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Catastrophe in Radiology: Considerations Beyond Common Emergencies

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A B S T R A C T

Disasters often occur without warning and have the potential to affect large numbers of people. Those in the radiology environment experience unique effects on them, their equipment, and their ability to provide quality patient care. Lessons can be learned by reviewing events and their impact on imaging departments around the world. Radiology departments need to be actively involved in the disaster planning and the management of disasters when they occur. Common themes emerge regardless of the type of disaster, and these themes should be included in all planning.

Organizations around the world increasingly prepare for the "what ifs" of our environments. Regulating and certifying agencies mandate organizational plans for threat management to include risk factor identification, threat mitigation, prevention (when possible), response to, and recovery from the event. The World Health Organization (WHO) estimates that natural disasters kill approximately 90,000 people annually and affect an additional 160 million people worldwide (WHO, 2019, 2011). The Disaster Recovery Reform Act of 2018 developed improvements to the Federal Emergency Management Agency (FEMA) by establishing a clearer framework for disaster management in both the preparation for and response to each event; prestaging now occurs with incident command centers, resource mobilization, and search/recovery teams on standby, ready to act (FEMA, 2018; Reynolds & Knox, 2019). The Joint Commission continually updates their expectations for organizations, uses information obtained through their postdisaster organizational debriefing, and supports organizations by providing informational resources (Joint Commission, 2018). The Occupational Safety and Health Administration provides a number of resources to assist organizations in the creation of their individual disaster management plans (OSHA, 2015). In 2011, a policy directive was developed to deal with all natural and manmade disasters, which evolved into The Hartford Consensus that addresses the loss of life and has a chief principle that no one should die from uncontrolled bleeding (Jacobs, Burns, Pons, & Gestring, 2017). Although disasters of every kind have occurred throughout history, the number and severity continue to increase. Society demands to be kept safer … demands that are, at times, difficult to achieve.

Even with an ever-increasing amount of information available and regulations to comply with, radiology departments are still often excluded from a hospital's disaster management plan and drills. Often, it is not until an organization experiences a catastrophic event that the identification of a plan for radiology's role during a disaster comes to mind. Regardless of the event type, radiology will be affected in some manner. Although no amount of preplanning can fully prepare any organization for the unpredictability of a catastrophic event, having a plan in place will provide for better response and care during any mass casualty incident (MCI), regardless of the type of catastrophe. Many radiology departments are now creating their own disaster management plan within their department: although the hospital may have an organizational plan, individual departments should be aware of the role they will need to play when a catastrophe occurs (Dargan, 2018; Haygood, 2018).

Anecdotal reports from events around the world are valuable to consider when creating an organization's disaster response plan. Firsthand lessons learned by others should be considered when organizations create their own disaster management plan, inclusive of considerations for the imaging departments. Whether external or internal in origin, many similar considerations apply to nearly all MCI events. Although catastrophic events may vary in type, length, recovery time, number of victims/relief workers, and a host of other important details, radiology departments should consider all types and create disaster plans accordingly. Redundancy and backup plans are essential to also have in place, as established disaster plans do at times fail (Dargan, 2018) The following chart lists types of disasters that could be catastrophic to any health care facility, its imaging department including some historical examples (Table 1).

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Hospitals are seen as part of the solution to any catastrophic event in the community; however, hospitals can also be problematic during MCIs as people often flock to a local hospital to seek safety and to look for loved ones, which creates additional issues for the health care team. The WHO describes an MCI as any event that results in a greater number of people seeking assistance and support than what a local system can provide (WHO 2007). MCIs are usually a sudden and dramatic event that causes a surge in patients or a change in normal business. Whether an act of violence or a natural disaster, the health care community must have an action

Table 1
Disaster types and deadly examples

Type	Deadly historical examples
Chemical weapons	
Chlorine, cyanide hydrogen sulfide, mustard gas, nerve agents, sulfur mustard	1915 World War I in Belgium (1st documented large-scale use of chlorine and mustard gas as a chemical weapon) 2018 Salisbury, England (nerve agent attack)
Biological weapons	
Anthrax, bubonic plague, cholera, smallpox, salmonella, tularemia	1335 BC Middle East Hittite Plague (1st documented biologic weapon) 2001 US mail (anthrax)
Violence	
Weapons of mass destruction	1788 NYC Doctors Mob riot (1st documented civil unrest w/fatalities)
Shooting incidents	1840 University of Virginia (1st documented school shooting)
Bombs	1995 Oklahoma City bombing
Vehicle as weapon	1999 Columbine high school massacre
Civil unrest	2001 9/11 terrorist attacks
	2012 Sandy Hook Elementary school shooting
	2013 Boston marathon bombing
	2017 Las Vegas, Nevada mass shooting
	2018 Douglas high school, Parkland school shooting
	2019 Christchurch, NZ: Mosque terror attack
	2019 El Paso, Texas, mass shooting
	2019 Dayton, Ohio, mass shooting
Cyber attacks	
	2017 Buffalo, New York
	• Ransomware attack at Erie County Medical Center
	2017 Dallas, Texas
	• Cyber attack set off 156 emergency sirens
	2017 Mecklenburg County, North Carolina
	• Ransomware attack against the city government
	2017 United Kingdom
	• Ransomware attack of 16 National Health Service hospitals
	2018 Atlanta, Georgia
	• Ransomware attack against local government
	2019 Baltimore, Maryland
	• Ransomware attack against government computers
Natural disasters/extreme weather	
Hurricanes	2004 Indian Ocean tsunami
Tornadoes	2005 Hurricane Katrina
Flooding/storm surge	2010 Haiti earthquake
Earthquake	2010 Mudslides in India
Mudslides	2011 Christchurch (NZ) earthquake
Wildfires	2011 Japan earthquake and tsunami
Volcano	2011 Tornadoes (62) in a single day, central Alabama
Blizzard	2012 North American derecho (thunderstorm complex)
Heat waves	2012 Super storm Sandy (both blizzard and hurricane)
Tsunami	2017 Hurricanes Harvey, Irma, and Maria
	2018 Wildfire (California Camp Fire)
	2018 Guatemala's Fuego and Hawaii's Kilauea volcanos
	2019 Hurricane Dorian in The Bahamas
	2020 Puerto Rico earthquake
Pandemic	
Hemorrhagic fever	1985 Listeria (food contamination), California
Influenza	2002 SARS-CoV-1 pandemic
Listeria	2009 H1N1 pandemic
Salmonellosis	2011 *E. coli* (food contamination) Germany
Coronavirus	2012 MERS-CoV pandemic
	2014 Ebola outbreak in West Africa
	2017 Listeria (food contamination), South Africa
	2019 SARS-CoV2 COVID-19 pandemic
Accidental/unintentional disasters	
Nuclear	1785 Hot air balloon crash, Wimereux, France
Explosions	• 1st documented fatal aviation crash
Mass transit accidents	1979 Nuclear event, Three Mile Island, Pennsylvania
Structure collapse	1986 Nuclear event, Chernobyl, Soviet Ukraine
Human tragedy	1989 Hillsborough Stadium Collapse, England
Stampede	2012 Nuclear event, Fukushima, Japan
	2013 Factory collapse in Bangladesh
	2015 Pilgrimage stampede in Saudi Arabia

