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Introduction

Nuclear accidents and disasters have resulted in extremely significant effects, and what has been addressed to prevent reoccurrences of such catastrophic events in the future. The general population, on average, is unaware of the actions, or lack thereof, that led up to the events of multiple nuclear accidents, such as Chernobyl in the former Soviet Union, Three Mile Island in PA, United States, and Fukushima-Daichi in Japan. Because of each of these disasters, safety precautions have evolved and been implemented as prevention measures towards future nuclear disaster potentials. This review of events aims to examine the aftermath and effects of nuclear disasters on populations, the environment, and the standards for safety and prevention of future accidents, as well as the cost involved on a large scale. The severity of devastation that nuclear accidents or disasters are capable of creating is often overlooked.

Root Cause: How Did This Happen?

Chernobyl:

The nuclear accident that occurred at Chernobyl in 1986 was a result of insufficiently trained laborers operating a reactor with a flawed design. The reactor was the RBMK, of Soviet design, meant to produce electric power and plutonium. The design was considered unique because it used a combination of water and a graphite moderator as a coolant. The outcome was a steam explosion accompanied by a series of fires that released, at minimum, five

percent of the reactor’s radioactive core both downwind and into the atmosphere at about 5200 PBq (Bq, or becquerel, is a quantitative measure of radioactive material that a single nucleus breaks down per second. A petabecquerel is equal to 1015 becquerels). This was directly related to Cold War isolation and the lack of safety culture. Two plant employees died during the accident, and another twenty-eight people died in the weeks that followed due to acute radiation poisoning.

Nearing a routine shutdown, on April 25, 1986, a crew of workers prepared to test the turbines spin duration and power supply, after losing main electric power, to circulating pumps at Chernobyl reactor 4. Multiple actions by operators, such as disabling the mechanisms for automatic shutdown, occurred before the test. When the operator finally took action to shut down reactor 4, it was already significantly unstable. A design error in the control rods resulted in a massive surge of power where the rods entered the reactor. Extremely hot fuel interacted with cooling water and caused multiple reactions resulting in pressure increase. Characteristics of the Soviet designed reactor dictated that damage to fuel assemblies could, and did, destroy the reactor in entirety. Excessive pressure detached the 1000-ton cover plate for reactor 4, which caused the fuel channels to rupture and the control rods to jam. Rapid generation of steam filled the core, causing an explosion and causing fission products to be released into the atmosphere. A few seconds after, another explosion occurred, spewing fuel channel and hot graphite fragments. The fuel and graphite started multiple fires, which caused radioactivity to be released into the environment. More than half of the radioactivity that was released was of biologically-inert noble gases.

Nearly five thousand tons of dolomite, boron, clay, lead, and sand were dropped by helicopter onto the reactor’s burning core in an attempt to extinguish the fire and limit the radioactive particles being released into the environment. For ten days, the fire burned.

The actions taken by Chernobyl plant workers were in direct violation of the technical specifications that were in place. The plant was operated at extremely low power with inadequate safety precaution, as well as poor communication with safety personnel. At low power, the RBMK reactors were extremely unstable. All of these factors led to the power surge that inevitably destroyed Chernobyl reactor number 4. A sudden heat increase caused a surge of power that caused fuel containing pressure tubes to rupture. Most nuclear power plants, in other areas of the world, commonly had containment structures. Chernobyl, however, did not have one of these structures, and without it, the environment was left unprotected from the radioactive material that escaped the reactor core.

Three Mile Island:

The accident that occurred at Three Mile Island nuclear power plant, located near Harrisburg, Pennsylvania, United States, in 1979, was the result of a cooling malfunction that caused a TMI-2 reactor core to melt, destroying the reactor. The plant had two water reactors, both pressurized, in use. TMI-1 began service in 1974, and today remains one of the highest performing reactor units in the United States. TMI-2 was still considered brand new when it was destroyed by the accident.

There was a low amount of radioactive gas released in the first few days following the accident, however, it was not enough to cause harm to proximal residents. The Three Mile Island accident did not result in any adverse health effects or injuries.

