2015

Emergency Preparedness for a Radiological Disaster: Davis-Besse Nuclear Power Plant Release

Meghan A. Jackson

Wright State University - Main Campus

Emergency Preparedness for a Radiological Disaster:
Davis-Besse Nuclear Power Plant Release

Meghan A. Jackson
Wright State University

Acknowledgements

This Culminating Experience (CE) would not have been possible without the extraordinary support and mentorship of my CE Advisor, Dr. Naila Khalil; the CE Director, Dr. Nikki Rogers; and Lori Metivier, the Wright State University MPH program coordinator.

Those who gave up their time, Kevin Reilly and Patrick Moylan, to act as my readers and professional advisors will always have my deepest thanks and respect.

More than the rest, my family has been instrumental in my determination to succeed and pursue all avenues of learning – both through direct academic achievement and a desire to chase those lessons that can only be derived from everyday life and personal growth.

It is with pride, honor, and privilege that I share this accomplishment with those who nurtured my determination for education and desire to better myself since before my remembrance: Mrs. Carmel Jackson, Mrs. Stephanie L. Jackson, both Mr. Michael Jackson's (Sr. & Jr.), Nick Jackson, and Dr. Janice Pata.

Mrs. Mary Langow, I have no words that can express neither how grateful I am for the time we shared nor the regret I have that I cannot present this to you in person. I hope you know your devotion was not lost on me and my admiration of you will never falter.

Table of Contents

Abstract

Over the course of human history, man has tried to find an ultimate source of energy. Nuclear energy has been paramount to this sustainability. There have been over 420 nuclear related disasters since 1944 and preparedness has only marginally increased in response. This study examines the potential outfall of a major nuclear accident within the United States at the Davis-Besse Nuclear Power Plant. Using data from the incident that occurred in Fukushima, Japan in 2011, radiation plumes were plotted using HotSpot software over northern Ohio to examine the dispersion and concentration of radioactive particles and their potential health effects on the susceptible population. The affected area is just over 0.55 square miles, will have direct effects on approximately 157 citizens (not including emergency or plant workers), and will require the hospitalization of nearly 12 of them. While the research shows that actual victim numbers requiring hospitalization may be minimal compared to public perception, medical establishments, specifically hospitals, are ill-equipped to respond to the influx of individuals who believe they are or may have been victims.

Keywords: radiation, nuclear, response, plume modeling

Emergency Preparedness for a Radiological Disaster: Davis-Besse Nuclear Power Plant Release

Over the course of human history, man has tried to find an ultimate source of energy. It began with wood and grasses for a small cooking fire. Over time, man found the potential of coal to power steam engines and then petroleum that could propel a car, truck or tractor. It was not until the middle of the 20^{th} century that man became able to harness the power of the smallest unit of elemental measurement: the atom. Encouraged by the power of the atomic bomb, society became intrigued by the possibility to expand its power into supplying the globe with electricity and so came the birth of the nuclear power plant. Today there are 104 commercial reactors in the United States operating at 65 sites spread over 31 states registered with the United States Nuclear Regulatory Commission (USNRC). These power plants contribute approximately 20% of the power used within the United States (United States Nuclear Regulatory Commission [USNRC], 2011b). As the use of nuclear power has become common so has the necessity to prepare for potential disasters associated with it. The research presented here is an analysis of a hypothetical release of radiation from the Davis-Besse Nuclear Power Plant in Oak Harbor, Ohio. It will show the potential distance that a radiation plume could travel, the number of citizens that may be affected by its contamination, and the number of hospitals that will be in its exposure pathway.

While there are many public and private facilities that will be affected during any radiation release, this study places a focus on hospitals in the affected area. Hospitals were chosen as a specific feature due to their accessibility by the public and their role in any health related hazard in the community they serve. By their nature, hospitals have a limited supply of medical supplies that can be dispensed to the demanding public and are as vulnerable to disaster as any home or person. They are extremely vulnerable to surge during a disaster. Surge is when the demand on the hospital is greater than what it can supply. This may be in terms of bed capacity, medical goods or treatment, as well as the medical professionals who deliver them. This report will demonstrate the need of hospitals to adequately assess their vulnerability to nuclear fallout. By being forewarned of potential outcomes, hospitals will be better prepared to streamline collaboration with other facilities that will be able to support them in a time of need.

Statement of Purpose

The purpose of this study is to assess the short term impact of a 2011 Fukushima, Japan size radiation event on the surrounding community in terms of number of individuals requiring medical care and hospitalization.

Literature Review

Between 1944 and 2005, the Radiation Emergency Assistance Center Training Site (REACTS) documented 428 international major radiation accidents. This is an average of seven accidents per year since the power of the atom was harnessed (Bushberg et al., 2007). Perhaps the most well-known disasters have been Three Mile Island, Pennsylvania in 1979, Chernobyl, Ukraine in 1986, and most recently Fukushima, Japan in 2011. Each of these disasters required medical response for the affected population. As demonstrated in many disasters of the last century, a major consideration for emergency planners and response personnel is that many citizens in areas affected by either natural or manmade disasters will attempt to find their way to a hospital for treatment whether or not medical attention is necessary (D. Gerstner, personal communication, March 9, 2012).

Radiation Basics

During and following a nuclear power plant disaster the population may be exposed to radiation by a variety of routes. There is a difference between human radiation exposure and contamination. Contamination refers to a person having contact with radioactive matter while exposure occurs when person absorbs energy form a radiation emitting source. A cloud of radioactive material may pass over a populated area and expose humans to external radiation. The particles within this cloud maybe inhaled by the population causing respiratory health problems. Beta particles maybe absorbed through the skin (Amano et al., 2011). Long term contamination of the ground may cause continuous exposure in the area. As particles do not discriminate where they land, food and water may also be affected (Amano et al., 2011).

Nuclear disasters have levels of severity. There are seven levels of disaster severity on the International Nuclear and Radiological Event Scale (International Atomic Energy Agency, 2012). Nuclear events that do not pose a concern to safety are called deviations and are termed Below Scale or Level 0. Levels 1-3 are considered incidents and Levels 4-7 are accidents. These levels are described in Table 1: International Nuclear and Radiological Event Scale.

Table 1

International Nuclear and Radiological Event Scale

Level	Classification	Description	Examples
1	Anomaly	Minor safety component problems; stolen radioactive source (such as fuel rods) or device	No real-life example. Breach of operation limits at nuclear power plant
2	Incident	Exposure to public of 10mSievert; exposure of workers over set limits	Cadarache, France (1993) Atucha, Argentina (2005) Forsmark, Sweden (2006)
3	Serious Incident	Exposure of 1 Sievert/hr or greater in operating area; non-lethal health effects	Vandellos, Spain (1989) Sellafield, United Kingdom (2005)
4	Accident with Local Consequences	At least one death from exposure; meltdown of or damage to fuel of 0.1% release of core inventory	Saint Laurent des Eaux, France (1980) Tokaimura, Japan (1999)
5	Accident with Wider Consequences	Several deaths from exposure; severe damage to core; significant public exposure	Windscale Pile, United Kingdom (1957) Three Mile Island, United States (1979)
6	Serious Accident	Significant radioactive release requiring preplanned countermeasures and evacuation	Kyshtym, Russia (1957)
7	Major Accident	Major radioactive release requiring extension of planned countermeasures and evacuation	Chernobyl, Ukraine (1986) Fukushima, Japan (2011)

Note: Information taken from International Atomic Energy Agency, 2012

Measurement

Ionizing radiation is the energy that is given off and/or the electromagnetic wave that can produce ions when it interacts with matter. There are three types of radioactive decay in escalating order: alpha (α), beta (β), and gamma or X-rays (γ). Radioactive decay is the process by which an atom gives off energy or particles (DiNardi, 2003, p. 573). Ionization can kill cells directly or cause genetic damage. High doses of radiation can result in burn effects and can kill cells. A low dose of radiation doesn't kill cells but if the cells are genetically damaged and can still replicate the mutated cell can form cancerous cells which can develop into tumors.

While we cannot see or feel it, radiation can enter the human body by penetrating skin, via inhalation and/or the ingestion of food or water contaminated by radiation. Alpha particles have the lowest penetrating ability and can be stopped by a piece of paper or an article of clothing. When alpha particles are inhaled, ingested or introduced into the body through an open they have the greatest potential for harm because of their ionizing power. Beta particles have a greater capacity for travel through the air than alpha particles and can be halted by a sheet of aluminum. The distance that a radioactive particle can travel is important is important to risk assessment because it will expand the risk area. If a beta emitting substance is left on the skin it can cause a burn or skin irritation. Gamma rays move at the speed of light and require a material, such as lead or thick concrete, to stop (Bushberg et al., 2007). In terms of a radiation release, individuals who stay within their home or building as a cloud passes will not be affected by alpha or beta energy but may be impacted by gamma radiation depending on the thickness and material of the structure.