(Schoeberl, 2018; Snair, 2018; Berger, 2016; Sen, 2013; CDC, 2018b; Flammarion, 1870, Richmond Enquirer, 1840; Torok, 1997; Goodwin Veenema, 2019; Trevisanato, 2007; Grojec, 2018; OPCW, n.d.; Sutherland, 2019; Haygood, 2018; Aarne Grossman, 2020).

plan that can be immediately implemented to provide safety and recovery to all people affected. Health care personnel by nature are dedicated to responding to any event they are faced with: it is this dedication that drives them to figure out a backup plan when the original disaster plan does not or cannot work.

The WHO outlines guiding principles which all disaster management plans should incorporate. Clear lines of responsibility should define roles, responsibilities, and assigned activities to all dealing with the event. The plan should have scalability and be flexible to meet the needs of any MCI which could occur. It should address whole health and be prepared to deal with injuries and death, environmental issues (water, sanitation, housing, food, transportation), disease management (communicable and non-communicable), health care delivery, and mental health services. The evidence-based plans should include case reviews of historical events and consider lessons learned from past events worldwide when developing their own plan. All plans must be multisectoral to be successful, with the inclusion of different organizations which will need to work together in a professional manner. These will often include but not be limited to communication providers, transportation, law enforcement, security forces, military, water/sanitation departments, social services, health care providers, emergency service personnel, local industry/businesses, and emergency response teams (Red Cross, governmental agencies, etc.) (WHO, 2007). It is essential for organizations and communities to drill repeatedly, looking for potential flaws in any disaster management response plan (Haygood, 2018)

Violence/terrorism

These acts can be difficult to predict or understand. The goals of these individuals who intentionally inflict harm and fear toward others are usually intended to impact the greatest number of victims possible. Sometimes, the goal is more about maximum disruption (hysteria) than maximum damage (injury, death, environmental destruction). The aggressor(s) may be a single individual, a small group of people, “homegrown” violent extremists, international terrorist groups, or transnational criminals (Breslin, 2019; Williams, 2019). The purpose of their destructive actions may be based on perceptions and beliefs and can be quite difficult for others to understand and explain. These could include beliefs or goals such as unfairness in social, racial, economic, or political arenas; spiritual or religious ideology; personal revenge toward another person or group; a statement in support of or against a person, group, nation, or ideology; some may have a mental illness; however, there is no clear proof that all people who commit aggressive acts toward others are mentally ill (Gotzsche-Astrup & Lindekilde, 2019).

When a violent act occurs, initial response focuses on neutralizing the threat and minimizing any additional damage. This is most successful when responding services have preplanned and carried out robust, ongoing training and practice drills. Partnerships must be formed and maintained between all agencies that may be involved. Ongoing monitoring of activity that may appear suspicious can pre-empt some attacks. It is difficult to smuggle bombs into a country or to transport them, so some terror groups are sending their bomb making recipes to home-grown terrorists in locations where an attack is scheduled to occur, and the bomb can be crafted close to where the attack will occur. To help combat this, the New York City Metropolitan Transportation Authority's Security Awareness Campaign introduced “*if you see something, say something*” in 2002, as a method to be able to report suspicious behavior or packages. In 2010, the Department of Homeland Security expanded this to be a nationwide campaign (DHS, n.d.).

(Dargan, 2018; Amoretti, 2018).

> In 2016, a terrorist drove a truck into a crowd of people in Nice, France. 86 people died, 458 were injured, and 202 people received care at local hospitals. Challenges included being able to properly identify patients as many were unconscious or did not speak French. One hospital that normally performed 15 computed tomography (CT) scans during an average night performed 42 CT scans on 42 patients in 2 hours.

