A Question of Benefit versus Risk: Pilgrim Nuclear Power Station

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ABBREVIATIONS

BRC – Blue Ribbon Commission

BWR – Boiling Water Reactor

DG – Diesel Generators

DOE – Department of Emergency

ECCS – Emergency Core Cooling System

EOP – Emergency Operating Procedures

EPA – Environmental Protection Agency

HVAC – Heating, Venting, Air-conditioning and Ventilation

IC – Isolation Condenser

ICRP – International Commission of Radiological Protection

IEEE – Institute of Electrical and Electronic Engineers

LOCA – Loss of Coolant Accident

NOAA – National Oceanic Atmospheric Administration

OBE – Operating Basis Earthquake

PWR – Pressurized Water Reactor

RCIC – Reactor Core Cooling System

SBO – Station Blackout Operation

SSE – System Shutdown Earthquake

SSW – Salt Service Water

TEPCO – Tokyo Electric Power Company

UNSCEAR – United Nations Scientific Commission on the Effects of Radiation

USNRC – United States Nuclear Regulatory Commission

EXECUTIVE SUMMARY

This report was requested by Representative Anne Gobi to discuss the benefits and risks associated with Pilgrim Nuclear Power Station and develop recommendations based on the data collected. Concern about the safety of the plant increased after the accident that happened at the Fukushima Daiichi Nuclear Power Plant on March 11, 2011. Extensive research was done to formulate recommendations on the safety of the plant and its evacuation plans.

Since there are a number of complexities surrounding the nuclear plant, the goal of this project was to discuss the benefits and risks associated with Pilgrim Nuclear Power Station and develop recommendations based on the data collected. To accomplish our goal, we established three primary objectives.

1. Assess the risks for an accident that currently exist at Pilgrim Nuclear Power Station.
2. Evaluate the current emergency response and evacuation plans at Pilgrim.
3. Analyze the societal, environmental, and economic impacts the plant has under both normal operating conditions and in the event of a disaster.

The data to accomplish these objectives was collected by means of archival research supplemented with key interviews.

Applying the Fukushima Disaster to Pilgrim

As a result of the insufficient flood protection and design, water from the tsunami disabled eleven of the twelve generators and the cooling water pumps at Fukushima (Mohrbach, 2011). The loss of these generators caused an entire station blackout. The loss of offsite power combined with the loss of diesel power at a nuclear power plant increases the risk of malfunction by approximately seventy percent (USNRC, 2005). Pilgrim has two diesel generators for the one active reactor on site, and they are both located in separate, elevated locations (Eldred, 2012). To further reduce the risk of a complete station blackout, Pilgrim has a third station blackout generator. This station blackout generator is also located in a watertight, elevated location. In the event that Pilgrim Nuclear Power Station lost power and both diesel generators were destroyed, the third station blackout generator would maintain safe function of the plant (T.Setzer, personal communication, October 3, 2012).

As a direct result of the destruction of both the generators and the cooling water pumps, the supply of cooling water available to cool the core of Reactor One at Fukushima was drastically limited. The ultimate heat sink at Pilgrim is called salt service water [SSW] and has five vertical pumps that draw water from the Cape Cod Bay (USNRC, 2007). The SSW consists of two open loops, and each loop requires two pumps. In the event of a loss of coolant accident [LOCA], only one loop of SSW is required to properly cool the core of the reactor. Pilgrim has a backup cooling water loop and a common spare in the event of a core shutdown (USNRC, 2007). Based on the structural differences between the generators and the cooling pumps at Pilgrim Nuclear Power Station and Fukushima Daiichi Nuclear Power Plant, the exact same cooling failure could not occur at Pilgrim Nuclear Power Station.

After the nuclear disaster at Fukushima, the USNRC immediately performed inspections at all United States nuclear power plants (T.Setzer, personal communication, October 3, 2012). The inspection assessed Pilgrim’s ability to mitigate the consequences of large fires and explosions, station blackout conditions [SBO], internal and external flooding, and the thoroughness of the emergency response procedures (USNRC, 2011d).

Spent Fuel at Pilgrim Nuclear Power Station

The spent fuel pool at Pilgrim has the capacity to hold 1000 fuel assemblies, and the reactor core at Pilgrim Nuclear Power Station has roughly 580 fuel assemblies (T.Setzer, personal communication, October 3, 2012). Approximately every 18-24 months, roughly 194 fuel assemblies in the reactor core at Pilgrim must be removed and placed in a spent fuel pool(T.Setzer, personal communication, October 3, 2012). This process is called a fuel outage (See Glossary). Fuel outages are completely necessary for the reactor to function properly, but this process fills the spent fuel pool in a matter of years.

While spent fuel pools are only a temporary means of storage for the fuel assemblies, dry cask storage provides a more permanent solution. Pilgrim recently licensed the company Holtec to begin building dry cask storage structures (T.Setzer, personal communication, October 3, 2012). In fact, Pilgrim Nuclear Power Station must have the dry cask storage up and running within the next few years because they are running out of space in their spent fuel pool (T.Setzer, personal communication, October 3, 2012). While dry cask storage is a safer means of storage in terms of Pilgrim Nuclear Power Station’s current spent fuel situation, it is not a feasible solution for all nuclear power plants. Under these circumstances, the nuclear power industry should shift their focus to developing a plan to remedy the dangerous spent fuel situation.

Possible spread of radiation around Pilgrim

Wind plays a crucial role in the spread of radiation. After the disaster at Fukushima, wind carried dangerous levels of radiation nearly 30 miles inland, covering an area of more than 700 square miles. If a similar disaster were to occur at Pilgrim, the radiation could contaminate the entire county of Plymouth and portions of Barnstable County as well. Wind patterns show that the majority of Cape Cod is susceptible to receive significant levels of radiation in the event of a disaster.

Evacuation response at Fukushima

Reports show that the evacuation after the Fukushima was poorly executed due to major communication failures between TEPCO, the owner of Fukushima, and the Japanese government. The evacuation radius was eventually expanded to twice the planned distance which caused a significant amount of confusion and chaos among Japanese residents. The Nuclear Accident Independent Investigation Committee (NAIIC) reports that 146,520 people were evacuated in total and many were relocated more than once due to the three evacuation zone expansion orders. This shows that all parties involved with emergency preparedness at Fukushima was completely unprepared to handle a disaster of this magnitude. We can learn a significant amount from this that we can apply to emergency response procedures at nuclear power plants in the United States in order to make the evacuation plans more appropriate for a potential disaster.

Emergency plan and Evacuation for Pilgrim

The evacuation plan at Pilgrim is designed and executed by the Nuclear Preparedness Department (NPD) of the Massachusetts Emergency Management Agency (MEMA). The Emergency Planning Zone (EPZ) surrounding Pilgrim includes the towns of Plymouth, Kingston, Duxbury, and portions of Carver and Marshfield (Entergy, 2011). The plan covers reception centers, Radiological Emergency Worker Monitoring & Decontamination Stations (RWEMDS), and transportation for schools, licensed day care facilities, children's camps, nursing homes, hospitals, group homes, and correctional facilities. The Radiological Emergency Response Plan also includes services such as environmental monitoring, public alerting, special needs assistance, crisis counseling, meal accommodations for evacuees, business restoration assistance, and many others. The training department offers training to the approximately 4700 emergency responders for Pilgrim and conducts federally evaluated emergency exercises every two years (Commonwealth of Massachusetts, 2012).

The current evacuation plan for Pilgrim involves a 10 mile radius as required by the NRC. This zone is home to more than 75,000 people, as well as 21 public schools and one hospital. In order to notify the public of a nuclear threat, Entergy owns and operates 112 emergency sirens within the 10 mile radius of the plant. These sirens will alert residents that there is a potential threat, and residents are instructed to tune to one of the Emergency Alert System (EAS) Radio Stations. The evacuation plan is only effective in the 10 mile radius so it is susceptible to many of the same failures that were experienced at Fukushima.

Cape Cod presents a unique scenario for disaster planning. Large portions of Cape Cod are at high risk for dangerous levels of radiation if a disaster were to occur at Pilgrim. Since the Cape does not fall within the 10 mile radius of the plant, there is no predetermined evacuation plan in place for a nuclear disaster. There is an emergency plan designed in response to hurricanes or other severe weather, however this plan does not take into account the issues involved with a nuclear scenario and most likely will not be implemented in the event of a nuclear disaster. If a disaster were to occur that would require the evacuation of portions or the entire cape, there are several issues that will need to be addressed. One primary concern is that there are only two bridges (excluding the railroad bridge) that cross the Cape Cod Canal, both of which are within 20 miles of the plant. Although this concern has been acknowledged by the NRC, an alternative plan has not been determined (Cassidy, 2012).

Environment after a Disaster

Chernobyl accident may have benefitted certain species of animals because of the creation of a mostly human-free exclusion zone. Species of eagles have been able to move into the zone to reproduce without any human disturbances, which has been beneficial for the eagles and other species. However, while there may have been some beneficial effect to the accident on the environment, the radiation did have a negative impact on the flora and fauna around Chernobyl. The worst effects on the environment occurred in a twenty mile radius around the plant. Radiation decreased the reproductive success of much of the flora and fauna, which decreased both the amount and variety of plants and animals in the areas around the plant (Geras'kin,S.A.; Fesenko,S.V.; Alexakhin,R.M., 2008). Even if not killed directly from the accident, if populations of fish are rendered sterile it could sharply decrease the population numbers for future generations. In a controlled study done on Tilapia it was found that at an exposure level of .0004 - .0005 grays of strontium-90 per day had a noticeable change on reproduction. These levels were maintained for 90 days providing a total dose of .036-.045 Gy, which is about four times above the normal background levels. The males had smaller gonads, reproduction started earlier, and there were 20 percent fewer normal offspring per female (Sazykina,T. G.; Kryshev,A. I.,2003).

The impact of the intake of the cooling system on the environment is also a concern. Over a period of twenty-six years the Pilgrim power plant was responsible for the impingement of at least 562,025 fish and shellfish and the entrainment of 24,314,325,386,670 (24 trillion) fish and shellfish eggs and larvae (Environmental Protection Agency [EPA], 2002). It is difficult to determine the impact this has had on Cape Cod Bay without further research being performed.

Human Health

The effects of radioactive iodine on the thyroid are some of the most documented topics when it comes to how radiation affects the human body. Because thyroid cancer develops in children who have been exposed to radioactive isotopes of iodine it became a noticeable trend after the Chernobyl accident. There was an international average rate of thyroid cancer in children of 1 for every million child per year before the accident while after the accident one measurement showed 44 cases of thyroid cancer in children for every million children per year in Belarus.

Recommendations

After extensive research, we came to the following conclusions and recommendations:

- Moving the spent fuel from the Pilgrim Nuclear Power Station to a permanent will need to be done in the future, and to do so, a permanent nuclear repository must be developed.
- A secondary evacuation plan with a 20 mile radius should be developed so that it can be executed in the event that a disaster at Pilgrim exceeds the scope of a 10 mile evacuation
- A disaster plan should be developed for Cape Cod that provides the same services offered to those within the current 10 mile evacuation zone, as well as evacuation routes for those living on the Cape within 20 miles of the plant.
- If an accident were to occur, the thyroid health of children should be the prime health concern.
- More research must be done to determine the effect Pilgrim's intake system has on Cape Cod Bay.

INTRODUCTION

In spite of its many benefits, the use of nuclear power has been debated since its establishment because of the associated risks. However, the complexities of nuclear power make it difficult to decisively evaluate the risks and benefits. For anyone living near Pilgrim Nuclear Power Station in Plymouth, MA, it is difficult to ignore the incidents that have happened at places like Chernobyl, Three Mile Island, and Fukushima. It is possible that a disaster could occur at any nuclear facility. For this reason, the prevention of disasters through study of previous disasters is the best approach to prevent future incidents from occurring in plants that are currently operating.

The goal of this project is to discuss the benefits and risks associated with Pilgrim Nuclear Power Station and develop recommendations based on the data collected. This goal was accomplished by analyzing the risks due to a catastrophic accident; analyzing the societal, environmental, and economic impacts associated with Pilgrim Nuclear Power Station under normal and emergency operating procedures; and evaluating the current emergency response and evacuation plans.

Pilgrim Nuclear Power Station, located in Plymouth, Massachusetts, is similar in design to the Fukushima Daiichi Plant. The similarities between these two nuclear power plants warranted a second look at the current condition of the plant, as well as an analysis of the plant's safety protocols. Pilgrim's operating license was renewed on June 8, 2012. The United States Nuclear Regulatory Commission [USNRC] can grant license renewals for between twenty and forty years depending on the mechanical degradation of the power plant (USNRC, 2011b). The renewal of Pilgrim's license means the plant will be able to operate for another twenty years, so there is concern that over the course of twenty years safety components could deteriorate causing Pilgrim Nuclear Power Station to have an increased risk of a disaster.

Our sponsor for this project is State Representative Anne Gobi, and she has requested a thorough evaluation of Pilgrim Nuclear Power Station. Representative Gobi is the representative for Worcester's fifth district which includes the towns of Barre, Brookfield, East Brookfield, Hardwick, Hubbardston, New Braintree, North Brookfield, Oakham, Spencer, Ware, and West Brookfield. As sponsor of this project and as a state representative, her job is to voice the concerns of the people she represents. Representative Gobi wants to ensure that the plant is not a potential threat to the citizens of Massachusetts. She is also the Chair of the Environment, Natural Resources, and Agricultural Joint Committee, which heightens her interest in the safety of the nuclear plant.

Studies published by organizations such as The Institute of Electrical and Electronics Engineers [IEEE], United Nations Scientific Commission on the Effects of Atomic Radiation [UNSCEAR], USNRC, and the International Commission on Radiological Protection [ICRP] examine the effects of radiation on humans and the environment. Case studies from Chernobyl (1986) and Fukushima (2011) provide information on how emergency protocols and evacuation plans can succeed and fail.

The outcome of the project has the potential to create further conversation within the state government and help Representative Gobi lead her committee to address the difficult questions that will be asked by her constituents and government officials. The recommendations are based on the team's research and are not attributable to Representative Gobi.

METHODOLOGY

The goal of this project was to discuss the benefits and risks associated with Pilgrim Nuclear Power Station and develop recommendations for our sponsor Representative Anne Gobi. To accomplish this goal, we established three primary objectives.

1. Assess the risks for an accident that currently exist at Pilgrim Nuclear Power Station.
2. Evaluate the current emergency response and evacuation plans at Pilgrim.
3. Analyze the societal, environmental, and economic impacts the plant has under both normal operating conditions and in the event of a disaster.

Upon completion of these three objectives, we made recommendations regarding how to reduce the risk of a disaster at Pilgrim and how to minimize the negative effects of a disaster if one were to occur.

