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Nuclear Waste Disposal and Managemnet

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by

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Abstract

In this literature review, an overview on nuclear waste, its history and proposed means for it's storage and disposal. The United States has been producing High Level Waste since the Manhattan project in the 40's. Since then, the US has produced 88,000 metric tons of waste and continues to produce 2,000 more tons every year without a proper site for long term storage and disposal. While other countries such as Finland and Sweden have already created long term deep geological storage sites, the United States has have yet to approve and create one themselves.

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1 Introduction

The Department of Energy places the start of the Nuclear Era in 1934 [21] accrediting the first instance of fission and the first nuclear reactor to Enrico Fermi. He was awarded a Nobel Peace Prize ”for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons”[28] in 1938. Shortly afterwards, the United States started the Manhattan Project in 1942 to further develop this principle into making weapons of war for World War II. Their efforts would prove fruitful in the first and last use of nuclear weapons in warfare. In a uranium bomb dropped on Hiroshima and a few days later a plutonium one dropped on Nagasaki. While its use in active warfare ends here, the development and use of nuclear power has continued with the stockpiling of nuclear weapons and more important to the overview of this paper, nuclear fuel and its nuclear waste.

High Level Waste (HLW) is the most well-known and the most dangerous mostly coming from the refinement process of nuclear fuel as well as spent nuclear fuel rods. Transient and Low Level Waste (LLW) are also produced during these processes and will be discussed in this paper, however our focus will remain on HLW. According to Mitch Jacoby, a journalist for Chemical and Engineering News with a PhD in Surface Chemistry and Physics, the United States has produced approximately 88,000 metric tons of spent nuclear waste with 2,000 more tons being produced every year [17]. Due to the slow yet dangerous decay of radioactive elements present such as Plutonium-239 ,which has a half-life of 24,000 years [24], the long-term storage and disposal of such waste has been a heavily debated topic. Most of the current storage for nuclear waste involves on-site storage in liquid cooling tanks made of cement and steel. However, most of these holding tanks were created in the 1970s and in some cases, even dating back to the end of WWII. These casks were only meant to be a short-term solution, lasting from 20-50 years [1] As of now the United States does not have a current long-term solution to store HLW and is still producing waste. This paper is meant to go over the country's history with nuclear waste, its current plan to deal with it as well as discuss potential solutions for this waste.

This review paper will be reviewed as follows: Chapter 1 will discuss what is nuclear waste and where it comes from. Chapter 2 will go over the history of nuclear waste in the United States, going up to the modern day. Chapter 3 will go over proposed ideas to dispose of nuclear waste. Chapter 4 will go over what the United States currently does for their nuclear waste and comparing it to other countries.

2 What is Nuclear Waste?

In this chapter, we will go into what exactly nuclear waste is, why we want to store it and give an idea of the health risks involved.

According to the NRC, "Radioactive (or nuclear) waste is a byproduct from nuclear reactors, fuel processing plants, hospitals and research facilities. Radioactive waste is also generated while decommissioning and dismantling nuclear reactors and other nuclear facilities"[9]. Most of the nuclear waste today comes from the refining process of plutonium and uranium for the purpose of making nuclear weapons, as well as nuclear fuel rods. The disassembly of said nuclear weapons and spent fuel rods also adds to the total amount of waste present in the US. When discussing nuclear waste, there are two main types: High Level Waste and Low Level Waste