Mass shootings

These events can occur anywhere, at any time. Mass shooting events externally to a hospital can result in a surge of injured patients coming to a hospital. Shooting events that happen inside of a hospital pose their own risks for a number of reasons. A person can plan their assault within a hospital by conducting surveillance ahead of the event, planning entrance and exits, identifying departments or offices to target, and studying the habits of security and other staff. Hospitals are open to the public, and the aggressor optimizes the sudden chaos and fear to their own advantage. Staff may be confused between saving themselves or someone near them. Some key facts about shooting events and hospitals include the following:

- Active shooting events often begin spontaneously and end quickly (average is less than 19 minutes).
- Since 2000, over 160 health care facility–related shootings occurred in the United States with 60% occurring inside of hospitals and 40% occurring outside of buildings on hospital property.
- Hospitals are high-stress environments where individuals may have weakened coping skills; experience fear, aggression, anger; and seek retaliation.
- There are large concentrations of potential victims.
- 67% of health care facility–based shootings occur before the police arrive.
- Smaller hospitals may be more vulnerable because of easier maneuverability and less security, (Blair, 2014; Bjelopera, 2013; Borchers, 2017; Schwerin, 2019).

To be best prepared in the event of a mass shooting, disaster plans must include threat assessment and frequent training and drills. Each department, including radiology, should have their own threat assessment conducted including a map of the department and the location of staff, patients, and visitors. Staff should be inserviced on policies, procedures, methods of communication, and behaviors that can preserve lives during such an emergency. Staff may be trained in the following for use during an active shooter event:

- Run (escape route, leave belongings behind, save self and not others);
- Hide (out of shooter's view, block/lock the door, silence electronics, turn off lights);
- Fight (last resort, incapacitate the shooter, throw items at the shooter).

(Morris, 2014, Goodwin-Veenema, 2019)

In 2002, Texas State University developed a response to an active shooter:

- Avoid (if safe to do so, leave the building);
- Deny (barricade a door to prevent the shooter access);

- Defend (if unable to avoid or deny, then protect yourself) (ALERRT, 2019).

What potential victims do during an active shooter incident can influence the injuries and deaths that occur at the hands of the gunman. Recommendations include the following:

- When calling for help, give essential information clearly and slowly to the operator (hospital, 911, etc.);
  - Who or what you saw;
  - When you saw it;
  - Where it occurred;
  - Why it is suspicious or if it is an actual event (DHS, 2007).
- Prepare the responding personnel for what they are going to encounter
  - Shooting incident (finite event) or active shooter (shooting in progress);
  - One person (give description);
  - A group of people (give description);
  - Weapons being used;
  - Where victims are and what injuries have occurred;
  - Where people may be hiding;
  - Known assailant (domestic violence, known patient/family member, worker to worker, etc.).
    - 7% of workplace homicide victims are often in leadership positions (Hunter Martaindale, 2017).
    - While waiting for help to arrive, administer first aid to those who are hurt (Jacobs, 2017).

In 2017, Las Vegas, Nevada, experienced a mass shooting that killed 59 people, injured 851 people (422 of them sustaining gunshot wounds). The shooter was positioned on the 32nd floor of a nearby building, fired 1,000+ rounds in less than 15 minutes into a crowd of 22,000 concert attendees. Many victims self-transported to area hospitals, "carloads" of gunshot wound victims appeared at unsuspecting hospitals.

- Most victims were cared for at three of the over 10 hospitals in the area.
- A national shortage of intravenous (IV) fluids complicated the care of the patients: it is estimated that 1000+ IV lines were started that night and supplies of IV fluids ran short.
- It is estimated that ~500 units of blood components were transfused in the first 24 hours after the incident (Lozada, 2019).

In 1994 at the Fairfield Air Force Base Hospital in Spokane, Washington, a mass shooting event killed 5 people and wounded 23. One of those wounded was 5 months pregnant and miscarried a day after the shooting.

- The shooter was a former airman who was diagnosed with schizophrenia and recommended for military discharge by two psychiatrists. These two physicians were among those murdered by the shooter. After killing the two psychiatrists, the gunman walked through the facility, firing randomly until he exited the building.

Bombs/Blasts

Theft of radiopharmaceuticals may occur for use in making "dirty bombs" (radiological dispersion device). These would typically result in "weapons of mass disruption" instead of "weapons of mass destruction." Victims of a dirty bomb may have radioactive shrapnel embedded in their bodies, respiratory injury from inhaled radioactive dust, or wounds with radioactive contamination but not likely have injury or illness directly related to the exposure to radiation. These attacks could occur inside of a hospital or in a community with the contaminated injured patients transferred to the hospital. Blast-related injuries are meant to cause massive injury to a large number of people with the most common injuries including blunt, penetrating, burn, amputation, and emotional trauma. The most common injury locations include the brain, ear, eye, lung, heart, abdominal region, and limbs.

In 2013, the Boston Marathon bombing occurred when 2 pressure cookers, packed with shrapnel (nails, metal pellets, etc.), exploded, killing 3 and injuring 275+ people. 90 of the patients were treated at 3 hospitals (patients were cared for by a total of 27 hospitals). Hospital emergency response teams were immediately alerted, outpatient schedules were cleared, and additional radiology teams were called in to work. CT scans and x-rays were able to quickly identify the scope of injuries caused by the shrapnel contained in the explosive devices (Goodwin, 2019; Gates, 2014; Singh, Goralnick, Velmahos, Biddinger, Gates & Sodickson, 2014; Ready.gov, 2019).

Cyber Attacks

Cyber attacks can happen to individuals, businesses, governments, and hospitals. Fraudulent access enters a computer system with goals to steal, dismantle, alter, extort, or take part in other criminal activity. These actions can be conducted by one individual or from an international criminal enterprise.

