NUCLEAR WASTE: A PRACTICAL SOLUTION

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Abstract

This study analyzes potential long-term nuclear waste disposal methods and determines which disposal method is the most practical solution for nuclear waste in the United States. Three disposal options in particular are studied: sub-seabed waste disposal, geologic waste disposal, and space disposal. This study examines each of these methods to determine which one is the most politically feasible and environmentally safe means of preventing nuclear waste from escaping into the biosphere. The deleterious impact of regular natural processes and the possibility of seismic activity are also evaluated for each method. This paper also investigates both the political and legal feasibility of each disposal method. It tentatively concludes that sub-seabed waste disposal, while under-studied, holds the most promise for long-term nuclear waste disposal.

Introduction

Nuclear energy benefits the United States in a plethora of ways. Greater nuclear energy production would reduce energy costs throughout the country, allowing every sector of the United States economy to become more competitive internationally. Increased nuclear energy enhances national security by reducing American dependence on foreign oil: currently, American dollars used to purchase oil from countries like Saudi Arabia can find their way into the hands of terrorist organizations, which in turn fund bloody civil wars and vicious attacks on civilians around the world. Additionally, nuclear energy can benefit the environment. Unlike burning fossil fuels, the production of nuclear energy is not associated with any dangerous atmospheric emissions.

With all the benefits of nuclear energy, what prevents America from making greater use of this resource? One major concern is nuclear waste. Nuclear energy production creates destructive radioactive byproducts capable of causing cancer and genetic defects, as well as serious environmental damage. There are already over 400,000 cubic meters of high-level nuclear waste (HLW) in the United States. Further production of nuclear energy may be unsustainable without a long-term solution.

The three most viable options for HLW disposal are: sub-seabed disposal, geologic disposal at the Yucca Mountain facility, and space disposal. This study researches which disposal method is the most practical long-term solution for nuclear waste. Two considerations are weighed in this study's exploration of the most practical disposal method: environmental safety and political feasibility. Each of the three disposal methods mentioned in the research question will be tested.

Literature Review

Sub-Seabed Disposal

One of the proposed disposal methods for HLW is sub-seabed disposal (SSD). The SSD method requires burying containers of nuclear waste deep in ocean sediment. In order for this method to be successful, the containers cannot be disturbed by geologic activity. Thankfully, the ocean contains the most geologically stable locations on earth. However, geological surfaces near the edges of tectonic plates are susceptible to disruption. The collisions of the plates constantly threaten to produce earthquakes and volcanoes, but the centers of the tectonic plates provide the safest environments to store nuclear waste.

There are three possible methods for delivering the waste to the final location (Bala, 2014). All three disposal methods call for penetrometers that would carry the containers several meters into the seabed floor. The simplest method is to drop containers of waste from ships and allow the containers to fall freely to the ocean floor. The second method requires storage containers, to be equipped with engines that propel the containers from the ship to a specific location on the ocean floor. A third possibility is to direct the containers into shafts that have previously been prepared for the purpose of nuclear waste disposal. This option is the most expensive. However, this method would provide scientists with the opportunity to recover the containers if SSD was deemed unsafe after the process began (Kaplan, 1991).

HLW would not permanently be contained by the canisters: within a few centuries, the water would corrode the containers. Contamination is avoided because, between the time the canisters are dropped into the ocean and point at which the canisters decay, the canisters will be covered in clay. The clay would become a self-sealing enclosure for the radionuclides. Ocean clay possesses plastic-like properties that stop or dramatically slow down the speed at which water seeps through sediment. Any radionuclides that managed to escape through the clay would be highly diluted by the stream of water. However, if even the tiniest amount of radiation escaped through this means, it would be disastrous (Calmet, 1989).

There are several potential challenges seabed waste disposal faces. Studies conducted by Kaplan (Into the Abyss: International Regulation of Subseabed Nuclear Waste Disposal) and Calmet (Ocean Disposal of Radioactive Waste: Status Report) both hold that more research must be conducted before the procedure is implemented. Another potential problem is the network of legal restrictions on the process of seabed disposal. Kaplan (1991) explains that under the current regulatory system, the legality of seabed disposal is contingent upon the findings of scientific investigation. If and only if future findings show seabed disposal is a safe procedure, the method is legal. Kaplan bases this conclusion on the two regulatory conventions: the London Dumping Convention (LDC) and the Third United Nations Conference on the Law of the Sea (UNCLOS III). LDC prohibits the dumping of high level waste at sea. What the LDC means by the term "dumping" is highly disputed.

