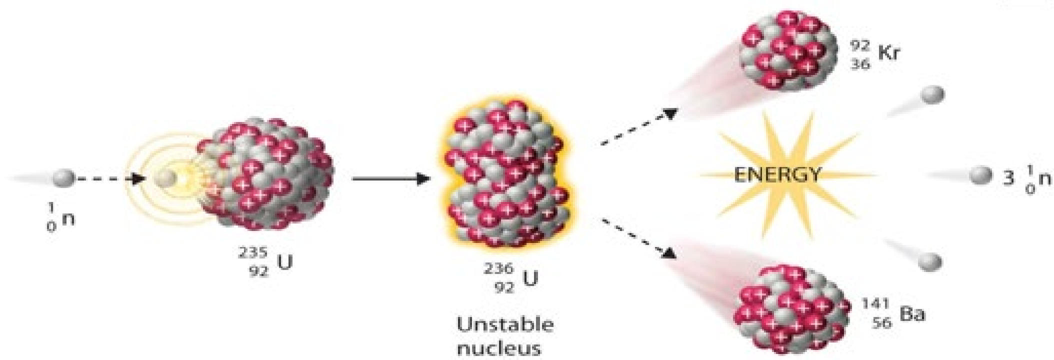
Chem 300A Chemistry in Modern Society
Report #1
Group F

Introduction

Currently, the world houses 250, 000 tonnes of highly radioactive waste and continues to produce 10,000 cubic meters of high-level nuclear waste per year (Geere, 2010). This radioactive waste is a by-product of nuclear energy, which is produced through a series of chemical reactions conducted in a nuclear reactor. Nuclear power has many potential benefits which have led to it being used on a large scale in many countries. Even though nuclear power can provide many benefits, there are downfalls that arrive with the use of nuclear energy. The radioactive waste produced as a by-product of nuclear energy can be extremely dangerous if not handled properly and with care. Since many countries have already opted to use nuclear energy, radioactive waste is rapidly piling up, raising many questions. How is the waste being managed? Is it being managed in the most efficient and cost-effective way? What are the implications of nuclear waste on the environment? Do the benefits of nuclear energy outweigh the risk of producing extremely radioactive waste?

Fission Reactions

Nuclear energy production has been a major milestone in the production of energy, as it is known to be a cheap and powerful source of energy. The production of nuclear energy is done by fission reactions, which is the process by which a heavy nucleus is split into two smaller, yet separate nuclei. To understand how this works, one should first know that every atom has a nucleus with electrons orbiting around it. The nucleus is composed of two smaller particles known as neutrons and protons, which are packed together in a very dense fashion. These nuclei are held together with a tremendous amount of force. They are very difficult, though not impossible, to split apart. The breaking of the forces which holds the nucleus together is known as a fission reaction. Fission reactions take place when a large and somewhat unstable atom is bombarded with neutrons, until it splits into two separate atoms. Upon splitting a nucleus, a substantial amount of heat energy is released due to the difference in mass between the two nuclei products and the original nuclei. Additionally, free neutrons and photons are also released in the form of gamma rays.



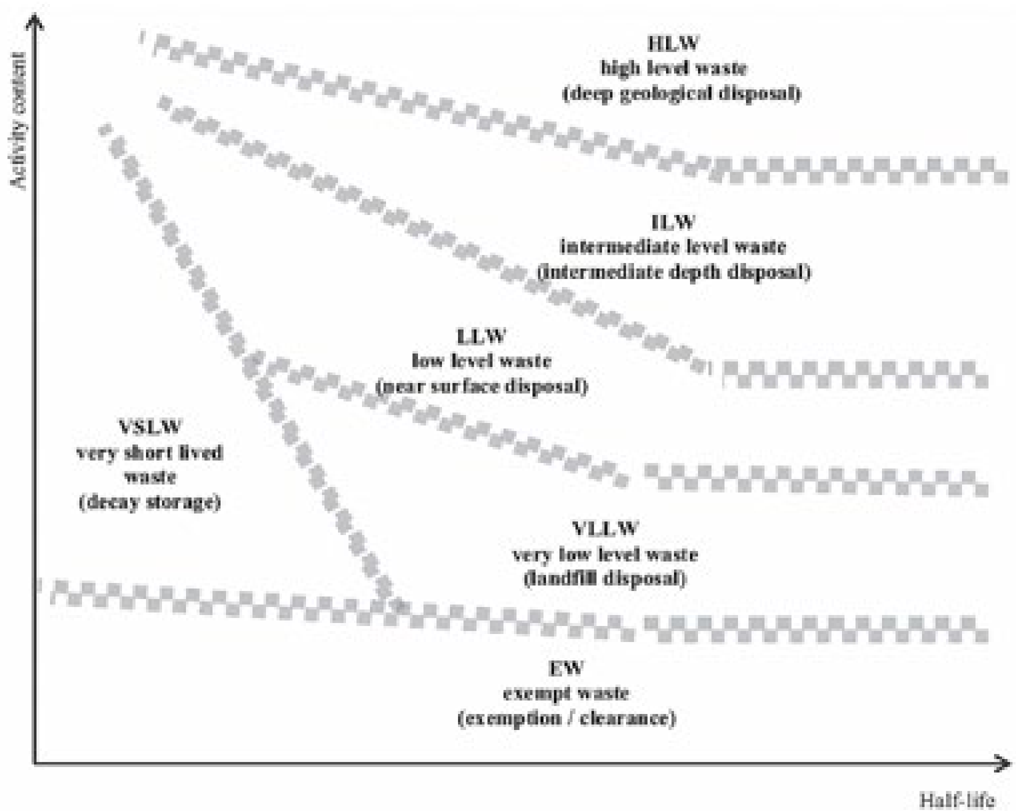
These reactions are extremely exothermic, and release about 200 million electronvolts of energy. This is a considerable amount when compared to the burning of coal, which releases only a few electronvolts of energy (Chemistry Libre Texts, 2019). This means that nuclear energy is largely more efficient than coal as a source of energy, especially considering only 0.1 percent of the original nucleus is converted to energy. (Chemistry Libre Texts, 2019) Furthermore, nuclear fission reactions are unique in that they can be harnessed and used in chain reactions. These chain reactions are the basis for nuclear weapons, such as atomic bombs.