In 2017, a ransomware attack occurred at the Erie County Medical Center (ECMC) in Buffalo, NY. It locked down 6,000 computers by encrypting files and severely affected the 600-bed hospital and 390-bed nursing home. ECMC did not pay the $40,000+ ransom; however, it did spend $10 million to recover from the attack. The hospital was forced to revert to paper charting for 6 weeks while they recovered from this event.

Earthquake

Earthquakes can occur suddenly and without warning. Those who live in earthquake-prone zones know that damage occurs quickly to infrastructure, buildings, and equipment. To minimize personal injury, it is important for people to get low to the ground, cover the head and neck, and avoid windows, doorways, and falling furniture/equipment. Imaging departments in earthquake-prone regions often have stabilizing construction in place to protect valuable and expensive imaging equipment (i.e., MRI, CT, IR, etc.).

In 2011, an earthquake (6.3 magnitude) struck Christchurch, New Zealand, necessitating Christchurch Hospital (600+ bed facility) to evacuate 350 inpatients in 35 minutes, while their emergency department remained open.

- Radiology services were affected by loss of power (power outages as well as failure of the backup generator), interrupted communication pathways, flooding, and large aftershocks. Elevators were inoperable. During the first 12 hours after the initial earthquake, only portable x-rays and ultrasound imaging were available to the emergency department patients. Without generator power available, radiologists relied on flashlights and headlamps for light. Nuclear medicine department received no damage, CT was up after the initial 12 hours. While this hospital was built with seismic upgrades, geotechnical failures did occur and lead to widespread damage to the hospital (walls/ceilings/floors cracked, tunnels flooded, damage to the roof/boiler stack/medical equipment, etc.) (Gregan, 2016; Haygood, 2018; Mitrani-Reiser, Kirsch, Jacques, Giovinazzi, McIntosh, & Wilson, 2011).

Hurricanes/Tornadoes/Flooding

Storm systems can be powerful (and at time, unpredictable), and may include strong winds, heavy rainfal, storm surges, rip currents, flooding, and landslides. Most areas have emergency communications and alerts that should be listened to carefully, and directions should be followed. Emergency crews will be mobilized, emergency supplies will be on standby (ready to infiltrate the disaster area), and individuals as well as businesses will make necessary arrangements and preparations (Reynolds, 2019). Hospitals can be best prepared by

- Frequent training drills that are comprehensive;
- Ensuring a 3- to 5-day supply of emergency power, water, medication, food, linen, and other essential supplies;
- The more emergency power a hospital has available, the more successful they can be during a catastrophic event;
- Hospitals located near known threats should be built to expect the worst (flooding, earthquake, tornadoes, etc.). This includes special windows that protect against flying debris (withstand up to 250 mph); underground wiring to guard against power outages with 2 different wiring pathways; a reinforced roof, safe interior rooms to protect against wind, rain, and flooding; watertight barrier storm doors; and equipment with extra battery backup (ventilators, bassinets, specialty equipment, etc.). (Hayes, 2005; Lallanilla, 2013a)

When a severe storm system attacks a hospital, care consideration and planning must occur that includes care of those within the structure (food, safe shelter, medical care) and evacuation. Care of the equipment should be considered as loss of electrical power, flooding, or wind damage can severely damage equipment and hinder the ability to care for patients.

Tornado-prone areas may have sirens that alert the community of an approaching tornado. Other indications of an approaching tornado include a dark or green-colored sky; large, dark, low-lying cloud; large hail; or loud roar that sounds like a freight train. Not all tornadoes will present with the characteristic funnel cloud. Danger exists from extremely high winds, flying debris, falling objects, and so forth. People should seek protection during a tornado, including underground shelter, interior part of a basement, or the lowest floor of a building away from windows and doorways. It is never safe to stay in a mobile home, car, bus, or long-span building (i.e., mall).

Regardless of the type of weather event, flooding is a potential danger. Fast flowing water or standing water pose a dangerous risk. Flood waters commonly test positive for water-borne and/or sewage contamination including the following:

• *E. coli*	• Cholera	• *Vibrio vulnificus*
• *Salmonella*	• Typhoid	• Yellow fever
• *Shigella*	• Balantidiasis	• Leptospirosis
• Hepatitis A	• Norovirus	• Cryptosporidiosis
• Coliform		

- Chemicals (arsenic, lead, mercury, cadmium, chromium, silver);
- Parasites (giardia, roundworm, tapeworm, hookworm, and whipworm);
- Standing water increases risk of vector-borne diseases (malaria, dengue fever, yellow fever, Zika, West Nile fever);
- Standing or rushing flood waters can harbor debris that contains sharp objects (glass, metal, etc.) and large objects (trees, vehicles, etc.);
- Workers handling corpses risk contamination (HIV, Ebola, Hepatitis A/B/C, tuberculosis, rotavirus diarrhea, salmonellosis, E. coli, typhoid/paratyphoid fevers, shigellosis and cholera).
- Dangers of displaced wildlife
  - Animals, reptiles, and insects: danger of attack and disease transmission;
  - Rabies from dogs, bats, mongooses, foxes, raccoons, and ferrets.

  (CDC, 2019a,b,c; Environment Texas, 2017; Scutti, 2017; UTSA, 2018; WHO, 2019)

In 2011, an EF-5 tornado (winds exceeding 200 mph) hit Joplin, MO, destroying 8,000 buildings and killing 161 people along its 14-mile × 1-mile path.