High Level Waste (HLW) as the name would imply, categorizes the most dangerous nuclear waste and poses the largest challenge for permanent storage. Most HLW comes from the processing of nuclear fuel or the spent cores of nuclear reactors. Often these materials are also "hot" sources, producing large amounts of heat and radiation. For example, a spent fuel rod after ten years of service can reach 10,000 rem/hour. For comparison, a full body X-ray delivers only 1 rem. This amount of radiation can deliver a lethal dose of radiation within 20 minutes of exposure without proper shielding [9]. These fuel cells are most commonly Uranium-235, thus the main worries after these cells have been cooled enough for handling are the byproducts afterwards. The first byproduct that Uranium-235 creates in the fission process is Cesium-137. This material decays into Barium-137 over its 30-year half-life before decaying approximately 2.5 minutes later into stable elements. While the decay of Cesium-137 produces mostly beta particles and Barium-137, its decay into stable elements is what constitutes 85% of the gamma radiation being emitted from Cesium-137. If in close proximity, it has been known to cause burns, radiation sickness, increase your chances of getting cancer, and in large enough amounts can lead to death. To make matters even worse, Cesium-137 has the potential to become soluble in the presence of water, making the chances of contamination much higher than its solid form, and the chances of ingestion/inhalation much higher as well [23].

The next HLW created in this process is Strontium-90. This isotope has a similar half-life to Cesium-137 but poses different health issues. Strontium-90 produces beta particles as it decays to Yttrium-90 with a half-life of 64 hours, which then decays into stable Zirconium-90. However what sets Strontium-90 apart from Cesium-137 is body accumulation. While Cesium-137 will eventually be excreted after entering the body, Strontium-90 is much more likely to stay in the body. Much like calcium, it is a bone seeking mineral and will accumulate in a person's bones, increasing the chances of bone and leukemia-based cancers[25].

Finally, we have transuranic waste. This is nuclear material is a type of HLW that is heavier than Uranium and is formed in either the enrichment or decay process of it. The most common and popular transuranic waste is Plutonium 239. Created from the fissile process of Uranium-238, it proves to be a problem for even long term storage, having a half-life of 24,000 years. Most of the risks involved with Plutonium-239 are similar to other alpha particle emitting sources, requiring only basic clothing to block most radiation. Plutonium-239 can still prove hazardous however, if it is inhaled in dust, lodging itself to an individual's lungs and enter the body from there. From there it accumulates in the bones, liver and spleen of the individual and like all the other HLW, irradiates them from the inside out. This internal radiation can increase the risk of cancers to most internal organs [24].

While not the focus of this paper, there also exists Low Level Waste (LLW). This usually entails items that come into contact with HLW or

Name	Half Life	Decay Type	Decays into	Health Risks
Cesium-137	30.05±0.08 Years	Beta decay	Barium-137m	Burns, acute radiation sickness, high risk of cancer, especially pancreatic cancer
Barium-137m	153 Seconds	Gamma radiation via photon emission	Barium-137 (Stable)	Burns, acute radiation sickness, High risk of internal cancers. If ingested can cause paralysis, anxiety, vomiting, cramps, diarrhea, numbness and muscle weakness
Strontium-90	28.79 Years	Beta Decay	Yttrium-90	Burns. If ingested, increased chance of cancer, especially bone cancer and leukemia. Also a known carcinogen
Yttrium-90	64.1 Hours	Beta Decay	Zirconium-90 (Stable)	Irritant to the eyes and lungs, scarring of lungs. If ingested, can cause pancreatic and liver damage
Plutonium-239	24,110 Years	Alpha Decay	Uranium 235	If ingested, is a known carcinogen, increases chances of cancer, especially to the lungs, bones and liver

Figure 1: HLW Isotopes and Health Risks [23, 24, 25, 22]

other high radiation sources. The most common LLW produced in industrial processes is usually water used in nuclear rod cooling, as well as tools, gloves, rags, vessels, and containers that came into contact with HLW waste and may contain trace amounts of plutonium and uranium. While most of the radiation coming from LLW is equivalent to background radiation, it could be just as radioactive as some HLW sources and increase your chance of cancer over time [22].

3 The History of Nuclear Waste

This chapter will serve as a brief history of radioactivity, the US's relationship with nuclear waste and how it has been handled up until modern day. The start of nuclear waste in the US is unclear. While there are extensive records of the history of nuclear fission and decay, there is no known start to when nuclear waste was created and where it was piled up. Therefore in order to capture the history of nuclear waste in it's entirety, one must know the history of radioactivity as a whole.

