Nuclear Power

By Gideon Smith

What do you think of when you hear nuclear power? Possibly you think of green goo oozing out of pipes and billowing clouds of smoke coming out of coolant towers, or you might think of a clean, green, safe power source that can be a long or short-term fix for climate change. In this paper, I will discuss the pros and cons of nuclear power as well as the types of nuclear power. I will also discuss some of the different accidents that have occurred and what lessons can be taken away from them. I picked this because this is a complex topic that people tend to not know much about. I think that people who are interested in solving the problem of climate change should read this.

Nuclear power plants use the process of fission, which is the process of splitting an atom which releases energy which had been binding the atom together. This is done by striking an atom with a neutron, a subatomic particle with no charge. This is found in every atom heavier than hydrogen. In the case of nuclear power plants, they mostly use uranium-235 as their fuel. Uranium-235 is used because it is unstable, allowing fission. The fission of uranium-235 results in the nuclei of two smaller elements as well as two to three neutrons and large amounts of energy in the form of heat and radiation. The neutrons from fission can cause more fissions in surrounding uranium-235, causing a chain reaction.

A moderator for a nuclear reactor is a material that slows down neutrons, increasing the chance that one will cause fission rather than absorption when it hits an atom of uranium-235 . A typical moderator for a nuclear reactor is water due to it already being in the core for transferring heat.

Fission reactions in nuclear power plants must be controlled. Control rods are rods which absorb neutrons inside of the reactor core that can be controlled by the operators. An example of a material used in control rods is boron because it absorbs neutrons well. The reactor core's heat gets picked up by water which circulates through a heat exchanger to transfer its heat to a second pipe that both cools the reactor and generates steam at the same time. The steam then gets fed into a turbine which powers a generator. Then the steam goes into a condenser which turns the stem back into the water. The condenser gets cooled by water which gets fed into a cooling tower or into the same source it came from. This is what

occurs in a boiling water reactor, one of the two types of currently operating power generating nuclear reactors in the United States.

The second type of reactor that is currently generating power in the United States is a pressurized water reactor. This is similar to a boiling water reactor. However, the water in the core is pressurized.

Surrounding the reactor is a five-foot-thick structure made of concrete and steel called a containment building to contain any possible radioactive material entering the environment from a meltdown or other accident.The worst possible scenario is a loss of coolant causing the fuel to overheat, melting through the containment structure and releasing radioactive elements.

On April 25, 1986 in Ukraine at the Chernobyl nuclear power plant it was decided to shut down the Number Four reactor for routine maintenance. It was also decided that they would perform a test to see if the reactor, in the event of an emergency, would be capable of activating its emergency systems from turbine power alone until the diesel generators could turn on. This test had been run before during a shutdown period. However, it produced inadequate results.

There was little communication on the testing process amongst the plant staff. The testing procedure being used had inadequate safety regulations. On the 23rd hour of the 26th of April, 1986 the reactor was operating at half power and was slowly lowering power. The reactor was supposed to have stabilized at 1000 MWt. However, due to operational error, the reactor dropped down to 30MWt. This led to the operators of the reactor withdrawing nearly all of the control rods to increase power, resulting in reactor power stabilizing at 200MWt at 1:00 AM April 26th. The number of control rods in the core was lowered to six control rods to compensate for the build up of xenon which absorbs neutrons. The number needed to maintain control of the reactor is 30. It is unclear why someone would withdraw that many control rods.

The low number of control rods in the core meant that the staff had to make adjustments nearly constantly to keep the reactor stable. The operators lowered the supply of water to the core presumably to increase steam pressure. causing more steam from a positive void coefficient, in which reactor power increases as water flow decreases. This created 100 times more power than usual, causing an increase in heat which ruptured the

fuel rods. The hot fuel particles released caused a steam explosion, destroying the reactor core.

This caused radioactive debris to be catapulted out of the reactor core and into the atmosphere and surrounding area. Fires at the building in which the core was held spread over the building's rooftop, sending radioactive fumes into the atmosphere. This led to 100 firefighters being called to extinguish the fire. The firefighters at the scene received some of the highest doses of radiation in the disaster. Around half an hour later the largest fires had been extinguished. Five hours after the explosion the graphite fire began. This was a major problem as there was little to no national or international experience fighting graphite fires, and at the time it was believed that attempts to extinguish the fire could lead to further release of radioactive material from steam or worse could cause fissions in the fuel. The end decision was to dump large amounts of neutron absorbing materials onto the fire that worked to put the fire out.

A heat sink was installed under the reactor core in an effort to cool the reactor core in a concrete slab. The concrete slab if needed could prevent radioactive contaminants seeping into the groundwater. A few months after the accident an international meeting was held on the topic of the accident. It is now considered the worst nuclear accident in history.

After the accident 67,000 people were evacuated from their homes. However, some people have started moving back today on their own accord. A 30 kilometer radius away from the reactor was made into an exclusion zone. However, people still live there today and it is safe to go there today. Inside of the Chernobyl exclusion zone animals and plants have experienced minor mutations, but life still flourishes there with many endangered species coming there, including boars, wolves, and rare birds. As a result of the Chernobyl accident, an international organization was formed for nuclear safety.

There has not been a meltdown as disastrous as Chernobyl. However, on March 11, 2011 a magnitude 9 earthquake struck the coast of Japan causing a tsunami. This caused a loss of power at the Fukushima Daiichi nuclear plant, leading to the reactor automatically being shut down. However, the tsunami had led to all but one diesel generator being destroyed. This generator supplied power for one hour after which the reactor safety

systems to cool the still hot fuel were powered from emergency battery banks and turbine power alone. However, this power only lasted for a day after which the fuel could not be cooled and melted down. The meltdown caused the release of contaminants and hydrogen into the containment building. The hydrogen exploded, releasing the contaminants into the environment.