The United Nations Convention on the Law Of the Sea prohibits any state from claiming or using the resources of the seabed beneath international waters. However, according to Kaplan, there is confusion over whether or not seabed disposal would be "using the resources" of the seabed. Bala (2014) considers both international and national laws as they relate to sub-seabed disposal. He points out that the 1996 Protocol to the London Convention has replaced the LDC. The 1996 Protocol prohibits sub-seabed disposal, but the United States has not signed onto the Protocol. Bala believes the broad-based restrictions of UNCLOS prohibit sub-seabed disposal. However, since the United States is not party to UNCLOS, this treaty does not legally bind the United States. Kaplan reaches the same conclusion as Bala.

Geologic Repository

The most studied proposal for long-term disposal of HLW is the geological repository. This was the first solution proposed for HLW and is still commonly believed to be the most effective way to contain radioactive material (Long, Ewing, 2004). In 2002, the United States selected Yucca Mountain as the location for a geological HLW repository. The site has been a source of heated political contention ever since the project began.

There are several factors that are critical to the safety of a nuclear repository. According to the Environmental Protection Agency, a high level waste repository needs to be capable of containing radiation for at least 10,000 years. (Roush, Service, 1995) The rock surrounding the repository should not be near a fault line where there would be a threat of volcanic eruptions or earthquakes. The natural barrier around the repository should be highly absorbent to prevent radionuclides from seeping down to the water table or escaping to the surface, and the geologic structures around the rock should prevent or slow water seepage to a sufficient rate to allow contaminated water surrounding the repository to decontaminate.

Studies conducted on Yucca Mountain have produced conflicting results. Long (2004) believes the percolation rate could cause contamination issues. The original percolation speed at the site was believed to be 4mm per year. Later estimates predicted a percolation speeds near 40mm per year. The high rate of speed indicates there is fracturing in the rock. However, there is still no known method to model how much water would make contact with the repository.

Long (2004) points out another potential problem with Yucca Mountain. The location is at risk a slight risk from seismic activity. In 1992, an earthquake with a magnitude of 5.2 on the Richter scale struck the area (Long, 2004). Other studies conclude that the Yucca Mountain repository is sufficiently safe. Peterson, Katzenberg, and Corroding, (2006) hold that the risks posed by global warming due to burning fossil fuels outweigh risks of disposal at Yucca Mountain.

Space Disposal

Some scientists suggest radioactive waste should be placed in specialized containers and launched into space. Once in space, there are several ways in which the containers could be disposed. The containers could be sent to a lunar surface, placed in solar orbit, or sent toward the surface of the sun to be destroyed. In a technical paper from NASA (Burns, Causey, Galloway, Nelson, 1975), scientists ascertained the procedures necessary to ensure safe disposal by this method. Procedures for launch site selection, transportation from the plant to the launch site, shuttle selection, and flight operations were all taken into account. The plan outlined in the NASA paper calls for the placement of nuclear waste on a lunar surface or into solar orbit. Under the Berkowitz plan, the containers would be sent towards the sun and be pulled by the gravity field towards the surface (Berkowitz, 2013). Berkowitz strongly believes the space disposal method should be considered as a viable option for disposal. He argues that this method has one clear benefit which no other method offers: this method eliminates the waste from the earth. All the other disposal methods focus on containing the dangerous substance here on earth.

Methods

This paper will conduct a qualitative study of previous research to determine which of three HLW disposal methods is the most practical solution for America's long term nuclear waste disposal needs. The three disposal methods considered are sub-seabed disposal, geologic disposal, and space disposal. Practicality will be determined by three factors: environmental safety, political feasibility, and legal feasibility.

Environmental safety is defined by the ability of a disposal method to prevent dangerous levels of radioactive waste from escaping into the biosphere. Political feasibility is determined by the level of public opposition likely to result from the implementation of a waste disposal method. If the level of opposition to the project is low, the political feasibility is high. Legal feasibility is measured by the conformity of the proposed project to applicable laws and regulations.