Results of Fission Reactions

With nuclear energy being characterized by the large amount of energy produced from a very small amount of fuel, it should come as no surprise that there is one major downside. Unfortunately, the by-product of such an energy rich reaction is nuclear waste. Nuclear waste is highly lethal due to its radioactivity, and it is extremely hard to dispose of. Nuclear reactions do not produce a lot of waste in comparison to other fuel sources, but nuclear waste is significantly more difficult to dispose of. This type of waste cannot simply be discarded, as it is extremely dangerous to humans and the surrounding environment. Furthermore, radioactive isotopes have extremely long half-lives, meaning that must be shielded from human contact for much longer than can be planned for in the future.

Classification of Nuclear Waste

In order to ensure effective management, nuclear waste is classified into 6 main categories, which will be discussed later on. The classification system is important and incredibly relevant as it ensures that different types of radioactive waste are managed appropriately. It is necessary to ensure that the management of radioactive waste suits the type, volume, and risks of the waste concerned. The waste classification system is generally organized according to the degree of containment and isolation required to ensure safety in both the short and long term. According to the Canadian Nuclear Safety Commission, the waste classification system also considers the hazard potential of the different types of radioactive waste (Canadian Nuclear Safety Commission, 2017). Although the categories of nuclear waste can vary by region, the classification scheme that will be outlined have been established by the International Atomic Energy Agency (IAEA). The agency is an international organization that seeks to promote peaceful usage of nuclear energy, and to impede any uses for military purposes (IAEA, n.d.). It also publishes the Radioactive Waste Safety Standards (RADWASS) which play a significant role in facilitating global nuclear waste management. The agency's classification scheme is based on two main factors; the half-life of radionuclides contained in the waste and the activity content of the waste (NNSA, 2016). The "activity content" is a generic term that covers the waste's activity concentration, specific activity, and total activity (IAEA, n.d.). The figure below depicts the waste classification scheme according to the IAEA:



(NNSA, 2016)

Cochran, & R., J. (2016, May 1). Classification of Radioactive Waste. Retrieved from https://www.osti.gov/servlets/purl/1368832

Exempt waste (EW)

Exempt waste refers to waste that contains such small concentrations of radionuclides that it no longer requires the provision for radiation protection, regardless of whether the waste will be disposed of in near-surface landfills or recycled (IAEA, n.d.). As the name suggests, it meets the criteria for exemption from any type of regulatory control.

Nuclear waste that meets the criteria for exemption must have an effective dose to an individual of 10 μSv or less in a year. However, this does not take into account low probability events that may lead to higher radiation exposures. Therefore, the IAEA deemed it critical to add that the effective doses due to such low probability events should not exceed 1 mSv in a year. Consideration is also given based on doses to the skin; the dose cannot exceed 50 mSv in a year (IAEA, n.d.). Regardless of a criterion, an important aim of the IAEA is to establish a clear definition for what will be unconditionally exempt, as nuclear waste may need to be transferred between member states. Reaching a consensus will greatly simplify procedures and will lead to increased levels of public confidence (IAEA, n.d.).

Very short-lived waste (VSLW)

As the name implies, very short-lived waste only contains radionuclides with very short half-life and activity concentration that just exceeds exemption levels. Such waste will still require storage up to a few years to reduce its radioactive content, at which point it will be managed as conventional waste. Some examples of very short-lived waste include waste from sources that contain ^{192}Ir and ^{99m}Tc, as well as other radionuclides with short half-lives, which come predominantly from the industrial and medical industries.