- St. Johns-Mercy Hospital received a 24-minute advanced warning and experienced a 45-second direct hit from the tornado. Windows, walls, floors, doors, ceilings, and roof were blown off. The tornado destroyed the generators, communication (telephones, computers, paging systems, etc.), water/gas/sewer lines, helicopter, and their disaster trailer.
- 183 patients were evacuated in 2 hours using wheelchairs, backboards, mattresses, Med Sleds, and doors that had been removed from their hinges.
- The 4-day cache of supplies was depleted in less than 4 hours after the tornado initially hit.
- Financial impact was 3 billion dollars.

(DOH, 2011; MedSleds Chinook Medical Gear; Reynolds,2011).

(Grossman, 2018; Haygood, 2018; Lallanilla, 2013b; Schubert & Busciolano, 2015).

Mudslide/Landslide/Avalanche

These disasters can occur without warning and create a sudden loosening of earth from a mountain side, which travels quickly

In 2012, Super storm Sandy (hurricane and blizzard) affected eight countries, resulted in 233 deaths, and caused damage over $75 billion worldwide. Twenty-four U.S. states were affected.

- In New York City area:
  - Three hospitals were forced to evacuate (Bellevue Hospital, NYU Langone Medical Center, and Coney Island Hospital).
  - 319,575 buildings were damaged.
  - 14-Foot storm surge occurred resulting in 15 million gallons of contaminated water.
    - Langone Medical Center experienced major flooding, power outages, loss of backup generator, failure of telephones (cell and landlines). Repairs reached over 1 billion dollars.

down the slopes. There is great danger to structures in the path of this disaster as the moving landslide carries with it any structure in its path, which increases the danger to those below. Roads can be disrupted, which increases danger to motorists and emergency vehicles and may hinder evacuation routes (CDC, 2019a,b,c). Victims suffer from crush injuries from rock, soil, mud, snow, ice, and debris (trees, cars, etc.). Drowning can occur from swift moving flood waters. Many victims also sustain ocular injuries because of infiltration of mud into the eyes and must be treated emergently to limit traumatic blindness.

In 2010, a sudden, heavy downpour resulted in a mudslide in Leh, India, sending mud, rocks, and boulders cascading down the barren mountains to the communities below. The closest hospital became inoperable because of overwhelming sludge and flooding.

- Disaster victims (549 patients in total) were diverted to the next nearest hospital. In the 48-hour period after disaster, the radiology department cared for a volume typical of a 5-day period. Communication, patient identification, and documentation were difficult because of the conditions of the situation (semiconscious victims, children, etc.).
- Prompt imaging during triage and patient assessment helped minimize delays in patient care, expedite accurate diagnosis and identification of patients needing emergency surgery, and the discharge of patients without critical injury findings.
- Delays in patient care were caused by increased volume of patients, time spent identifying patients, undressing/cleaning patients (patients caked with mud made imaging difficult), utilization of hallways as patient care areas (which increased transport time and time spent looking for particular patients).

(Sen, 2013; Singh & Bhatnagar, 2016).

Tsunami

This disaster occurs as a result of a series of enormous waves (known as seismic sea waves) caused by displaced water after underwater earthquakes, volcanic eruptions, landslides, or meteorites. Tsunamis are not preventable nor entirely predictable, other than a few warning signs that may include the following:

- The ocean may appear to be “boiling” as large quantities of gas bubble up from far below the ocean surface;
- The ocean water may smell of rotten eggs, be hot, and/or sting the skin;
- A loud thunder boom may be heard, followed by a roar or whistle;
- The ocean shoreline may recede a large distance from the coastline;
- The horizon may appear red in color;
- Animals often are seen running to higher ground in advance of the receding water line.

Tsunami damage is often catastrophic in nature as powerful waves destroy structures in its path, injure or kill living beings, destroy basic infrastructure (transportation, communication, public water/sewage, etc.), and cause widespread chemical contamination and debris to be washed over land. Resulting health risks occur from contaminated water, destruction of safe housing, food supply, health care services, and so forth. There is usually a high death toll from drowning, resulting in fewer victims seeking emergency health care.

In 2011, the Great East Japan earthquake (magnitude 9.0) and resulting tsunami caused the evacuation of 150,000 people, claimed the lives of over 15,000 people (90% of those deaths were from drowning), damaged over 750,000 structures, and cost over $235 billion in damage and 4,000+ people were missing.

- Three hospitals were completely destroyed. Half of all clinics and health care facilities were damaged. Medical care was rendered at makeshift centers. For health care facilities able to remain open, there was a shortage of staff to care for patients, food, fuel, and supplies.
- Imaging capabilities were greatly diminished, if available at all.
- Three days after the earthquake and tsunami, the Fukushima Nuclear Power plant accidental meltdown occurred.
- Because there was such a great loss of life, there were fewer disaster victims seeking emergency treatment.

(Ehara, 2011; Fuse, 2012; Goodwin Veenema, 2019; McCurry, 2011; Nohara, 2011; Oskin, 2017).

Volcanoes

Volcanoes are an opening in the earth that allow molten rock, gases, and debris to erupt and flow across land at up to 100 mph. Volcanic ash can travel hundreds of miles and cause respiratory difficulties and skin/eye/nose/throat irritation for all living beings. Volcanic activity can be monitored and be somewhat predictable; however, they are also quite unpredictable. Areas that would be affected by a volcanic eruption have emergency alert systems that announce instructions for those in danger. Volcanic eruptions can additionally cause flooding, mudslides, and loss of infrastructure (roads, power, communication, clean water, etc.). Common injuries and diseases include multiple traumas, burns, infectious diseases,

respiratory compromise/suffocation, ocular injuries, and so forth.