Objective 1: Assess the risks for an accident that exist at Pilgrim Nuclear Power Station

In order to determine whether Pilgrim is at risk for a nuclear disaster, it was important to understand what factors would contribute to the development of a disaster scenario. We examined technical documents to understand the extent of redundancy and backup devices involved in the engineering of this power plant. We also accounted for the environment and weather conditions to determine whether or not these would have any effect on the operation of the plant. Researching the recent disaster at Fukushima played a critical role in this aspect of the project. Since the design of Pilgrim is similar to that of Fukushima, we can determine what design flaws contributed to the Fukushima disaster and determine whether they pose a threat to Pilgrim. In addition, we researched other unique conditions at Pilgrim that pose a potential threat to safe operation.

Objective 2: Evaluate the current emergency response and evacuation plans at Pilgrim

In order to evaluate the effectiveness of the existing evacuation plans at Pilgrim, we have conducted archival research on the emergency response and evacuation plans at Pilgrim. We examined case studies regarding the successes and failures of emergency procedures that were executed in response to disasters such as Fukushima and Chernobyl. Using that data, we were able to determine whether any of the flaws experienced in those plans are present in Pilgrim's emergency plan. Another valuable resource was reports from practice drills and exercises at Pilgrim. Those reports illuminated potential weak spots, allowing us to make recommendations to improve the safety and effectiveness of emergency and evacuation procedures.

Objective 3: Analyze the societal, environmental, and economic impact the plant has under both normal operating conditions and in the event of a disaster

It is unrealistic to deny that a disaster at any nuclear power plant is possible. However large or small the risk may be, there is always a possibility of a catastrophic failure at a nuclear power plant and it is important to understand the implications of this risk. Radiation is known to have detrimental effects on health and the environment so we researched how the fallout from a disaster at Pilgrim could potentially affect the surrounding communities and ecosystems.

In order to understand societal effects of radiation, we compiled relevant information by performing archival research on this topic. Searching online databases for journal articles and published works was the best method to accomplish this. The information needed in order to assess the possible health effects on the population living near the power plant was mainly case studies of the impact that accidents such as Chernobyl had on the victims. Controlled testing of the effects of radiation on humans is unethical, and therefore there is no documentation of this;

however we found controlled studies on animals done by researchers as well as research done on humans exposed to radiation for the treatment of cancer.

Radiation effects on plants and wildlife have been studied in relation to the environment surrounding Pilgrim. Massachusetts' environment and agriculture differs from that of Fukushima, so special considerations were taken. We have placed an emphasis on the potential impact an accident could have on the agricultural industry of Massachusetts. Again, studies on Chernobyl have been reliable sources to review. Another important environment to examine is marine life and the fishing industry due to Pilgrim's close proximity to the Cape Cod Bay. Reports on controlled radiation studies performed on plant life were used from different databases.

A disaster of any magnitude will evidently have dramatic economic costs; however this cost is determined by many factors such as the severity of the disaster and the location of the plant in regards to population density and infrastructure. In order to make an assessment, we researched how all of these factors contribute to the cost of a disaster, as well as researched what other factors may have an effect. This was done by collecting documents that detailed the evacuation, reparation, and cleanup costs of previous disasters and applying this data to Plymouth and the Eastern and Central Massachusetts areas.

DATA AND DISCUSSION

Understanding the history of both the Plymouth and Fukushima power plants is vital in being able to analyze and understand the risks that Pilgrim Nuclear Power Station may face in case of a catastrophic failure. Pilgrim Nuclear Power Station is owned and operated by Entergy Energy Corporation. Entergy is primarily involved with power distribution and currently owns and operates twelve reactors in the United States (Entergy, 2012).

Pilgrim Nuclear Power Station is located in Plymouth, Massachusetts and has been operating since 1972. Entergy acquired the plant in July of 1999. The previous owner was the Boston Edison Company. The single GE Mark I-BWR type three reactor at Pilgrim has a 685-megawatt (MW) output (Nuclear Information and Resource Service, 2011). Nuclear power plants are examined after forty years of operation to ensure the integrity of the nuclear plant has not become weakened by age. Since the plant has been operating for forty years, its license was up for renewal in June of 2012. The license renewal was granted, and Pilgrim Nuclear Power Station was permitted to operate for another twenty years (USNRC, 2011b). Pilgrim Nuclear Power Station’s power output is enough to power 550,000 homes in Massachusetts; there are currently approximately 2.8 million homes in Massachusetts (U.S. Census Bureau, 2012). Information about Pilgrim can be publicly accessed through the United States Nuclear Regulatory Commission [USNRC]. The USNRC is responsible for rectifying the mechanical degradation of safety related components and relicensing all power plants in the United States.

Our sponsor, State Representative Anne Gobi, asked our team to determine whether Pilgrim would exhibit the same response if submitted to the same circumstances that caused the Fukushima disaster. In order to analyze Pilgrim Nuclear Power Station’s risk in terms of its infrastructures, the function of the boiling water reactor [BWR] employed by both Fukushima and Pilgrim will be explained followed by a theoretical application of the sequence of events that caused the disaster at Fukushima. Apart from analyzing the disaster at Fukushima, our team also analyzed risk factors posed by the large amount of spent fuel stored at Pilgrim Nuclear Power Station.

The Boiling Water Reactor System

General Electric created the boiling water reactor in the mid 1950s, and thirty-five GE boiling water reactors operate in the United States (Andrews, 2011). The other sixty-nine reactors in the United States use a pressurized water reactor [PWR] (Andrews, 2011). The design of a boiling water reactor is surprisingly simple and can be explained in five steps (USNRC, 2012). First, fission reactions take place in the core of the reactor. Nuclear fission is a

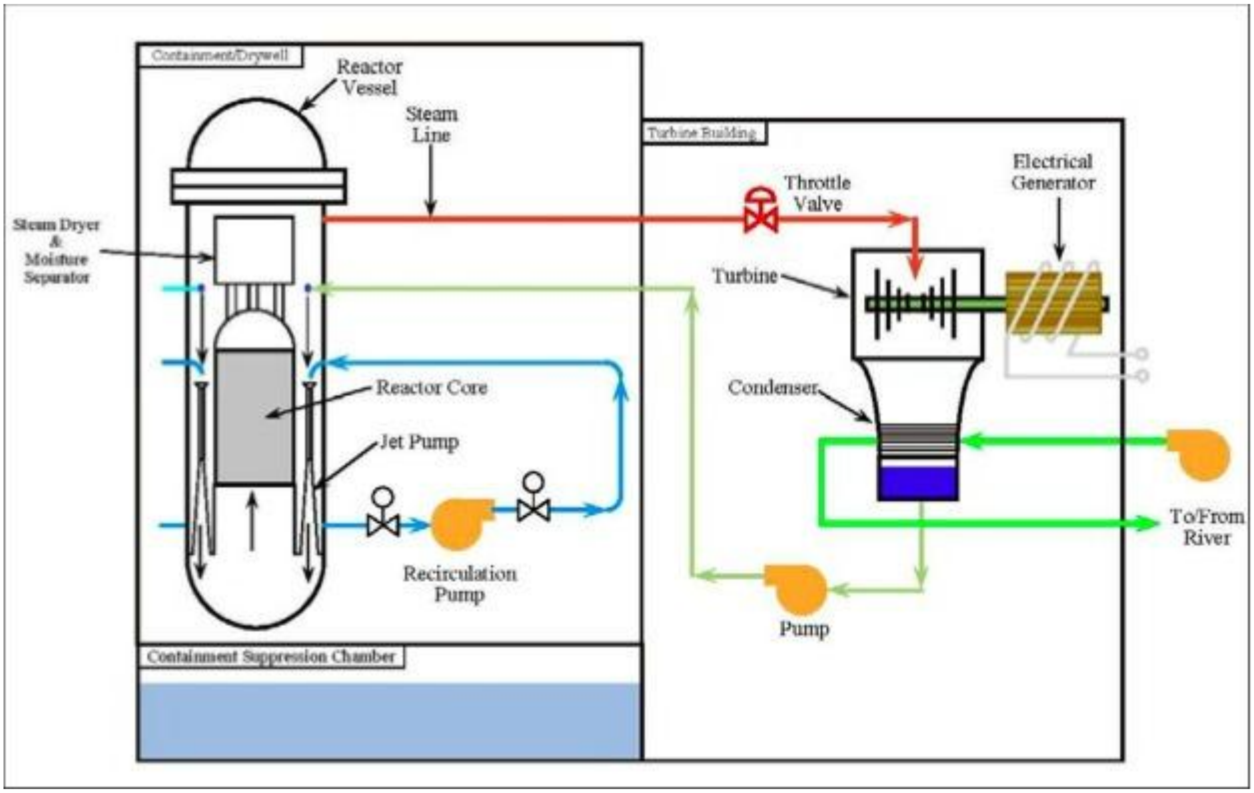


Figure 1. A schematic of commercial boiling water reactors used in the United States (Andrews, 2011).

radioactive decay (See Glossary) of the nucleus (See Glossary) of a heavy isotope (See Glossary). The nucleus releases enormous amounts of energy as it decays into smaller more stable compounds. Consequently, the energy is released in the form of electromagnetic radiation (See Glossary) and kinetic energy (See Glossary) in the form of heat. In the second step, the heat produced by the fission reactions in the core is absorbed by high purity water. As a result of absorbing heat, the high purity water is converted into a mixture of both steam and water. Next, the water is removed from the mixture in a two-step separation (USNRC, 2012). All the water must be removed from the steam before it can enter the steam line. In the fourth step, the steam line powers a turbine connected to a generator. The turbine activates the generator, and the generator produces electricity. Lastly, any unused steam is compressed back into water via a condenser. Accordingly, the water from the condenser is pumped back to the reactor where it will begin the process again (USNRC, 2012).

The fission reaction previously described may be stopped for the purpose of maintenance. During safe shutdown, the steam line bypasses the turbine. Instead, the steam goes directly to the condenser where it will be converted into water for core cooling (Andrews, 2011). When the pressure in the reactor reaches approximately 50 pounds per square inch (psi), shutdown-cooling mode removes residual heat by means of water and a recirculation loop (Andrews, 2011).

Despite the term “safe” shutdown, stopping the fission reaction can cause a number of accidents. On Tuesday May 22, 2012 at Pilgrim Nuclear Power Station, a routine shutdown of the fission reaction presented a problem (Young, 2012). The whole plant was shut down after a condenser lost vacuum pressure. This particular condenser at Pilgrim Nuclear Power Station was designed to operate in a vacuum to increase efficiency and provide essential cooling to the core during shutdown. The condenser’s main function was to cool water removed from the bay and also to convert steam into cooling water. One the one hand, this shutdown at Pilgrim has been viewed as an ominous, foreshadowing event to a future containment failure that could occur if Pilgrim were submitted to unplanned reactor shutdown. On the other hand, the shutdown has also been viewed in a more positive light. The regulation and testing of the core shutdown process illuminates issues that can be corrected. Moreover, Pilgrim representatives assure that every shutdown is followed by a rigorous evaluation (Young, 2012). Nevertheless, the question still remains whether Pilgrim Nuclear Power Station would exhibit condenser failure during an emergency situation. In spite of the dangers, the fission reaction must be stopped for maintenance and calibration.

Throughout the years, changes have been made to the different systems of the boiling water reactor for the purpose of increasing the safety of core shutdown. For example in 1955, isolation condensers [IC units] were employed as a backup cooling system in the boiling water reactor (Andrews, 2011). Since their establishment, isolation condensers have played a key role in core cooling after the reactor is shutdown. IC units are especially useful because they require no auxiliary power. As a matter of fact, an operating isolation condenser in Reactor One at Fukushima could have prevented the core from melting down. The following year in 1956, the emergency core cooling system [ECCS] and the reactor core cooling system [RCIC] were employed. Both systems are vital for core cooling (Andrews, 2011). The importance of these structural evolutions mentioned above will be elaborated upon in this objective.

Applying the Disaster Scenario at Fukushima Daiichi to Pilgrim Nuclear Power Station

At exactly 2:46 pm on March 11, 2011, a 9.0 magnitude earthquake struck Japans east coast (Strickland, 2011). The earthquake occurred almost 100 miles northeast of the Fukushima

Daiichi nuclear power plant (Mohrbach, 2011). At the time of the earthquake, only Reactors One, Two, and Three were active.

As a measure of protection against earthquakes, nuclear power plants subjected to seismic activity have different design specifications. The vigorous forces of earthquake motions cause safety-related structures to display integral damage in the form of stresses and distortions. Moreover, nuclear power plants endangered by earthquake hazard must provide opposition to two earthquakes: a system shutdown earthquake [SSE], and operating basis earthquake [OBE] (Newmark, Hall, USNRC, 1980). Operating basis earthquakes have a high probability of occurring. Fortunately, operating basis earthquakes are lower magnitude and less severe. During OBE earthquakes nuclear power plants are able to operate safely. Conversely, a shutdown earthquake is a very severe, high magnitude earthquake. Despite being more dangerous, system shutdown earthquakes have a very low probability of occurring. During SSE earthquakes, the nuclear power plant is automatically shutdown to maintain a safe environment.

The 9.0 magnitude earthquake that occurred on March 11, 2011 was classified as an SSE. Fukushima responded automatically by scramming (See Glossary) the reactors. The reactors are scrammed by means of control rods that can generate enormous amounts of heat and must be cooled constantly (Strickland, 2011). The earthquake caused a severe power outage. To mitigate the loss of power, Fukushima responded immediately with twelve diesel backup generators that continued to cool the control and fuel rods. The automatic response to the earthquake seemed flawless, but the tsunami that followed changed everything.

At 2:52, shortly after the fission reactions in the three active reactors were stopped, a supervisor noticed that the core of Reactor One was cooling too quickly due to the deployment of a backup cooling system (Strickland, 2011). The backup cooling system in Reactor One at

Fukushima was an isolation condenser. The particular IC unit located in Reactor One at Fukushima had to be manually turned on and off. Subsequently, the need for electric power to manipulate the IC unit proved to be a fatal design flaw (Strickland, 2011). When the operators turned off the back up cooling system and could not turn it back on due to the power loss, the core of the reactor did not receive proper cooling. As a result, improper cooling caused the reactor to eventually melt down (Mohrbach, 2011).

The exact type of core meltdown due to partial backup cooling system failure that occurred at Fukushima could not occur at Pilgrim Nuclear Power Station because they use different back up cooling systems. Even though isolation condensers are practical because they do not require off-site power, Pilgrim does not employ this system for back up cooling (USNRC, 2007). Under these circumstances, the cooling system in place would be the reactor core cooling system (USNRC, 2007). Isolation condensers and RCIC systems are similar in the way that they require no auxiliary power to cool the core of the reactor vessel. However, the reactor core cooling system at Pilgrim can be manually turned on by the operator or will turn on automatically without off-site or diesel power (Lee, et al, 1994). Therefore, the same issue that occurred with the IC unit at Fukushima could not occur at Pilgrim Nuclear Power Station. Above all, the lack of an isolation condenser is a decisive difference between the structures that contributed to the meltdown at Fukushima; and the structures employed at Pilgrim.