After any radiation release into the air from a nuclear power plant, exposure and contamination will be measured in one of two ways; either as an absorbed dose or an effective dose. The absorbed dose is “the amount of energy deposited per unit mass of matter” and is measured in units of rad (Bushberg et al., 2007) or in gray (Gy), an international term where one gray is equal to 100 rad (DiNardi, 2003, p. 574). Effective dose is the measure of biological damage caused per each unit of dose received and is measured in units of rem (Bushberg et al., 2007) or Sievert (Sv) where one Sievert is equal to 100 rem (DiNardi, 2003, p. 574). Simplified, absorbed dose is the measurement of radiation before it enters the body and effective dose is the measurement of radiation within the body. For all intents and purposes, a rad and a rem are used interchangeably to calculate doses of beta and gamma radiation (Bushberg et al., 2007).

Similarly, the terms Gray and Sievert are used interchangeably during an emergency so that responders can estimate the absorbed dose based on the effective dose. Researchers may measure in Gray rather than rad when the radiation levels are very high.

Radiation Health Effects

The average person living in the United States receives approximately 300 mrem of radiation per year from natural sources such as radon and cosmic rays in combination with manmade sources. Individuals who have X-rays or radiation therapy will have higher doses of radiation than individuals who do not. Also, some individuals will have increased radiation exposure from their workplaces or occupation (Bushberg et al., 2007). The National Council on Radiation Protection and Measurements and the International Council on Radiation Protection estimate individuals providing emergency response may receive a dose up to and exceeding 50 rem while administering lifesaving aid during a release event. These groups suggest that the low cancer risk associated with this exposure is acceptable when it is compared to the potential of lives saved by their efforts (Bushberg et al., 2007). Emergency department workers who handled Chernobyl victims received radiation doses less than one rem (Bushberg et al., 2007). Workers and firefighters at the Chernobyl nuclear power plant received between 70 and 1,300 rem during and immediately following the explosion of the reactor (Sevior et al., 2012).

Acute radiation syndrome (ARS) is a rare illness because it requires a victim to have a radiation dose greater than 100 rad. Its severity is dependent on the amount of the body that is exposed (the more exposure, the greater the severity), and the level and the type of radiation. Symptoms and indicators of ARS present in four stages: prodromal or initial, latent period, manifest illness, and recovery or death. The onset of the initial stage is dependent upon the dose received. The latent period is when the victim will feel an alleviation of symptoms prior to the manifest stage. During the manifest illness stage, the radiation exposure will cause effects to the hematopoietic system. After the manifest stage, the victim will either die from their radiation exposure or they will recover. Those who survive may develop long-term health effects from their exposure.

Initial onset of ARS ranges from a few minutes to several hours depending on the exposure level. When exposure is between 100 and 200 rad, onset can take up to six hours. The first symptoms will present as nausea, vomiting, diarrhea and fatigue and can last between 24 and 48 hours. Lymphocyte counts will also decrease in response to the level of dose received. The central nervous system will be affected when the dose exceeds 200 rad. When exposure is over 3,000 rad, onset of ARS will occur within minutes (Bushberg et al., 2007).

The latent period of ARS is only experienced with dose levels below 800 rad and can occur up to two weeks post exposure. The lower the radiation exposure the individual experiences the longer the latency period can be. During the latency period, the ARS victim will feel healthy and will be without any major symptoms. It will appear as though the patient has recovered from ARS and will require little medical attention. However, following the latency period, medical attention is of the utmost importance (Bushberg et al., 2007).

The manifest period of illness will occur from one day to two weeks post exposure. The onset of the manifest period will occur sooner as the dose absorbed increases. During this time, it is critical that the individual receive medical care to decrease the risk of mortality. During the manifest illness stage, damage is done to the hematopoietic system. Blood cell leukocyte and platelet counts are lowered when radiation dose is between 100 and 800 rad is received. At this stage, decreasing infection is the primary objective for medical personnel. This can be done through the use of broad-spectrum antibiotics and other traditional infection care. When a victim has a dose over 800 rad, damage is primarily to the intestines resulting in diarrhea, sepsis and electrolyte imbalance. These symptoms are treated through hydration and antibiotics (Bushberg et al., 2007).

The fourth stage of ARS is either recovery or death. When radiation doses exceed 600 rad, the likelihood of survival past 90 days is minimal. With doses exceeding 1,000 rad, there is little that medical treatment can do to prevent death. When the dose is over 3,000 rad, death will most likely occur within a day or two post exposure (Bushberg et al., 2007).

Burns are the leading cause of death in radiation exposure patients due to high infection rates associated with them. Burns that appear immediately following exposure to radiation are most commonly due to thermal heat whereas radiation burns tend to appear days after the exposure. Individuals with radiation burns may also present with the initial symptoms of ARS such as nausea and vomiting (Bushberg et al., 2007).

Hereditary radiation effects have not been observed in human studies even when the subjects were exposed to high levels of radiation though they have been demonstrated in animal models (Bushberg et al., 2007). There is some evidence to suggest teratogenic effects of radiation when the dose received by the embryo or fetus was greater than ten rem and may increase the rate of post-natal cancer (Bushberg et al., 2007). Teratogenic effects are those that do not affect the parent but impact the child. These effects may either appear at birth or throughout the child’s life.

Radiation Exposure Treatment

Decontamination of radiation victims follows the same process as chemical decontamination. Decontamination showers have a high flow of water and victims use hand soap to cleanse themselves. Radiation decontamination should not take precedent over medical treatment. For example, individuals who suffer from burns may lose skin tissue during the decontamination process which increases the healing time of the victim. After medical treatment has been administered, decontamination may begin. It may not be possible to remove all traces of radiation from a victim so decontamination should just try to reduce the levels to twice background levels or until no further reduction can be achieved (Dainiak et al., 2006).

The most important aspect of any medical intervention is time. The sooner treatments are started; the greater the chances are that the victim will survive the exposure. There are several medical treatments for radiation exposure and related conditions; many are specific to symptoms or the isotope to which the person was exposed. Burns caused by the thermal heat of radiation or those that are caused by radiation directly are treated in the same fashion as traditional burns (Dainiak et al., 2006).

To help treat patients and assess the damage from Chernobyl, the Soviet government enrolled more than 100 medical experts, radiobiologists, transplant specialists and physicists from within the Soviet Union and the United States (Gale & Baranov, 2011). This team treated more than 200 people who were exposed to between one and 15 Gray of ionizing radiation. Of the 200 patients only 29 died from radiation exposure. The focus of the medical team was to provide immediate response, such as help with decontamination and tending to burns, and short term medical attention. The team was most successful in treating those exposed to radiation by administering broad-spectrum antibiotics and anti-viral drugs to reduce infections caused by thermal burns. The medical team also gave transfusions of red blood cells and platelets to those exposed to increase oxygen levels in the blood and clotting. Other medical interventions included infusions of human fetal liver cells and bone marrow transplants were used to decrease infection and boost white blood cell counts. To promote production of blood cells in bone marrow the team used molecularly-cloned granulocyte-macrophage hematopoietic growth factor (also known as cytokines) (Gale & Baranov, 2011). Cytokines reduce the potential for infection from thermal burns, the number one cause of death from radiation exposure (Dainiak et al., 2006). The sooner victims are treated with cytokines, the higher the rate of survival. It is suggested that hospitals have enough cytokines to treat between four and six victims for two to four days at which point additional supplies will be required. Cytokines are also included in the Strategic National Stockpile supplied by the Centers for Disease Control and Prevention (Dainiak et al., 2006). The Strategic National Stockpile is made up of 12 separate stockpiles of drugs that can be deployed to any location in the United States within 12 hours of a terrorist attack, infectious disease outbreak, natural or manmade disaster.

Reducing the time an individual is susceptible to radiation absorption is key to limiting its health effects. Potassium iodine (KI) will flood the thyroid with iodine limiting its ability to absorb radioactive isotopes. While this may be considered prophylaxis against the effects of radiation, it is likely that potential or actual victims will only receive it after a release has already occurred and after they may have already been exposed. One of the benefits of KI is that it is safe for both adults and children. When taken within an hour before or after exposure it can prevent over 90% of absorption of radioactive iodine. If KI taken between three and four hours post exposure it can prevent up to 50% of iodine uptake. It can be taken for several days at a time to limit uptake from contaminated spaces. However, as time after exposure increases, the effectiveness of KI decreases (Solon & Rosenberg, 1981). In Connecticut, citizens living within a ten mile radius of nuclear power plants have access to KI tablets via their town halls upon request and stockpiles are held at both public and private schools to be provided to children and staff in the event of a radioactive disaster. For infants less than one month old, the KI dose is 16 mg. Children under three years of age should take 32 mg and those between three and eighteen should take 65 mg. Adults will take a dose of 130 mg. All of these doses are for daily intake until there is no longer a risk of radioactive iodine uptake (Dainiak et al., 2006).

Much like KI many treatments for radiation exposure are specific to one radioisotope. The specificity of radiation treatments poses a barrier for treatment as it is necessary for emergency responders and medical personnel to know the type of isotope exposure victims received in order to properly treat them (Weiss & Landauer, 2009). Diethylenetriamene pentaacetate (DTPA) is used a chelating agent against the effects of the radioisotopes plutonium, curium and americium. DTPA decreases the body burden of actinides when given as a treatment after radiation exposure. Actinides are the metallic elements with high atomic numbers including thorium and uranium. Prussian Blue and Radiogardase® are used for decorporation of cesium-137 (Weiss & Landauer, 2009). Decorporation is the removal of radionuclides from the body by the body (Maidment, 2012).