The main criteria for classification depend on the half-lives of the more highly concentrated radionuclides. Classified VSLW must contain radionuclides with half-lives of 100 days or less. Although this is the determining factor, authorities generally follow a case-by-case basis. For example, the boundaries for the half-life of radionuclides cannot be the only determinant, as it also depends on the planned duration of the storage, as well as the initial activity concentration of the waste (IAEA, n.d.).

Very low-level waste (VLLW)

Artificial VLLW are usually by-products of nuclear facilities, with levels of activity concentration just exceeding exemption levels. Sources of other VLLW containing naturally occurring radionuclides are ore/mineral mines, but can also be something as simple as soil coming from a site that was formerly contaminated with uranium or radium (CNSC, 2017). Unlike exempt waste, VLLW does require consideration from radiation protection authorities. They are disposed of in near-surface landfill-type facilities that consist of active and passive institutional controls. These controls assess the decay period in order to determine the complexity of future disposal systems (IAEA, n.d.).

Low-level waste (LLW)

As we proceed towards waste with higher activity content, most operative definitions will be based on what the waste is *not*. Radioactive material that is *not* high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material, but still requires containment, is considered low-level waste (NNSA, 2016). Similar to VLLW, low-level waste is contained in near-surface disposals. However, due to the fact that this class covers the widest range of waste, disposal options may include more robust structures that could be situated below ground by as much as 30 meters. This level of waste products consists of long-lived radionuclides with low levels of activity concentrations, and short-lived radionuclides with higher levels of activity concentration (IAEA, n.d.).

Intermediate-level waste (ILW)

This class puts more emphasis on waste that contains long-lived radionuclides in amounts that exceed the criteria for near-surface disposals. As opposed to LLW, this class of waste requires shielding when transported and a built-in system that will effectively provide heat dissipation (IAEA, n.d.). According to the IAEA, "a contact dose rate of 2 mSv/h was generally used to distinguish between the two classes of waste [between LLW and ILW] (IAEA, n.d.). Disposal depths vary between tens to hundreds of meters in order to prevent human intrusion and therefore reduce the risk of exposure (Institute for Energy and Environmental Research, 2020).

High-level waste (HLW)

This class contains waste that has the highest concentration of both short- and long-lived radionuclides, which require a higher level of containment and isolation. Geological disposals in which these waste products are being stored need to prioritize the integrity and stability of the structure along with depth. Depths usually need to be at least 500 meters below surface to avoid any form of exposure and ecological contamination (IAEA, n.d.). Due to the fact that HLW generates enormous amounts of heat through radioactive decay for incredibly long periods of time, effective heat dissipation is crucial. Known activity concentrations of HLW range between 10^4-$10^{6\ TBq}/m^3$, which can include fresh spent fuel from nuclear reactors. Origin is also an important factor in deciding whether the waste will be ILW or HLW, as some waste products contain elevating levels of radionuclides (IAEA, n.d.). This is a very relevant and pressing issue for the IAEA to address as complications can arise when trying to trace the origin elements present in the waste.

Disposal Methods at a National Level

Canada and France generate massive amounts of electricity via nuclear power and are at the forefront of nuclear waste management. Indeed, each of these governments have formed central organizations dedicated to managing their respective nation's nuclear waste. However, neither Canada nor France have introduced long-term, stable methods of storing HLW. These organizations have attempted to integrate the general population in their waste management decisions. However, since nuclear power generation is a polarizing topic, it follows that nuclear waste management is equally as controversial. Currently, there is a consensus among experts that deep geological repositories (DGRs) are the safest method of disposing HLW (Fieveson *et al.,* 2011). Despite this, groups all over the world oppose this endorsement, believing nuclear waste management (or nuclear power, in general) comes with more danger than benefit.

Canada and the Saugeen-Ojibway First Nation

In parts of Ontario where most of Canada's nuclear power plants are located, there are currently two multi-billion-dollar projects in the works for DGRs. In the meantime, Canada uses an *interim* method of storing HLW called dry cask storage. This consists of surrounding HLW in a large, air-tight cask made of thick steel and populating the inside of the cask with inert gas.

This method is relatively safe *so far*, but experts suggest this should not be a permanent storage method (Reitenbach, 2015).

Figure x: Dry cask tanks at Bruce Power.
From:
https://globalnews.ca/news/5329835/canadas-nuclear-waste-to-be-buried-in-deep-underground-repository/

Located near Lake Huron, Bruce Power is a nuclear power plant which is built on Saugeen-Ojibway First Nation land. The Ontario Power Generation (OPG) company owns the plant and currently stores nuclear waste in dry-casks on site. In 2015, OPG proposed building a DGR beside Bruce Power in a nearby forest (Sorensen, 2019). Given that the power plant is built on Saugeen-Ojibway land, OPG has stated consent is needed from the Indigenous community to expand their operations and build the DGR. However, the original plant was built *without consent* from the Indigenous peoples. This creates high tension between these two groups, especially as OPG is vying to use more and more land.