The accident to TMI-2 occurred at 4 in the morning on March 28th. The reactor was functioning at ninety-seven percent power. The reactor experienced a malfunction in its secondary cooling circuit, resulting in a temperature increase in the primary coolant, causing an automatic shutdown of the reactor. When the automatic shutdown took place, the relief valve malfunctioned and did not close, allowing the primary coolant to drain, subsequently not removing the residual decay heat from the core of the reactor. This caused significant damage to the core. Operators failed to diagnose the problem and therefore failed to properly respond to the unanticipated reactor shutdown. The root causes of the Three Mile Island accident proved to be a lack of control room instrumentation and poor training for emergency response. Had the operators had an instrument that notified them of the relief valve had not shut, the accident may have been avoided.

Fukushima:

The Fukushima Daiichi accident was much different than the incidents at Chernobyl and Three Mile Island. On March 11, 2011, three reactors at the Fukushima Daiichi nuclear power plant were disabled after the power supply and cooling were disabled, following a fifteen-meter tsunami that resulted from a major earthquake. In three days, immediately following the events, all

three reactor cores melted. Units 1-3 instantly shut down operation automatically. Reactor units 4-6 were not in operation during the event, but were still affected. During days four, five, and six, radioactive release totaled roughly 940 PBq. Because of damage from the accident, four other reactors were inevitably written off. Two weeks later, reactor units 1-3 stabilized after water addition, and they were able to be cooled with water that was recycled from the new plant by July. In mid-December, it was officially announced that the plant was in ‘ cold shutdown condition’.

Aside from cooling, prevention of radioactive material release was the biggest ongoing task. This was particularly true for contaminated water that the three reactor units were leaking. In August of 2013, this information was officially made news to the public.

There were no deaths reported of the Fukushima nuclear accident, nor were there any reported cases of sickness from radiation exposure. 100, 000 people, however, were evacuated from their homes, and the government delayed their return for quite some time out of precaution. More than 1000 deaths have been linked to maintaining the evacuation for an extended period of time. A series of earthquakes took place between April 7 and April 12 with similar magnitudes to the one that caused the nuclear disaster on March 11, however, no further damage was inflicted on the nuclear plant.

Radiation Exposure and Health Effects

People can unexpectedly be exposed to radiation from nuclear disasters, nuclear or radiologic explosions, or the inadequate disposal of equipment used in radiotherapy. It is more likely for children, than it is for adults, to

experience higher levels of internal and external radiation exposure. This is because their bodies and organs are smaller in size, and they possess physiological characteristics that leave them with common tendencies to randomly pick up items that could be contaminated, or to consume foods that may be contaminated.

In investigating the incidence of cancer in those living in close proximity to the Three Mile Island plant, overall there was zero childhood cancer association.

After the nuclear accident at Fukushima in 2011, there was an effort made to estimate radioactivity release, however, difficulties surrounding initial organization, contamination of measuring devices, and elevated natural background radiation, information was limited.

In comparison to other nuclear power plant disasters, the estimation of dosage and the long-term health risk assessments performed following the Chernobyl nuclear accident proved to be far more comprehensive. Studies have shown that children and adolescents who experienced radioactive exposure from the Chernobyl fallout revealed consistent, sizable increases in thyroid cancer related to dosage, with the largest risk affecting children who, at time of exposure, were youngest.

In regards to low-to-moderate radiation exposure, data is rather limited on the late effects of exposure, with the exception of cancer. Children and adolescents have been observed showing adverse effects on cognitive and mental function. The same radiation exposure has shown increased lens opacities risks in infants and individuals exposed to radiation at young ages

by the atomic bomb. Children and adolescents who experiences internal exposure from Chernobyl have been linked to elevated risks of nonmalignant nodules of the thyroid. Other risks associated include thyroid autoimmune disease, hyperthyroidism, and hypothyroidism. Circulatory disease has been associated with high doses of radiation, but low-exposure evidence is still controversial. Increasing evidence is being used to connect radiation exposure from children exposed during the atomic bombings to significant risk of heart disease, hypertension, and stroke.