Nuclear Power Plant Basics

Nuclear power plants have been used for power production since the 1950s. Many plants are older and are in the process of being retrofitted or decommissioned and replaced with newer plants. Due to the necessary safety concerns surrounding plants, they are constantly being monitored and inspected in-house to ensure that they are up to code. There are 104 active nuclear power plants in the U.S. Of these 69 are pressurized water reactors and 35 are boiling water reactors. Pressurized water reactors use water as a moderator and primary coolant. The water that is used as a coolant is not the same water that is used to create steam which powers the turbine. Nuclear fission occurs when a heavy atomic nucleus absorbs a neutron causing the atom to split into two lighter atoms.

Uranium, one of the rarest elements on Earth, is the fundamental element used in electrical power production. Uranium-238 is almost exclusively found in combination with uranium-235. In its natural state, uranium is 99.3% uranium-238 and 0.7% uranium-235. Within a reactor, uranium-238 absorbs a neutron and becomes uranium-239. The uranium-239 quickly undergoes decay by releasing an electron or beta particle converting it to neptunium-239 which will then lose an electron to become plutonium-239; plutonium-239 can also be used to create electrical power. One gram of uranium can produce the same amount of electrical energy as three metric tons of coal (Sevior et al., 2012). Uranium-235 can sustain a fission chain reaction which makes it more important to nuclear power as it releases 200 mega-electron volts. The radioactive bi-products of uranium-235 fission include cesium, iodine, and xenon (World Nuclear Association, 2014). It is important to understand the concept of nuclear fission so that both emergency response personnel as well as public health practitioners understand why there are so many different isotopes that may be released during a radiation incident.

Nuclear fission creates energy in the form of heat. Heat is the transfer of energy from one substance to another. Coolant is used to move heat away from the fuel source and disperse it throughout the reactor. This allows the reactor to maintain a working temperature and reduces the risk of reactor melting.

A number of different processes have been developed to cool nuclear reactors; the most commonly used are pressurized water reactors, heavy water reactors, and high temperature gas cooled reactors. In pressurized water reactors heat is used to turn water into steam which runs a turbine. In boiling water reactors, the water used to make steam becomes the coolant for the reactor after it is cooled. In high temperature gas cooled reactors, a gas (helium or carbon dioxide) is used as a coolant. The gas coolant works in a similar fashion as water by dispersing the heat throughout the reactor to lower the temperature of the nuclear fuel. As heat is released from the fuel rod, the gas molecules surrounding it move faster. This movement allows the heat to be dispersed throughout the reactor. As the heat spreads, the energized molecules mix with those that are cooler to regulate the temperature. High temperature gas cooled reactors operate at much higher temperatures than water systems. Higher temperatures result in greater efficiency though the power output is limited because gas does not cool as efficiently as water. Heavy water reactors use water that is enriched with the deuterium isotope of hydrogen. The most significant benefit of these plants is that unenriched uranium can be reused within the reactor (Sevior et al., 2012).

A major concern about the process of generating electricity is that as uranium is broken down within nuclear power plants nuclear waste is generated. The waste includes many different isotopes, the most common of which are cesium-137, cesium-135, iodine-129, plutonium-239, and strontium-90. This waste is a public health concern because the radioactivity degenerates very slowly. The deterioration is measured in half-life, the length of time that it takes for the isotope to decrease its radioactivity by half. The radioactivity of an isotope determines its half-life. The more highly radioactive isotopes have a shorter half-life. For example, strontium-90 has a half-life of 28 years and is more radioactive than iodine-129 which has a half-life of 15.7 million years (Sevior et al., 2012). In the case of a nuclear event, iodine isotopes are likely to be in the fallout. These isotopes are particularly dangerous to human health because of their rapid uptake in the thyroid. Awareness of the level of threat of radioactive waste is an important public health concern.

Isotopes that make up radioactive waste also have human benefits. Iodine-131, a byproduct of nuclear power, is used in medical treatments for thyroid cancer. Iodine-131 is highly radioactive with a half-life of 8.02 days (Chow, 2005).

Nuclear Power Plant Disasters

Of the 428 major nuclear incidents, most people have only heard of three: Three Mile Island, Chernobyl, and Fukushima. Other nuclear incidents have occurred but due to a lack of severity, they have gone unnoticed by the general public. Three Mile Island Nuclear Power Plant, the site of one of the most notorious nuclear plant disasters in the United States is located in Dauphin County, Pennsylvania. On March 28, 1979 a pressurizer relief valve in reactor two became stuck in the open position. When emergency cooling pumps that would have flooded the reactor with coolant turned on, operators shut them off believing the problem was due to a broken indicator light. With the pumps shut off the coolant levels within the reactor became too low to keep the reactor from overheating and subsequently melting (Tunnicliffe, 2011). As the reactor melted, it began releasing radiation within the facility's containment dome. The radiation level being emitted by the melted reactor reached as high as 30,000 rad per hour. This high level of radiation required the containment dome be decontaminated (Walker, 2004, p. 193). At the beginning of the clean-up stage there were two million liters of contaminated water. Zeolite, an aluminosilicate mineral that absorbs strontium and cesium from the water, was used to decontaminate the water and turn it into potable water. Continued pumping of water to cool the reactor resulted in a total of over ten million liters of potable water being processed by the time the decontamination of the plant was concluded. Clean-up efforts continued for years, it was not until 1990 that the reactor was completely defueled (Tunnicliffe, 2011).

President Carter established the Kemeny Commission to investigate the incident. The commission reported that the only public health threat posed by the incident was mental distress. In a subsequent report the Pennsylvania Health Commissioner, Gordon MacLeod, found more than twice the number of hypothyroid cases in babies nine months following the meltdown than in the nine months prior to it. MacLeod also found that there was more than twice the number of infantile deaths within a ten mile radius of the plant six months following the release compared to the same six months of the previous year (Mangano, 2004). An article written by New York health officials reported a three-fold increase the normal level of xenon-133 in the state's capital for five days following the meltdown (Mangano, 2004). Increased levels of beta radioactivity were reported in Portland, Maine (Mangano, 2004). Columbia University researchers investigated the increase cancer risk of the areas affected by the plant meltdown. Though the researchers found that there was a 64% increase in cancer rates from 1981-1985 when compared to 1975-1979 no association between the meltdown and the cancer rate was found. Mangano (2004) concludes that the health effects of Three Mile Island have not been thoroughly examined and many questions remain unanswered.

On April 26, 1986, one of the worst recorded nuclear disasters occurred at a nuclear power plant in Chernobyl, Ukraine. An explosion within the plant followed by a fire sent a plume of approximately 20,000 roentgens[1] (R) per hour into the air radiation across Ukraine, Belarus, and Russia within ten days of the disaster. The Soviet Ministry of Medium Machine Building, the department of government that oversaw the nuclear plants within the Soviet Union, was not notified of the explosion within the plant until April 27th. The ministry was not given complete information about the disaster until the 28th. After receiving this information, the

[1] A roentgen is equal to one rad of absorbed dose or is equivalent to 0.01 Gray of gamma radiation (DiNardi, 2003, p. 574).

ministry began notifying the public. Two people were reported killed by the explosion. Two hundred-thirty-seven workers were diagnosed with Acute Radiation Sickness by the World Health Organization. Another 50 workers died while fighting the fire at the plant (Gorbachev, 2011). Immediately after the disaster, the Soviet government evacuated more than 135,000 citizens from the fallout zone. In the following months 200,000 additional citizens were moved out of the fallout zone (Gorbachev, 2011).

Radiation alarms are positioned in many cities around the globe to monitor background radiation levels as well as fallout from disasters. On the day of the Chernobyl incident, radiation alarms at the Forsmark Nuclear Power Plant in Sweden – over 700 miles away – sounded. Seventy-seven thousand square miles of Europe and the former Soviet Union were coated with radiation fallout from the plant. Some areas surrounding the plant are still off limits to the public due to high radiation levels. This high level of radiation has the potential for long-term consequences such as increased risk of thyroid cancer (Gorbachev, 2011).

On March 11, 2011 an M 9 earthquake occurred off the eastern coast of Japan causing tsunami waves to hit entire east coast of Honshu from Chiba to Aomori Japan. The combination of these two natural disasters resulted in severe damage to the Fukushima Dai-ichi Nuclear Power Plant. This damage resulted in the release of radiation from the power plant (Amano et al., 2011).

Amano et al. (2011) studied the radiation fallout of the Fukushima nuclear power plant for two months following the disaster. Chiba is a metropolitan area approximately 220 km (about 136.7 miles) south-southeast of the plant. On March 15th the researchers documented the first evidence of the radioactive plume in Chiba City (Amano et al., 2011). Over the course of the study, the external irradiation from the passing cloud resulted in primary peaks of radioactive substances, mainly of iodine (^{131}I and ^{132}I), xenon (^{133}Xe), and cesium (^{134}Cs and ^{137}Cs). All five of these isotopes produce gamma radiation. The study found the maximum dose rate was 0.5 µGy[2] or 0.0005 rad per hour. Researchers estimated that the external exposure was 135 µSv[3] or 0.0135 rem within the first month and then reduced to 101 µSv or 0.0101 rem during the second month. The total radiation level at the end of the study was found to be 0.13 µGy or 0.0013 rad per day. The researchers suspect that because much of the surface radiation contamination was from the cesium species. The half-live of cesium-134 has a half-life of two years and cesium-137 has a half-life of 30 years. It is anticipated that the radiation levels will take years to show a measurable decline (Amano et al., 2011).

