Establishing universal standards for the disposal of nuclear waste

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Overview

On December 2nd, 1942, Enrico Fermi created the first self-sustaining nuclear reactor underneath the University of Chicago's Stagg football field (1). Since then, the issue of nuclear waste and its disposal has only become a bigger and bigger issue. Nuclear waste is defined as a byproduct from nuclear power plants, fuel processing plants, hospitals, and research facilities. This nuclear waste can be classified into three distinct groupings, Low-level(LLW), Intermediate-level(ILW) and High-level waste(HLW) (2). Low-level waste can be classified as rags, clothing, tools, or any small object that contains a small amount of short-lived radioactive material. Intermediate-level waste requires small amounts of shielding, while High-level waste requires immediate cooling and isolation.

Nuclear waste poses a hazard to human health and safety as a whole. As a byproduct of nuclear reactions, nuclear waste releases radiation into the surrounding area, as particles are removed from the nuclear waste atoms in order to achieve stability. These particles, in the form of radiation, can harm humans and the environment in several ways. Direct exposure is the most deadly, as direct exposure to nuclear waste can cause exposure to high-energy Gamma and X-ray radiation. These types of radiation can easily penetrate skin and clothing(often being able to penetrate through solid concrete), causing irreparable damage to the human body, down to the molecular level. On the surface, in addition to deep radiation burns on the skin, afflicted individuals will experience Acute Radiation Syndrome(ARS), including symptoms such as nausea, vomiting, disorientation, and loss of consciousness (3). If dosages are high enough, ARS can progress into the Onset phase, with more severe symptoms presenting, and eventually death. Even if an individual survives initial exposure to radiation, the molecular damage done to the DNA of cells can lead to development of cancer later on. This is simply one of the ways that undisposed/improperly disposed nuclear waste can harm society. Another way is through ingestion. These would come from Alpha particles, particles without enough strength to penetrate skin, but when ingested, wreak havoc on internal organs, leading to the aforementioned ARS symptoms and cancer as well (4).

There are existing solutions to the increasing buildup of Nuclear waste. One of the most efficient and sustainable practices is Spent Fuel Reprocessing. Instead of being disposed of, spent radioactive waste is first decanned and sheared to remove the metal fuel cladding. Next, the radioactive waste is combined with nitric acid to create a solution containing Uranium, Plutonium, and various fission products. Then, the solution undergoes a process called PUREX, Plutonium Uranium Redox Extraction, which separates the Uranium and Plutonium from the solution by taking advantage of Uranium and Plutonium's natural affinity for organic materials. This process creates two byproducts, a liquid containing the Uranium and Plutonium, and a highly radioactive waste byproduct called Raffinate. The Uranium and Plutonium are solidified and stored for later re-use in new nuclear fuel rods, while the Raffinate is converted into a stable solid in a process called Vitrification. Then, the stabilized and solidified Raffinate is stored in stainless steel containers until a disposal site is available (5). However, even this method that recycles nuclear waste generates additional waste. In addition to Raffinate, the pond water that is used to cool initially extracted nuclear waste can be contaminated with ion exchange resins, classified as ILW (6).

This is simply one example, but nuclear waste disposal is becoming a bigger issue day by day. Although the comparative generation of nuclear waste is arguably insignificant due to the sheer energy that is generated by nuclear energy, the longevity of nuclear waste remains a concern for many. Furthermore, as nuclear energy appears to be one of the only viable options to fossil fuel usage, as it appears to be the only scalable version of a reliable, pollution free energy source. As nuclear energy usage inevitably increases, so does the need for extensive and comprehensive international guidelines for disposal of nuclear waste, especially since different nations dispose of waste differently.

Russia in particular has been a perpetrator of unsafe dumping of nuclear waste. For years now, the Russian Navy has dealt with its nuclear waste by disposing in the sea, and to this day, portions of the Barents sea, Kola sea, and Sea of Japan have all had areas that are contaminated

(7). However, Russia is not the only country without safe disposal methods. The United States still does not have a permanent national nuclear waste disposal site, despite having a clear national strategy of deep geological disposal in Yucca Mountain(although the status of this site is ambiguous) (8)(9). Instead, most of the time, radioactive waste is stored in dry casks on site. While this can be a temporary solution lasting for decades, it is not enough for the thousands of years that radioactive decay lasts for.

Because of the inherent risk that improperly disposed of nuclear waste poses to humanity and the environment as a whole, countries must come together to work towards a solution to this issue. The lack of international regulations allows certain countries to establish their own regulations, with their own disposal grounds, which could lead to environmental and human damages as well. Yet, moving forwards into the green-age of energy, because of the immense benefits that nuclear energy can provide to humanity, we cannot abandon nuclear energy as an avenue. Countries must find a middle ground no matter what, given the alternatives are unimaginably detrimental to humanity.