After the accident the International Atomic Energy Agency thoroughly monitored the radiation levels close to the plant. Additional strict laws were put into place after the accident.

While these accidents were horrible, there have been far stricter safety regulations put into place on nuclear energy and newer safety systems that make the possibility of meltdown nearly miniscule, including the installation of hardened vents for containment buildings.

The second large concern with nuclear power is waste. There are two broad types of nuclear waste: high level and low level waste. High level nuclear waste is typically spent fuel from a reactor. Low level waste, on the other hand, may include clothing, shoe covers and rags that have been contaminated with light amounts of radioactive material that can be treated or placed in underground storage facilities. High level waste go to spent fuel pools which are large cement pools 40 feet deep with water which absorbs heat and radiation. These fuel pools are located at the power plant. The spent fuel stays in the pool normally for five years before going to dry cask storage large cylinders of cement and steel. Dry cask storage can last for over a century before needing to be replaced.

Nuclear waste is a large problem. However, it can be overcome by making a permanent waste repository. Currently there is not one being used in the United States. The United States attempted to make one in Nevada. However, they received heavy objection to it.

In my opinion, nuclear power is a power source that should be pursued along with renewables due to it being a zero carbon source of energy. A nuclear power plant can produce over a thousand times the power of an offshore wind turbine. Nuclear power can produce far more power in far less space. In my opinion nuclear power is a viable tool to be used alongside renewables due to it being carbon free space efficient.

This interview occurred over Zoom on May 31, 2024 with John Krohn, the Deputy Chief of Staff at the Office of Nuclear Energy.

How did you begin to get interested in nuclear power?
He cares deeply about the environment and believes nuclear power is currently the only source of near zero carbon dioxide energy that has been proven to work at scale weil, keeping the United States economy competitive.

What are the pros and cons of nuclear power?
The largest con is a lack of a permanent waste disposal site in use; there is a waste repository built in the US but it has not been used. The waste is currently stored on site. There are many pros of nuclear power. One of the largest is that it has hardly any carbon emissions; it is also the most energy dense source of energy as wind and solar require a larger area for the same amount of power which can have an impact on habitats. At the most recent COP28 summit many nations said they wanted to rely on nuclear power to meet their carbon goals. The United States could leverage nuclear power in relationships with other nations.

Why are there different numbers of water loops depending on if a reactor is a boiling water reactor or a pressurized water reactor?
The main difference between the two types of reactors is the pressurized water reactor does not come into contact with radioactive substances.

Why does the slowing down of neutrons by moderators increase the chance of a fission if it does not change the trajectory of the neutron?
The reason for the use of moderators like graphite and water is to slow down fission, decreasing byproducts that could build up and slow down the reactions.

What are the safety precautions that get used by modern nuclear power plants? What safety improvements have been made in nuclear power throughout its existence?
There are now nuclear power plants that are being designed that will have passive safety systems no longer relying on human interaction and that will have naturally driven coolant systems that rely less on pumps. They are working on making a walk away safe reactor which means that if it malfunctions it will react in an automated way. Generation 4 nuclear reactors in some cases use molten salt as a coolant which has higher heat absorption capabilities than water. Other reactors will use gas as a coolant. There have also been improvements being made in materials being used for neutron absorption. There are better containers for spent nuclear fuel being designed that can provide storage for 100 plus years using new materials including gasses. A person could stand next to these containers with no adverse health effects.

What is the current state of nuclear power in the United States?
Equal parts hopeful and uncertain. We may see a resurgence in nuclear power beyond the 94 nuclear power plants in the US today. Before the Inflation Reduction Act nuclear power was not competitive with coal or other renewables. However, the act added new incentives for nuclear power. We have gone from the risk of closing nuclear plants to a company trying to reopen a closed plant in Michigan. The policy for nuclear fuel has changed as in the 1990s the policy was to give Russia a large section of the nuclear fuel market in order to improve relations with Russia. Now the US is trying to be more self-sustaining. Congress has awarded 2.7 billion dollars to develop a more robust nuclear supply chain. Still there is a lack of people making investments in nuclear energy due to its large cost and long construction times.

What is the most important thing people should know about nuclear power?
It is the only source of carbon-free energy that has been proven to work at scale to meet current and future needs which will be greater from an increase in communication technology. He grew up in Pennsylvania close to the Three Mile Island nuclear accident. At the time it was not known whether or not there would be death or health impacts from the accident. However, it turned out there were no significant health impacts. He said it is comforting that the public is moving from scared to appreciative of nuclear power. Radiological things are scary because we cannot see them but know they're harmful. However, from an engineering perspective we know how to make nuclear power safe.

Something I found interesting in the interview was him saying that the life span of modern nuclear waste containers is over 100 years. This is interesting to me because the license for them is only 40 years. I would recommend this source to another student interested in nuclear power because there was lots of information in the interview.

In conclusion This project was largely made in part by using the Nuclear Regulatory Commission, International Atomic Energy Agency, and Nuclear Energy Agency's online materials as well as an interview with John Krohn, Deputy Chief of Staff of the Office of Nuclear Energy. I found it hard to find a satisfying answer to how moderators increase reactor power. The survey results that I got were quite surprising with some people not knowing what nuclear power was. The survey helped me realize what my audience was. During this project I learned how to use Gnu Octave for data analysis for the survey.

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