Amano et al. (2011) also measured the effective inhalation dose of radiation for infants (less than one year of age), children (two to seven years of age) and adults (greater than 17 years of age). They found that ^{131}I, ^{134}Cs and ^{137}Cs were the primary sources of inhaled radiation. Adults in the first month had an effective inhalation dose of 65 µSv (0.0065 rem) and 0.4 µSv (0.00004 rem) in the second. Children had an effective dose of 108 µSievert the first month and 0.6 µSievert the second. The study calculated the inhalation effective dose as a worse case, where an individual was outside and exposed all day (Amano et al., 2011). The findings of this study may help plan for the effects of a radiation release in future disasters.

Cleanup of radiation contamination is important for both immediate response to a nuclear disaster as well as the long term response. Radiation is continuously released throughout the life of an isotope. The continued release poses as much of a health risk as the initial release. The government of the former Soviet Union and the current government of the Ukraine recognized this fact and established the Exclusion Zone around the destroyed reactor at Chernobyl. The

[2] A µGy is equal to 1.0 x 10^{-6} Gy.
[3] A µSv is equal to 1.0 x 10^{-6} Sv

Exclusion Zone, also called the Zone of Alienation, is a 30 kilometer in diameter area. Despite efforts over the years to clean it, the area it remains highly radioactive (Petryna, 2011).

The Fukushima incident released more radiation than was released during the Chernobyl event. Because the nuclear power plant was close to the coastline a greater proportion of the radiation fell into and was absorbed by the ocean with a smaller amount falling on land. As a result, there was a decreased burden of radiation on the land area near the plant (Tunnicliffe, (2011). Radioactive material that falls on land is absorbed and attaches to different soil types at different rates. How radioactive material responds depends on the isotope and soil composition. Not all radiation will be deposited in the immediate area of the incident. The wind may carry radiation long distances in a short period of time (Monte, 2010). As the distance radiation travels increases, the concentration of radioactive material that is dispersed decreases as the radiation settles and is deposited in the environment (USNRC, 2011a). This makes it necessary to understand the impact of radiation travel (Monte, 2010).

In an attempt to decontaminate the area that was affected by the fallout from the Fukushima incident, the Japanese government has budgeted $14 billion toward the effort through 2014. As part of the cleanup plan, they have been removing the top two inches of topsoil in the area. The goal is to reduce the radiation to 0.2 μSv. Past the removal stage of the cleanup, the Japanese government is having difficulty deciding what to do with the waste that will be generated. At this stage of the process, some 60 tons have been collected (Yamaguchi, 2012).

Endo et al. (2010) estimated the external dose for locations within and outside of the evacuation zones. An external dose is the dose to the environment that could be equal to the absorbed dose. One sample was taken within five kilometers, fifteen were between 20 km and 40 km away from the plant, and two were 60km. The density of radiation found in the soil was used to determine the variation in time from the air dose rate. The researchers also accounted for the decreasing dose by adjusting for the half-life of the isotopes and the time of radioactive deposition. As would be expected, the location closest to the plant received the highest dose of radiation. However the farthest location, Fukushima Niihama Park at 62 km had the fifth highest dose rate at 39 µSv/hour. It is estimated that for one year following the incident the cumulative dose at Niihama Park will exceed 40 mSv. This dose is greater than the emergency exposure limit (Endo et al., 2011). This study shows that radiation levels outside the boundaries of the established evacuation zones may still pose a health risk.

Potential Areas at Risk

Emergency response plans are established by nuclear power plants as a way of protecting their workers as well as the surrounding populations. As a part of these plans, they work with local authorities to create evacuation zones based on safety guidelines established by the United States Nuclear Regulatory Commission (USNRC). Evacuation zones are essential for protecting the population and reducing the number of individuals that will be exposed to radiation. As the regulating body of nuclear power plants, the USNRC is responsible for overseeing the creation of emergency preparedness plans of nuclear power plants within the United States. During a radiation release, the USNRC requires a minimum evacuation zone with a radius of two miles for all individuals as well as those within a five mile radius downwind of the release point with exaggerated boundaries on the sides. The USNRC refers to this as a “keyhole pattern” (see Figure 1) (USNRC, 2011a). This pattern allows adjustments for changes in wind speed and direction which carry radiation from the release point. According to the USNRC, the population within a 10 mile radius will most likely be advised to stay indoors until they receive further instructions. As the disaster unfolds, extensions of the evacuation zones will be determined based on need (USNRC, 2011a).

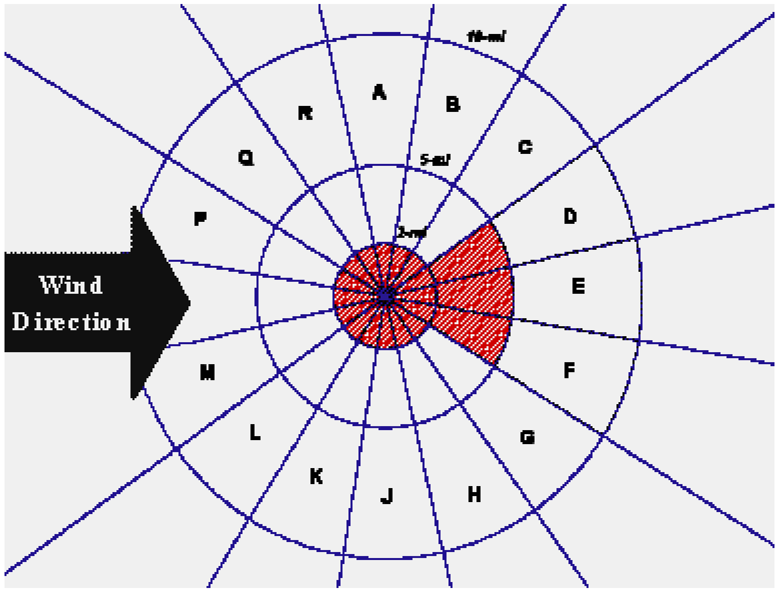

Figure 1. Radiological release evacuation zones demonstrated as a keyhole pattern.
Note: Graphic from USNRC, 2011a

Following the Fukushima incident, the Japanese government initially evacuated a three kilometer range and then extended that to first 10 km and then 20 by the second day (Endo et al., 2011). Expecting the worst, the USNRC advised the 300 or so United States citizens living within a 50 mile radius of the plant to evacuate the area. When Japanese citizens heard the US advisory it, caused a disruption to the Japanese government's plan as there were for the two million Japanese citizens living within the 50 mile radius of the plant the same area (von Hippel, 2011).

The USNRC utilizes two emergency planning zones around nuclear power plants. The first 10 miles surrounding the plant are called the plume exposure pathway and was defined by the USNRC. Within this area, the primary concern of emergency planners is public exposure to airborne contamination from a radioactive plume. The second zone, established by the

Environmental Protection Agency, is a 50 mile perimeter surrounding the plant in which foods and water may be contaminated by radioactive waste; a serious concern for emergency planners (USNRC, 2011b).

Evacuation Plans

A release of radiation from a nuclear power plant may require that populations near the plant be evacuated. There are many limits to emergency response and evacuation plans. Lack transportation and crowding on evacuation routes are just two of the limits that can hinder a plan's efficiency. Any delays in a response or evacuation plan can cause or exacerbate medical problems resulting from exposure to radiation such as burns and acute radiation sickness. It is essential that emergency planners and those responsible for the implementation of emergency response plans test all aspects of their plan from medical response to road capacity (Georgiadou, Papazoglou, Kiranoudis, & Markatos, 2010).

In response to the release at the Fukushima Daiichi plant, the USNRC developed a Task Force to look into the ability of nuclear power plants in the United States to respond to a radiation release of that magnitude. The USNRC defined this as a release from more than one reactor, power failure, communication blackouts, and a release from stored spent fuel pools, the majority of which is stored onsite at reactor stations. The Task Force found that the United States is severely unprepared for a nuclear disaster of nearly any magnitude (Miller et al., 2011). The Physicians for Social Responsibility is an advocacy group that works to prevent the use of nuclear weapons produced a report that includes analysis of the impact of a natural disaster on nuclear reactors in the U.S. This report indicates that if a release occurred at the Indian Point facility outside of New York City, 17.3 million people would have to be evacuated from the 50 mile radius around the plant (Physicians for Social Responsibility, 2012). A release from the

Davis-Besse Plant in Oak Harbor, Ohio would require an estimated 16,494 people from ten miles surrounding the plant and 2,013,948 people in a 50 mile radius be evacuated or affected by a radiation release not including Canadian populations that could potentially be effected (evacuee numbers are for the entire area population and are not correlated to wind direction) (Physicians for Social Responsibility, 2011). These evacuation zones are shown in Figure 2. The red inner circle represents a 10 mile radius and the blue outer circle represents a 50 mile radius. The icon containing the radiation symbol in the center of the circles marks the location of the Davis-Besse facility.