Operationalization

In order to operationalize the concept of environmental risk, this study will examine the potential of radioactive waste to escape into the biosphere. For geologic disposal and sub-seabed disposal, two potential threats will be considered: the potential of nuclear waste to escape into the biosphere through regular natural processes over time and the possibility for seismic activity to damage the facilities as well. Space disposal will not pose the same kind of dangers as the other two disposal methods because the waste will be removed from the earth rather than stored underground. However, there may be other significant risks associated with this method. For space disposal, I will examine the possibility of radioactive waste escaping during the transportation to the launch facility and during the launch itself.

This study will operationalize the concept of political feasibility by examining the level of local and national political opposition to any particular solution. Many people recognize a long-term solution must be implemented to dispose of HLW. However, they will not allow the construction of a waste facility in their vicinity. A practical disposal plan must be able to mitigate public opposition to the disposal method. I will also assess the legal barriers that may impede implementation.

Data

Environmental Risk

Sub-seabed Disposal. The process of sub-seabed disposal places much of the burden of containing waste on natural barriers. The sub-seabed disposal method calls for sending "penetrometers" full of nuclear waste into the ocean floor. Of the three variations of this method mentioned previously—allowing the penetrometers to fall undirected to the ocean floor, penetrometers that are equipped with engines to direct the penetrometers to specific locations, and drilling a repository in the ocean floor—the last possesses a major environmental advantage over the other two methods. Using this method, if research shows that particular sub-seabed repositories are not safe, the disposal containers can be removed from the sea (Kaplan, 1991).

While the radioactive waste would be dangerous for up to 10,000 years (Roush, 1995), the salt water would cause the containers holding the waste to decay in less than a 1,000 years. However, even without the engineered barrier, the environment may still be safe from contamination. The natural barrier created by the clay of the ocean floor is the primary impediment to nuclear radionuclides. The clay at the ocean floor possesses plastic-like qualities that make the floor self-sealing (Kaplan, 1991). This guarantees the radioactive waste will not be released directly into the ocean water. Two additional factors add to the security of the natural barrier: the impermeability of the clay and the sorbent qualities of the clay. Radiation is drastically reduced when the ions that are part of the radioactive waste attach to the clay, blocking movement of the radiation. The ocean floor is comprised of impermeable sediment and clay. While water does penetrate the clay, it moves extremely slowly (Kaplan, 1991). This gives the clay time to sorb the waste. Scientific studies conducted in the 1970s and 1980s by an international team of scientists found that nuclear waste buried only ten meters in the sediment may stay isolated for millions of years (Bala, 2014). Furthermore, if some radiation did escape from the site, it would be diluted by the huge amount of water.

Seismic activity will not impact the sub-seabed disposal sites: the most geologically stable places on the earth are on the sea floor. While, earthquakes and volcanoes occur at the edges of the tectonic plates, but there is an abundance of suitable space on the ocean floor that is not susceptible to tectonic disturbance.

While much of the research conducted on sub-seabed disposal is favorable, there are some concerns. Even a small amount of radiation leaking into the ocean is seen as problematic (Kaplan, 1991). More research is necessary to determine if sub-seabed disposal is truly safe or not.

Geologic Disposal. The United States has poured billions of dollars into a geological waste facility at Yucca Mountain (Long, Ewing, 2004). The design at

Yucca Mountain calls for a tunnel bored into the mountain hundreds of feet under the surface. The nuclear waste would be placed in metal drums, which would be placed in containers. Concrete would be poured into the containers surrounding the metal drums. When the repository filled to capacity, backfill would be placed around the tanks (Nuclear Energy Agency, 2000). The mountain itself would form a powerful natural barrier because it is high above the water table, and made of unsaturated volcanic tuff (Carter, 2005).

However, even with these precautions in place, there are still many concerns about the facility's ability to isolate the radiation. For example, the tuff is highly fractured, and it contains significant amounts of water. The volcanic rock was laid down in a series of layers as hot ash. When the ash cooled, the layers fractured. The depths of fractures range from a few meters deep to hundreds of meters deep (Long, Ewing, 2004). These fractures accelerate the rate at which water passes through the mountain.