In February 2020, 85% of the Saugeen-Ojibway people eligible to vote opposed the development of the DGR. (Perkel, 2020). Because of this, OPG is still searching for a stable geological formation on which to build a DGR. Many other communities around Ontario have expressed interest in having a DGR built on their land in hopes that it would be a major economic boost for years to come, but nothing is set in stone so far.

France's Mounting Nuclear Waste

France generates the most nuclear waste per person of any other country in the world. They produce 75% of the energy consumed via nuclear sources. Once again, the country has no long-term solution currently in place. However, there are plans to build a DGR in France. Additionally, the Nobel-prize winning French physicist Gerard Mourou hopes to develop a laser capable of changing the nucleic makeup of radioactive materials, effectively rendering them safe to handle without protective equipment.

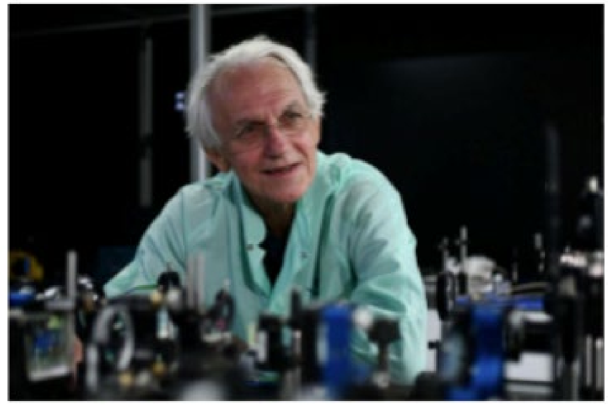


Figure x: Gerard Mourou in his laboratory
From:
https://www.bloomberg.com/graphics/2019-nuclear-waste-storage-france/

Andra, the designated French national nuclear waste management organization, is currently working towards building a DGR near Bure, a village in the north east of France. It is expected to house nuclear waste as early as 2025 (Fouquet *et al.,* 2019). However, there is dissent from some French anti-nuclear groups. These groups are against nuclear power generation of any kind, so it follows that they are against nuclear waste management. Given that the DGR would industrialize a rural region of France and could cause the region to become inhabitable in the future, groups like Burestop 55 and Bure Zone Libre have been protesting around Bure ever since the DGR was announced (Noria, 2017).

Gerard Mourou is currently working with two Lithuanian laser companies to develop the SYLOS Laser, which "transmutes nuclear waste by bombarding atoms" (Birch, 2019). In the past, researchers successfully transformed atoms of Iodine^{129} into Iodine^{128}, which decreased the half-life of the radioactive Iodine^{129} from ~15 million years to 25 minutes. If Mourou is able to scale this method up to a commercial level, it would be a revolutionary method of dealing with radioactive nuclear waste and could become the future of nuclear waste management.

Indirect Emission of Carbon Dioxide

Nuclear energy is highly considered to be "clean" energy source for the environment. For some people it even seems to be the solution for today's dramatic escalation of climate change concerns. One of the main arguments for the use of nuclear energy is that it produces zero emissions of carbon dioxide (CO_2) and air pollutants. With the reputation of producing no CO_2, nuclear energy is seen as a great form of renewable energy. This is especially true when it is compared to the burning of fossil fuels, which release toxins into the environment (EIA, 2020). Although nuclear energy does not produce CO_2 emissions directly, it does contribute to

CO_2 production in other ways. For instance, the efforts that take place to build a nuclear energy plant emit a lot of CO_2. The mining and milling of uranium, the manufacturing of steel, the resourcing of concrete, and the actual construction of the plant contribute to CO_2 production (EIA, 2020). Since CO_2 is not directly released from the nuclear plant itself, it's CO_2 emissions from creating the plant are still considered a lower carbon-emission power source than fossil fuels (EurekAlert!, 2007). The underlying concern within nuclear waste management is that there is a potential threat of radioactive waste negatively impacting the health of humans, animals, and the environment as a whole.

The Cost of Storing Nuclear Waste

As with most large-scale operations, there is a considerable cost associated with the storage and management of nuclear waste. By the end of their operations, the total expected waste from Canada's currently operating plants is expected to be 5.4 million fuel bundles. The cost to deal with this waste was estimated in 2016 to be approximately $23.6 million CAD (NWMO, 2016).