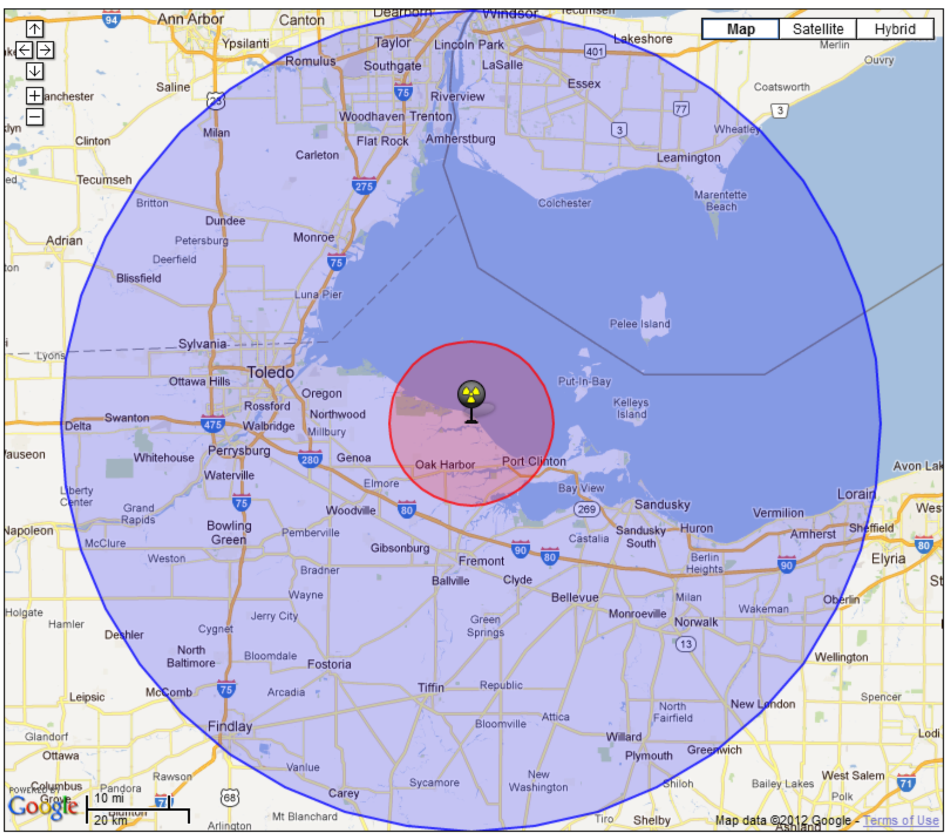

Figure 2. Davis-Besse nuclear power plant 10 and 50 mile evacuation zones.

Hospital Response and Capacity

Hospitals are governed by the Joint Commission on Accreditation of Healthcare Organizations which requires hospitals to develop emergency response plans for mass casualty events that can be coordinated with the National Response Plan. The Connecticut Radiation Response Planning Group prepared a manual to be used in for emergency response entitled "Radiation Preparedness and Response for the Public Health and Hospital Workforce" (Dainiak et al., 2006). The "Radiation Preparedness and Response for the Public Health and Hospital Workforce" manual (herein referred to as "the Connecticut manual" or "manual") provides guidelines for Connecticut hospitals when responding to a nuclear disaster. The manual is designed to be scaled to events of any size whether only a single individual or hundreds of people are affected. Much of the plan focuses on the emergency department because whether they are brought in by emergency response personnel or if they walk in of their own accord the majority of victims from a nuclear incident will arrive in the emergency department (Dainiak et al., 2006). Transportation is also covered because many injured and contaminated individuals will be transported to hospitals in ambulances. This will expose both emergency response personnel and the ambulance to radiation. These vehicles will need to be decontaminated and labeled with radiation warning signs prior to reuse. Emergency response personnel who come into contact with radiation will require decontamination prior to returning to work (Dainiak et al., 2006).

The Connecticut manual establishes the emergency department nurse supervisor as the person responsible for initiating and ensuring that the hospital plans are followed. Doctors are responsible for patient care and are under the supervision of the emergency department medical director. The manual establishes six classes of triage based on level of injury and radiation exposure. Individuals who are neither injured nor have been exposed to or contaminated with radiation will be triage into Class I (Dainiak et al., 2006). In the event of a serious nuclear event, these individuals may arrive at the hospital out of panic rather than necessity (Bushberg et al., 2007). Individuals who present with injuries but without radiation exposure or contamination will be triaged into Class II. Individuals who have been exposed but are not contaminated and do not have physical injuries will be triaged into Class III. Individual who have been exposed and present with physical injuries but are not contaminated will be triaged into Class IV. Individuals who are contaminated but do not have physical injury will be triaged into Class V. Individuals who are contaminated and have physical injuries will be triaged into Class VI (Dainiak et al., 2006).

The Connecticut manual recommends that individuals triaged into Class V be processed in a decontamination area, most likely outside of the hospital itself. Individuals in Class VI should have their injuries tended to prior to decontamination especially if the injuries are life threatening. The model recommends that decontamination trailers used for chemical exposures be used for decontamination of radiation. It is recommended that decontamination aim to lower the level of contamination to below twice the background level or below 0.05 mR[4] per hour. (Dainiak et al., 2006).

The "Radiation Preparedness and Response for the Public Health and Hospital Workforce," indicates that a variety of hospital staff have a role both preparing the hospital for the arrival of contaminated patients as well as providing treatment for those patients. The radiation safety officer will help assess risk to staff as well as the patient from the radiation exposure. The nuclear medicine department which normally deals with radiation cancer treatment as well as nuclear diagnosis procedures will help the radiation safety officer, help analyze samples taken from patients, and assist in the monitoring of patient transport vehicles for radiation. Housekeeping staff who normally change and clean linens should help in preparing

[4] mR is milliroentgens.

areas for patient arrival as well as cleanup after the event. The engineering staff should help with decontamination of the facility as well as providing assistance in blocking off the rest of the hospital from areas that are contaminated. Other personnel not essential to immediate patient care should be placed under the supervision of the radiation safety officer. Medical staff such as nurses and doctors will undertake their normal responsibilities of patient care while protecting themselves from any radiation present by wearing personnel protective equipment including double gloves, face masks, and gowns to protect their clothing (Dainiak et al., 2006).

Methods

This report will examine a hypothetical nuclear release of radiation from the Davis-Besse Nuclear Power Plant in Oak Harbor, Ohio. This plant was chosen due to its history of flaws reported by the USNRC including “cracking of control rod drive mechanism (CRDM) nozzles, degradation of the reactor pressure vessel (RPV) head, potential clogging of the emergency sump, and potential degradation of the high-pressure injection (HPI)” in FY2002 (USNRC, 2009).

Tools

Radiation levels found following the Fukushima incident will be applied to the area around the Davis-Besse plant using Google Earth. The plume will be created utilizing HotSpot software developed by the National Atmospheric Release Advisory Center (NARAC) (2013). When the plume pathway is overlaid on a Google Earth map, population totals for the area of the plume can be determined. The effected population will be determined by the finding the total geographic area for each dose group and multiplying it by the population density for the state of Ohio.

Assumptions and Limitations

The estimation of exposure will be assumed at a "worse case" scenario. If this scenario were to actually happen, following notification that there was an incident at the plant, citizens within the area would be told by responding officials to shelter in place (stay indoors) or to evacuate. For the purposes of the research presented here, it will be assumed that these directives were not given for the duration of exposure, i.e. 48 hours. Since radiation does not behave in the same way other environmental contaminates do, exposure will be assumed to be continuous. This is because while the walls of a building may shield individuals from the source outside, their bodies, clothing and objects would become radioactive themselves and result in continued exposure.

Exposure through continuous soil contamination decay and the exposure from consuming water and food will not be explored within this paper. It will be assumed that there is no evacuation of the area and that there will be no treatment prior to the release such as with potassium iodine tablets to reduce the uptake of iodine into the system.

To provide an estimate of victims and casualties, it will be assumed that individuals who are exposed to five to 50 rad will develop changes in their blood chemistry affecting their ability to heal (United States Environmental Protection Agency [USEPA], 2011) (Bushberg et al., 2007). Those who are exposed to 50 to 100 rad will develop a variety of symptoms but will not develop ARS. Individuals exposed to radiation levels over 100 rad will develop ARS but to varying degrees (Bushberg et al., 2007). The health consequences that will be used in this assessment are described in Table 2.

Table 2

Health Consequences of Nuclear Release Scenario

Dose (rad)	5-50	50-100	100-200	200-600	600-800	800-3,000	More than 3,000
Disease/ Symptom	Changes in blood chemistry	Nausea, fatigue, vomiting, hair loss, diarrhea	ARS	ARS & Burns	ARS & Burns	ARS & Burns	ARS & Burns
Percent of People Needing Hospital Care	None	Depends on degree of symptoms	Less than 5%	90%	100%	100%	100%
Length of Hospital Stay	None	Symptoms may not present immediately	45-60 days	60-90 days	90+ days	Weeks to Months	Days to Weeks
Mortality	None	None	Minimal	Low if Treated	High	100%	100%

Note: Information derived from Bushberg et al., 2007 and USEPA, 2011.