Definitions of important terms

Raffinate: Liquid radioactive waste that is left over after the milling processes

Nuclear Waste: This refers to any material that is radioactive and is no longer useful for its original purpose, such as spent nuclear fuel from nuclear reactors or radioactive waste from medical, industrial, and research activities.

Dry casks: A method of temporarily disposing nuclear waste by sealing the spent fuel, often twice, once within a stainless steel container and a second casing consisting of concrete.

Deep geological disposal: A method of permanently disposing of nuclear waste deep underground in stable geological formations, such as deep repositories excavated in suitable rock formations, to isolate the waste from the environment and prevent its release into the biosphere.

Radioactivity: The property possessed by some elements to spontaneously emit radiation in the form of particles or electromagnetic waves.

Low-level waste: This category includes a broad range of radioactive materials that have lower levels of radioactivity.

Intermediate-level waste: This waste category falls between high-level and low-level waste in terms of radioactivity. It includes materials such as reactor components, contaminated materials from decommissioning activities, and certain types of medical and industrial waste.

High-level waste: This type of nuclear waste typically consists of spent nuclear fuel from nuclear reactors. It is highly radioactive and requires careful handling and storage due to its long-lasting hazardous properties

Decommissioning: The process of safely shutting down and dismantling a nuclear facility, such as a power plant, research reactor, or nuclear processing facility, at the end of its operational life.

Radioactive half-life: The time it takes for half of the radioactive atoms in a substance to undergo radioactive decay.

Timeline of key events

December 1942: Fermi creates the first self sustaining nuclear chain reaction

Under the University of Chicago's Stagg Stadium, Enrico Fermi created the first self-sustaining nuclear chain reaction. This marks the world's first nuclear reactor to undergo criticality, and sparked development of nuclear energy as a whole (10).

August 1945: Atomic bombings of Hiroshima and Nagasaki

On August 6th and 9th of 1945, the U.S detonated two atomic bombs over the Japanese cities of Hiroshima and Nagasaki. Although successful in ending the war, the bombs led to bloodshed and arguably unnecessary civilian casualties. However, the Manhattan Project that led to the creation of these bombs had seen massive oversights in waste disposal, often disposing of nuclear waste in rivers, into the air, or in various waterways (11).

July 1951: U.S authorizes construction of Nuclear powered Submarine

Although impressive in design, the use of nuclear reactors for military purposes raises questions about the sustainability of such weapons, specifically with what to do about spent fuel rods, as those are also forms of nuclear waste. Indeed, nowadays, most military vessels are nuclear-powered to this day (12).

December 1951: The Experimental Breeder Reactor I generates electricity

The first nuclear reactor in the U.S is constructed and generates electricity for the first time, and marks the start of Nuclear energy production in the U.S. However, this wasn't a commercially-scaled project, which would come years later (13).

August 1954: The U.S passes the Atomic Energy Act of 1954

This was intended to amend the Atomic Energy Act of 1946, with the purpose of promoting the peaceful use of atomic energy in combination with the health and safety of the public (14).

August 1957: Soviets launch their own Nuclear powered Submarine

The K-3 Leninsky Komsomol was the Soviets first successful attempt at building a nuclear powered submarine. Just like with the U.S, nuclear waste was being generated through this application of nuclear energy for military use. However, the Soviets decided to dispose of their waste through a much more destructive venue (15). It is estimated that around 17,000 radioactive objects are scattered throughout the Arctic and Barents sea, including 18 nuclear reactors and an entire nuclear submarine (16).

September 1957: National Academy of Sciences first proposes disposal via geological disposal

Although exact dates cannot be determined for when this paper was published, in 1957, the NAS published a paper that proposed disposal of nuclear waste via geological disposal. Over the next few decades, the U.S would struggle to find a suitable location for storage (17).

December 1957: The U.S constructs the first commercial, full-scale nuclear reactor

In Shippingport, Pennsylvania, the first commercial, full-scale nuclear reactor is constructed and begins service (18). Most nuclear waste was stored on-site or buried underground in military facilities (19).

June 1970: The U.S announces plans to build a repository at an abandoned salt mine in Lyons, Kansas

Although a "permanent" solution, the government had multiple other alternatives in case this location didn't work, and there were certainly concerns about practical and safety aspects, including possibilities of water entry and potential radiation leakages. Indeed, in 2 years, the project would be canceled (20).

May 1974: India detonates a nuclear weapon, becoming a nuclear power

India's detonation of a nuclear weapon by utilizing existing nuclear infrastructure to create both fission and fusion nuclear devices. Although western powers cut off financial and technical help to the nuclear program, this event raises concerns about whether or not international cooperation can continue as a whole, much less concerning disposal of waste. How can we think about disposing waste when we continue to create waste through proliferation and testing of nuclear weapons? What about waste that is generated inevitably when even peaceful uses of nuclear power increase as population increases (21)?