In 1985, the Nevado Del Ruiz volcano erupted in Columbia, South America. The enormous lahar of molten lava and mudslides buried the small town of Armero, killing 25,000 people (the deadliest lahar in history). The entire town was submerged in lava and mud. All buildings and infrastructure were completely destroyed, and the town was eventually declared a 'national cemetery.'

- For those few who were able to be rescued, they suffered abrasive burns and other injuries from the caustic substances mixed in with the mud.
- The loss from this disaster included 50 schools, 2 hospitals (including all equipment), roads, railroad tracks, bridges, water/sewer systems, pipelines, 6,000 acres of farmland, and livestock.

(CDC, 2019a,b,c; NRC, 1991)

Wildfires

Wildfires are often fast moving and unpredictable. A raging fire can travel 6.7 mph through a forest and 14 mph in open fields, and these speeds can be higher if there is an upward slope involved (Siegel, 2017). Those areas in the danger zone should heed evacuation orders, routes, and instructions. The smoke from a nearby fire can quickly consume a building and cause irritation to the eyes, nose, throat, and lungs. Dangers include burns, carbon monoxide poisoning, and unstable structures (CDC, 2019a,b,c).

In 2018, a wildfire named "Camp Fire" destroyed Paradise, CA. It was the most destructive and deadliest wildfire in US history. It destroyed 153,000 acres (240 square miles), killed 86 people, destroyed 19,000+ structures, and caused estimated losses of $13 billion.

- Feather River Hospital (150 beds) in Paradise, California, had 2 hours to evacuate 80 patients (67 were inpatients) and 200 staff.
- Fire surrounded the hospital property and began to burn structures. No firefighting resources or ambulances were available to assist with protecting the hospital or with the eventual evacuation because of the overwhelming nature of this fast-moving fire, thick smoke, and evacuation of the entire town.
- Owing to the high cost of repairs, the hospital was closed and 1200+ employees laid off.

(Gabbert, 2019; Sutherland, 2019)

Organizational preparation and plans

Preparing for the "what ifs" and the "worst-case scenarios" in our world can be very difficult. Disasters are difficult to anticipate and properly plan for perfectly. By listening to the experts in the field of disaster management and learning from those who have lived through catastrophes, we can better evaluate our own environment and strengthen the disaster management plan that we create.

Community services, emergency response organizations, industries, businesses, and governmental agencies must work together when responding to a crisis in a community. Intelligence and law enforcement agencies must work together with effective communication and role delineation. During the initial event and response, competition should be set to the side and the focus placed on the safety of all members of the community. From a review of case studies looking at disasters that have occurred, there is a repeated recommendation to have a "backup plan" in case the original disaster management plan fails (Reynolds, 2019).

Each health care organization must have an individualized plan that is fitting of the facility, the size, the patient populations, layout, and security (onsite and also municipal). In addition to the organization's plan, each imaging department should have their own disaster management plan that works in concert with the organization's overall plan. Investing large amounts of capital into resilient infrastructure can be difficult to justify when there are competing projects that need to be completed in the immediate future. Until an organization has endured great hardship and loss as the result of a catastrophe, investing money into a project that may never be needed is often pushed to the side (Grain, 2014; Lau, 2013).

The events listed earlier are examples of what can happen during a disastrous event. Hospitals in earthquake zones should invest in appropriate foundations and watertight rooms to protect their expensive equipment. Radiology reading rooms should always be on a backup generator, and remote reading capability should always be in place. Regional businesses should be included in the responsibility for disaster plans and their backup: the financial district of New York City, the oil/gas industry in Texas, and the shipping industry in Southern California are essential to the well-being of not just their local communities but also the nation as a whole. Including key players in the preparation for catastrophic events for the entire area should be a priority for all involved (Lau, 2013).

Communities and organizations that have experienced catastrophic events can offer valuable firsthand accounts of the lessons learned and offer suggestions for others to consider when creating their own disaster management plan. Precise needs for each individual catastrophe may differ; however, there are many common considerations that should be included in all plans.

Lessons Learned From Hospitals That Endured a Catastrophe

Electrical considerations

- Guard against flooding of the generators and have ample fuel available to run generators.
- If there is a loss of power to industry, water treatment stations, and so forth, may negatively impact the hospital.
- The more emergency power a hospital has available, the more successful they can be during a catastrophic event.

Communication

- Incident command centers must be deployable and not fixed.
- Organizations must keep up-to-date phone lists (employees, local business, vendors, fuel companies, utility companies, medical equipment companies, etc.).

- Portable Wi-Fi units can be used if IT is down or power outages occur.
- Satellite telephones, wireless radios, amateur radios, and other forms of communication may be used if cellular telephones and/or landlines fail.
- Organizational leadership must be visible around the building, which is calm, optimistic, and ready to respond to issues (Bluth, 2007).
  - Communication must be honest, transparent, and frequent to counter the spread of inaccurate rumors and contain mounting fear among staff, patients, visitors (Jones et al., 2017).
- When calling for emergency assistance ("911") or reporting suspicious activity, essential facts should include the following:
  - What is the emergency;
  - Where are you located;
  - How many people are involved (assailants, victims, trapped, rescuers, etc.);
  - Who or what you saw;
  - When did this occur;
  - Description of those involved;
  - Threats identified (weapons, flooding, structure collapse, people trapped, etc.);
  - Where victims are located;
  - Is the situation safe or the danger ongoing.