Scenario

The level of release will be within the range of the incident at Fukushima, maxing out at 400 mSievert[5] per hour (AFP/Reuters, 2011). It will be assumed that this release is predominately ^{131}I and ^{137}Cs (Hamada & Ogino, 2011). Iodine-131 will have a total release of 13,515,513 curies; cesium-137 at 270,270 curies (USNRC, 2013). The presented research will focus on air exposure beginning at the initial release and continuing over two days (48 hours). This time frame was chosen because it is equal to length of time that the United States assumes that it can provide prophylaxis to the entire population in the event of a public health emergency (Institute of Medicine (US) Forum on Medical and Public Health Preparedness for Catastrophic Events, 2008).

[5] One mSievert is equal to 0.001 Sievert or 0.01 rem.

The weather conditions for this hypothetical situation were chosen by using the average conditions for a day in April measured by the National Oceanic and Atmospheric Administration (NOAA) in Toledo which is the closest city to the plant. The wind speed used in this analysis in 10.9 miles per hour in a southeasterly direction (National Oceanic and Atmospheric Administration [NOAA], 2008). The temperature will be assumed constant at 60.1°F (NOAA, 2012). It will be assumed that there is no rainfall or snow occurring at the time of the incident. The inversion layer and mixing height is set to 15,000 feet.

Overlaying of the data files was done by the author unless otherwise cited. Figure 3 shows the location of the two nuclear power plants within the state of Ohio: the Davis-Besse plant and the Perry 1 plant. Major cities are noted by name and a small red dot while the nuclear power plants are noted by name with a green circle with a black dot in the center of it. Both of these plants are located on the border of Ohio and Lake Erie. Their position to the lake is advantageous for providing easy access to water for cooling the reactors. However this also makes them vulnerable to climatic events that occur in relation to the lake such as high wind speeds and potentially dangerous waves.

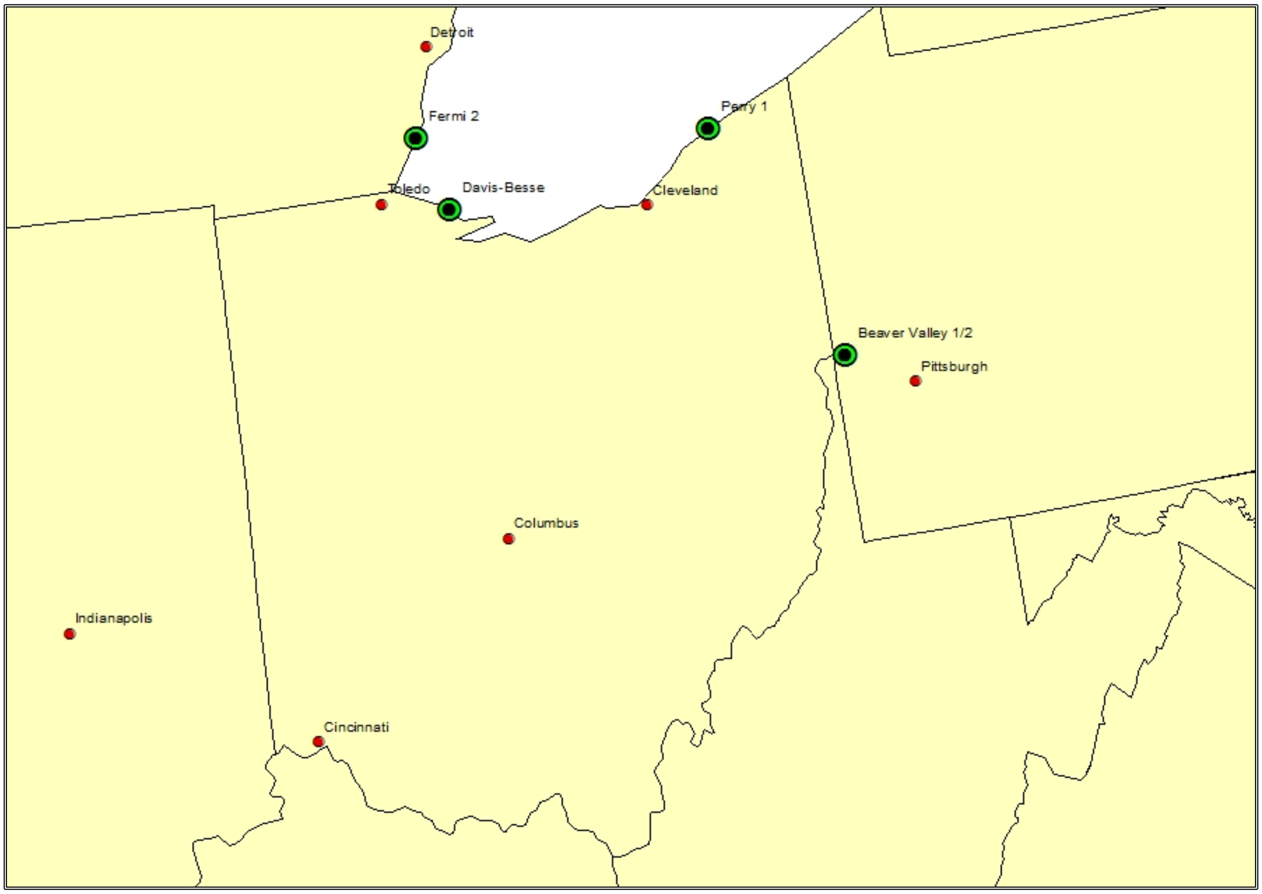

Figure 3. Nuclear power plants in and around Ohio, US.

Results

Using Hot Spot software (NARAC, 2013) with the inputted values for the scenario, the radiation plumes following a radiation release of 48-hours were plotted on Google Earth maps (Figure 4). The five (5) rad plume radius extends 1.68 miles from the plant and is the outer radius of the exposure. The 50 rad plume is 0.48 miles; 100 rad hits its limit at 0.33 miles; and 200 rad at 0.23 miles. The 600 rad (0.13 miles), 800 rad (0.11 miles), and 3,000 rad (0.05 miles) all fall within the confines of the plant.

Figure 4. Radiation plumes scenario for Davis-Besse plant release.

Radiation plume areas requiring hospitalization shows the plumes which would result in at least some or all of the victims requiring hospitalization (Figure 5). The highest radiation dose limit for these victims is 50 rad. Victims requiring hospitalization within the 50 rad plume area would depend on the severity of their presented symptoms. As shown in Table 3, it is assumed that all victims would require some form of hospitalization or medical attention to combat their symptoms.

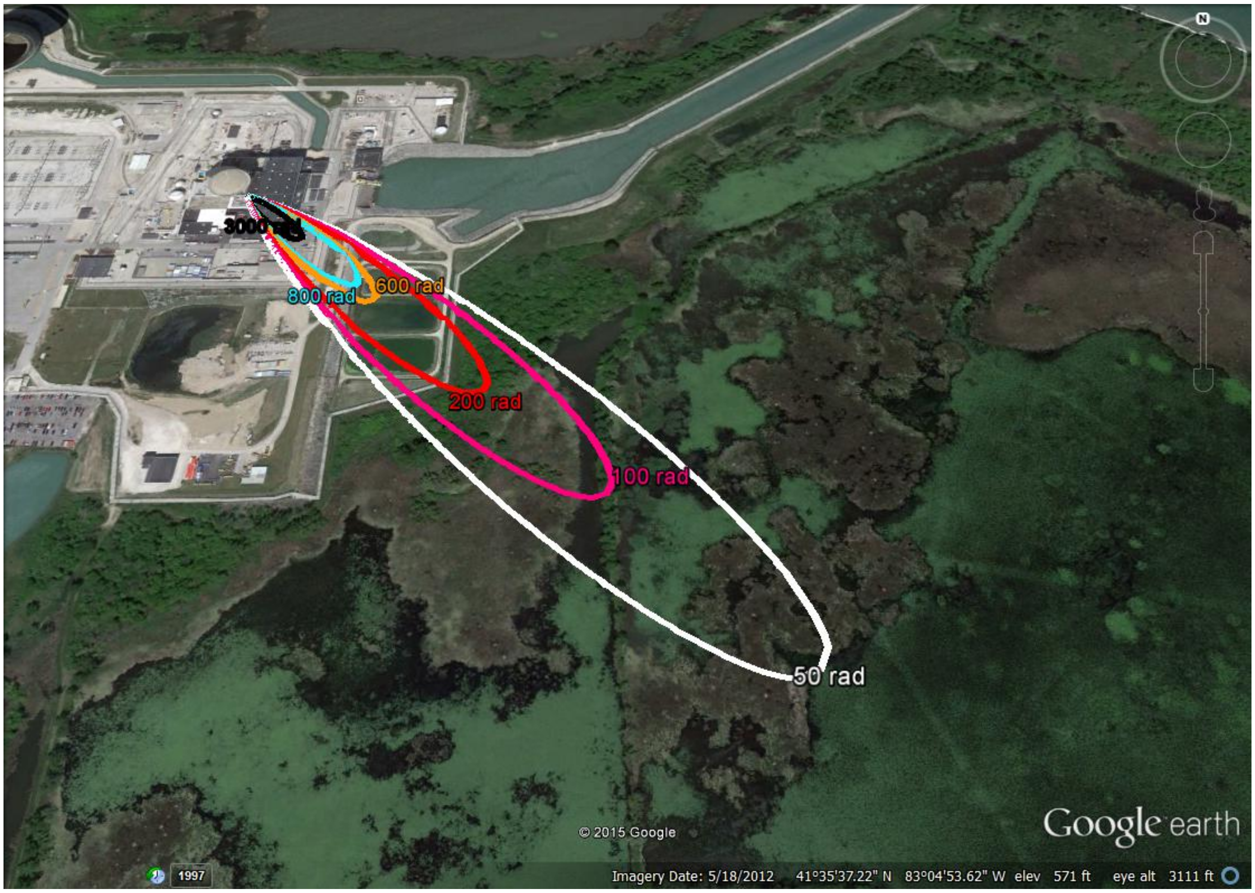

Figure 5. Radiation plume areas requiring hospitalization.