About an hour after the earthquake, a tsunami with astonishing 46ft waves moved past the protective sea walls (Mohrbach, 2011). The damage caused by tsunamis can compromise the structural components of nuclear power plants. In order to understand effects of a tsunami on a nuclear power plant, it is important to understand the mechanisms of tsunamis, and how they are created. A tsunami is defined as a water wave formed due to tectonic activity (Jain, Argwhal, Hirani, 2005). The location and specifications of the earthquake directly relate to the characteristics of the tsunami that could potentially be generated (USNRC, 2009). First and foremost, the location of the earthquake determines whether a tsunami is generated. Consequently, only earthquakes with magnitudes greater than 6.5 can generate observable tsunamis (USNRC, 2009). Direct flooding, as a result of the tsunami, can cause severe damages to a nuclear power plant. Therefore, external and internal flooding design specifications are applied to nuclear plants near rivers and coastal areas.

To protect against tsunamis, Fukushima Daiichi had a total of 32.8ft of protection against flood waters (Mohrbach, 2011). However, Fukushima's 14.1ft elevation was no match for the 46ft tsunami waves that easily overpowered the 18.7ft levees (Mohrbach, 2011). As a result of the insufficient flood protection and design, water from the tsunami disabled eleven of the twelve generators and the cooling water pumps at Fukushima (Mohrbach, 2011). Six of the generators

Figure 2. As a result of the insufficient flood design, this valuable equipment in reactor building three was rendered useless (Strickland, 2011).

were flooded directly, while the other five were disabled due to flooding in their power distribution panels.

The loss of these generators caused an entire station blackout. The loss of offsite power combined with the loss of diesel power at a nuclear power plant increases the risk of malfunction by approximately seventy percent (USNRC, 2005). Complete loss of power is a grave situation because the instruments and gauges that provide crucial information about the status of the reactor core cannot be used. Although complete station blackouts rarely occur, the operators at Fukushima knew the severity of their situation. The location of the twelve diesel generators at Fukushima proved to be a critical design flaw. Even more, the only generator that provided power continuously throughout the disaster was located on level one near reactor six. After the tsunami, the power supplied by the only functional generator at Fukushima prevented reactors five and six from going critical (Strickland, 2011). For this reason, the different locations of the backup generators between Pilgrim and Fukushima are a crucial difference between the two nuclear power plants.

At Fukushima, eleven of the twelve diesel generators were located on the basement level of the different reactor buildings. Pilgrim has two diesel generators for the one active reactor on site, and they are both located in separate, elevated locations (Eldred, 2012). Pilgrim goes even further to protect the fuel source of the generators by housing the fuel piping in underground water tight vaults (Eldred, 2012). To further reduce the risk of a complete station blackout, Pilgrim has a third station blackout generator. This station blackout generator is also located in a watertight, elevated location. In the event that Pilgrim Nuclear Power Station lost power and both diesel generators were destroyed, the third station blackout generator would maintain safe function of the plant (T.Setzer, personal communication, October 3, 2012).

After completing a comprehensive study of the disaster by means of interviews with members of the Toykyo Electric Power Company [TEPCO], Japan's Nuclear and Industrial safety Agency, USNRC, International Atomic Energy Agency, local governments, and by reading hundreds of reports, Eliza Strickland speculates, "Some of these [system failures] are astonishingly simple: If the emergency generators had been installed on upper floors rather than in basements, for example, the disaster would have stopped before it began"(Strickland, 2011). An evaluation of the disaster at Fukushima compared with the structural differences of power plants in Germany completed by Ludger Mohrbach supports Strickland's claim naming the location of the generators as one of the most critical weak points at Fukushima Daiichi (Mohrbach, 2011). Tom Setzer, a Senior Reactor Inspector for the USNRC, agreed with Strickland's claim. When questioned about the disaster, Setzer reiterated that functional diesel generators could have entirely prevented the disaster (T.Setzer, personal communication, October 3, 2012). The differences between Pilgrim and Fukushima's generators are a major structural differences that drastically reduce Pilgrim's risk for the same exact disaster.

Regarding safety component failure at Fukushima, the loss of the cooling water pumps as a result of the flooding was another crucial system malfunction that took place. The cooling water pumps provided a crucial system called an ultimate heat sink (See Glossary) (A. Gunderson, personal communication, 2012). An ultimate heat sink is essentially an endless supply of water for core cooling during shutdown. As a direct result of the destruction of both the generators and the cooling water pumps, the supply of cooling water available to cool the core of Reactor One at Fukushima was drastically limited. The ultimate heat sink at Pilgrim is called salt service water [SSW] and has five vertical pumps that draw water from the Cape Cod Bay (USNRC, 2007). The SSW consists of two open loops, and each loop requires two pumps. In the event of a loss of coolant accident [LOCA], only one loop of SSW is required to properly cool the core of the reactor. Pilgrim has a backup cooling water loop and a common spare in the event of a core shutdown (USNRC, 2007). Based on the structural differences between the generators and the cooling pumps at Pilgrim Nuclear Power Station and Fukushima Daiichi Nuclear Power Plant, the exact same cooling failure could not occur at Pilgrim Nuclear Power Station.

Approximately two hours after the earthquake, Reactor One at Fukushima began experiencing cooling issues. The cooling issues started with the backup cooling system, but new malfunctions were discovered in another part of Reactor One. After the tsunami disabled the diesel generators at Fukushima, the blackout DC batteries were powering the turbo pumps. However, DC batteries die after roughly eight hours (T. Setzer, personal communication,

Figure 3. Temporary batteries were used to read crucial instruments throughout the station blackout (Strickland, 2011).

October 3, 2012). After they die, the DC batteries cannot properly cool the core of a nuclear reactor. As a consequence of improper cooling, temperatures in Reactor One at Fukushima exceeded 900°C (Mohrbach, 2011). The extreme temperature caused the zirconium alloy cladding (See Glossary) in the fuel rods to react. This reaction was an exothermic (See Glossary), oxidation reaction (See Glossary). Exothermic reactions are chemical reactions that release energy in the form of heat or light. Alternatively, oxidation reactions increase the oxidation state of the compound and release hydrogen. The combination of these two reactions caused a layer of hydrogen gas to begin forming in the building of Reactor One at Fukushima (Strickland, 2011).

At approximately eleven the night of March 11, 2011, the radiation levels inside the building of Reactor One became too high for workers to enter (Strickland, 2011). The radiation level had increased because the core had started melting as a result of improper cooling and the dangerous reactions mentioned in the previous paragraph (Strickland, 2011). For this reason, the workers at Fukushima tried to release the pressure on Reactor One. Unfortunately, the replacement of back up cooling by means of water injection had been started too late because of the station blackout (Mohrbach, 2011). By the time the workers had connected car batteries to the primary containment pressure gauge in Reactor One, they learned the vessel was already operating at maximum capacity and could explode (Strickland, 2011). Because of the lack of proper cooling, the pelleted fuel that built up in the fuel cans prevented the flow of more fuel (Mohrbach, 2011). Subsequently, the buildup in the fuel cans compressed and melted. The containment of Reactor One at Fukushima suffered three partial failures: the fuel itself, the fuel rod claddings, and the third containment barrier (Mohrbach, 2011).

At 3:45am on March 12th, the crew working on Reactor One needed to get a measure of the radiation levels (Strickland, 2011). As a preparatory measure, the crew took iodine tablets and dressed in head to toe suits before they entered reactor building one. In addition, the crew was also equipped with dosimeters. Dosimeters are hand held devices that measure radiation levels, but the crew was not able to use the devices. When the crew opened the airlock to Reactor One, they saw what they thought could be an enormous amount radioactive steam (Strickland, 2011). Almost as soon as the airlock had been opened, it was slammed shut by the crew, and they left without a radiation level reading. Despite not getting a reading of the radiation levels at that time, they were aware that the situation was critical. If the crew had been able to look inside the pressure vessel of Reactor One just a few hours later, they would have seen a melted mixture of zirconium and uranium (Strickland, 2011). This volatile mixture was what was left of the core of Reactor One. As a result of the improper cooling, there was immense pressure on Reactor One; and the crew knew they had to relieve the pressure as soon as possible. Around midnight the night before, the government had received word from TEPCO that in order to save Reactor One they would have release radioactive material (Strickland, 2011).

At 9:03am on March 12th, the crew at Fukushima received word that residents within 10 km had been evacuated, and they could begin to relieve the pressure in reactor one (Strickland, 2011). Relieving the pressure in Reactor One seemed as simple as releasing the valves, but the dangerous radiation levels presented a new issue. Workers in a nuclear power plant under normal conditions are permitted to receive 50 millisievets of radiation per year (Strickland, 2011). If the situation is critical, a worker is permitted to receive 100 millisievets of radiation per year. Workers entered the building to release the valve, but they were unable to complete this task because of the high radiation levels. With this in mind, the decision was made to force the valve open with a portable air compressor. Meanwhile, the hydrogen build up had started during core heat up and formed a dangerous layer under the building of Reactor One. Accordingly, hydrogen recombiners take combustible hydrogen gas and convert if back into steam. By 3:30pm the pressure had appeared to be relieved, but the release in pressure was hydrogen flowing through the venting stacks and building up the outer ceiling in reactor building one (Strickland, 2011). Six short minutes later, a spark ignited the hydrogen and the top of reactor building one was blown off in an explosion. Unfortunately, Reactor One was not the only reactor at Fukushima to explode and release radioactive material. In total, Reactors One, Two, Three, and Four experienced massive hydrogen explosions releasing enormous amounts of radioactive material (USNRC, 2011d). The majority of the radioactive material released in the disaster at Fukushima consisted of Iodine, Cesium, Strontium, and Plutonium (Winter, 2011). TEPCO grossly underestimated the amount of radioactive material release after the disaster (Demetriou, 2011). In spite of all this, the radiation did not harm the surrounding areas to the extent that it could have because approximately eighty percent of the total radioactive emissions were blown over the Pacific Ocean (A. Gunderson, personal communication, 2012).

After the nuclear disaster at Fukushima, the USNRC immediately performed inspections at all United States nuclear power plants (T.Setzer, personal communication, October 3, 2012). The inspection at Pilgrim Nuclear Power Station was performed approximately a month after the accident, and the objective of the inspection was to determine if Pilgrim could alleviate the events that occurred at Fukushima (USNRC, 2011d). The inspection assessed Pilgrim’s ability to mitigate the consequences of large fires and explosions, station blackout conditions [SBO], internal and external flooding, and the thoroughness of the emergency response procedures (USNRC, 2011d).

When evaluating the fire protection capabilities at Pilgrim Nuclear Power Station, emphasis was placed by the USNRC on the spent fuel structure (USNRC, 2011d). The spent fuel structure is fully elaborated upon on page 23. With respect to fire protection and explosions, Entergy performed equipment inventory of necessary operational tools. After the inventory, Entergy performed a test of a portable diesel powered pump (USNRC, 2011d). The inspector from the USNRC independently assessed interior fire water supply piping and hose stations, portable pump, associated suction discharge hoses, adapters, portable DC power supplies, portable radios, and equipment lockers involved in fire protection (USNRC, 2011d). Neither Entergy nor the inspector from the USNRC found any major deficiencies with Pilgrim's capabilities to relieve large fires or explosions.

A safety evaluation performed by the USNRC in 2007 mentioned the nuclear plant previously employed an electrolytic hydrogen water chemistry system to remove dangerous gases that could cause an explosion (USNRC, 2007). However, Entergy requested that the system be excluded from the license renewal as of July 31, 2006 (USNRC, 2007). The electrolytic hydrogen water chemistry system was used to prevent the build of dangerous hydrogen and oxygen mixtures. When the USNRC questioned Entergy about the removal of the electrolytic hydrogen water chemistry system, Entergy responded that the heating, venting and air conditioning [HVAC] system in the turbine building mitigate dangerous hydrogen mixtures. In addition to the HVAC system in the turbine building, Entergy explained that any hydrogen leak that could cause a fire or detonate would not affect the system piping or safety components because they are at an adequate distance. For this reason, the USNRC accepted the response from Entergy and excluded this system from the license renewal on August 30, 2006 (USNRC, 2007).

Pilgrim’s ability to mitigate station blackout conditions was evaluated after the fire protection assessment reported no major deficiencies. Entergy evaluated the SBO diesel generator [DG] and SBO control stations (USNRC, 2011d). The USNRC inspector accompanied by an electrical design engineer and a responsible system engineer (see glossary) conducted an independent inspection of the SBO diesel generator and SBO control stations (USNRC, 2011d). The USNRC inspector found two minor problems during the investigation. The inspector concluded SBO diesel generator cooling radiator could be damaged by flying debris from high winds (USNRC, 2011d). In response to this, Entergy issued a corrective action to fix the problem. Regarding the second minor issue, the inspector found that the switchgear battery was not restrained in a battery rack (USNRC,2011d). Entergy responded again with corrective action. The specific corrective actions regarding the minor deficiencies mentioned cannot be publically accessed, but the corrective action identification orders are listed at the end report.

After the station blackout conditions were evaluated, the next inspection was to test Pilgrim Nuclear Power Stations ability to mitigate internal and external flooding. The United States Nuclear Regulatory Commission offered a document containing the guidelines for adverse weather protection in nuclear power plants. The guidelines for a nuclear power plant to cope with external flooding include: an evaluation of the licensees design for flood levels with special arrangements for areas containing safety related equipment, a structural design according to the propensity for flood to occur at the licensee location supplemented by weather related information in that selected area, and a walk down (See Glossary) conducted by both the licensee and a USNRC inspector (USNRC, 2010). Entergy completed a walk down of the specific areas designed to mitigate internal and external flooding and reported no major deficiencies (USNRC, 2011d). After, An inspector from the USNRC accompanied by a structural engineer surveyed

Pilgrims ECCS pumps, RCIC cooling room, turbine building room, control rod drive room, intake structures, surface water pump rooms, and the emergency diesel generator rooms with respect to the systems and structures ability to alleviate internal and external flooding (USNRC, 2011d). Neither the USNRC inspector nor the structural engineer found any issues with Pilgrim Nuclear Power Station's flood design (USNRC, 2011d).

The last parameter in the inspection was assessing the adequacy of the comprehensive emergency management system. Entergy tested this procedure by asking engineers and operators to perform specific procedures (USNRC, 2011d). Additionally, the inspector from the USNRC reviewed Pilgrim Nuclear Power Station's transition into Emergency Operating Procedures [EOP] (USNRC, 2011d). The inspector from the USNRC concluded that the review was sufficient, and no corrective action was needed with regards to emergency procedure.

In spite of the USNRC's thorough inspection of Pilgrim after Fukushima, the validity of the USNRC's documents is now being called into question; notably by Richard H. Perkins, a risk and reliability engineer for the agency, who spoke to Huffington Post about a suspected cover up by USNRC of nuclear vulnerabilities (Zeller, 2012).. Recently, a nuclear risk engineer working for the USNRC spoke out about a redacted inspection in which data was purposely omitted because of its significance (Zeller, 2012). After the meltdown at Fukushima, the USNRC conducted inspections to determine whether power stations operating in the United States could mitigate the destructive combination of events that caused a disaster at Fukushima. Specifically, the vulnerabilities consist of flood risks in power stations located downstream from dams (Zeller, 2012). Moreover, the complete failure of the dam due to any number of reasons could simulate the flooding experienced at Fukushima (Zeller, 2012). The flooding at Fukushima caused the backup diesel generators to fail leading to an entire station blackout. Furthermore, nuclear power station blackouts can initiate or augment any current system failures and severely compromise the workers ability to safely maintain the function of the power plant. Perkins elaborated upon the USNRC removing the information about the threat posed by dams; even more how the USNRC struggled to give a reason about why the information was removed (Zeller, 2012). The Huffington report concluded that the risk posed by dams is higher than acceptable. The USNRC assured there is an ongoing investigation being conducted. Nonetheless, the USNRC covering up information of any sort raises red flags because of important position they hold with respect to nuclear power. Above all, the USNRC is essentially responsible for regulation of all matters concerning nuclear power in the United States and can be directly liable for any harm done to the environment and human beings.