Health outcomes related to radiation include, but are not limited to, mental health conditions, cancer, organ and tissue reactions, and acute radiation syndrome (ARS). Since the Fukushima nuclear plant accident, health outcomes are closely evaluated. Also evaluated are health risks from medical radiation equipment that has been inappropriately discarded, and health effects associated with populations who live in close proximity to nuclear power plants.

Child mutations are a major adverse health effect that resulted from the Chernobyl disaster, and easily one of the most difficult to visualize. Heart defects were one form of genetic mutation that was caused by radiation in some children; which was complicated to treat in many, due to the cost of medication and the unavailability of it. In 1986, the year of the Chernobyl accident, the rate of children born with mutations, or birth defects, increased by 200 percent. The number of cases that were reported continued to increase, many other cases most likely were not reported at all. Most of these defects have been concluded as genetic mutations, which means they are far more likely to be passed on to generations to come. This could mean

that more radiation related mutations and birth defects from Chernobyl may be yet to come. Downs Syndrome also became an occurrence that was relatively common, due to the effects of radiation.

Environmental Effects

Not only were people affected by exposure to radiation from the Chernobyl accident, but animals, trees, microbes, insects and fungi were affected as well. The catastrophic event that was the nuclear disaster at Chernobyl occurred more than 30 years ago, and yet the impacts are lasting and still felt today. Even though people were evacuated and no longer live in exclusion zones, other life forms still exhibit signs and symptoms from radiation poisoning.

Plant mutations are extremely common, especially in the zones surrounding the epicenter. High radiation levels meant that the animals of Chernobyl did not have safe food to consume; this was especially true for cows, which ultimately led milk to be contaminated. Plant roots can absorb radiation easily. Today, forests remain contaminated due to caesium radioactivity that insects, and other wildlife, share by occupying the areas. Mushrooms and berries, as well as animals from Chernobyl, have been declared to contain extremely high radiation and it has been advised that they not be consumed. Also related to high levels of radiation, shrubs and trees have changed their coloring and/or have completely dried up, while others remain short when they naturally would have grown tall. What was once a beautiful landscape, has been destroyed by the Chernobyl disaster. In what is now infamously known as “ The Red Forest”, shortly after the meltdown, the pine trees in

this area turned a burnt-reddish color and then died; however, some fifteen to twenty years later, they did not show any evidence of decay.

Birds found living near Chernobyl radioactive zones have been found to have much smaller brains in comparison to birds living in areas not poisoned by radiation. Trees grow at a significantly slower rate, and a much lower number of insects and spiders can be found living in radioactive areas as well (including but not limited to grasshoppers, butterflies, and bees). In addition, wild game found outside of the zones, even some found as far as Germany, have continued to exhibit dangerous and abnormal radiation levels.

Decomposing organisms, such as fungi, microbes, and certain insects that aid in the decay process, have also been affected by contamination. These organisms are important to all ecosystems as they are responsible for recycling nutrients and organic substances back into the soil; therefore, the entire ecosystem is drastically affected by this process.

Studies show that fire is a major risk for the Chernobyl area. This is not just because of the possibility of environmental destruction, but because a fire could cause radioactive elements to be redistributed to places that are not in the exclusion zone. Studies are currently being performed to determine if a similar microbial scenario is affecting Japan from the Fukushima disaster.

Nuclear Safety and Energy Policy

In the past, when nuclear power plant accidents have occurred, authorities quickly realized that existing emergency plans were too broad to be able to

effectively address the evolving challenges. Experts often assured that situations were being controlled, while others feared that continuing emissions of radioactivity would cause catastrophic damage. Evacuation policies were also a huge debate; public panic, total release of radioactivity, costs, proximity to capitals, etc., were all things considered.

Three times this scenario has played out: Chernobyl in 1986, Three Mile Island in 1979, and Fukushima Daiichi in 2011. When Three Mile Island happened, authorities were optimistic that an evacuation was unnecessary. A few days after the Chernobyl explosion, the rapid release of radioactivity forced the Soviet government to notify Kyiv, the capital of Ukraine (62 miles away) that evacuation may be imminent. Japanese officials faced a similar situation after the Fukushima crisis; unsure of the extent of contamination.