The beginning of radioactivity started in the 1890s, when the first few major discoveries of nuclear decay were found. Radioactivity as a concept was discovered in 1896 by Becquerel and Marie Curie [5]. This came across them experimenting with phosphorescent materials and exposing them to photographic paper. They decided to wrap the paper in a black paper and out of all the materials they used, only uranium was able to penetrate the paper and leave it's impression on the covered photographic paper. In 1934, Irène Joliot-Curie and Frédéric Joliot-Curie discovered induced radioactivity (also known as artificial radioactivity) by bombarding aluminum with a stream of alpha particles, causing this previously stable element to become an unstable and radioactive isotope of phosphorus [27]. This process would create multiple different isotopes of phosphorus, giving it a half-life from as long as 280 days to as fast as 2.5 minutes. Later that same year, Fermi bombards Fluorine-19 and Aluminum-27 with neutrons from a radon-beryllium source, causing them to decay into other elements. He publishes his finding of neutron-induced decay in the Italian journal La Ricerca Scientifica on

March 25, 1934 [14]. This is the first recorded incident of nuclear fission.

However, fission and its associated waste was first created on a large scale in the 1940s. Due to the radical laws in Italy at the time, Fermi immigrated to the US in 1938 and accepted a position at Columbia University the following year. As a physics professor, here he would discuss the potential of the atom and convey his ideas and findings to fellow colleagues in the field such as Albert Einstein, Bohr and Leo Szilard. Their discussion about the German lead Hahn-Strassman-Meitner experiment in 1938 lead them to believe the possibility of a self-sustaining fissile chain reaction. With World War II in full swing at this point, the race to achieve nuclear power had begun. After receiving federal funding in 1941, Fermi and his colleges developed the plans for a nuclear reactor. By November 1942, the first ever nuclear reactor was created dubbed "Chicago Pile-1". This crude pile composed of graphite bricks, uranium bricks, and oxides placed in between graphite layers. This pattern would be repeated on a crude wooden platform and some bricks would have holes drilled through them for the neutron absorbing cadmium rods. On December 6, 1942, these safety rods were pulled partially out of the squash-court-sized pile and for the first time, created sustained nuclear chain reaction [20]. While this was an impressive feat for the possibilities of nuclear energy, the US government saw the potential to create a weapon to end the war. The government shortly after this demonstration created the Manhattan Project whose sole purpose was to weaponize the realized power of the atom. Three years later the work done on this project would meet its deadly debut. On August 6, 1945 the first nuclear bomb was dropped on Hiroshima. Dubbed "the Little Boy", this uranium filled bomb detonated

800ft above the city, killed 70,000 people and injuring 70,000 more. The blast released 66.9 $\pm$ 8.4 Tera Joules of energy, considered "inefficient" due to only fizzling 1.7% of its uranium. Three days later, the final bomb used in warfare was dropped on Nagasaki. Dubbed "the Fat Man" this plutonium filled bomb detonated 1650 ft above the city, releasing 87.9 $\pm$ 8.4 Tera Joules of energy, killing anywhere from 22,000-75,000 residents and injuring 60,000 more in the ensuing destruction [11]. While this was a grand display of scientific progress and power, in order to create such a weapon also created a nuclear problem back in the US.