Spent Fuel at Pilgrim Nuclear Power Station

The spent fuel pool at Pilgrim has a large concrete base; the concrete base, which is is plated with stainless steel. Inside the concrete base, storage racks form a square grid. These storage racks are made of a material called Boraflex (USNRC, 2007). Boron is the active component of the Boraflex. When fuel assemblies are placed in the square grid formed by the storage racks, they are still radioactive. For this reason, the Boron is needed to remove the radioactive neutrons (See Glossary) from the fuel assemblies. Apart from being radioactive, the fuel assemblies placed in the spent fuel pool are also very hot because of their decay heat (See Glossary)(T.Setzer, personal communication, October 3, 2012). To cool the fuel assemblies added to the spent fuel pool, very pure water is cycled through the spent fuel pool at Pilgrim by the SSW (USNRC, 2007).

The spent fuel pool at Pilgrim has the capacity to hold 1000 fuel assemblies, and the reactor core at Pilgrim Nuclear Power Station has roughly 580 fuel assemblies(T.Setzer, personal communication, October 3, 2012). Approximately every 18-24 months, roughly 194 fuel assemblies in the reactor core at Pilgrim must be removed and placed in a spent fuel pool(T.Setzer, personal communication, October 3, 2012). This process is called a fuel outage (See Glossary). Fuel outages are completely necessary for the reactor to function properly, but this process fills the spent fuel pool in a matter of years. The storage racks in the spent fuel pool at Pilgrim Nuclear Power Station have been reracked to provide more space, but according to (T.Setzer, personal communication, October 3, 2012) there will be no more space after the next fuel outage.

While spent fuel pools are only a temporary means of storage for the fuel assemblies, dry cask storage provides a more permanent solution. The casks are between eighteen to twenty feet

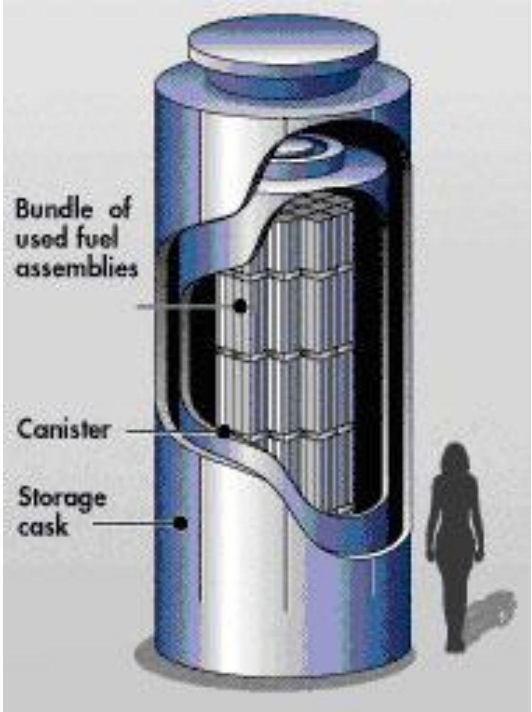
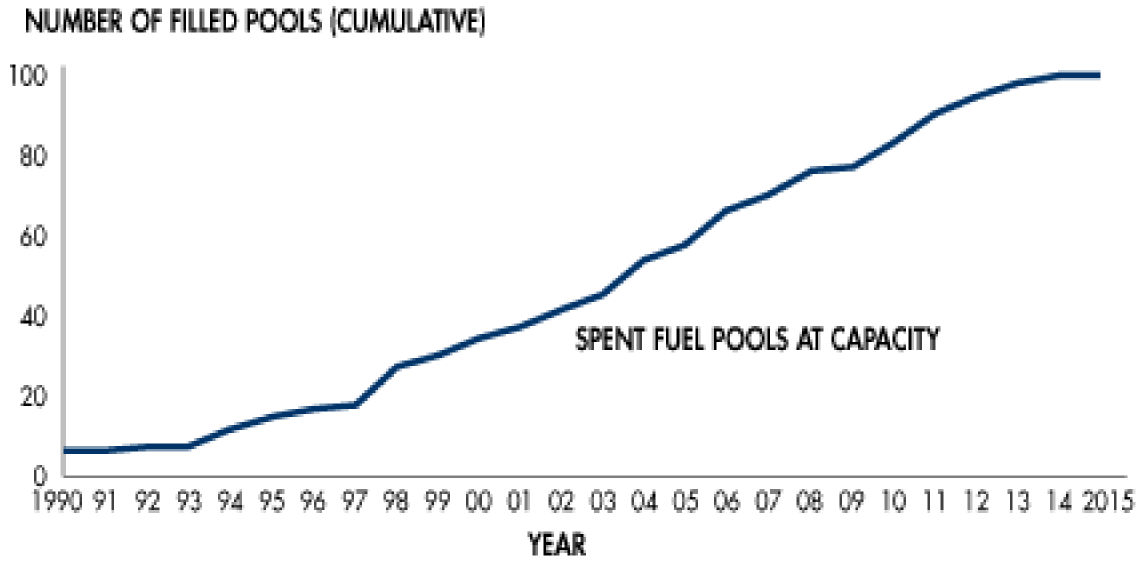


Figure 4. An example of the dry cask storage structurs currently being built at Pilgrim Nuclear Power Station (Entergy, 2012).

tall and are eleven feet in diameter(Entergy, 2012). Additionally, the casks can hold up to three hundred thousand pounds and require no electricity (Entergy, 2012). Approximately thirteen nuclear power plants across the United States use dry cask storage as a form of permanent spent fuel storage, and there has never been a crack or leak of radioactive material recorded with this type of storage (Entergy, 2012). Pilgrim recently licensed the company Holtec to begin building dry cask storage structures (T.Setzer, personal communication, October 3, 2012). In fact, Pilgrim Nuclear Power Station must have the dry cask storage up and running within the next few years because they are running out of space in their spent fuel pool (T.Setzer, personal communication, October 3, 2012).

While dry cask storage is a safer means of storage in terms of Pilgrim Nuclear Power Station's current spent fuel situation, it is not a feasible solution for all nuclear power plants. In the opinion of Thomas Setzer, during the 1970s and 1980s, nuclear operators were under the impression that by the millennium there would be a permanent nuclear repository (See Glossary)

(T.Setzer, personal communication, October 3, 2012).



Note: All operating nuclear power reactors are storing used fuel under NRC license in spent fuel pools. Some operating nuclear reactors are using dry cask storage. Information is based on loss of full-core reserve in the spent fuel pools.

Source: Energy Resources International and DOE/RW-0431 – Revision 1

Figure 5. Percentage of spent fuel pools at capacity over time.

The figure illustrates the dire need for a permanent spent fuel site. In spite of the spent fuel pools across the United States quickly reaching their capacity, the focus of nuclear power industry is still on building new nuclear plants. Under these circumstances, the nuclear power industry should shift their focus to developing a plan to remedy the dangerous spent fuel situation.

The Impact of Catastrophic Failure

The disaster at Fukushima resonated throughout the world. For example, the United Kingdom’s government was perplexed when six nuclear power companies announced they would no longer be funding nuclear plants. In addition to that, Germany recently passed the Nuclear Energy Act. This act declares that Germany will phase out of nuclear energy by 2022 (BBC Monitoring Europe, 2012). After Germany’s announcement, one of Scotland’s nuclear operators announced a similar decision to abandon their nuclear power projects (BBC Monitoring Europe, 2012). The stepping away from nuclear power plants as an energy source has stimulated a number of opinions in both opposition and favor of nuclear power.

As a result of passing the Nuclear Energy act, Germany faces the daunting task of dismantling their reactors. Dismantling nuclear reactors is very expensive. The German government has set aside 1.9 billion euros for the dismantling of the reactors Brunsbuettel, and this base cost to decommission the nuclear reactors has posed major issues. Aside from the reactors Brunsbuettel, nine other nuclear reactors in Germany also need to be shut down because of the nuclear energy act. The estimate for the decommissioning of these nuclear plants is in the tens of billions of dollars. Despite the issues surrounding Germany's nuclear power plants, the Nuclear Energy Act presents the nuclear operators with two options for the decommission. Option one is a "safe enclosure". A safe enclosure of a nuclear power plant is the least expensive option. Unfortunately, mothballing (See Glossary) a site renders it uninhabitable for decades. The second option involves immediate dismantling of the reactor. However, this option is estimated to cost billions and take at least a decade. Another issue surrounding the second option is the lack of experience in dismantling nuclear reactors. Germany has an estimated sixteen nuclear power stations set for decommissioning; however the reactors at each station are extremely different (The Scotsman, 2012). Because the reactors are so different from each other, there is no accepted procedure on how to decommission them.

In spite of Germany’s plans to abandon nuclear power, Japan recently decided not to move away from nuclear power. After the accident at Fukushima, Japanese officials originally set a goal declaring they would phase out of nuclear power by 2040 (Hiroko, 2012). However, intense opposition stopped the goal from being formally adopted. Businesses and communities throughout Japan protested the move away from nuclear power because they did not want to lose the subsides, tax revenues, and jobs provided indirectly by nuclear power (Hiroko, 2012). A Plymouth local has the same view. Allan Burgess stated that if Pilgrim Nuclear Power Station were shut down the taxes would increase so much that he and his family would have to move (A. Burgess, personal communication, 2012).

The communities and businesses of Japan do not only fear the economic repercussions of a nuclear phase out. They also do not want their offline nuclear power plants to become spent fuel storage sites (Hiroko, 2012). To prevent their offline nuclear power plants from becoming spent fuel repositories, Japanese officials announced the decision not to move away from nuclear power. In spite of this decision, the accident at Fukushima showed that the close relationship between the supposed regulators of the nuclear industry and those who operate the nuclear plants needed to be terminated. So when the Japanese government made the announcement not to phase nuclear power, they also announced the creation and installment of a new nuclear regulation agency (Hiroko, 2012). By means of strict federal regulation, the Japanese government hopes to once again make nuclear power a success in their country.

Spread of radiation around Fukushima

In order to determine the magnitude of the effects a nuclear disaster at Pilgrim would have on the surrounding area, it is important to measure the radiation levels at certain distances from the Fukushima disaster site and compare this data to corresponding distances from Pilgrim. Information on the basic definition of radiation can be found in the appendix at the end of this report. This will give us an approximation of how far dangerous amounts of fallout could spread and what areas of Massachusetts and Rhode Island could be affected. The figures below show radiation concentration data around the Fukushima Nuclear Generating Station following the disaster on March 11, 2011. The first figure shows readings at monitoring posts around Fukushima taken on April 16, while the second figure depicts a graphic representation of readings taken on April 29. We can use these data points to estimate the radiation levels at similar locations with respect to the Pilgrim Nuclear Generating Station.

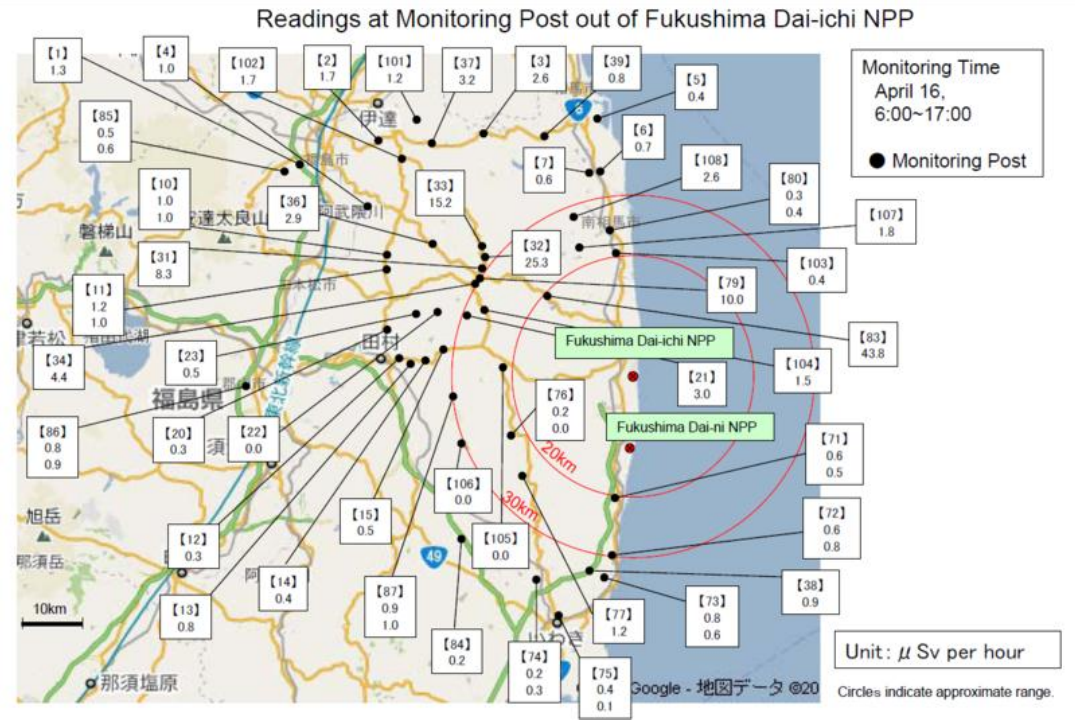


Figure 6. Readings at monitoring post out of Fukushima Dai-ichi NPP. This figure shows radiation levels measured at monitoring posts near the Fukushima Daiichi disaster site on April 16, 2011 (Zeiss, 2011).