    (DHS, n.d.; Sen, 2013)

Transportation

- Roads become congested and gridlocked;
- Fuel may become scarce;
- Employees may have difficulties getting to and from work and home.

Health care facilities

- Safety and security
  - Security during any disaster becomes essential and at times difficult.
  - Crowd control of patients, visitors, and other people who may be in the hospital becomes imperative ... it is essential to keep calm during a stressful event.
  - Disgruntled people may display poor behavior, which must be controlled to prevent a riot.
  - When supplies run low, people become desperate (food, water, medications, etc.).
  - Looting must be prevented.
  - Plan for secondary dangers of flooding (mold, wildlife, chemical exposure, etc.).
  - Surround damaged health care facilities with tall fences asap to reduce looting and increase safety and security of facilities.

    (NASEM 2017; DOH, 2011; Reynolds, 2011)
- Plans (general considerations)
  - Planning in advance improves response to the event and interaction among all involved.
  - Disaster plan should include predetermined evacuation muster stations.
  - All employees must know where to locate copies of plans and know their role during a disaster.
  - Designate stairs as "up" or "down" … facilitates movement if elevators are not functional.
- Evacuations
  - Evacuations can become chaotic and deadly.
  - Ambulances and emergency personnel may be tied up responding to the needs of the community and be unable to transport evacuated patients away from the hospital.
  - When evacuating mothers and newborns, consider putting infants in the arms of the fathers while the staff assist the mothers in evacuating.
  - If the receiving organization is not able to access the electronic medical record (EMR), then hard copies should be sent.
    - If power has been lost, printing medical records becomes difficult.
  - Buses may be used to evacuate ambulatory patients.
  - Roads may be damaged, severely congested, and fuel may become scarce.
  - Difficult to move bedridden patients if elevators are inoperable.
  - Medication/sedation may need to be considered when moving psychiatric or incarcerated patients.
  - Portable oxygen supplies will be limited and considerations must be made when transporting patients.
  - Decision to evacuate is complex (risk of moving patients; cost, how, and where to move them; etc.).
  - Tracking where patients are sent is essential especially for fragile patients and their families (newborns, pediatric patients, adults with dementia, etc.).
  - Special considerations need to be made for vulnerable populations (dialysis, ventilator dependent, neonatal intensive care unit, dementia, severe mental illness, traction, bariatric).
  - Where possible, remove IV lines and make patient IV saline locks during the storm and evacuations (IV poles can become missiles).

    (DOH, 2011; Gray, 2007; Lallanilla, 2013).
- Supplies
  - Most facilities store enough supplies for 2-5 days ... during a disaster, many run out of their stored supplies in the first 4-48 hours.
  - Many organizations have reported shortages of supplies, especially food, water, health care supplies, staff, backup generator capabilities, medications, blood supplies, personal protective equipment, and so forth.
  - Flashlights should be headlamps and handheld (plenty of extra batteries).
  - Store emergency response supplies close to where you will need to use them.
    - Plenty of paper, pens, gloves, flashlights, headlamps, batteries, first aid supplies, and tools (crowbars, shovels, etc.).
  - Verify sterility of supplies (lack of temperature and moisture control can contaminate sterile supplies).
  - Stock up on linen.
  - Personal protective equipment should include the following:
    - Hard hats;
    - Goggles, face shields, and/or safety glasses;
    - Gloves (sterile, disposable vinyl, work, waterproof, etc.);
    - Isolation gowns;
    - Hospital-laundered scrubs for staff;
    - Masks.

      (Gray, 2006).
- Buildings and equipment
  - Communication devices (radios, phones, megaphone, walkie-talkie);
  - Identification vests;
  - Vital equipment may cease to function because of uncontrollable heat, cold, loss of electricity;
  - Elevators may not be safe to use for patient transport, evacuation, or moving equipment;

- Lack of running water and water pressure leads to sewage backup and inability to perform hand hygiene and cleaning of equipment;
- Morgue loses refrigeration to preserve the deceased;
- Consider portable toilets on site asap;
- Stairways may be damaged and/or have a loss of lighting.
  - Designate stairways for “up only” and “down only” to expedite movement.
- Keep shut-off tools near equipment;
- Protect equipment from leaking roofs, broken windows, and flooding.