The Nuclear Waste Management Organization (NWMO) is an organization responsible for developing and executing nuclear waste management in Canada. This non-profit works with Canadian nuclear facilities to manage waste in a way that follows the guidelines set out by the Nuclear Fuel Waste Act. Members of the NWMO include Ontario Power Generation, New Brunswick Power Corporation, and Hydro-Quebec. Members are required pay for the management of nuclear waste produced by their facilities. This is done by developing a fund from the proceeds of nuclear energy production, with the costs being built into the consumer's payment (NWMO, 2016). This is common in many countries that rely on nuclear energy, and it is generally considered to be an effective way to save money for disposal without drastically increasing costs to the consumer. (World Nuclear Association, 2020).

Despite consumer concerns about the cost of nuclear waste disposal, the management of nuclear waste is less costly than would be expected. While the storage of nuclear waste is an expensive endeavor, it's total costs generally only make-up approximately 10% of the cost to produce nuclear energy (World Nuclear Association, 2020). In the United States, there is conflict between the Department of Energy (DoE) and the nuclear power production facilities regarding who should take responsibility for managing the fuel. The DoE has a fund of $40 billion USD intended to be used for nuclear waste management, but this money has instead been used to pay off national debt. Currently, the U.S. taxpayers pay approximately half a billion USD a year to the nuclear power production facilities for waste management. While this may seem like a lot of money, it is significantly less than what is currently being used to manage waste from the Manhattan Project. $6 billion USD a year is being used towards the disposal of military nuclear waste, and the Manhattan project will have cost $300 billion USD once it has been entirely cleaned up (Feldman, 2018). This suggests that a major issue with funding nuclear power and its subsequent waste management may not actually be the lack of funds, but rather the prioritization of other interests over the production of clean energy.

Risks of Storing Radioactive Material

Working with nuclear energy comes with very large risks that can significantly impact humans and the environment. One of the largest issues with nuclear energy is how to dispose of the nuclear waste. If not done properly, many problems can arise. In order for nuclear waste to be disposed of safely, it needs to be done in a secure facility where the nuclear atoms are able to cooldown. Once cooled, the radioactivity within the waste can be sealed to the best of its capability. The radiation itself cannot be removed because it needs time to decay, but with the ability to store the waste, the decaying can be done in a controlled manner. The half-life of the nuclear waste ranges from 1,000 to 10,000 years and is dependent on the hazardous concentration of the nuclear waste (World Nuclear Association, 2017). With this timeline, the space to store nuclear waste can be used up quite quickly, and additional storage will be needed. The storage of nuclear waste can lead to serious consequences for the environment because it threatens plants, soil, and human health. Although the waste is kept in a controlled and secure facility, there are many factors that can lead to waste being leaked out. Human error can lead to improper storage. Additionally, unpredictable natural events like earthquakes can break down a storage facility and cause a huge release of radiation to the environment. With these risks, the radiation from the waste can create a larger environmental impact than initially predicted from something considered to be “clean” energy (Shellenberger, 2018).

Nuclear Waste and its Negative Impact on Wildlife

High levels of radiation can affect numerous species and their habitat, leaving long-lasting effects on animal and plant life cycles. Radioactive material can damage plant tissue and cells, which can hinder the growth of plants (Essay, 2018). The toxic radiation can also create mutations within the plant DNA, causing alterations in that species which will be passed down to later generations (Essay, 2018). This happens with direct contact to the radioactive waste in the soil. Soil absorbs the radioactive waste, leading plants to become infected. These plants are no longer able to intake their proper nutrients and may become infertile, leading to some species being wiped out in regions close to nuclear plants (Essay, 2018). The infected soil causes a domino effect when it comes to production of agriculture and the health of wildlife. The soil transfers contaminants into the environmental life cycle and can reach far distances. For example, contamination can sink deep into the earth and make its way into water supplies or be carried out to the ocean. Researchers have found that the radiation levels in the sea water off the coast of Fukushima have very high levels of radiation, with some sea creatures beginning to build a tolerance to certain levels of radiation such as potassium^{40} (Huff, 2012).

In areas where a nuclear disaster has occurred, such as Chernobyl and Fukushima, scientists have discovered a large decline in insects. Due to the radiation, many insects were not able to survive or reproduce, eventually leading to very little or no insects living in these areas. Insects were not the only creatures to be affected. The number of birds living in these areas also declined. Studies show that male birds were not able to produce healthy sperm or were found to be completely sterile. For birds that were able to reproduce, tests were done to see if they were genetically altered by radiation. It was found that young birds had smaller brains, brain tumors, and cataracts. However, it has not been determined whether these issues were a result of environmental factors, such as the contaminated food and water, or if it was from birth (Mousseau, 2016).