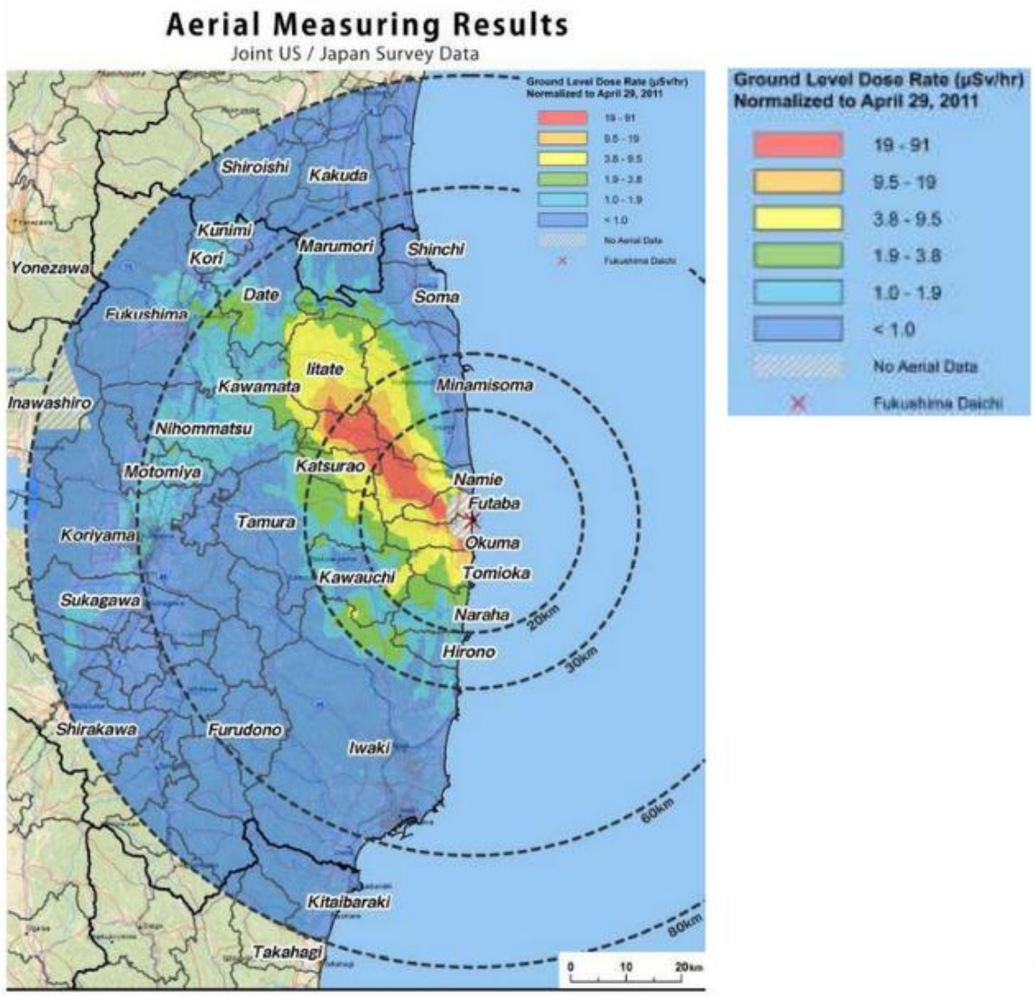


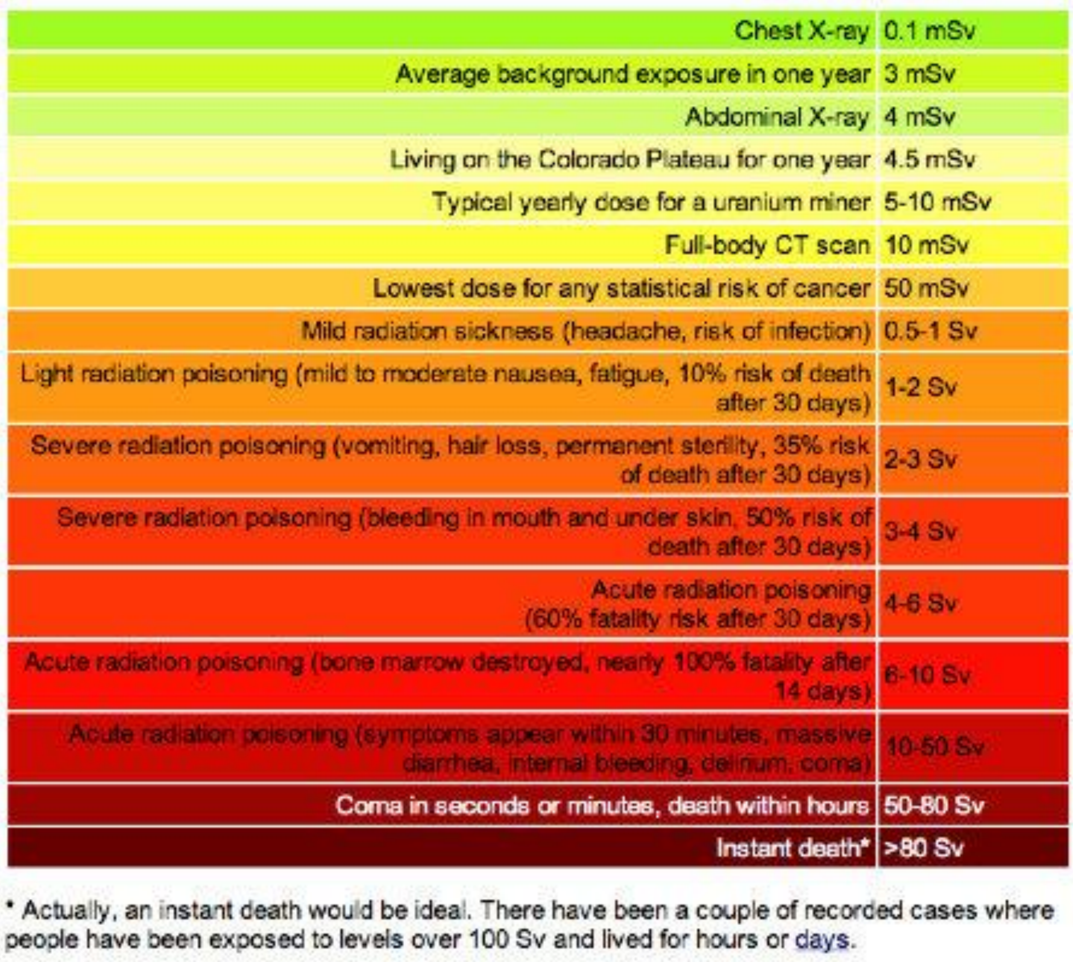
Figure 7. Arial Measuring Results. This figure shows a graphical representation of the measured radiation near the Fukushima Daiichi disaster site (Sandeen, 2011).

Radiation levels 10 kilometers northwest of Fukushima Daiichi were measured at more than 40 uSv/hour (microSieverts per hour), or 0.350 Sv /year, which is nearly 120 times normal background radiation level of 3 mSv/year (Wang, 2011). Radiation levels 20 kilometers northwest of Fukushima were measured at about half that, however this is still 60 times normal background radiation levels. At 80 kilometers from Fukushima Daiichi, radiation levels were measured at less than 0.01 Sv/year. Though this is only three times normal radiation levels, this statistic shows that the disaster at Fukushima had a noticeable radiological impact on the environment 80 kilometers away from the site. The Nuclear Accident Independent Investigation Committee (NAIIC) reports that more than 1800 square kilometers are contaminated with a cumulative dose of 5 mSv/year or more (National Diet of Japan, 2012).

Risks of radiation exposure

Radiation stays within the body, so it accumulates over time (Caldicott, 2011). Being exposed to radiation for prolonged periods of time causes irreversible damage to the body. According to the figure below, living within this radius greatly increases risk of death over time and may quickly cause radiation sickness and poisoning. This figure demonstrates that cancer is possible at 50 mSv, which would accumulate after only four to five months of exposure 20 miles from the plant and just two months of exposure 10 miles from the plant.

Radiation levels directly inside the basement of reactor 1 at Fukushima were measured at 10,300 mSv/hr which is enough to kill a human being within hours (MarketWatch, 2012). One quarter of a mile from Fukushima, radiation levels were measured at 1 mSv/hr, which could cause cancer in a human being within several days. (New York Times, 2011).



Chest X-ray	0.1 mSv
Average background exposure in one year	3 mSv
Abdominal X-ray	4 mSv
Living on the Colorado Plateau for one year	4.5 mSv
Typical yearly dose for a uranium miner	5-10 mSv
Full-body CT scan	10 mSv
Lowest dose for any statistical risk of cancer	50 mSv
Mild radiation sickness (headache, risk of infection)	0.5-1 Sv
Light radiation poisoning (mild to moderate nausea, fatigue, 10% risk of death after 30 days)	1-2 Sv
Severe radiation poisoning (vomiting, hair loss, permanent sterility, 35% risk of death after 30 days)	2-3 Sv
Severe radiation poisoning (bleeding in mouth and under skin, 50% risk of death after 30 days)	3-4 Sv
Acute radiation poisoning (60% fatality risk after 30 days)	4-6 Sv
Acute radiation poisoning (bone marrow destroyed, nearly 100% fatality after 14 days)	6-10 Sv
Acute radiation poisoning (symptoms appear within 30 minutes, massive diarrhea, internal bleeding, delirium, coma)	10-50 Sv
Coma in seconds or minutes, death within hours	50-80 Sv
Instant death*	>80 Sv

* Actually, an instant death would be ideal. There have been a couple of recorded cases where people have been exposed to levels over 100 Sv and lived for hours or days.

Figure 8. Effects of radiation. This figure demonstrates the dosages of radiation administered by certain scenarios as well as dosages required to cause different levels of radiation poisoning. (Wang, 2011).

Possible spread of radiation around Pilgrim

Wind speed and direction are important determinants in how radiation is spread over a region. Fortunately for Japanese residents, at the time of the Fukushima disaster winds headed east carried the majority of the radiation towards the Pacific Ocean and away from civilization, though unfavorable winds began to carry radiation inland several days after the disaster (Kitamoto, 2011). Since we cannot predict exactly how the wind might behave at specific dates in the future, we must examine some of the worst case scenarios in order to determine whether the current disaster plan is appropriate for such situations. One particular case would be if the wind were to be directed south during the time of a disaster at Pilgrim. This would spread significant amounts of radiation across southern Plymouth and Barnstable counties, potentially cutting off all road access to Cape Cod, leaving hundreds of thousands of residents stranded. This unique case will be discussed in a later chapter. Another important case to examine would be if radiation spread toward either one of the nearby city centers of Boston or Providence. Both of these large cities are located close enough to Plymouth that the proper wind conditions could contaminate either of these cities with unsafe levels of radiation and pose health risks to hundreds of thousands of people. We will also be examining this scenario in a later chapter.

Disaster response and evacuation

By observing the successes and failures of how the Fukushima disaster was handled, we can better understand what procedures and regulations must be in place to effectively minimize the repercussions of a disaster at Pilgrim. There are many ways in which the Fukushima disaster could have been better handled. Many mistakes were made that could have been easily prevented. We can learn from these mistakes so that disaster planning and response at Pilgrim can be more comprehensive and successful.

Government Response

The first evacuation orders for citizens within a two kilometer radius of Fukushima Daiichi were not given until 8:50 PM, followed by a three kilometer evacuation order at 9:23 PM. The Prime Minister ordered a 10 kilometer evacuation at 5:44 AM on March 12 which was extended to 20 kilometers at 6:25 PM (Japan Nuclear Technology Institute, 2011). Fukushima's governor Yuhei Sato, at a hearing by the Nuclear Accident Independent Investigation Commission (NAIIC), stated that Japan's central government did not declare an emergency until two and a half hours after they received the initial report from TEPCO (Yomiuri, 2012). Furthermore, the Fukushima prefecture government did not receive notice of the disaster from the central government for another hour after that (Yomiuri, 2012). The earthquake and tsunami caused massive blackouts across the eastern coast of Japan, which in turn disabled many of the emergency response systems and organizations (National Diet of Japan, 2012). One of the primary systems that were disabled was the off-site Emergency Response Center (ERC) which was supposed to be used to communicate with the Nuclear and Industrial Safety Agency (NISA). The main organizations of the government's emergency response plan that were in charge of coordinating all emergency response measures were the Prime Minister's Nuclear Emergency Response Headquarters, the Secretariat of the Nuclear Emergency Response Headquarters of NISA, and the Regional Nuclear Emergency Response team. The NAIIC concludes based on their interviews and findings that overall, none of these organizations functioned as planned. All of the emergency response organizations that were not dedicated nuclear disaster response organizations, such as the Crisis Management Center, were already too busy with the earthquake and tsunami to divert any attention towards the nuclear disaster. The failure of communication between the central and local governments forced the Fukushima prefecture government to make their own decision to evacuate without approval from the central government. When the central government announced their own orders for evacuation, these two different orders given by different governments caused mass confusion among Japanese citizens and many people were still unaware of what they were supposed to do (National Diet of Japan, 2012).

TEPCO's Response

Tokyo Electric Power Company (TEPCO), the owner of the Fukushima plant, also had a difficult time making decisions and relaying information because the chain of command was severely disrupted due to the fact that most of the officials charged with making decisions, such as TEPCO's chairman and president, and Fukushima Daiichi's general manager, were unreachable. In addition, TEPCO's manual describing emergency response procedures was outdated and completely ineffective. This resulted in many conflicting orders, which in turn only heightened the confusion of the emergency responders. Many of the issues faced by the Fukuhsima Nuclear Power Plant were caused by a failure to account for a disaster of this magnitude. Almost all of the regulations in place were based on precedent, and did not protect the facility against a natural disaster larger than any that had occurred previously in history. Although there were many safety regulations in place that would have been effective in the event of a small disaster, most were rendered useless due to the blackout caused by the earthquake and tsunami (National Diet of Japan, 2012). This complete failure of the emergency response system can be linked to widespread communication and management failures by TEPCO and the local and central governments of Japan. Had any of the organizations and governing bodies been prepared to handle a disaster of this magnitude with detailed, functional, and up to date instructions and emergency response plans, the severity of the radiation leak could have been minimized, if not avoided completely.

Evacuation Response at Fukushima

The evacuation of Fukushima was chaotic to say the least. At 8:50 PM March 11, the Fukushima prefecture government ordered a two kilometer evacuation based on their prior training experience. At 9:23 PM March 11, the central government ordered a three kilometer evacuation. The 10 kilometer evacuation was not announced until 5:44 AM the next morning and the 20 kilometer evacuation was announced at 6:25 PM. The severe infrastructure damage from the earthquake and tsunami slowed the relay of these announcements to local municipalities and citizens. Many residents were not even aware of the evacuation orders until several days after the disaster. The NAIIC determined that 146,520 residents were relocated in total. Due to the numerous revisions in evacuation orders, thousands of these evacuees were relocated more than once, causing much confusion and stress. Many of the hospitals and nursing homes had difficulty relocating due to a lack of transportation. Sixty deaths among hospital patients in March were directly linked to the evacuation difficulties (National Diet of Japan, 2012). The 20 to 30 kilometer zone was declared a voluntary evacuation zone, so it was entirely up to the residents to decide whether to relocate or shelter in place. Unfortunately, most of these people had very little information on the nature and severity of the disaster so they had to make this decision with little to no facts. It can be concluded that TEPCO and the Japanese government were all extremely unprepared for a disaster at the Fukushima Daiichi power plant. They failed to account for a large disaster, failed to keep safety procedures and manuals up to date, failed to react to the disaster timely and efficiently, failed to announce evacuation orders when the disaster was known, and failed to protect the health and safety of Japanese citizens near the power plant.