Water could create additional serious risks for the nuclear repository. There are two primary problems created by water seepage. Water contact with containers holding the waste would accelerate corrosion, and water molecules would transport radionuclides faster than the nuclides would be able to travel on their own (Long, Ewing, 2004). Two studies conducted in the 1980s (Scott et al. and Montazar & Wilson) found there would be extremely slow water seepage past the repository. According to these studies, no radioactive waste could reach the water table during the EPA mandated time period. Studies conducted in the 1990s (Gauthier et al. 1992 and Further, Flint & Flint) assumed higher percolation flux rates, less lateral deflection, and considered the effect of fractures on water speed. These studies found that this rate was much faster than the rate reached by the Scott and Montazar & Wilson studies. The new rate of flow would make it highly unlikely for the repository to prevent contamination for the time period required by the EPA (Long, Ewing, 2004). Some scientists dispute the standards the EPA is requiring the repository to meet (Kerr, 2000). A panel at the International Academy of Sciences has expressed opposition to the standards, claiming the standards are unnecessarily duplicative and based on obsolete data. The Department of Energy maintains that engineered and natural barriers are sufficient to keep the nuclear waste isolated (Rept. 109th Cong.).

Another consideration at the Yucca Mountain facility is the possibility of seismic disturbance. The history of volcanic activity in an area is the best way to predict the probability of volcanoes in the future. According to Smith and Keenen (2005), eight volcanoes have erupted in the area in the last million years. Most scientists do not think the risk of volcanic activity is sufficiently high to prevent the development of the repository (Kerr, 1991). Kerr finds that the possibility of an eruption is 0.01 percent in the next 10,000 years (Kerr, 1991).

Space Disposal. Sending the nuclear waste to space is another proposed method for nuclear waste disposal. NASA has considered the possibility of this disposal method (Burns, Galloway, Causey, Nelson, 1975). One space shuttle and a high performance orbit transfer vehicle would be required for this method. Once in space, the waste could be sent to towards the sun to be destroyed (Berkowitz). Space disposal possesses a major advantage over the other two methods examined in this paper: it eliminates the issue of long-term isolation. However, this does not completely eliminate the risk of radioactive waste escaping into the biosphere. Radioactive waste could escape during the transportation to the launch facility or during the launch to outer space. According to Burns (1975), the most dangerous period would be during the transportation of the waste to the launch facility and the loading of waste onto the shuttle. However, a 2004 NASA study indicates the transportation and loading of the waste would not pose significant danger to the public (Berkowitz). The NASA study concluded that in the worst case scenario, an on the ground traffic collision, the greatest threat to human life was latent cancer. The study found that the probability of this happening was less than one in one billion (Berkowitz). The study also assessed the loading of the waste into trucks. The predicted fatality rate was one in 140,000 (Berkowitz, 2004).

The Cassini mission to Saturn is also pertinent to discussions of nuclear waste disposal in space. The Cassini orbiter was nuclear powered and contained the Huygens probe, which carried nuclear components. NASA examined the possibility of launch accidents and accidental reentry. The environmental impact investigation found that the median cancer fatality rate would be in the range of one in thirteen billion and one in two hundred eighty billion. These two activities (the transportation of highly enriched uranium and the Cassini mission) are pertinent to this discussion because of the similarity to the launching of nuclear waste into space (Berkowitz, 2004). However, even though these results shed light on the risks associated with nuclear waste disposal in space, the activities are not identical. More studies would need to be conducted if this method is pursued. One critical difference is the total amount of radioactive material involved. A shipment of nuclear waste destined for solar destruction will involve substantially more radioactive material than either of the other two activities examined. The increase in the amount of radioactive material will almost certainly increase the amount of harm resulting from an accident.

Political and legal feasibility

Sub-seabed Disposal. One of the advantages of seabed disposal is the drastic mitigation of political opposition. Most nuclear waste disposal proposals face a major backlash from the local area in which the project's construction is planned. Sub-seabed disposal can avoid this problem. Sub-seabed disposal projects would be located in the deep sea, far away from coastal areas. With no human population in the area where the project is constructed, local concerns will be mitigated or entirely absent.