The start of the nuclear waste problem starts in Hanford Washington processing site. Built in 1943, the Hanford site was created to produce the uranium and plutonium that was put into "the Little Boy" and "the Fat Man", as well as other nuclear cores that never saw use in the war. Afterwards in 1948, it continued to produce weapons grade plutonium with the ramp up of the Cold War and the need for nuclear armaments. It also boasted 9 different nuclear reactors by 1964 to generate power for the refinement portions of the site. The site continued to run its reactors and refine plutonium up until 1989. By this point in the site's lifespan, it had created: 200 million gallons of liquid waste, some of which went straight into the Colorado River, 270 billion gallons of contaminated ground water, 25 million cubic feet of buried/stored solid waste, 2300 tons of spent nuclear fuel, 20 tons of plutonium laden materials, and 53 million gallons of waste in 177 tanks [10]. Some of these tanks have not been upgraded since the 1960's (which were meant for 50 years of storage) and some tanks have not been upgraded since the site's construction in 1943 (these were only meant for 20 years of storage). The decay and degradation of 67 out of 177 of these tanks accounts for approximately 1,000,000 gallons of leaked liquid nuclear waste into the surrounding soil [4].

On the other side of the country, the Savannah River Site was built in 1951 to produce plutonium and tritium for nuclear weapons and more common nowadays, nuclear batteries for space exploration. This site had 51 holding tanks, totaling 36 million gallons, for its nuclear waste during its heyday from 1954-1989. As of now, only 27 of the 51 tanks are up to date and not leaking. Others do not have a backup system in place in case of failure. 99% of the radioactive waste this plant has created is still stored on site in these tanks. Some of the radioactive waste that does escape the plant is in the form of radioactive tritium water which the plant has released 8,741,000 curies worth from its opening til 1991 [2]. For comparison, the maximum acceptable concentration per liter of water is 2*10^-7 curies per liter [8].

Between these two processing plants, Savannah and Hanford created 99% of all nuclear waste in the United States [6]. With this much waste piling up, people started to want solutions as to where this waste is to be handled and stored. This was the goal of the 1982 Nuclear Waste Policy Act [30], to determine a suitable location for nuclear waste to be stored. The act would later be amended in 1987 which allowed for the siting and planning for a national geological repository for HLW. After 24 years since this amendment, the Department of Energy found a possible location: Yucca Mountain in Nevada [13]. This site would store HLW into the side of this mountain and be the solution to long term storage. The plans for it hit the congress floor in 2002 and is approved for further sighting and planning[13, 29]. However after backlash from the state government and the Shoshone people of the area, the DOE's license application would prove fruitless, as the plan is axed by congress in 2009. It was further put down by 2011 as the funds to investigate this proposal were cut [13]. As of now, there are no further plans from congress to pursue Yucca Mountain.

From here we enter the era of the Blue Ribbon Commission and into modern policy of nuclear storage. For more info on what is being done now, refer to Chapter 4.

4 Proposed Methods of Storage and Disposal

Below are some of the proposed methods to store HLW: Vitrification, Glacial Storage, Oceanic Disposal, Seabed repository, Digging a very deep hole, In a Cave, Deep Well Injection, Rock Melting, In Space.

4.1 Vitrification

A common way to prevent this waste from spreading as well as reduce its overall radioactivity is vitrify it. Vitrification is the process of melting nuclear waste and mixing it with large amounts of borosilicate glass, the same material used in Pyrex dishes and lab grade glassware. This solidifies and entombs liquid waste and reduces the product's radioactivity to about 10% of what it was [15], making it safe to handle and be removed from