Emergency Plan for Pilgrim

The evacuation plan at Pilgrim is designed and executed by the Nuclear Preparedness Department (NPD) of the Massachusetts Emergency Management Agency (MEMA). They are responsible for designing evacuation procedures, training emergency responders, and maintaining equipment for the ten mile Emergency Planning Zones (EPZ) in Massachusetts. This includes not only Pilgrim, but parts of Vermont Yankee and Seabrook in New Hampshire as well since their 10 mile emergency planning zones overlap into Massachusetts (Commonwealth of Massachusetts, 2012). The EPZ surrounding Pilgrim includes the towns of Plymouth, Kingston, Duxbury, and portions of Carver and Marshfield (Entergy, 2011). The plan covers reception centers, Radiological Emergency Worker Monitoring & Decontamination Stations (RWEMDS), and transportation for schools, licensed day care facilities, children's camps, nursing homes, hospitals, group homes, and correctional facilities. The Radiological Emergency Response Plan also includes services such as environmental monitoring, public alerting, special needs assistance, crisis counseling, meal accommodations for evacuees, business restoration assistance, and many others. The training department offers training to the approximately 4700 emergency responders for Pilgrim and conducts federally evaluated emergency exercises every two years (Commonwealth of Massachusetts, 2012).

Evacuation Plan for Pilgrim

Entergy, the owner and operator of the Pilgrim Nuclear Generating Station, has outlined the basics of the procedures for emergency preparedness and evacuation on their website. The emergency plan in place around Pilgrim details an evacuation radius of 10 miles as required by the NRC (Entergy, 2011). According to the 2010 US Census, there are more than 75,000 people living within this potentially hazardous zone (U.S. Census Bureau, 2012). The Natural Resources Defense Council (NRDC) reports that there are also 21 public schools and 1 hospital located within this zone (Natural Resources Defense Council, 2012). In order to notify the public of a nuclear threat, Entergy owns and operates 112 emergency sirens within a 10 mile radius of the plant. These sirens will alert residents that there is a potential threat, and residents are instructed to tune to one of the Emergency Alert System (EAS) Radio Stations. The Emergency Planning Zone (EPZ) is divided into twelve subareas as shown in the figure below, each containing a designated evacuation route to one of the three Reception Centers outside of the EPZ (Entergy, 2011). There is also coordination with the Massachusetts Department of

Public Health's Radiation Control Program to protect the food supply within the 50 mile radius, also known as the Ingestion Pathway Zone (IPZ) (Commonwealth of Massachusetts, 2012).

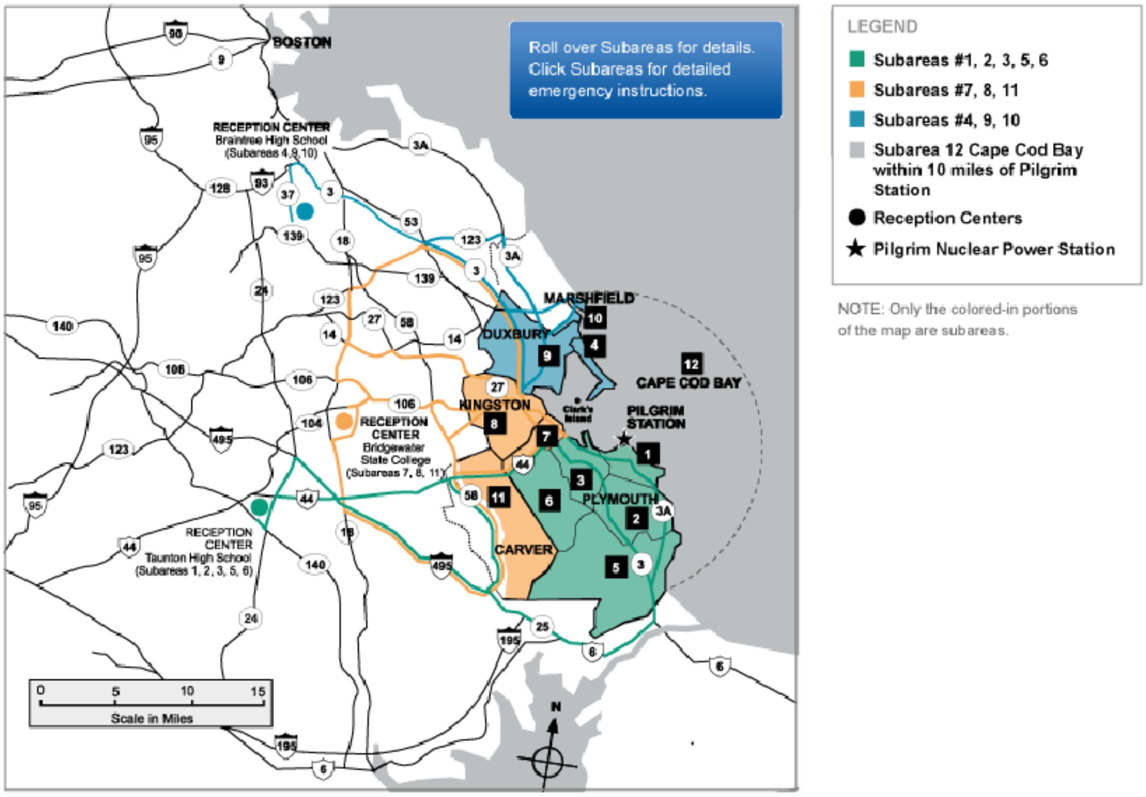


Figure 9. Emergency planning zone. This figure depicts the 12 different subareas, evacuation routes, and reception centers designated in the evacuation plan for the Pilgrim Nuclear Power Plant (Entergy, 2011).

Complications with Pilgrim's Evacuation Plan

This evacuation plan relocates everyone within a 10 mile radius to reception zones just outside of this 10 mile radius. While biennial exercises show that this plan may be adequate for evacuating this ten mile radius, a major disaster causing unforeseen circumstances like what occurred at Fukushima would affect a much larger area and this plan would quickly fail. Most of the reception zones are still within 20 miles of Pilgrim, which allows the possibility that these reception zones are still within an area at risk for dangerous levels of radiation. Fukushima had a similar plan in place with reception zones and emergency radiation treatment facilities immediately outside of the planned evacuation radius, though unfortunately due to the unplanned expansion of the evacuation zone, most of these facilities were never used (National Diet of Japan, 2012). It can easily be predicted that Pilgrim would encounter a similar situation if the evacuation radius were to be expanded beyond the planned 10 miles during a disaster situation. Radiation levels measured in Japan led the US State Department to recommend a 50 mile evacuation radius in Japan. The figure below shows the 10, 20 and 50 mile radii around Pilgrim. It is evident how large of an area would be affected if a disaster similar to Fukushima were to occur at Pilgrim.

Ten, twenty, and fifty-mile radii around the Pilgrim Nuclear Power Station in Plymouth, Massachusetts.
The State Department recommended that all US citizens within 50 miles of Fukushima evacuate.
2010 Census data indicates the population within 10 miles of Pilgrim was 75,835;
the population within 50 miles was 4,737,792. Boston center is 35 miles away.

Figure 10. Eastern Massachusetts. This figure shows the 10, 20, and 50 mile radii centered on the Pilgrim Nuclear Power Plant, as well as the population within these radii from the 2010 Census (Capedownwinders, 2012).

The red circle represents the area of Massachusetts that is planned to evacuate in the event of a nuclear disaster at Pilgrim. The yellow circle represents the approximate area required to evacuate around Fukushima due to the disaster, while the white circle represents the area around Fukushima that the US recommended to be evacuated. It is evident from this map that the evacuation plan for Pilgrim needs to be reevaluated to accommodate for a larger disaster. Evacuating a larger region would require many additional resources such as an increase in the number of Reception Centers outside of the evacuation radius, coordination and increase of public transportation, multiple/alternative evacuation routes and improved communication between public safety officials. An attempt at evacuating this large region without a proper evacuation procedure in place would be extremely difficult to say the least.

Cape Cod

Cape Cod presents Massachusetts with a unique challenge in disaster planning. The entire Cape Cod region falls within 50 miles of the Pilgrim Nuclear Generating Station. Cape Cod has a year round population of approximately 220,000 and during the summer months tourism causes this population to nearly triple to over 650,000 residents and tourists on any given day (U.S. Census Bureau, 2012). Since the Cape does not fall within the 10 mile radius of the plant, there is no predetermined evacuation plan in place. If a disaster were to occur that would require the evacuation of the cape, there are several issues that will need to be addressed. One primary concern is that there are only two bridges that cross the Cape Cod Canal – The Sagamore Bridge on Route 6 and the Bourne Bridge on Route. Each bridge is designed for four lanes of traffic – two inbound lanes and two outbound lanes (United States Army Corps of Engineers, n.d.). Given a worst case scenario of a disaster happening during the peak tourism months, these 8 total lanes of traffic can be converted to all outbound traffic and would be the only land evacuation route for more than 600,000 people. However, this brings up the concern that the Bourne Bridge is 16 miles from Pilgrim and the Sagamore Bridge is only 13 miles from Pilgrim. Bottlenecking traffic so close to the source of the radiation would be a severe hazard to all evacuees. Although this concern has been acknowledged by the NRC, an alternative plan has not been determined (Cassidy, 2012). If the wind during the time of a disaster were to be directed toward the south at all, this could cause extremely unsafe radiation levels along both of these evacuation routes potentially requiring them to be shut down completely. This scenario provokes the need for alternative nuclear disaster preparations to protect the hundreds of thousands of people threatened by this risk.

Boston/Providence

The city of Boston is just 35 miles from the Pilgrim Nuclear Power Station, and Providence, Rhode Island is 36 miles from Pilgrim. These heavily populated cities have close enough proximity to Pilgrim that they are both potentially at risk for significant radiation contamination. While this risk is extremely small, it is still a possibility and needs to be taken into consideration for Pilgrim’s disaster plan. Based on the highest radiation readings 35 to 36 miles from Fukushima, a disaster at Pilgrim would not warrant an evacuation of either of these cities, however residents should be aware that a disaster would put them at risk for higher than normal radiation levels and should also be aware of what the health implications involved are.

Radiation from Power Plants

Nuclear power plants expel a variety of radioactive particles including gamma ray, alpha particle, and beta particle emitting radioactive isotopes. The radioactive particles that are emitted

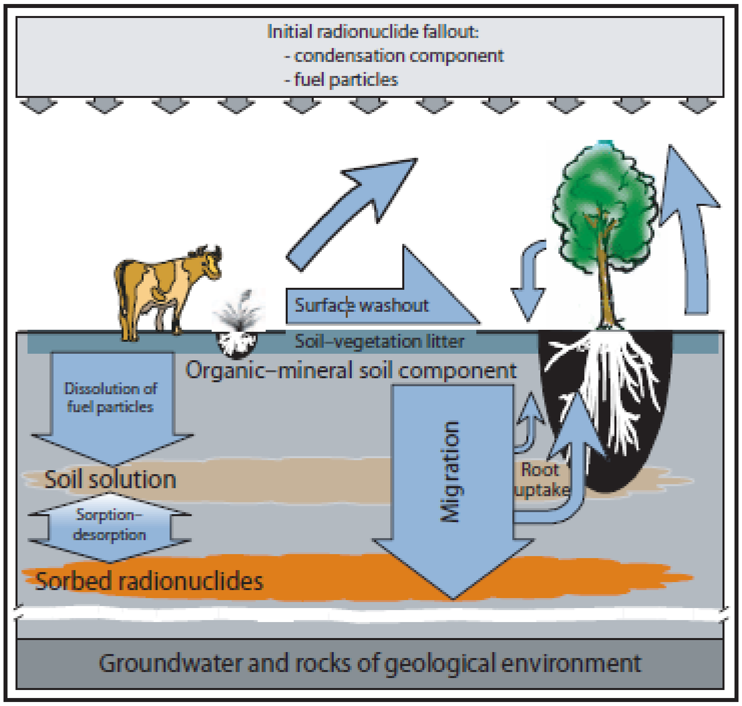


Figure 11. Path of fallout. This figure demonstrates some of the paths radioactive fallout takes to enter the environment and human food sources (UNSCEAR, 2011).

from nuclear power plants differ significantly from the type that is generated from atomic bombs. Victims of atomic bombs are usually exposed to a single, large dose of gamma rays and neutrons. Alternatively, most of the total exposure to radiation from reactor accidents comes from the fallout (Wiliams, E. D., 2006). The significant particles in the fallout from Chernobyl were the radioactive isotopes, iodine-131 and cesium-137. The significance of these particles comes from their interaction with the human body (United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], 2011). Figure 11 from the UNSCEAR report demonstrates the path of fallout after an accident at a nuclear power plant. There are several different possibilities, but much of the fallout can end up into human food sources especially grass-grazing livestock. The fallout can spread over vast areas because it can travel large distances in the atmosphere before coming down as contaminated rain.

Radiation and Living Systems

When explaining how radiation affects living systems it is simplest to describe what happens when a cell, the simplest unit of life, is hit with a radiation. Alpha particles can be thought of as molecular bullets. They are large and will go through a cell destroying molecules in their path. This includes DNA, which is the genetic material of the cell. If DNA is significantly damaged it results in cell death, and if DNA is only slightly damaged it can lead to a mutation that generates a cancer cell. Gamma rays and beta particles can be thought of in a similar way though they work through chemical means. The end effect is cell damage and potentially cancer. Not all cells that are hit with radiation will become cancerous, but there is a chance. For this reason, it is better for living systems to not be exposed to radiation. (Jefferson Lab, 2012).

Environment

Historically environmental harm has been an accepted consequence of the development of energy, but how much harm is unjustifiable? This section considers the harm done to the Massachusetts' ecosystem from nuclear energy and the potential harm that could be done in the event of a Fukushima level disaster with a special focus on how the fish and shellfish population are affected by the plant.