Table 3

Radiation Exposure Victims & Medical Response

	5-50 rad	**50-100 rad**	**100-200 rad**	**200-600 rad**	**600-800 rad**	**800-3000 rad**
Total Area (square miles)	0.50	0.03	0.01	0.01	0.00	0.00
Population Within Area	142.2	7.6	3.4	1.7	<1	<1
Number of Affected Persons Requiring Hospitalization (adapted from percentages found in Table 2)	0	7.6	<1	1.5	<1	<1
Disease/Symptoms	Changes in blood chemistry	Nausea, fatigue, vomiting, hair loss, diarrhea	ARS	ARS & Burns	ARS & Burns	ARS & Burns
Length of Hospital Stay per Person	None	Symptoms may not present immediately	45-60 days	60-90 days	90+ days	Weeks to Months
Mortality	None	None	Minimal	Low if Treated	High	100%

The total square miles of each plume and effective population based on the population density of Ohio is described in Table 3. Based on these figures, the majority of victims requiring hospitalization and highest incidents of mortality will be Davis-Besse employees, not civilians. The area receiving more than 3,000 rad in this scenario would be too small to make calculations relevant and was therefore not examined.

Discussion

Based on the scenario's plume data, the greatest number of individuals exposed to radiation will fall in the lowest dose range and will not require immediate medical care or hospitalization. Those with the greatest dose levels and will require extended medical care will likely be plant workers and emergency responders. The total area affected - within the established rad limits – for this scenario was 0.55 square miles.

The population density of the state of Ohio was used to calculate the number of victims within each plume. This creates artificiality in the results as the population within the surrounding area of the plant may be higher or lower than the state average. For example, while the number of victims receiving doses of 600 rad and greater are very low (less than one victim), these numbers could be expected to be higher due to the density of employees within the plant within those plume areas. On the other extreme, the number of individuals receiving lower doses may be exaggerated as the area surrounding the plant is relatively undeveloped compared to metropolitan areas of Ohio.

Despite effective efforts to triage the arrival of actual victims and those who arrive out of panic, hospitals are likely to be extremely unequipped to handle the influx. Following the arrival of a single individual with minor injuries and radiation contamination at the emergency room at the White Plains Hospital (White Plains, New York) in the 1990s, it took approximately 20 individuals from the engineering department to adequately prepare the department. The associate director of the hospital noted that while the hospital and staff were prepared for this one patient because of practiced drills, it is unlikely that it would be prepared to respond to large numbers of contaminated patients even today (Tucker, 2012).

While the scenario presented here creates the illusion that the affected population would remain manageable, Bushberg et al. (2007) suggests that because many individuals may arrive at the hospital out of panic, triage should takes place outside of the hospital. This triage strategy is often used during other mass casualty events such as mass transit accidents or chemical spills. This strategy will limit the number of people entering the hospital; keeping the emergency department as spacious as possible for patient treatment. Outside triage will also limit the amount of radiation entering the facility (Bushberg et al., 2007). Decontamination of the hospital should aim at reducing the amount of radiation to less than twice that of the background levels (Bushberg et al., 2007). Plans similar to the "Radiation Preparedness and Response for the Public Health and Hospital Workforce" are or should be in place in hospitals throughout the country (Dainiak et al., 2006).

Conclusion

The scenario presented here accurately represents a radiation plume that has a limited life span of 48 hours. While useful for short term planning, the half-lives of the radioactive isotopes presented here far exceed that time frame. This study also does not take into account the environmental resources including food stuffs and water that would drastically increase the internal dose of individuals within and outside of the air borne plume area. Utilizing the state's population density is both a strength and limitation of the study and other model projections. In less dense areas, it will provide an exaggerated estimate of the effected population allowing for increased preparedness however, the opposite is true if used in areas that far exceed the state's density.

From the research presented here, it becomes clear that hospitals and emergency response agencies should work in concert with nuclear power plants in their area as well as emergency preparedness organizations to increase their readiness to respond to a nuclear event. Future research should examine long term airborne plumes and the impacts of environmental contamination on the public. Research should also be conducted into more effective methods of decontamination and controlling the spread of contamination. The global community has been fortunate to have seen relatively few high consequence nuclear events. As nuclear power plants continue to age, the likelihood of these events occurring will also increase and the need for preparedness even greater. When the consequences of an event are high, it should not be the industry standard to react but rather to be proactive.

References

AFP/Reuters. (2011). Nuke plant blasts raise radiation threat. *ABC News*. Retrieved March 19, 2012 from http://www.abc.net.au/news/2011-03-15/nuke-plant-blasts-raise-radiation-threat/2656398

Amano, H., Akiyama, M., Chunlei, B., Kawamura, T., Kishimoto, T., Kuroda, T.,…Morimoto, T. (2011). Radiation measurements in the Chiba Metropolitan Area and radiological aspects of fallout from the Fukushima Dai-ichi Nuclear Power Plants accident. *Journal of Environmental Radioactivity, 111*, 42-52. doi:10.1016/j.jenvrad.2011.10.019

Bushberg, J. T., Kroger, L. A., Hartman, M. B., Leidholdt, E. M., Miller, K. L., Derlet, R., & Wraa, C. (2007). Nuclear/Radiological Terrorism: Emergency Department Management of Radiation Casualties. *The Journal of Emergency Medicine, 32*(1), 71-85. doi:10.1016/j.jemermed.2006.05.034

Chow, S M. (2005). Side Effects of High-dose Radioactive Iodine for Ablation or Treatment of Differentiated Thyroid Carcinoma. *Journal of Hong Kong College of Radiologists, 8*, 127-135.

Dainiak, N., Carpini, D. D., Bohan, M., Werdmann, M., Wilds, E., Barlow, A., …Rockwell, S. (2006). Development of a Statewide Hospital Plan for Radiologic Emergencies. *International Journal of Radiation Oncology Biology Physics, 65*(1), 16-24. doi:10.1016/j.ijrobp.2005.12.047

DiNardi, S. R. (2003). *The Occupational Environment: Its Evaluation, Control, and Management* (2nd ed.). Fairfax, VA: American Industrial Hygiene Association.

Endo, S., Kimura, S., Takatsuji, T., Nanasaw, K., Imanaka, T., & Shizuma, K. (2011). Measurement of soil contamination by radionuclides due to the Fukushima Dai-ichi

Nuclear Power Plant accident and associated estimated cumulative external dose estimation. *Journal of Environmental Radioactivity*, *111*, 18-27. doi:10.1016/j.jenvrad.2011.11.006

Gale, R. P. & Baranov, A. (2011). If the unlikely becomes likely: Medical response to nuclear accidents. *Bulletin of the Atomic Scientists*, *67*(2), 10-18. doi:10.1177/0096340211399849

Georgiadou, P. S., Papazoglou, I. A., Kiranoudis, C. T., & Markatos, N. C. (2010). Multi-objective evolutionary emergency response optimization for major accidents. *Journal of Hazardous Materials*, *178*, 792-803. doi:10.1016/j.jhazmat.2010.02.010

Gorbachev, M. (2011). Chernobyl 25 years later: Many lessons learned. *Bulletin of the Atomic Scientists*, *67*(2), 77-80. doi:10.1177/0096340211399746

Hamada, N. & Ogino, H. (2011). Food safety regulations: what we learned from the Fukushima nuclear accident. *Journal of Environmental Radioactivity*, *111*, 83-99. doi:10.1016/j.jenvrad.2011.08.008

Institute of Medicine (US) Forum on Medical and Public Health Preparedness for Catastrophic Events. (2008). *Dispensing Medical Countermeasures for Public Health Emergencies: Workshop Summary*. Retrieved from http://www.ncbi.nlm.nih.gov/books/NBK4111/

International Atomic Energy Agency. (2012). *The International Nuclear and Radiological Event Scale* [Fact Sheet]. Retrieved from http://www.iaea.org/Publications/Factsheets/English/ines.pdf

Maidment, B. W. (2012). *Radionuclide Decorporation Agents for Radiation/Nuclear Emergencies: Project BioShield (R01)*. Retrieved April 16, 2012 from http://grants.nih.gov/grants/guide/rfa-files/RFA-AI-06-030.html

Mangano, J. (2004). Three Mile Island: Health Study Meltdown. *Bulletin of the Atomic Scientists*, September/October, 31-35.