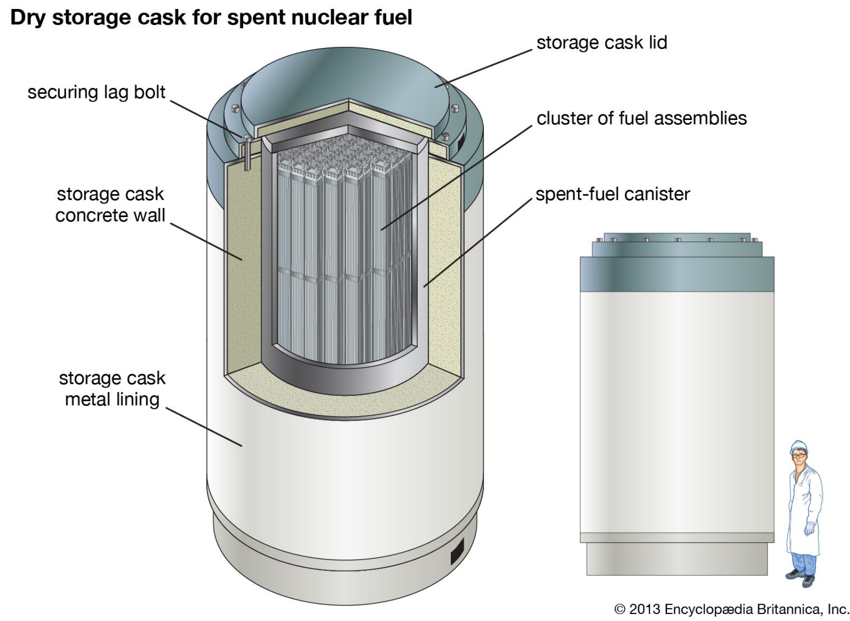

Figure 2: Diagram of Nuclear Waste canister

the plant. This refined glass mixture is then placed inside a stainless-steel container that is welded shut and is moved to further storage.

While this is a well-documented way of solidifying liquid waste and significantly reducing the radioactivity of HLW, there is still research being done about the long-term properties and subsequent storage of it [17, 1, 26]. Some outstanding questions about this process include the physical durability of the vitrified material and its cask, the chemical interactions between the cask and the vitrified material, and the possibilities of HLW leeching out of the vitrified material and out of the cask. And while the radiation coming from it is significantly reduced, it still has to be stored somewhere, preferably for long term storage. Regardless, vitrification has proven vital to the movement and storage of HLW for more than 50 years and will likely continue to be a technique used in future projects.

4.2 Glacial Repository

Glacial Repository is a method involving storing nuclear waste within a glacier. Depending on the type of waste we deposit on a glacier, it could be just as simple as leaving the hotter waste and having it melt its way to the bottom of the glacier. If not, a bore hole can be dug to get to similar depths to be deposited. Depositing our nuclear waste in a glacial ice sheet would prove effective at keeping the nuclear waste cold. Also doing so would coat any capsule or waste in water, acting as an excellent radiation absorber. Another benefit of glacial sheets is that their movements are on the timescale of thousands of years, making the movement of waste underneath them relatively slow as well [26, 18, 3].

However the benefits of encasing nuclear waste in tons of ice may also become a major detriment. What would happen if a canister cracks and water gets into it? Would it cause these radioactive isotopes to become aqueous and flow out from it? Would large amounts of waste cause the glacier to move more rapidly due to the water created from melted ice? This plan also requires the availability of such glaciers, so while the US has a few within their borders, such a strategy is not available to countries lacking easy access to glaciers in their borders. Additionally, any such storage outside the US has been banned by the Antarctic Treaties and other international agreements concerning the disposal of nuclear waste outside of one's country.

4.3 Oceanic Repository

This one is as simple as it gets. This involves taking the nuclear waste and throw it into the ocean, either having it implode at a certain depth to be dispersed, or to have it land intact on the seafloor. Much like other methods described in this list, the idea is to diffuse the waste down to a safe level, somewhere where we would rarely ever see it again. Oceanic disposal has the added benefit of not only absorbing radiation rather quickly, but also thermally cool any hot sources we would deposit. And unlike other methods, this one has been utilized to great effect. While outlandish to some, the practice has been done in the past with multiple countries such as Belgium, France, South Korea, the US, the UK, Italy, Germany, the Netherlands, Sweden, Switzerland, and Japan [3].

However this method has only ever been used to dispose of LLW, not the more deadly HLW. Also due to ecological concerns about polluting the ocean, this practice has been outlawed by international agreements since 1994.