It is difficult to determine the exact scope of the effects the accident at Chernobyl had on the environment because of the variety of species that exist and the sampling that would be required. "Whether the observed levels of genetic anomalies in plants and animals inhabiting areas affected by Chernobyl accident have any detrimental biological significance to populations is still not known" (Geras'kin,S.A.; Fesenko,S.V.; Alexakhin,R.M., 2008). Surprisingly the Chernobyl accident may have benefitted certain species of animals because of the creation of a mostly human-free exclusion zone. Species of eagles have been able to move into the zone to reproduce without any human disturbances, which has been beneficial for the eagles and other species. However, while there may have been some beneficial effect to the accident on the environment, the radiation did have a negative impact on the flora and fauna around Chernobyl. The worst effects on the environment occurred in a twenty mile radius around the plant. Radiation decreased the reproductive success of much of the flora and fauna, which decreased both the amount and variety of plants and animals in the areas around the plant. The figure below diagrams a variety of the effects the radiation had with comparison to the levels that had been determined to be safe. One alarming point of the figure is that plants were being negatively impacted by radiation exposure at levels that were much lower than the threshold levels set by

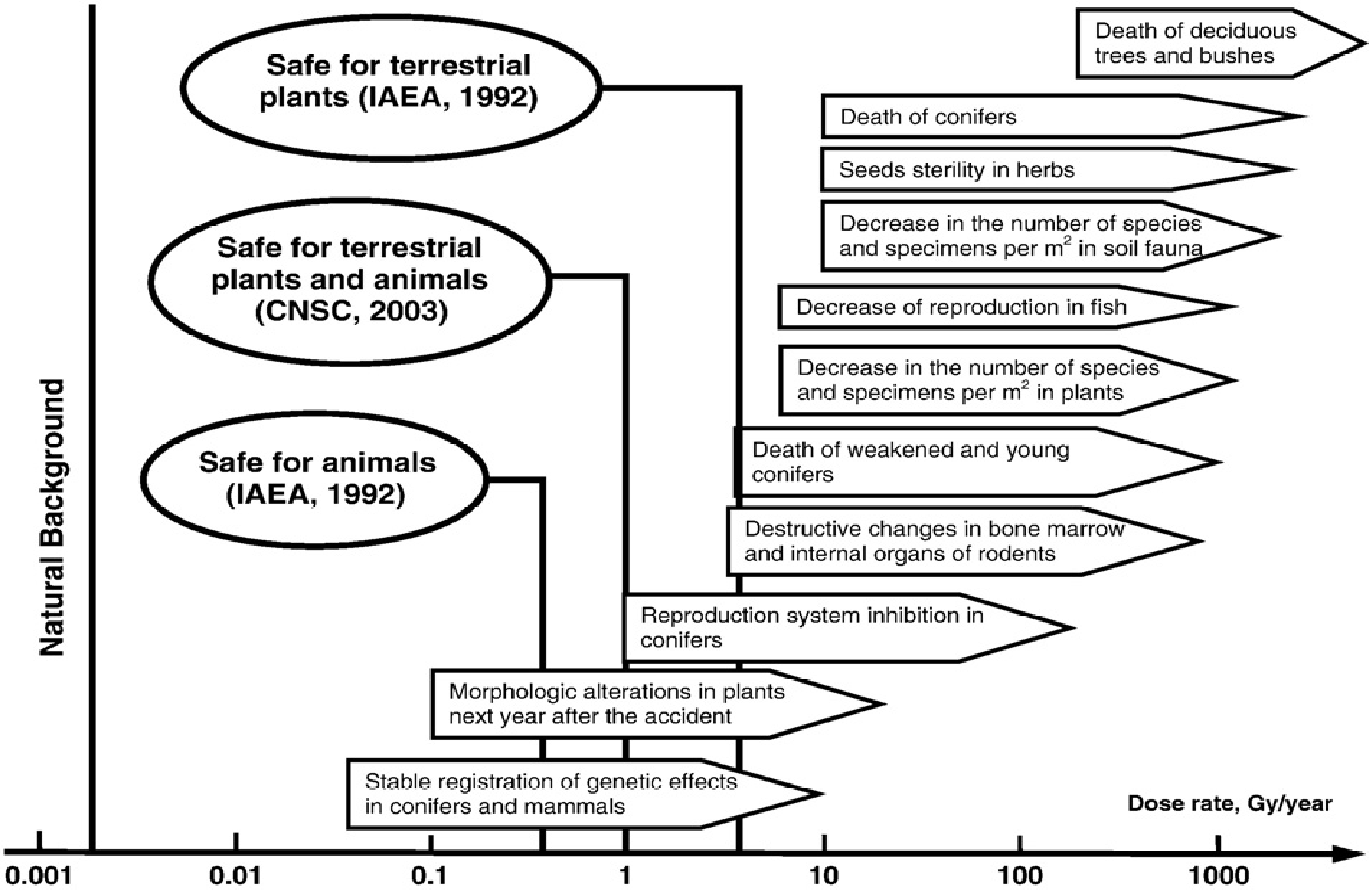


Figure 12. Effects of radiation in the Chernobyl 30km exclusion zone. The figure shows the levels suggested being safe for plants and animals and the effects the different levels had (Geras'kin,S.A.; Fesenko,S.V.; Alexakhin,R.M., 2008).

the IAEA. This demonstrates how little was and is currently know about accurately predicting the effects of radiation. (Geras'kin,S.A.; Fesenko,S.V.; Alexakhin,R.M., 2008).

Regulation and the Environment

The United States Department of Energy [DOE] does not define threshold levels for the environment in the same way as the threshold levels for human exposure are defined. For example the DOE limits the dose that can be absorbed by aquatic animals to “1 rad per day from exposure to the radioactive material in liquid wastes discharged to natural waterways”. This is equivalent to ten times the yearly dose set by the DOE for humans (United States Department of Energy, 2011). This does not necessarily mean fish are being exposed to an unsafe amount of radiation, but demonstrates that the thresholds vary between the environment and humans. The DOE requires that any review of facilities dealing with radioactive waste must conform to the DOE’s “ALARA” principles. ALARA is an acronym for as low as reasonably achievable, and it’s the principle that facilities must have the best methods and equipment to limit the amount of radiation that is emitted into the environment. Between the United States Nuclear Regulatory Commission and the Department of Energy there is regulation on the management of radioactive waste, but it is often the enforcement of the regulations that is put under scrutiny.

Overview of Massachusetts’ Fishing Industry

Massachusetts has always had a thriving fishing industry. According to the National Oceanic and Atmospheric Administration [NOAA] the fishing industry of Massachusetts made $6,711,215,000 in sales in 2009 and creates nearly 78,000 jobs in the state (National Oceanic and Atmospheric Administration, 2009). Any disruption of this industry would have a negative effect on the state’s economy, and if the fish and shellfish coming from the ocean waters near the Massachusetts’ coast were deemed unsafe for human consumption then the loss of jobs and income for the state could be immense.

Effects of the power plant on fish reproduction

Radiation can have negative effects on the reproduction of any living organism including fish. The possibility exists that radiation exposure could render populations of fish sterile. It is less likely in large bodies of water because of the quick dilution of radioactive particles, but fallout from an accident at Pilgrim could reach Massachusetts’ lakes, rivers, and reservoirs. For this reason it is important to determine if an accident at Pilgrim would have an effect on the reproduction of fish. Even if not killed directly from the accident, if populations of fish are rendered sterile it could sharply decrease the population numbers for future generations. In a controlled study done on Tilapia it was found that at an exposure level of .0004 - .0005 grays of strontium-90 per day had a noticeable change on reproduction. These levels were maintained for 90 days providing a total dose of .036-.045 Gy, which is about four times above the normal background levels. The males had smaller gonads, reproduction started earlier, and there were 20 percent fewer normal offspring per female. The study did not consider the generational effects the radiation might have had. When exposed to .03 - .04 grays of radiation per day for 90 days all of the male Tilapia became sterile. A study of the goldfish living in Lake Berdenish, which was contaminated from the Kyshtym radiation accident, showed that up to one-fourth of the goldfish were sterile (Sazykina,T. G.; Kryshev,A. I.,2003). Based on the information available pertaining to the effects of radiation on the reproduction of fish, an accident at the Pilgrim Nuclear Power Station would have an impact on the reproduction of the fish exposed to the fallout. We would expect that an accident would result in the mild reduction of fish populations.

Effects of the power plant on the health of fish

Pilgrim is required to submit the numbers of impinged (See Glossary) and entrained (See Glossary) fish and shellfish to the EPA. Impingement is the killing of adult fish and shellfish while entrainment is the killing of fish and shellfish eggs and larvae. This data is collected at specific times, averaged, and calculated as a value per year. It cannot be certain how accurate the information is, but it can be assumed that Entergy would not inflate the numbers as the EPA sets a maximum number for the number of fish that can be impinged. Over a period of twenty-six years the Pilgrim power plant was responsible for the impingement of at least 562,025 fish and shellfish and the entrainment of 24,314,325,386,670 (24 trillion) fish and shellfish eggs and larvae (Environmental Protection Agency [EPA], 2002). It is difficult to calculate the exact effects this has had on the populations of fish in Cape Cod Bay because fishing and pollution also affects the populations of fish because of other influencing factors such as pollution and overfishing.

Human Health and Radiation Exposure

Some exposure to radiation is a normal and unavoidable occurrence since there are natural sources of radiation in the environment. There are certain threshold levels of radiation that have been set by different scientific organizations as well as the government to define what is considered an elevated or dangerous level of radiation exposure. These thresholds are typically measured in a level of radiation exposure at a single time or in the level of exposure over a year. The United States Department of Energy (DOE) has set a standard of 1mSv per year total exposure for citizens. The level used to be higher at 5 mSv per year, but the DOE changed the level to 1mSv per year to reflect the International Commission on Radiological Protection's (ICRP) standards (Stewart, F.A. et al, 2012); (United States Department of Energy, 2011).

If an event were to occur at any nuclear facility, human exposure to radiation would be a concern that must be considered in any emergency preparedness plans. In order to prevent further contamination and illness, those exposed to radiation must take the proper steps to decontaminate. According to a study, exposure to radiation has been shown to be linked to thyroid cancer and leukemia (Davis, 2012). Different levels of radiation exposure will have different effects on the human body. Christodouleas, et al., (2011) outlined the different dosage levels received from medical procedures, and the dosages received from victims of Chernobyl.

Information on dosages and treatment is necessary for emergency planning. Exposure to iodine-131 (I-131), an isotope of iodine, is responsible for the increased risk of thyroid cancer in victims who have been exposed to it. The treatment for exposure to I-131 is potassium iodide, but it must be administered before or within a few hours of exposure in order to have the best effect. In the event of a large scale emergency at a nuclear power plant the individuals at risk for exposure would need to have the potassium iodide available in order for it to be effective (Christodouleas et al., 2011). Hatch et al. (2005) makes an additional point that the Chernobyl incident has shown that thyroid cancer is linked to radiation exposure, especially in children. The thyroids of children were more sensitive to radiation than the thyroids of adults, and even small doses increased the risk of developing thyroid cancer later in life (Hatch, 2005). Radiation exposure can come from the initial accident or background radiation that has been left in the environment after the accident. Any future genetic effects of the radiation contamination must also be considered.

Thyroid Cancer

The incidence of thyroid cancer after the Chernobyl accident increased particularly among children. The thyroid gland in children is more susceptible to radiation exposure because children require a higher amount of iodine than adults. The effects of radioactive iodine on the thyroid are some of the most documented topics when it comes to how radiation affects the human body. Because thyroid cancer develops in children who have been exposed to radioactive isotopes of iodine it became a noticeable trend after the Chernobyl accident. There was an international average rate of thyroid cancer in children of 1 for every million child per year before the accident while after the accident one measurement showed 44 cases of thyroid cancer in children for every million children per year in Belarus. (Wiliams, E. D., 2006). There were no cases of thyroid cancer in a study of about 9500 children, who were born in the two years following the Chernobyl accident. There was 1 case of thyroid cancer recorded among about 2400 children that would have been in utero during the Chernobyl accident, and there were 31 cases of thyroid cancer recorded in about 9700 children who were of the age three or younger during the accident (Shibata, Yoshisada et al., 2001). This strongly indicates that the Chernobyl accident was the cause of the increased cases of thyroid cancer in children. Iodine-131 has a short half-life, so children born in the years after the accident would not have been exposed to high levels of the radioactive isotope, and thus would not display an increased risk for thyroid cancer. Figure 13 from UNSCEAR's 2008 report on Chernobyl displays the annual incidence rates of thyroid cancer per million for females and males in Belarus. In years following the accident the incidences has increased well past the previous rates. The large difference between the rates for females and males in the figure implies that females are more susceptible to

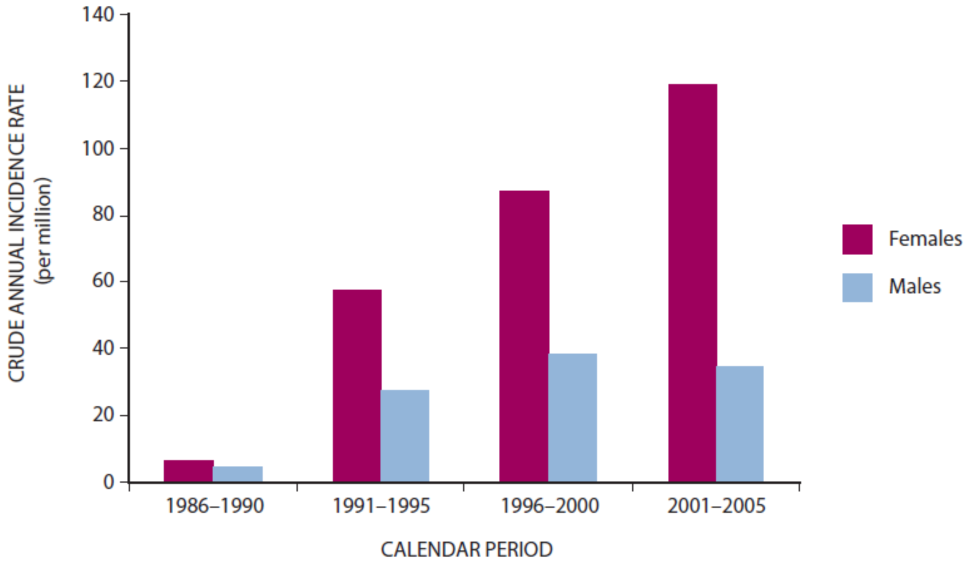


Figure 13. Thyroid cancer incidence in children in Belarus. The pink bars signify females and blue bars signify males in the graph. The annual rate of incidence is seen as increasing after the Chernobyl accident (UNSCEAR, 2011).

developing thyroid cancer. After the Fukushima accident, citizens were being exposed to levels of iodine-131 which were higher than 80 percent of the average annual intake, but more time is required for conclusive studies to be done on how this will have affected the exposed victims (Murakami; Oki, 2012). We believe, based on the research, that if an accident were to occur at Pilgrim, children would be the most susceptible demographic to negative health effects from the fallout.

Leukemia

Leukemia was the first cancer linked to radiation exposure after the atomic bombs were dropped on Hiroshima and Nagasaki, however, leukemia is a rare disorder, and has not been shown to be statistically important in any European countries after the Chernobyl accident. While not statistically significant, there was a slight increase in the number of leukemia cases in Ukraine after Chernobyl (Cardis; Hatch, 2011). The workers who were exposed to fallout after the accident have had a slight increase in the rates of leukemia, although studies have not been conclusive as to whether there were increased rates of leukemia after the Chernobyl accident (UNSCEAR, 2011). Since leukemia is a rare disease, even in the event of a disaster like Chernobyl occurring at Pilgrim, it would be unlikely that Plymouth's population would experience a significant increase in leukemia cases.

Mental Health Related Effects of Nuclear Disasters

Disasters do not only have the potential to cause physical harm, but also mental harm. Disorders like post-traumatic stress disorder (PSTD) and depression can be caused by any traumatic event especially ones involving the loss of life. Individuals who lived through a disaster can develop negative feelings and outlooks toward anything they relate to the disaster. We assume that enough individuals in an area have a distrust of nuclear energy then it becomes a less viable source of energy for the area. The mental health of the citizens of Plymouth and the mental health of the surrounding area's older population could be of the most concern. Having lived through the Cold War would most likely have predisposed them to negative feelings and fear toward anything related to radiation. Additional fear and the development of PSTD would be possible in the event of a disaster. This can be seen in Japan, where the grandchildren of survivors of the Hiroshima and Nagasaki nuclear bombing tend to have more negative outlooks about nuclear power (Palgi et al., 2012). It will be important to watch the victims of the Fukushima accident for depression, schizophrenia, and PTSD especially those who were displaced from their homes because of the evacuations (Sugihara; Suda, 2011). According to the United States Census Bureau, there are approximately 20,000 individuals living within ten miles of the power plant. Of the 20,000, about 16 percent are age 65 or older and about 22 percent is 18 or younger. Those who are children at the time of the accident might keep a distrust and fear of nuclear power into their adult life. This could influence future generations similarly to what was found in the Journal of Psychiatric Health's article, *Mental Health and Disaster Related Attitudes among Japanese after the 2011 Fukushima Nuclear Disaster* (Palgi et al., 2012).