Health Concerns Due to High Exposures of Radiation

Another concern about nuclear waste is the negative impact it can have on humans. This concern stems from the research that has been done on people that have lived near nuclear plants or have experienced an unfortunate nuclear disaster. It is clear that their lives have been severely impacted by the nuclear waste and radiation in multiple ways. Nuclear disasters have been known to cause life-threatening illnesses after exposure. Just like in plants and soil, high-level radioactive waste can cause cancer, birth defects, abnormalities and even death in humans (Jablonski, n.d.). A research study identified that radioactive iodine and cesium were being released into the environment in Japan from old nuclear reactors (Rettner, 2011). The release of this radioactive material can harm human lives in two ways. It can kill cells directly, or create mutations in the DNA sequencing, which can eventually develop into cancer (Rettner, 2011). Both instances can cause lifelong struggles for people. It was also discovered that iodine radiation has downstream effects on the thyroid glands in people, resulting in thyroid cancer. Making matters more unbearable, it is also more likely to occur in children (Rettner, 2011). Radioactive cesium can stay in an environment for up to a century and can have lingering effects from 4 to 10 years after an accident, as seen in Chernobyl, Ukraine. (Rettner, 2011). This means, as people are born and raised within this 4-10 year span, they are continuously ingesting radiation. Although it might be smaller amounts, it is still enough to cause impacts. Another health concern to consider is radiation sickness, which depends heavily on the amount of radiation an individual's body is absorbing. A symptom of radiation sickness is the bleeding and shedding of the gastrointestinal tract lining, and if not treated, it can lead to death (Rettner, 2011). High-level radiation exposure is around 200 rem, whereas a humans exposure to natural radiation yearly is around 0.24 rem. For someone to be diagnosed with radiation sickness they need to have an exposure level of 200 rem (Rettner, 2011).

Overall, a person's health after exposure to nuclear waste depends on the amount of exposure, the level of radiation, and the decay mechanism of the waste. The higher the radiation, the higher the probability of becoming ill or being diagnosed with cancer (Jablonski, n.d.).

The Impact on the Environment in Fukushima

The environment has been exposed to radioactive waste and materials over time in multiple situations. Two of the most significant incidents took place in Chernobyl, Ukraine, and in Fukushima Daiichi, Japan. In Fukushima Daiichi, an earthquake led to a nuclear disaster causing immense radiation exposure to the people and the environment. The people of Fukushima lost trillions of dollars because of the nuclear plant being destroyed. The economy went into a downward spiral after dealing with the cost of clean-up, decontamination, decommissioning of the plant, and compensation for the employees affected by the explosion

(Green, 2016). Even after years of trying to repair the damage, the government of Fukushima is still facing a lot of economic hardship as they pay for importing fuel and outsource to electric power companies. Due to the impacts of radiation the tourism industry has also completely declined (Green, 2016). Outside of the economy, both animals and people were greatly affected by radiation. The nuclear waste contaminated the soil, poisoning the food and water used by animals, humans, and plants. Much of the radiation from this disaster was released into the Pacific Ocean, which led to marine life also being poisoned and mutated (Bendex, 2019).

Nuclear Waste Management - Past, Present and Future

Nuclear waste management has long been an environmental and economic issue that has troubled humanity. The enriched product from a nuclear reaction is used very inefficiently, with only 5% being used in the nuclear reactor. This leaves 95% of it to exit the reactor as waste. Once this waste exits the system, it must be kept in a controlled water reservoir for 10 to 20 years as it becomes less radioactive and safer to handle. It is then casted and transported to a facility - which may be above or beneath the surface of the Earth - in attempt to block the radiation from affecting surrounding life. All of the current storage options, however, are not considered truly long-term, as they will require further advancements in technology in order to ensure their radiation will never leak into the environment. Unfortunately, similar storage techniques have been being used since the dawn of nuclear power. Once casted, spent nuclear fuel rods are kept at a repository which aims to ensure no nuclear waste will emit radiation into the surrounding environment. However, this is susceptible to a plethora of problems over time, including leakage and maintenance issues. The risk associated with storage is high. If the medium blocking the radiation is compromised, radiation can leak into the environment and wreak havoc on whatever life forms are in the surrounding area. Scientists have stored nuclear waste underground for a long time. However, this method leaves open the possibility of radioactive leakage into groundwater, which can have devastating effects (Schwartz, 2019). These waste disposal sites are also susceptible to natural disasters and require regular maintenance. This presents a huge problem for humanity, as some waste will remain dangerously radioactive for tens of thousands of years. As Hyatt *et al.*, noted, a safe solution for disposal of this waste is synonymous with a successful harvesting of nuclear energy.

The Onkalo Spent Nuclear Repository is a site in Finland which is attempting to safely store spent nuclear waste. The repository is a massive, deep, geological tunnel on the West Coast of Finland. Built into the granite bedrock, it is protected from natural disasters. Scientists plan to fill this massive underground tunnel with copper capsules of nuclear waste for the next 100 years. The site plans to accept nuclear waste until 2120, at which point it will be permanently sealed (Kuppler and Hocke). However, if it is permanently sealed, there is concern about what can be done if there is a leak. If a capsule leaks radiation into the groundwater, there must be a way to halt the leak once the repository has been sealed. Research done by the Royal Institute of Technology in Switzerland suggests that the capsules being made are not as corrosion-proof as the companies making them claim they are (Swedish Radiation Safety Authority, n.d.). In addition to this, scientists must ensure that no one attempts to excavate the area in the future. All these valid concerns prompt the need for a solution which attempts to recycle and reuse the nuclear waste, as opposed to storing it.