International agreements could impede U.S. efforts to implement sub-seabed disposal. The waters of the deep seas are generally considered common territory of all countries. Various international regulations have been implemented to promote the health and cleanliness of the ocean. There are two major documents regulating disposal in the oceans: the London Convention of 1972 and the Protocol of 1994 on the London Convention of 1972. The London Convention of 1972 prohibits the dumping of nuclear waste into the ocean (Bala, 2014). The United States signed this agreement and the country is bound to conform to the stipulations of the treaty. However, sub-seabed disposal is not dumping of waste. The London Convention defines dumping as "the deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures, as well as the deliberate disposal of these vessels or platforms themselves." In sub-seabed disposal, the waste remains in sealed containers while it passes through the ocean to arrive at its destination beneath the ocean floor (Bala, 2014). As long as the procedure works as it is intended, nuclear waste will not escape into the ocean. Therefore, the waste is not "disposal at sea", and the treaty does not prevent the United States from engaging in sub-seabed disposal. The Protocol of 1994 does expressly prohibit sub-seabed disposal, but the United States did not sign the protocol and therefore the treaty does not bind the United States.

Geologic Disposal. The public opposition to the geological repository at Yucca Mountain poses a significant political impediment to the project. In the early 1980's, Congress passed the Nuclear Waste Policy Act (NWPA) of 1982. The NWPA placed Yucca Mountain on a list of possible locations for the construction of a nuclear waste repository (DuVivier, 2012). Section 116 of the law allowed states selected as potential locations for a repository to veto construction, but the state's veto would not make the final decision. Congress retained the power to override the state veto by a vote in both houses of the national Congress (DuVivier, 2012). Nevada vetoed the selection, but Nevada's veto was overturned by Congress. Over the course of three decades, the United States spent over fifteen billion dollars conducting research at the site. In 2008, the Department of Energy submitted an application to the Nuclear Regulatory Commission for a license to construct the repository (Macfarlane, 2011). In 2008, when Senator Barrack Obama was running for the presidency, one of his campaign points was his intention to cut funding for the Yucca Mountain Repository. In August of 2010, the Nuclear Regulatory Commission published a report stating that the Department of Energy met all the requirements of the Nuclear Regulatory Commission's regulations (Nuclear Regulatory Commission, 2010). However, several months before the Nuclear Regulatory Commission finished its review of the application, the Obama administration cut the funding for the Department of

Energy to spend on the project (Beaver, 2010). The site at Yucca Mountain would have to surmount major political obstacles in order to continue onward.

Space Disposal. At first glance, it may seem that space disposal would be the most politically feasible of the options analyzed in this paper. The waste would be sent into space, which means no specific area would be threatened by the permanent storage of nuclear waste. There might be some opposition to this method near the launch site, but it seems unlikely that the opposition would reach the pitch that Yucca Mountain faced.

However, the cost of space disposal is a major obstacle to its success. It is currently estimated that space disposal would cost $10,000 per pound disposed (Berkowitz, 2013). The United States already has 60,000 tons of waste stored around the country. At this price, the United States would spend 1.2 trillion dollars disposing of current waste. Clearly, the economic considerations may make the project politically unfeasible.

Conclusion

Nuclear energy is an abundant natural resource that possesses the potential to power American economic development into the future, and make our country more secure. As with all other resources, nuclear energy comes with certain responsibilities. One of these responsibilities is the disposal of spent fuel. The United States has failed to deal with the issue of nuclear waste and the problem grows larger every year. There are 60,000 tons of spent nuclear fuel contained at 129 sites (Klein, 2011). Nuclear waste is spread out among thirty-nine states, and thousands of pounds of additional waste are created every year. America needs to implement a strategy for nuclear waste disposal.

In this paper I have outlined three possible solutions to the issue: sub-seabed disposal, geologic disposal, and space disposal. The study tested each method by two variables, environmental risk and political feasibility, to determine which method was the most practical. Each method contains strengths and weaknesses. Sub-seabed disposal has not been tested sufficiently to determine whether or not it is a safe disposal method, but it is politically feasible. Many studies have been conducted at the geologic repository at Yucca Mountain. The studies have raised significant concerns about water seepage and faults in the rock. Yucca Mountain is by far the least politically feasible. The site has undergone extraordinarily intense scrutiny, and the federal government blocked nuclear waste disposal at the location. However, space disposal is environmentally friendly. The waste is sent off the planet entirely, so there are no concerns about long-term seepage and contamination. However, no direct studies have been conducted on the safety of transportation to the launch site or the launch itself. Without any studies that have directly assessed the risk of the transportation, the safety of this method is uncertain. The economic costs required to carry out this method make the method politically unfeasible.

Of the three nuclear waste disposal options I have considered, sub-seabed disposal appears to be the most practical and politically feasible. More research should be conducted to assess this disposal method, but nearly all research to date has reflected favorably on this solution.

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