Miller, C., Cubbage, A., Dorman, D., Grobe, J., Holahan, G., & Sanfilippo, N. (2011). *Recommendations for Enhancing Reactor Safety in the 21st Century*. Retrieved April 22, 2012 from http://pbadupws.nrc.gov/docs/ML1125/ML112510271.pdf

Monte, L. (2010). Modelling multiple dispersion of radionuclides through the environment. *Journal of Environmental Radioactivity*, *101*, 134-139. doi:10.1016/j.jenvrad.2009.09.006

National Atmospheric Release Advisory Center (NARAC). (2013). *HotSpot: Health Physics Codes for the PC*. Retrieved October 4, 2015 from https://narac.llnl.gov/HotSpot/HotSpot.html

National Oceanic and Atmospheric Administration (NOAA). (2008). *Wind- Average Wind Speed- (MPH)*. Retrieved March 19, 2012 from http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/avgwind.html

National Oceanic and Atmospheric Administration (NOAA). (2012). *Toledo Normals and Records for April*. Retrieved March 19, 2012 from http://www.erh.noaa.gov/cle/climate/tol/normals/tolnrtapr.html

Petryna, A. (2011). Chernobyl's survivors: Paralyzed by fatalism or overlooked by science?. *Bulletin of the Atomic Scientists*, *67*(2), 30-37. doi:10.1177/0096340211400177

Physicians for Social Responsibility. (2011). *Evacuation Zones for Nuclear Reactors*. Retrieved April 21, 2012 from http://www.psr.org/resources/evacuation-zone-nuclear-reactors.html

Physicians for Social Responsibility. (2012). *Nuclear Power and Public Health: Lessons From Fukushima, Still Dangerously Unprepared*. Retrieved April 21, 2012 from http://www.psr.org/resources/nuclear-power-and-public-health.html

Sevior, M., Okuniewicz, I., Meehan, A., Jones, G., George, D., Flitney, A., & Filewood, G. (2012). *Everything you want to know about Nuclear Power: The Science of Nuclear Power*. Retrieved March 12, 2012 from nuclearinfo.net/Nuclearpower/TheScienceOfNuclearPower

Solon, L. R. & Rosenberg, K. (1981). The release of radioiodines in a nuclear emergency. *The Bulletin of the Atomic Scientists, 37*(8), 54-56.

Tucker, C. (2012). U.S. unprepared to respond to nuclear incidents, reports say. *The Nation's Health, 42*(4), 1-12.

Tunnicliffe, H. (2011). Fukushima's Future: lessons from Three Mile Island. *TCE: The Chemical Engineer, 841*, 22-24.

United States Environmental Protection Agency (USEPA). (2011). *Health Effects*. Retrieved May 13, 2012 from http://www.epa.gov/rpdweb00/understand/health_effects.html

United States Nuclear Regulatory Commission (USNRC). (2009). *Results, Trends, and Insights of the Accident Sequence Precursor Program*. Retrieved April 22, 2012 from http://pbadupws.nrc.gov/docs/ML0921/ML092190728.pdf

United States Nuclear Regulatory Commission (USNRC). (2011a). *Backgrounder on Emergency Preparedness at Nuclear Power Plants*. Retrieved May 13, 2012 from http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/emerg-plan-prep-nuc-power-bg.html

United States Nuclear Regulatory Commission (USNRC). (2011b). *Fact Sheet on Emergency Preparedness at Nuclear Power Plants* [Fact Sheet]. Retrieved March 19, 2012 from http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-emerg-plan-prep-nuc-power.html

United States Nuclear Regulatory Commission (USNRC). (2013). *Fukushima Health Effects* [Power Point]. Retrieved 4 October 2015 from http://homer.ornl.gov/nrc/conf/fukushima_health_effects_nov_2013.pdf

von Hippel, F. N. (2011). The radiological and psychological consequences of the Fukushima Daiichi accident. *Bulletin of the Atomic Scientists, 67*(5), 27-36. doi:10.1177/0096340211421588

Walker, J. S. (2004). *A Nuclear Crisis in Historical Perspective: Three Mile Island*. Los Angeles, CA: The University of California Press.

Watkins, S. M., Perrotta, D. M., Stanbury, M., Heumann, M., Anderson, H., Simms, E., & Huang, M. (2011). State-Level Emergency Preparedness and Response Capabilities. *Disaster Medicine and Public Health Preparedness, 5*(Suppl. 1), S134-S142.

Weiss, J. F. & Landauer, M. R. (2009). History and development of radiation-protective agents. *International Journal of Radiation Biology, 85*(7), 539-573.

World Nuclear Association. (2014). *Physics of Uranium and Nuclear Energy*. Retrieved 5 December 2015 from http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Introduction/Physics-of-Nuclear-Energy/

Yamaguchi, M. (2012, March 11). Japan’s radiation zone cleanup costly, no guarantee of success. *Dayton Daily News (Dayton, OH)*, p. 8A

Appendix 1: List Competencies Met

Tier 1 Core Public Health Competencies

Domain #1: Analytic/Assessment Skills
Describes factors affecting the health of a community (e.g., equity, income, education, environment)
Identifies quantitative and qualitative data and information (e.g., vital statistics, electronic health records, transportation patterns, unemployment rates, community input, health equity impact assessments) that can be used for assessing the health of a community
Applies ethical principles in accessing, collecting, analyzing, using, maintaining, and disseminating data and information
Uses information technology in accessing, collecting, analyzing, using, maintaining, and disseminating data and information
Selects valid and reliable data
Collects valid and reliable quantitative and qualitative data
Describes public health applications of quantitative and qualitative data
Uses quantitative and qualitative data
Describes assets and resources that can be used for improving the health of a community (e.g., Boys & Girls Clubs, public libraries, hospitals, faith-based organizations, academic institutions, federal grants, fellowship programs)
Contributes to assessments of community health status and factors influencing health in a community (e.g., quality, availability, accessibility, and use of health services; access to affordable housing)
Describes how evidence (e.g., data, findings reported in peer-reviewed literature) is used in decision making
Domain #2: Policy Development/Program Planning Skills
Contributes to state/Tribal/community health improvement planning (e.g., providing data to supplement community health assessments, communicating observations from work in the field)
Contributes to development of program goals and objectives
Contributes to implementation of organizational strategic plan
Gathers information that can inform options for policies, programs, and services (e.g., secondhand smoking policies, data use policies, HR policies, immunization programs, food safety programs
Explains the importance of evaluations for improving policies, programs, and services
Describes how public health informatics is used in developing, implementing, evaluating, and improving policies, programs, and services (e.g., integrated data systems, electronic reporting, knowledge management systems, geographic information systems)
Domain #3: Communication Skills
Communicates in writing and orally with linguistic and cultural proficiency (e.g., using age-appropriate materials, incorporating images)
Solicits input from individuals and organizations (e.g., chambers of commerce, religious organizations, schools, social service organizations, hospitals, government, community-based organizations, various populations served) for improving the health of a community
Describes the roles of governmental public health, health care, and other partners in improving the health of a community
Domain #4: Cultural Competency Skills
N/A
Domain #5: Community Dimensions of Practice Skills
Describes the programs and services provided by governmental and non-governmental organizations to improve the health of a community
Recognizes relationships that are affecting health in a community (e.g., relationships among health departments, hospitals, community health centers, primary care providers, schools, community-based organizations, and other types of organizations)
Suggests relationships that may be needed to improve health in a community
Supports relationships that improve health in a community
Provides input for developing, implementing, evaluating, and improving policies, programs, and services
Domain #6:Public Health Sciences Skills
Identifies prominent events in the history of public health (e.g., smallpox eradication, development of vaccinations, infectious disease control, safe drinking water, emphasis on hygiene and hand washing, access to health care for people with disabilities)
Retrieves evidence (e.g., research findings, case reports, community surveys) from print and electronic sources (e.g., PubMed, Journal of Public Health Management and Practice, Morbidity and Mortality Weekly Report, The World Health Report) to support decision making

Domain #6:Public Health Sciences Skills (Cont'd)
Recognizes limitations of evidence (e.g., validity, reliability, sample size, bias, generalizability)
Describes evidence used in developing, implementing, evaluating, and improving policies, programs, and services
Domain #7: Financial Planning and Management Skills
N/A
Domain #8: Leadership and Systems Thinking Skills
Describes the ways public health, health care, and other organizations can work together or individually to impact the health of a community

Concentration Specific Competencies

Emergency Preparedness:
Demonstrate the understanding of model leadership in emergency conditions
Communicate and manage information related to an emergency
Demonstrate the mastery of the use of principles of crisis and risk management
Use research and/or evaluation science methodologies and instruments to collect, analyze and interpret quantitative and qualitative data
Employ ethical principles in the practice of public health emergency preparedness
Demonstrate an understanding of the protection of worker health and safety