A Travelling Wave Reactor is an interesting potential solution to the growing nuclear waste dilemma. The Travelling Wave reactor is a proposed type of nuclear reactor which utilizes depleted uranium - a type of nuclear waste (Chen *et al*). By using an unrefined form of uranium, this type of reactor can produce energy while simultaneously eliminating nuclear waste. In addition, this reactor would eliminate the need to transport large amounts of dangerous, radioactive material. The reactor can reuse its own fuel, making it extremely efficient. These reactors are incredibly integral to the future of nuclear energy harvesting due to their consumption of depleted uranium, as well as their ability to reduce waste. The ability to reuse its fuel derived from depleted uranium, and the convenience and added safety of the reactor, makes it a prime candidate for the future energy production.

Conclusion

All things considered, nuclear energy is an important source of energy. By separating an atom into two smaller atoms through nuclear fission, there is a net loss in mass, which is transformed into large amounts of energy. By controlling the nuclear fission reactions, we can harness this substantial amount of energy for use in numerous different ways. There are many advantages to nuclear energy, such as the relatively low cost in comparison to the output of energy, as well as a low pollution rate. It is for these reasons that nuclear energy is becoming increasingly more popular, with nuclear energy making up 10% of the world's electricity from about 440 reactors (World Nuclear Association, 2017). On the other hand, nuclear energy is known to be one of the more controversial sources of energy, due to its downsides which can be potentially disastrous. Whilst nuclear energy emits negligible amounts of air pollutants, it does produce radioactive waste in its place. Radioactive waste is especially toxic to people, and the environment alike, and cannot be easily disposed of. Furthermore, radioactive waste has an extremely long half-life, and thus will continue to be harmful for thousands of years. For some, the dangers of radioactive waste outweigh the benefits of nuclear energy, though there are over 50 countries that have begun to use nuclear energy (World Nuclear Association, 2017). With the increasing popularity, more and more solutions to the nuclear waste dilemma are being suggested and researched, which provide a promising future for nuclear energy. Even with the clear dangers associated with nuclear energy, one can be certain that it will only continue to grow in popularity as humankind continues to investigate the possibilities of this high yield, and potentially sustainable energy source.

References

Bendix, A. (2019, June 17). Chernobyl was the world's worst nuclear-power-plant accident. Here's how it compares with Fukushima and Three Mile Island. Retrieved from https://www.businessinsider.com/chernobyl-fukushima-three-mile-island-nuclear-disasters-2019-6

Birch, S. (2019, August 5). High-power SYLOS laser could 'transmute' nuclear waste: Nuclear Energy Insider. Retrieved from https://analysis.nuclearenergyinsider.com/high-power-sylos-laser-could-transmute-nuclear-waste

Chemistry Libre Texts. (2019, June 23). Fission and Fusion. Retrieved from https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Nuclear_Chemistry/Fission_and_Fusion

Classification of Radioactive Waste Safety Guide. (2019, February 28). Retrieved from https://www.iaea.org/publications/3817/classification-of-radioactive-waste-safety-guide

Classifications of Nuclear Waste. (n.d.). Retrieved from https://ieer.org/resource/classroom/classifications-nuclear-waste/

Cochran, & R., J. (2016, May 1). Classification of Radioactive Waste. Retrieved from https://www.osti.gov/servlets/purl/1368832

Energy Information Administration (EIA). (2020, January 15). Nuclear explained Nuclear power and the environment. Retrieved from https://www.eia.gov/energyexplained/nuclear/nuclear-power-and-the-environment.php

Essays, UK. (2018, November). Effects of Nuclear Radiation on the Environment. Retrieved from https://www.ukessays.com/essays/biology/effects-of-nuclear-radiation-on-the-environment-biology-essay.php

EurekAlert!. (2007, November). CGD ranks CO2 emissions from power plants worldwide. Retrieved from https://www.eurekalert.org/pub_releases/2007-11/cfgd-crc111207.php

Feldman, N. (2018, July 3). The steep costs of nuclear waste in the U.S. Stanford Earth. Retrieved from https://earth.stanford.edu/news/steep-costs-nuclear-waste-us

Feiveson, H. (2011, June 27). Managing nuclear spent fuel: Policy lessons from a 10-country study. Retrieved February 11, 2020, from https://thebulletin.org/2011/06/managing-nuclear-spent-fuel-policy-lessons-from-a-10-country-study/

Fouquet, H. (2019, April 1). Zapping Nuclear Waste in Minutes Is Nobel Winner's Holy Grail Quest. Retrieved from https://www.bloomberg.com/graphics/2019-nuclear-waste-storage-france/

Geere, D. (2010, Septemeber 20). Where do you put 250,000 tonnes of nuclear waste. Wired. Retrieved from https://www.wired.co.uk/article/into-eternity-nuclear-waste-finland

Hyatt, N.C.; Ojovan, M.I. Special Issue: Materials for Nuclear Waste Immobilization. *Materials* 2019, *12*, 3611.