4.4 Seabed Repository

There are two ideas behind Seabed Repository. The first is to place the solidified waste in the floor of the ocean far away from civilization. The idea is that by placing nuclear waste in a geologically inactive place in the ocean seafloor, that by the time it reaches landfall or civilization, any of the radioactivity in the HLW will have cooled and decayed into mostly stable material [26, 18, 3].

The second idea is to place the HLW in a subduction zone on the floor of the ocean. Over time the hope is that the shifting of plates will subduct the waste deep into the earth's crust and melt into the molten magma well below the surface. From there, the mixing of molten hot granite and shale will expedite the decay of HLW and churn it up in the rock to the point of reduced nuclear activity. This process would also take thousands of years for HLW to be swallowed by the earth [18, 3].

While the former sounds like a relatively easy way of storage and the latter an easy way to dispose and destroy HLW, there is much hesitancy in doing so by official researchers and governments. Would we be able to create an effective cask to weather the corrosiveness of salt water? And if it breaks, what kind of ecological damage would it do to the local sea life? There are also concerns about when the waste gets subducted and broken up, what would it do to the surrounding region? Could those nuclear materials float to the surface or to underground water tables? Could such material destabilize that part of the geological plate? And this is all without discussing the political problems with disposing of HLW in international waters. Unfortunately, this method is not a popular one because of the unknowns involved, international agreement and potential ecological damage [3].

4.5 Dig a Very, Very, Very Deep Hole

This method is perhaps one of the better methods discussed. Deep geological repository is essentially digging a very deep hole in the ground and putting our waste in it. With this process, there are two type of holes for waste storage: mined out repositories and borehole repositories.

Mined out repositories are perhaps one of the most popular option when it comes to nuclear waste storage. This involves digging out a cavern some 250m-1000m below the surface in a geologically inactive part of the crust. From here waste would be stored in large dry casks in large hallways. Once one section of the mine was filled up, it would be sealed in by cement and stone. From there it would only be a matter of drilling more halls for more waste, thus making this option enticing for large volumes of waste [26, 18, 3].

Borehole repositories uses deep borehole drills to dig up to half a kilometer down into the ground. Much like seabed repository, you could either drill the hole in a geologically inactive location to prevent movement and breaking of casks or you could drill at a subduction zone where the waste would be sucked into the earth's mantle. The first 2000m would be used to store casks of waste separated by layers of cement and asphalt. The other 3000m would be filled with more cement and bentonite to seal the waste away. This plan was originally pitched by the National Academy of Science in 1957 but has yet to see practical use [24]. Both methods have the added benefit of not having to worry about international treaties and potentially damaging oceanic wildlife. [3]

Just like seabed repository, however, it still poses very similar ecological problems in the event of the casks breaking open. It would also pose a larger risk of contaminating ground water and water tables due to being drilled on land. Also most subduction zones in the United States are next to or in the ocean, thereby violating international law if the waste moves into the ocean.

4.6 In a Cave

In a similar vein of deep geological repositories, surface geological repositories are one of the more easily accessible options. The idea here is to either take an existing cave or create one in the side of a mountain and store the waste there. The idea originally came from the National Academy of Science, published under "Report on Disposal of Radioactive Waste on Land". This report was written by the National Research Council Division of Earth Sciences, Committee on Waste Disposal and they proposed the use of salt caves or abandoned mines, since "...no water can pass through salt" and "Fractures are self-sealing". However, the report also notes that salt does not make for a good construction material and thus would need reinforcements [26]. While no such repository currently exists, the general idea of burying our waste in a mountain is perhaps one of the most straight forward. This is the proposed method behind the Yucca Mountain project that was abandoned in 2010. It also has the added benefit of being easily accessible in case of emergency or a use for such waste later down the line is discovered.

This easy access, however, proves to be one of its weak points as well. Such a location would require its location to be built on geologically inactive land. It would also be vulnerable to surface bombings or unprecedented earthquakes and leak radiation. Finally due to its easy to reach access, it has the potential to be stolen or taken by bad actors, those who will misuse it, or future generations who do not know its risks [26]. Despite this, it is perhaps one of the most viable and more economically plausible than some other proposed ideas.