January 1983: The Nuclear Waste Protection Act is established

The NWPA established multiple provisions concerning the location and method of nuclear waste disposal. Specifically, it designated Yucca mountain as a spot for geological disposal (22).

April 1986: Chernobyl Disaster

One of the most infamous nuclear meltdowns in history, the disaster at Chernobyl led to the complete uninhabitability of around 2,600 km^2 worth of land surrounding the Chernobyl nuclear power plant (23). In addition, it led to the deaths and suffering of hundreds of thousands. Exact figures are not known due to the unknown amounts and times of radiation exposure, as well as the difficulty in determining causes of long-term radiation exposure. To this day, spent fuel still remains at Chernobyl, and efforts are underway to remove the nuclear waste still held there (24).

September 1997: The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management is adopted

This was the first international legal instrument to deal with the issue of spent fuel and radioactive waste. It established fundamental safety guidelines, as well as a "peer review" system similar to the Convention on Nuclear Safety (25).

March 1999: The Waste Isolation Pilot Plant (WIPP) begins operation in New Mexico, USA

The opening of the WIPP was majorly dedicated for the permanent disposal of radioactive weapons that have been used by the US during the Cold War. The disposal area is mostly contaminated with plutonium-239, with the Department of Energy spending about $2.5 billion in total for WIPP, whereas the total of operating this disposal area would be an extra $19 billion to operate for 25-30 years after its opening (26).

May 2009: The U.S attempts to close Yucca mountain as a designated area for waste deposit

United States Secretary of Energy Steven Chu stated that "Yucca Mountain as a repository is off the table". Although other alternatives were being researched, the state of Yucca mountain as a waste depository remains ambiguous, as various bills have proposed the re-opening and closure of the mountain.

August 2023: Finland is first to open a final repository for nuclear waste

Finland's final repository is modeled around a method developed by the Swedish Nuclear Fuel Management Company named SKB, which consists of layers of copper, bentonite clay, and bedrock (27).

Position of key nations

United States:

Although the United States has, for years, been a global leader in nuclear fuel waste disposal, recently this has not been the case. About 88,000 metric tons of spent nuclear fuel are still sitting at reactor sites across the U.S, and this number grows by 2,000 metric tons per year. The U.S appears to be indecisive as to what to do with the massive amount of nuclear waste that only grows larger day by day. Without the presence of a permanent/long-term solution, the situation for the U.S will only get worse. At present, the U.S maintains a stance of indefinite storage at centralized sites, but this method only kicks the metaphorical(and literal) can down the road, as the cost and risk is only shifted to future generations as future generations will need to deal with the issue of above-ground storage of aging and deteriorating dry casks. Yet despite the lack of commitment to solutions to waste management, over the past few years, the U.S has continued to expand its use of nuclear power, as the U.S plans to open at least 3 more nuclear power plants in 2023 (28)(29). At the moment, the U.S is stuck in a dilemma. With Yucca Mountain site off the table, the U.S is left without a permanent disposal facility, and searching for and developing another one will take decades and billions of dollars of funding, resources that the U.S appears not to be willing to commit. The ambiguous position of the U.S, the simultaneous desire to develop nuclear energy while not willing to commit to solutions, stresses the need for international regulations, so that nations can become responsible actors with nuclear energy.

The Russian Federation

As mentioned before, Russia (formerly the Soviet Union) has primarily dealt with all of its nuclear waste by disposing of it in the ocean. Although Russia, in recent years, has moved away from such practices, Russia still faces significant challenges in dealing with the leftover nuclear waste that is generated, both from civilian nuclear power and leftover nuclear reactors for military use, primarily from the navy. In fact, it's estimated that in the year 2000 alone, there were around 300 nuclear reactors awaiting scrapping, while an additional 180 nuclear submarines also await scrapping. While to this day, exact numbers are difficult to obtain, it cannot be denied that these numbers have gone up, as old nuclear-reactor based warships are decommissioned. To this end, Russia has begun to take action to clean up the existing nuclear waste, and the most dangerous objects are planned to be removed by 2029, but the recent conflict in Ukraine has delayed these plans (30). The war in Ukraine has only exacerbated issues, as in October of 2023, Russia reported that nuclear waste levels in the Ukrainian Prydniprovsky chemical reached dangerously high levels due to a lack of regulations surrounding nuclear waste disposal. Concerningly, it is "processing wastes that are presently stored in nine open-air dumping grounds containing sand-like low-radioactive residue", which has the potential to spill 12 million tons of nuclear waste into the Dnieper river (31). Yet in addition to military-based nuclear waste concerns, civilian-based nuclear waste concerns also remain a primary issue, as Russia is one of the world's largest users of nuclear energy, as 20.28% of total energy consumption came from nuclear energy (32). Russia, like many other nations, struggles with nuclear waste management, and has been attempting to improve its capacity for such management. Yet its geopolitical situation only exacerbates these issues, and stresses the need for universal standards regarding nuclear waste disposal.