Financial Effects of an Accident

The accident at Chernobyl and Fukushima resulted in an evacuation of the land immediately surrounding the plants at which the nuclear accidents occurred. Chernobyl's accident created a zone that is still not safe for human use. The land will remain contaminated with radioactive elements such as plutonium and americium for hundreds of thousands of years because of the high half-lives those radioactive particles that were emitted by the plant. In both cases families lost their homes and industrial and agricultural land was lost. An accident at the Pilgrim Nuclear Generating Station will have an impact on the land, environment, and thus the economy of Massachusetts. It may be a temporary impact, or like Chernobyl, it could be a long-term impact. The following section will analyze the possible consequences of an accident similar to the Fukushima accident.

As has been observed at Chernobyl, a nuclear disaster can be economically crippling (IAEA, 2006). The ongoing cleanup and reparation costs accumulate over decades and can be in the hundreds of billions of dollars. The Chernobyl accident has cost Belarus and other surrounding governments an estimated $235 billion over the last hree decades, and one source estimates that Fukushima could cost nearly $250 billion in the first decade alone (IAEA, 2006; NewsOnJapan, 2012). Furthermore, high radiation levels would remain for decades and inhibit settlement of the surrounding area. If cities such as Boston or Providence were quarantined, nearly five million people within Eastern Massachusetts and Rhode Island would be displaced and the societal and economic costs could be in the hundreds of billions of dollars over the following decades (U.S. Census Bureau, 2012).

Nuclear Power Versus Coal Power

Currently the world uses coal as an electricity generating fuel more than any other fuel source. Nuclear comes behind renewables and natural gas, but still accounts for a significant source of the world's electricity production See the figure below for a graph of the net electricity generation by fuel showing estimated growth through 2035. Nuclear power plants tend to garner most of the attention when it comes to safety and environmental concerns, while coal plants are not as regulated when it comes to emissions. This is reflected in the cost per kilowatt output of each type of plant. Coal plants without carbon capturing are about $3000 less per kilowatt to run than a nuclear power plant. Coal plants with carbon capturing equipment cost about the same as a nuclear power plant per kilowatt (VujiA,Jasmina; AntiA,Dragoljub P.; VukmiroviA,Zorka, 2012). Coal plants without carbon capturing equipment are less expensive to run, but release a large amount of carbon dioxide into the environment. Carbon dioxide is very harmful to Earth's ecosystem and contributes to global warming. Electricity generating plants using coal also emit radioactive particles such as uranium (Gordanic et al., 1997). According to the United States Department of Labor, there were a total of 364 deaths related to coal mining in 2012 by the 14th of September (United States Department of Labor, 2012). When considering the negatives of nuclear power, it is necessary to compare nuclear power to its alternatives, and between coal and nuclear energy there is not strong evidence that either is better than the other. The figure below estimates the growth for electricity generated by coal and nuclear power through 2035. Coal power is expected to become a more significant source of electricity than nuclear power. Because coal power is less feared than nuclear power, the effects that it might have on the environment and human health may have been overlooked, and it is difficult to recommend coal as a good alternative to nuclear power. Renewable energy is the best option for the future because it provides a long term solution to energy needs as long as it can keep up with human energy consumption.

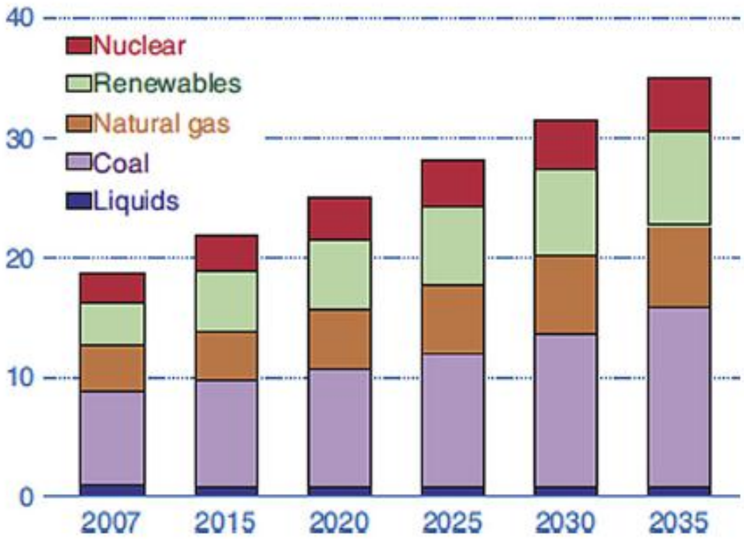


Figure 14. World net electricity generation. The figure shows nuclear energy has being the fourth largest source, while coal is the most significant source of energy (VujiA,Jasmina; AntiA,Dragoljub P.; VukmiroviA,Zorka, 2012).

CONCLUSION AND RECCOMENDATIONS

When Pilgrim Nuclear Power Station's license was renewed on June 6, 2012, it stimulated discussion in the surrounding communities regarding the future of the nuclear power industry. In the opinion of a USNRC official (T. Setzer, personal communication, October 3, 2012), those who support nuclear power also support strict regulation by separating those who work for the nuclear power corporations and those who regulate it. Since the regulating body for nuclear power in the United States granted Pilgrim Nuclear Power Station the capacity to operate for the next twenty years, it is evident that the disaster at Fukushima did completely change the presence of nuclear power in the United States.

In spite of the similarities between Fukushima Daiichi Nuclear Power Plant and Pilgrim Nuclear Power Station, the analysis and application of the Fukushima disaster scenario proved Pilgrim is not at risk for the same disaster. The strict regulation of Pilgrim Nuclear Power Station's current operating procedures combined with the USNRC's thorough inspections after Fukushima shows the worst-case scenario preparation at Pilgrim that could have prevented the disaster at Fukushima.

Upon examining Pilgrim Nuclear Power Station's unique risk factors, the most prominent risk was the spent fuel pools at Pilgrim. Entergy and the USRNC temporarily mitigated the risks posed by spent pools at Pilgrim Nuclear Power Station by building more permanent dry cask storage Although dry cask storage is regarded as a safe way to store spent fuel, it is still not a permanent solution. The most permanent means of spent fuel storage is a nuclear repository, but there are none for nuclear power in the United States.

Storing spent fuel is now the most prominent issue in the nuclear power industry. As of June 2012, no new nuclear power plants can be licensed or existing ones relicensed until a permanent nuclear repository is established (Dolley, 2012). There were plans to build a repository in the Yucca Mountains of Nevada, but the plans were abandoned by the Obama administration (Reardon, 2012). Instead, the Obama administration formed the Blue Ribbon Commission [BRC] and charged them to find an alternative repository to the Yucca Mountains. Alison Macfarlane, part the BRC and now one of the USNRC's chairwomen, explained it is Congress and the DOE's responsibility to manage nuclear waste and provide a permanent storage facility (Dolley, 2012).

It has been the Department of Energy's responsibility to provide a permanent solution for nuclear spent fuel since the establishment of the nuclear power industry, and they have not. Since the DOE has not provided a solution, a bipartisan bill is up for consideration next year that could remove this responsibility from the DOE (Sands, 2012). Jeff Bingaman, a democratic Senator from New Mexico, drafted the Nuclear-Waste Bill mentioned in the previously (Sands, 2012). The bill calls for the establishment of a federal agency specifically in charge of spent fuel and nuclear waste management. Additionally, the Blue Ribbon Commission also recommended a separate federal agency in charge of nuclear waste management (Sands, 2012).

Our team agrees with Senator Bingaman and recommends a single federal agency in charge of spent fuel and nuclear waste management be established. Upon evaluating the risk factors regarding Pilgrim Nuclear Power Station, it is obvious the problems of spent fuel storage and nuclear waste management are central problems the entire nuclear industry is facing. If a body in charge of spent fuel and nuclear waste management is created, these problems that have threatened the future of nuclear power can be managed solely by one accountable agency.

It would be futile for our team to merely recommend the need for a permanent nuclear repository because a permanent nuclear repository has been needed since the establishment of the nuclear industry. Building a nuclear repository is not a simple task, but the first solution is charging a competent legislative body with the responsibility. Because the DOE, the governing body responsible for providing a nuclear repository has not completed this task, our group recommends the establishment of a federal agency that will.

Pilgrim collects information on the number and species of fish and shellfish killed by the plant's intake system, however there are currently no studies available on the exact effects of the plant on the Cape Cod's bay. There should be a study performed by a third party on the plant's intake system and whether it is doing significant harm to the fish populations in the waters around the plant. If it is found that the intake systems of the plant are contributing to a population loss then the intake must be altered to be safer to the ecosystem. The third party should not be affiliated with the energy sector or Entergy. For additional safety, more measures of radioactivity should be taken in Plymouth and the surrounding towns. There was not as much information available on monthly or yearly measures of radioactivity for Plymouth as there was for a city like Boston for example.

The current evacuation plan in place does not account for a disaster of the largest possible magnitude. This puts the lives of hundreds of thousands of people at risk for serious medical conditions including cancer and death. We have made the following recommendations based on our findings so that the NRC, Entergy, and the Massachusetts government may use them to make policy changes to maximize the safety and welfare of the population surrounding the Pilgrim Nuclear Power Station.

A complete disaster plan should be able to effectively respond to any situation that arises in order to minimize damages and loss of life. A secondary disaster plan should be formulated so that it may be executed if a disaster were to occur that is outside of the scope of the current disaster plan. Based on the evacuation that took place at Fukushima, this plan should include a larger evacuation radius encompassing a majority of Plymouth County, which would require more Reception Centers at safe distances from the power plant. This would involve creating several more Emergency Planning Zones that include high risk towns such as Pembroke, Marshfield, Bridgewater, Halifax, Hanson, Middleboro, Lakeville, Plympton, Rochester, Wareham, Bourne, Falmouth, and Sandwich, among others. Formulating such an evacuation plan would evidently be costly; however this cost is dwarfed in comparison to the cost of medical treatment and lives lost in the event of a disaster in which these communities are not evacuated.

With the Chernobyl disaster costing more than $200 billion and Fukushima estimated to cost even more, it is evident that money invested in the protection and safety of Massachusetts residents is money well invested. The average of the estimates of the value of a life by the EPA, FDA, and the Transportation Department is approximately $7 million (Associated Press, 2012. This figure would value the lives of the 400,000 people within 20 miles of Pilgrim at $2.8 trillion– far above the cost of preventing many of these illnesses and deaths. It is impossible to predict how much a disaster would cost, however we can estimate that the cost could be similar, if not more than, the Chernobyl and Fukushima disasters.

There is a high likelihood that Cape Cod would experience severe immediate and long term effects of a large disaster at Pilgrim so it is evident that the large population of the Cape needs to have a disaster plan. Though the Cape may not be ordered to evacuate, we can predict that many people will feel unsafe and evacuate voluntarily. This can cause a significant amount of chaos and will most likely interfere with the existing evacuation plan. It would be extremely beneficial to develop an evacuation plan for resident of the Cape closest to the plant so as to expedite the evacuation and ensure order and safety among evacuees. For those living farther west, a large disaster at Pilgrim may result in a shelter in place order. Services should be provided to those ordered to shelter in place, such as radiological monitoring and potassium iodide provision.

If an accident were to occur, the health of the children in the area should be the top priority. Considering fallout will spread over large areas, the impact of an accident would have implications for large areas. There are preventative measures that can be taken to help prevent children from developing thyroid cancer in the years following the accident. Potassium iodide can be taken to prevent an uptake of radioactive iodine immediately after the accident. This is not a long term solution, but a measure that should be given to those living within the immediate radius of the plant. We predict that considering the wide spread of fallout is likely, and the source of exposure to radioactive iodine for most children is drinking milk from cows that have consumed contaminated feed, special measures will have to be taken for all of Massachusetts, and likely additional areas out of state. The Massachusetts Department of Health already has a publication, which details the measures that should be taken by dairy farmers in Massachusetts. The publication should be distributed and followed in the event of a disaster as the response of the food industry will be vital to the lessening the severity of the health impacts caused by the accident.

It should also be noted that the website run by Entergy to provide emergency planning information to the public, www.pilgrimpower.com, has not been updated since 2011 and several of the important external links no longer work. This reflects poorly on Entergy’s ability to keep updated emergency procedures available to the public.

GLOSSARY

Cladding – a covering, protective measure for a system or structure

Decay Heat – heat released as a result of radioactive decay

Electric field – region around electric material

Electromagnetic radiation – any kind of radiation in which the electric fields (See Glossary) and magnetic fields (See Glossary) deviate at the same time, ex-rays, gamma rays, radio waves, and visible light.

Entrain – the killing of adult fish or shellfish during cooling water intakes

Exothermic reaction – any reaction that releases energy in the form of light or heat

Fuel Outage – every 18-24 months the fission reaction at a nuclear power plant is shut down and one third of the fuel assemblies are replaced

Heavy Isotope – large molecules that contain more neutrons in the nucleus

Impinge – the killing of fish larvae during cooling water intakes

Kinetic Energy – energy characterized by a body in motion

Magnetic Field– region around magnetic material

Mothball – a state of being unfit for further use and being in a state of protective incasement

Neutron – a subatomic particle located in the nucleus of an atom. Neutrons have no charge and contain the same mass as protons

Nuclear Repository – a multi-barrier permanent spent fuel storage site

Oxidation Reaction – a reaction that increases the oxidation state of an element and can release hydrogen

Responsible System Engineering – a sub-field of systems engineering

Scramming – a planned shutdown of the fission reaction taking place inside a nuclear reactor

Ultimate Heat Sink – a virtually endless supply of water used for reactor core cooling

Walk Down – a physical inspection any designated nuclear power plant structures

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APPENDIX

Definition of Radiation

The definition of radiation is “energy radiated by waves or particles” (Merriam-Webster, 2012). In the case of nuclear radiation the energy is coming from isotopes that give off alpha or beta particles or gamma rays. Gamma rays are electromagnetic rays while alpha and beta particles are energized particles. An alpha particle is composed of a helium nucleus, and a beta particle is an energized electron (Nave, 1999). The differences are not limited to gamma rays, alpha particles, and beta particles. There is a vast variety of radioactive isotopes and elements, which can decay into a completely different radioactive particle. It is not a simple science procedure to determine the exact effects a plant has on the environment or human life. It is most important to examine trends and the levels of radioactivity in the environment in determining if the power plant is operating safely.