In all of the three nuclear events, effective emergency plans were hindered by uncertainty. History has shown us that, even after the fact, terms from accidents regarding nuclear reactors are difficult to predict or measure. Even though the radiological inventory that the reactor core contains is typically known by operators of the plant, it is much more complicated to try to predict and understand how and how much could escape in the event of an accident.

The Fukushima disaster urged a review of protection plans against potential nuclear plant accidents worldwide. The NRC (Nuclear Regulatory Commission) ordered regulations to be inspected and many new safety upgrades were approved for implementation, however, the United States is

far from close to not being vulnerable to potential nuclear disasters. Safety improvements and risk assessment need to continue to improve.

Cost Estimation and Economic Impact

The nuclear catastrophe that occurred at Chernobyl in 1986, has a general cost estimation at around $700 billion over the last three decades. The largest portion of indirect costs is represented by health-related expenses. These costs are far greater than the costs that are related directly to the power plant. This is because the health costs span a lifetime, with the potential to include the generation to come. The most expensive and widespread effects are those of neuropsychological nature, as they have consequences that last long-term.

The damage that nuclear accidents cause directly is a considerable economic impact. The cost alone of sealing off the Chernobyl reactor was significant. “ The Sarcophagus” enclosure that was completed in 2017 to house the remains of reactor 4 costed more than 2. 6 million dollars. Other economic impacts include the resettlement of more than 330, 000 individuals and forcibly creating an “ exclusion zone” around the accident site.

Benefits payments are still being distributed to more than seven million people in Ukraine, Russia, and Belarus; which costs Belarus around six percent, and Ukraine a minimum of five percent of their annual budgets. Research is still being funded to figure out methods to produce food that is uncontaminated. Other expenses include, but are not limited to, radiation monitoring of the environment, clean-up and disposal of toxic and/or

radioactive waste, and the cancellation of the nuclear power program in Belarus, which is estimated to be a $235 billion loss.

The Chernobyl disaster happened at a terrible time. The Soviet Union ended with the fall of the Berlin Wall in 1990, leaving both Belarus and Ukraine on the verge of independence after being satellite countries of the former Soviet Union. Developing new businesses also became more trying, as areas contaminated by radiation were far from desirable to investment companies. Had the accident at Chernobyl occurred in an industrial, more heavily populated area, rather than a rural, farming area, the disaster could have been significantly higher.

Hurricane Katrina was estimated to cost between $125 and $250 billion, in 2005. It drastically affected oil production in the United States and sent gas prices soaring to $5 per gallon. The Fukushima disaster produced economic damage comparable to Chernobyl, as it forced eleven of Japan’s fifty nuclear reactors to shut down and it decreased the generation of electricity by nearly forty percent for the country. Radiation release, however, was significantly lower. Chernobyl proved to have drastically more radiation release than the accident at Three Mile Island did, however, the economic impact was greater following Three Mile Island. This was due to the development of new plants being completely shut down in the United States. Following the Three Mile Island accident of 1974, new plant applications were not introduced in the United States until 2007. Because of this, the United States nuclear engineering companies completely lost the ability to compete with other countries on the nuclear power forefront.

Conclusion

The Chernobyl disaster of 1986 is considered to be the largest, most well-known, and most devastating nuclear disaster in history. When the incident occurred, the severity of the event was not broadcasted. A substantial amount of time passed before the full extent of harm was released, and even today, many who were affected by the radiation exposure have not been acknowledged. The Fukushima and Three Mile Island nuclear disasters were also significant. Research continues to shed light on the full extent of the impact that certain catastrophic nuclear accidents have had on, not just areas proximal to disaster locations, but the world in entirety. In utilizing newly, and more readily available information on the multiple nuclear accidents that have occurred over the last few decades, and comparing the causes and effects of each, people may start to grasp an accurate depiction of the horrific possibilities should history ever repeat itself.

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