IAEA Safety Standards, Classification of Radioactive Waste. (n.d.) Retrieved from https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf

Jablonski, S. M. (n.d.). Radioactive Waste. Pollution Issues. Retrieved from http://www.pollutionissues.com/Pl-Re/Radioactive-Waste.html#ixzz6D6YGT6gX

Mink, P. T. (2011). Nuclear waste: the most compelling environmental issue facing the world today. Fordham Environmental Law Review, 8(1). Retrieved from https://ir.lawnet.fordham.edu/cgi/viewcontent.cgi?article=1433&context=elr

Mousseau, A. Timothy. (2016, April 25). At Chernobyl and Fukkushima, radioactivity has seriously harmed wildlife. The conversation. Retreieved from https://theconversation.com/at-chernobyl-and-fukushima-radioactivity-has-seriously-harmed-wildlife-57030

Noria, A. B. (2017, August 19). Nuclear waste disposal, Bure, Meuse, France: EJAtlas. Retrieved from https://ejatlas.org/conflict/nuclear-waste-disposal-bure-france

Nuclear Waste Management Organization. (2016). Project Costs. Retrieved from https://www.nwmo.ca/en/ABOUT-US/Who-We-Are/Funding/Project-Costs

Perkel, C. (2020, February 1). Indigenous community votes down proposed nuclear waste bunker near Lake Huron. Retrieved from https://www.ctvnews.ca/canada/indigenous-community-votes-down-proposed-nuclear-waste-bunker-near-lake-huron-1.4793412

Radioactive waste. (2020, January 7). Retrieved from http://nuclearsafety.gc.ca/eng/waste/index.cfm

Reitenbach, G. (2015, January 2). Dry Cask Storage Booming for Spent Nuclear Fuel. Retrieved February 11, 2020, from https://www.powermag.com/dry-cask-storage-booming-for-spent-nuclear-fuel/?pagenum=1

Rettner, R. (2011, March 15). How Does Nuclear Radiation Harm the Body? Live Science. Retreived from https://www.livescience.com/13250-radiation-health-effects-japan-nuclear-reactor-cancer.html

Rinkesh. (n.d.) Nuclear Waste Disposal. Conserve Energy Future. Be Green. Stay Green. Retrieved from https://www.conserve-energy-future.com/dangers-and-effects-of-nuclear-waste-disposal.php

Schwartz, M.O. Bull Eng Geol Environ (2019). https://doi.org/10.1007/s10064-019-01591-2

Shellenberger, Micheal. (2018, May 23). If solar Panels Are So Clean, Why Do They Produce So Much Toxic Waste. Forbes. Retrieved from https://www.forbes.com/sites/michaelshellenberger/2018/05/23/if-solar-panels-are-so-clean-why-do-they-produce-so-much-toxic-waste/#7494ef9a121c

Sophie Kuppler & Peter Hocke (2019) The role of long-term planning in nuclear waste governance, Journal of Risk Research, 22:11, 1343-1356

Sorensen, E. (2019, May 31). Canada's nuclear waste to be buried in deep underground repository. Retrieved from https://globalnews.ca/news/5329835/canadas-nuclear-waste-to-be-buried-in-deep-underground-repository/

Strålsäkerhetsmyndigheten. "Technical Note 2012:17: Corrosion of copper canister" ISSN 2000-0456. Retrieved 2012-12-30.

Huff, A. Ethan. (2012, Feburary 25). Fukushima radiation detected 400 miles away in Pacific Ocean at levels 1,000 times higher than previous readings (Japan). The Ocean Update. The retrieved from https://whalesandmarinefauna.wordpress.com/2012/02/25/fukushima-radiation-detected-400-miles-away-in-pacific-ocean-at-levels-1000-times-higher-than-previous-readings-japan/

World Nuclear Association. (2017). Radioactive Waste - Myths and Realities. Retrieved from https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-wastes-myths-and-realities.aspx

World Nuclear Association. (2017, July). Transport of Nuclear Materials. Retrieved from https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/transport-of-nuclear-materials/transport-of-radioactive-materials.aspx

X.-N. Chen, F. Gabrielli, A. Rineiski, T. Schulenberg. Boiling water cooled travelling wave reactor, Annals of Nuclear Energy. 134:(2019). 342-349. ISSN 0306-4549