4.7 Deep Well Injection

Another variant of geological repository, this method involves taking liquid waste and injecting it into a porous stone layer that is surrounded by a more impermeable one. Such a method would limit and prevent the waste from moving upward or laterally and prevent brine or groundwater from penetrating the encapsulated waste. Such practices are favored by the Russians and have had a few attempts in the US [3].

However there is a reason that the US doesn't do this anymore. Such a geological set up is difficult to come across and is very susceptible to geological activity. If the impermeable stone cracks or fractures, the liquid waste can leak into surrounding stones and groundwater. This method would also require any and all waste to be a liquid. While it can be done, liquid waste is notoriously harder to contain and transport. This and concerns about the geological stability of the area has made this method obsolete in favor of other methods.

4.8 Rock Melting

This process is a variant of deep geological repository but with a different goal. Instead of just storing the waste in an underground facility, why not just pour molten hot nuclear waste down the hole instead to speed up the process? That is the idea behind the rock melting method. The idea is that as the liquid hot waste comes into contact with the surrounding rock it is drilled into, it will melt the rock and fuse with the waste and crystallize into a hodge podge of both. The rock would work to not only keep the nuclear waste together, but also provide a barrier if water seeped into the surrounding rock. A subvariant of this would be to have it in it's own container, superheat the container and have the surrounding rock melt around it, and entomb it underground. Another such variant proposed by Russian scientists is to detonate a nuclear bomb where the waste was deposited and have the waste be immobilized by the fiery explosion [3].

However, even without the aid of a nuclear bomb this process has not seen any feasibility nor succeed in any intermediate experimentation. Doing so would require specific rock compositions that crystallize with the molten nuclear waste, which may not be easily accessible. There is not enough research done to prove that this method would prevent the pollution of groundwater, running into similar problems and issues of glacial repository. Also the use of nuclear arms in any capacity is generally frowned upon internationally.

4.9 Send it into Space

Perhaps one of the more enticing solutions, ejecting all of our waste into the void of space would provide one of the most permanent solutions. The main benefit of space disposal is the fact that it is not on Earth, therefore we would not have to deal with the far future maintenance and consequences of all other forms of storage and disposal. You no longer have to deal with treaties for international waters or possible seepage into the environment or even digging a hole and building a housing facility. Once it gets to space and far from orbit, it is essentially gone forever [18, 3].

However there are a few issues and reasons that space disposal is not currently used. The first is the cost of sending stuff to space. According to NASA, it costs roughly $10,000 per pound of payload being sent into Earth's orbit [19]. With our current HLW stockpile of 80,000 metric tons of waste, sending all of that would cost $1.94 quadrillion dollars or 61 times the current US national debt of $32 billion as of this writing. The second major issue with sending our waste to space is the potential failure would be catastrophic. If the rocket were to catastrophically fail at any point in its journey before reaching terminal velocity, it would atomize its nuclear payload and spread the fallout to the whims of the winds. Even if it were to malfunction and detonate on ground zero, it would render the site and all the surrounding area a radiation hazard, not unlike the aftermath of Chernobyl [18, 3]. While it is entertained as a solution for the worst of the worst HLW, the risks and costs involved heavily outweigh the benefits.

5 What is Being Done Today?

While Chapter 2 discussed the history of nuclear waste here in America, this chapter serves to determine what the US is currently doing to overcome its nuclear waste problem and perhaps learn from what other countries are doing as well.