China

In recent years, China has begun to ramp up its own nuclear energy programs, as it plans to open at least 45 more nuclear power plants as of May of 2023. China has been outspoken in its criticisms of other nations' handling of nuclear waste, especially Japan. The recent release of Fukushima's diluted wastewater into the sea was especially criticized by China, despite China's own nuclear programs creating wastewater with almost 200 times the tritium as compared to Fukushima's release (33). China has defended itself by stating that "There is a fundamental difference between the nuclear-contaminated water that came into direct contact with the melted reactor cores in the Fukushima nuclear disaster and the water released by nuclear power plants in normal operation". China's release of wastewater raises concerns about potential contamination, as the very concerns that China has accused Japan of ignoring have been ignored by China's own government (34).

France

Ever since France has gained access to nuclear energy as a source for energy generation, it has attempted to be a responsible actor concerning waste management and disposal. A long-term solution is available for 90% of all nuclear waste, while the remaining 10% is stored safely, pending the availability of a storage facility in accordance with 2 laws established in 1991 and 2006 (35). Furthermore, since 1985, the French integrated electricity provider, EDF, has reduced almost two-thirds of the volume of nuclear waste that is created by nuclear power plants (36). France has such a high capacity for nuclear waste storage, that the introduction of 6 new nuclear power plants would only moderately increase waste, as the existing solutions could be adapted (37). France is amongst the world's highest users in nuclear energy, amounting to nearly 72% of total energy in 2018 (38). Much of the reason for the efficiency in nuclear waste management is because of the strict policies regarding nuclear waste recycling, standardization of nuclear reactors, and strong regulatory bodies.

India

Over the next few decades, India is attempting to invest heavily in its nuclear sector, with 20 new nuclear reactors being planned to be commissioned by 2031 (39). Nuclear energy would be especially effective for population-dense nations such as India, where Nuclear power plants could efficiently generate large amounts of electricity for hundreds of thousands, if not millions, without the need for vast fossil fuel facilities. Yet, at the moment, India's nuclear energy sector remains relatively small, accounting for just 1.1% of total generation in 2021 (40). Yet despite the lack of use of nuclear energy in India, issues have already arisen concerning nuclear waste management. In August of 2014, an official inquiry revealed that the nuclear industry had exposed tens of thousands of workers and villagers to dangerous levels of radiation, heavy metals, and other carcinogens (41). The exposure came from multiple sources, but primarily from the domestic ponds that are used to store the radioactive byproducts known as tailings. The contents of these ponds leached into the surrounding environment, and when the ponds evaporated, the toxic dust would blow over nearby villages. Furthermore, during monsoon season, ponds regularly overflowed onto nearby land, contaminating both the groundwater and crops. The lack of strict regulation and restrictions on nuclear waste management remains a concern to this day, and must be addressed through international regulations.

Sweden

Sweden has remained one of the world's leaders in nuclear waste management. A report from the IAEA states that Sweden has a "comprehensive, robust, and well-functioning system for safely managing radioactive waste and spent nuclear fuel from nuclear power plants" (42). Sweden has been able to accomplish this through a special method of final disposal, called KBS-3, which consists of three protective barriers of copper canisters, Bentonite clay and bedrock. The method serves as a long term solution, aiming to keep radioactive waste isolated for at least 100,000 years. Although the KBS3 method is subject to criticism and questions, such as the resistance of copper to corrosion, it cannot be denied that Sweden is a global leader in responsible nuclear waste management (43).

Suggested solutions

Establishing international mandates on where nuclear waste should be disposed + appropriate repercussions

One of the most simple solutions is establishing definitions on where it is and isn't safe to dispose of waste. Yet simply establishing definitions is not enough, nations need to agree on what possible repercussions should be handed out for violations of these regulations, as definitions are meaningless if countries have no reason to follow them. These can include restrictions on financial and technical aid from the IAEA,

Mandating each nuclear nation establish a deep geological repository site

At the moment, one of the few long-term solutions concerning nuclear waste management is deep geological repositories. Although finding a suitable repository may take decades and billions of dollars worth of investment, it is undeniable that it would help in the short-term, as nations would be able to store large quantities of high-level nuclear waste underground and away from population centers, until either the waste becomes stable or effective and efficient fuel recycling programs can be implemented

Investing in research, development, and implementation of nuclear waste recycling programs

Although existing methods exist to recycle nuclear fuel, the recycling process often creates more radioactive byproducts and waste. Investing in implementing existing recycling programs would limit the amount of waste that is produced from nuclear fuel rod consumption, while further research and development could reveal newer ways to reduce or use byproducts created from recycling

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