- Documentation and patient identification
  - Hard copy documentation, policies, and so forth, if the computer system goes down … including copies of the disaster plan.
  - If identification bracelets are not available, consider using permanent markers to write patient's name, date of birth, medical record number, allergies, and so forth, on their forearm.
  - Patients may speak a foreign language, which hampers patient identification, locating their family, and so forth.
  - Print copies of EMR for each inpatient, and prepare to send copies if transferring patients to other facilities.
  - iPads/tablets can be used if desktop computers go down.
  - Imaging department specifics
  - Radiology departments should have regular exercises that simulate MCI events. These should include the following: how many examinations can be carried out in each modality within a given time period; how long does image transfer take; reading time and report completion times; patient transport to/from the radiology department (Berger, 2016).
- If the disaster is an approaching storm, all studies should be dictated, rooms stocked with supplies, phone numbers updated, and disaster management plan reviewed with the team.
  - Extra staff should be called in.
  - Consider moving some portable equipment to essential upper floors (in case elevators fail during the storm event) (Bluth, 2007).
- The role of imaging in an MCI is to increase triage accuracy, identify injuries, and more precisely assign resources.
  - Whole body CT scans using an MCI protocol can increase the number of CT scans per hour and also detect indirect injuries that could otherwise be missed. A disadvantage is the large number of images generated that the technologists then need to reconstruct and the radiologists need to read (Korner, 2011).
- Radiology should have its own command center during an emergency with one phone number that all staff can call.
  - Frequent updates should occur, which will keep staff organized, reduce inaccurate rumors, and allay fears.
  - Staff should receive open, honest, and frequent informational updates and reassurance from leadership.
- Where possible and appropriate, establish unidirectional traffic flow through the imaging department so patients and staff enter through one end of the department and exit through the other end to prevent congestion, chaos, and overcrowding.
- Imaging departments are essential during any disaster and the complex equipment requires adequate power supply. Backup generators should supply all areas of the imaging department, including the radiologist reading suite. There should be a backup plan for times that the generator fails.
- Imaging equipment can easily become damaged by dust, water, moisture, power interruptions, room temperature variations (too hot, too cold), and vibrations (earthquake).
- Prioritize requests for imaging.
  - Only the most important imaging should be performed when resources are limited.
  - Streamline patient throughput for imaging services (assign additional personnel to identify and prepare protocol, place IV lines, and so forth, for patients coming to imaging).
- Consider other modalities (x-ray or ultrasound if CT or MRI is damaged).
- Consider other departments if the main radiology department is damaged (clinic x-ray machines, radiation oncology, OR C-arms, etc.).
- If the main radiology department is damaged, portable equipment early after the initial event may be used (portable x-ray, ultrasound, etc.).
- Remove wet or muddy clothes from patients before imaging (poor image quality, damage to equipment, etc.).
- During bio/chemical or pandemic disasters, clean equipment per infection prevention guidelines. Consider having a “clean technologist” in the control room and a “dirty technologist” working with the patient in the room.
- If technology is intact, remote radiologists may be able to assist in reading examinations.
- All steps of imaging may be affected by a catastrophic event: orders from referring physicians, patient transport, images (acquisition, coding, worklist, storage, retrieval, viewing, reporting, etc.).
  - Communication may need to be flexible (face to face, paper notes, etc.) if telephones, computers, and so forth, are inoperable.
- Some hospitals have found that having a radiologist go to the emergency department with the technologists to perform bedside x-rays and ultrasounds allows for immediate reading of images ... which allows for immediate identification of injuries, streamlines communication between the radiologist and emergency physician, and reduces the risk of errors from high volume and miscommunication or lost information, incorrect patient ID, and so forth.
- Storage of images and data is vital, and redundancy is essential (Orenstein 2016).
- Protecting equipment
  - Nuclear medicine cameras
    - Lack of power and air conditioning for extended periods of time can lead to rusting of the electronic components of the gamma camera.
  - MRI systems
    - Disaster plans should be in place to prevent quenching of the magnet.
    - MRI's cold head and vacuum pump should have its own emergency power.
    - Magnets should be filled with cryogen before predictable storm seasons.
    - Plans to prevent water damage should include the following:
      - MRI room should be watertight.
      - Elevate any equipment that could be water damaged if flooding occurs such as coils, control consoles, and MRI quench duct.
    - MRI suites should close until threat of quench passes (Gregan, 2016).
      - Risk of quench if the quench pipe is damaged, loss of temperature regulation of the liquid helium, movement of the helium inside the cryostat vessel.
      - MRI rooms should be designed to be watertight, with an additional stabilizing foundation construction. (Hayes, 2005)
- Staff

- Staff shortages (staff cannot come to work, and those who cannot leave will face exhaustion).
- Plan for 150% of normal staffing levels with enough food and water.
- Care of the staff must include risk protection and the following:
  - Physical needs must be met.
  - Protection from chemical, biological, infectious, and radiologic exposure.
  - Psychological and behavioral health should be provided.
- Staff coming into work should bring own supplies (water, food, medicines, etc.) and waterproof clothing for both hot/cold temperatures.
- Staff must stay, until replacements have arrived. Consider staffing up, in case future replacements cannot get into the hospital, and those on duty, must work elongated shifts.
- Maintain employees on payroll … need to have adequate staff for disaster recovery periods.
- Staff should be encouraged to create a family emergency plan in advance, which covers all possible disasters. Plans should cover a minimum of 3 days (best if 2 weeks of supplies on hand) and should include the following:
  - Phone numbers (family, legal, medical, community, etc.);
  - Bottled water (1 gallon/day for each person and each pet);
  - Nonperishable food;
  - Supplies for infants and pets;
  - Flashlights, headlamps, lanterns with extra batteries;
  - Medications, first aid supplies, feminine hygiene products;
  - Fire extinguisher, hand tools;
  - Location of nearest shelters;
  - Educate family members regarding local warning sirens;
  - Sleeping bags and extra blankets;
  - Hand sanitizer, personal hygiene products (wipes, toothbrush/paste);
  - Important legal documents (birth certificate, cash, credit cards, etc.);
  - Monitor for carbon monoxide poisoning;
  - Cars should have full gas tanks;
  - Wear life jackets if evacuating through standing or rushing water;
  - Avoid exposure to chemical and oil spills;
  - Avoid contact with wildlife, rodents, mosquitoes, or snakes. (CDC, 2018a, 2019a,b,c)

Conclusion

There is no perfect plan, when preparing for a catastrophic event. The best preparation includes an evidence-based plan, consideration of past events (case reviews, lessons learned, etc.), ongoing education, frequent drills, and stock piling of essential supplies. Considerations need to be designed for the individual (person, patient, staff, etc.), the departments that could be affected, the organizations that could be involved, and the community as a whole.

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