Compared to other nuclear capable nations, the United States is not at the forefront. At the moment, the United States does not possess a long term repository for HLW and does not have any plans to create one in the near future. The Yucca Mountain project was proposed as the solution for long term storage but a lack of funding by the Department of Energy in 2011 has left the project on the cutting room floor. As of now any further long term storage for HLW has been put on the back burner. In their 2013 response to the Blue Ribbon Committee titled, “Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste”, the Department of Defense outlined their goals of opening up a pilot interim storage site as well as a large scale interim storage site before moving to long term geological storage [7]. However, they did state goals for the creation of a long term storage site, stating, “Administration’s goal is to have a repository sited by 2026; the site characterized, and the repository designed and licensed by 2042; and the repository constructed and its operations started by 2048.” This process of selecting a site would also be on a consent based approach, meaning the land that would harbor such a site, the local people, city and government must approve of the federal government’s proposal before siting and construction can begin.

For what is currently being done at the moment to help with the pileup of HLW, most of it is stored on site at most facilities and is being processed in case such a repository is opened up. Both the Savannah and Hanford sites have moved towards the vitrification of most of their waste[10, 4, 2]. The Hanford site is almost exclusively dedicated to vitrifying waste and cleaning up the mess it left the last 80 years. Since 1989 they have cleaned up 4.4 billion gallons of contaminated groundwater, moved all of their spent nuclear fuel into dry storage, and pumped out all 146 of their liquid waste tanks. They have converted the place into their own vitrifying and treatment plant in 2000, and by 2022 started treating LLW and chemical waste too[10]. While the Savannah site does still make plutonium and tritium, they too started vitrifying some of their waste in 1995, aiming to reduce their 6,000 canisters of waste and vitrifying it down to 5,000 over the next 20 years [31].

While these individual sites are doing the best with what they can, it is nowhere close to the projects and programs in place in other nuclear countries. Finland has already created the world's first repository for HLW. Their site, dubbed "Onkalo", is located on the forested island of Olkiluoto, some 420 meters below sea level. This cavern is hollowed out from the Finnish bedrock and each branch of the cavern is meant to hold 30-40 copper and iron layered casks and sealed up with bentonite and cement, meant to seal away these "giraffe sized" canisters for 100,000 years [12]. The success of such a project is attributed to the lack of state-level government and local understanding of the project and what it entails for the community. Sweden is also planning the construction of their deep, geological repository in Östhammar by 2032. This was done over 40 years of planning and siting, $2 billion from a government grant, and conversations with the Östhammar and Oskarshamn municipalities [16].

6 Conclusion

The nuclear waste stockpile continues to grow every day. There are plans in play to reduce their toxicity and develop a long term storage location. The work being done at the Hanford site and the Savannah River site to vitrify HLW has been stellar the past 30 years, but it is only one step of many to maintain this hazard. Vitrification only lessens the immediate danger to workers and the environment. Surface storage containers and the facilities using them were only meant for short term relief until a better solution is presented. While the Department of Energy does have a plan to site and store this waste for long term disposal, this plan must be executed swiftly and with the full support of the NRC, the DOE and the Blue Ribbon Commission. While Yucca Mountain may be seen as a failure on the fault of the Department of Energy, they can learn from this project's shortcomings as well as other nations to provide a new cite.

While not the most glamorous solution, the most practical was as of now is to return the material back to the earth from once it came. Deep geological repository is likely the best solution for a permanent solution. It is perhaps the most studied method, can last tens of thousands of years, and is one of the best ways to store waste in bulk. If Finland and Sweden are already building mined out repositories for their nuclear waste, why shouldn't the US follow suit? Perhaps it is a lack of education to those it may affect and a lack of communication from the Department of Energy on their plans. Once the public mind has become knowledgeable in the safety of such storage and the Department of Energy can communicate their plans as well as ensure public safety, a solution to nuclear waste can be achieved.

Regardless of if we achieve this solution, the nuclear waste problem is not one that can be ignored and passed onto the next generation. Waste will continue to be produced regardless of whether we have a current long-term solution. Therefore, the search for a suitable site must continue and a site must be found soon to ensure the health and safety of our generation and to future generations to come.

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