supporting Japan's efforts to disseminate aid to those people, and lastly, the international markets who were invested in Japan's economy. While this disaster left thousands of people homeless, it hit one of the most disaster-prepared countries in the world; Japan is very much in control of the recovery efforts and is able to provide the majority of necessary resources.

The fallout from the Fukushima power plant and the disruption to businesses affected stakeholders well beyond Japan's borders. Japan has the third-largest economy in the world. The closing of plants, highways, and ports caused disruption of production and investment

flow that was felt worldwide. It was estimated that $287 billion in market capital was wiped out when stocks dropped just after the disaster. Japanese car manufacturers, electronics companies such as Sony, and other global companies such as GlaxoSmithKline all shut down due to the disaster. With so many lives at stake and the stability of the global market at risk, Japan needed to quickly assess the damage and begin the recovery process as efficiently as possible.

Returning to economic strength will require the same degree of national will and sacrifice that produced the "Japanese economic miracle" following the devastation of the Second World War. By 1945, nearly half the surface area of all Japanese cities had been reduced to rubble by American bombers. Still, the Japanese rebuilt their country to become the number two economy in the world only 4 decades later. In the Kobe earthquake of 1995, 5,000 people perished and more than 100,000 were left homeless. Today, Kobe is once again one of the loveliest and most prosperous cities in Japan. The Japanese will rebuild after this latest catastrophe, as they have always done—with calm patience and determination.

DISCUSSION QUESTIONS

1. Which competencies described in the Appendix does this case demonstrate?
2. Describe two examples of ways of mitigating the impact of such events using the following two preparedness strategies:
   - Disaster Vulnerability Assessment
   - Critical Infrastructure Protection of Health Care Delivery Systems
3. What is the difference between a tsunami and a tidal wave?
4. Give three examples of how you would lead when preparations are insufficient and when core values are threatened? How would you respond to unanticipated situations when time is of the essence, and planned approaches do not work?
5. "Reputations are made or lost in crises" is a core observation from almost all major past disasters. Please give three examples in recent history of natural or human-generated disasters where this was a particular outcome.
6. How might the nuclear reactor disaster have been prevented or repaired more quickly with proper planning and tools and more effective media relations? What is the meaning of the word "Tomodachi"?

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