THE NEW OPTION: NUCLEAR ENERGY

From its definition to its safety.

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Abstract

Nuclear Energy, first introduced to this civilization as a means of mass destruction, is now used to obtain massive amounts of energy in probably the best way there is. Yet, the safety of this energy form is questionable among many citizens, which also has negative impacts on the nuclear industry around the globe.

Nuclear energy is harnessing the power in the nuclei of atoms via nuclear fission in well-engineered nuclear reactor cores. The energy that is generated by bombarding nuclei, eventually boils water to form steam that moves a turbine. The process itself seems harmless, but the fuel used, is where most people have their doubts; uranium.

Uranium is a highly radioactive material that people fear can be exposed, leading to release of lots of radiation, such as in a nuclear explosion. While something like this did happen in Chernobyl, Fukushima and Three Mile Island, it is a very rare chance due to the constant advancement in technology and several levels of safety measures insured by numerous global institutions.

Nuclear energy is ranked among the safest, densest and most environment friendly forms of energy source in the world according to research conducted by various people over the course of existence of the nuclear energy generation industry.

This research study aims to highlight and discuss the technicalities behind most aspects and past incidents involved.

Nuclear Reactions

Nuclear reactions are changes occurring in the atomic nuclei. They lead to change in the Atomic Number (Z) and the mass number (A) of an atom.

Causes of Nuclear Reactions

An element is radioactive when its atomic nucleus is unstable. According to our current understanding, their instability is attained only if the following 2 conditions are achieved:

1. *High **N/P** ratio*

   The very first reason for an unstable nucleus is a relatively high *N/P ratio*. The N/P is a ratio to compare the amount of *Neutrons* in an atom to its *Protons*.

   An atom that takes part in nuclear reactions, must have an *N/P ratio over 1.5***.** An atom with N/P ratio exactly 1 is considered stable. For example, an inert gas like Helium (He) has the N/P ratio 1.

2. *Mass Number*

   Another reason for unstable nucleus is the mass number. The range in which an atom is considered relatively stable is between *40 amu and 80 amu*. Atoms with other mass numbers may be unstable.

Nuclear Energy

Nuclear Energy is basically, in brief the energy inside these atomic nuclei; that is realised in form of radiations by radioactive elements.

Nucleons in the atomic nuclei are under high pressure due to ‘strong force’ present between them. Extreme force between nucleons is present to overcome to repulsive force between protons (as explained by Coulomb’s law) and attractive force between the protons and electrons. An even higher force than the strong force is required to disintegrate them. Hence, it is only natural that breaking such a strong bond formed by one of the 4 fundamental forces, releases massive amounts of energy. Harnessing this energy can be done in 2 ways. Nuclear reactors (our main interest as of now) use one of these called *Nuclear Fission.*

Nuclear Fission

Unlike *nuclear fusion* (where atoms fuse together to form bigger atoms), in nuclear fission atoms split their nucleus to make other smaller atoms (all to gain stability). This process of splitting the nucleus, breaks the bond of strong force to release the energy that is used in the nuclear reactor core to generate electricity.

The energy released in this nuclear reaction, is in 2 forms: heat and radiation. While nuclear radiation is a harmful by-product of the reaction, the heat generated is the main source under consideration.

Nuclear fission reaction starts with a single neutron beam, called the *incident neutron*. Neutrons are of choice (in a controlled nuclear reaction) as they are not partially charged and will neither be attracted to electrons nor protons.

The incident neutron hits the nucleus of a radioactive element, called the *fissile nucleus*. The incident neutron travels at a very high velocity, having huge momentum. The momentum is transferred to the fissile nucleus when in contact, leading to high instability. The instability generates disruption causing the fissile nucleus to start splitting into smaller atomic nuclei. Once they split, they release loads of energy (as discussed above). Along with these 2 (or in some cases more than 2) nuclei, few other neutrons are also released. These neutrons become incident neutrons for surrounding nuclei. This chain reaction continues and releases heat and radiation.

For example, uranium-235 would be split into 2 nuclei (barium and krypton) along with 3 other neutrons and Energy.

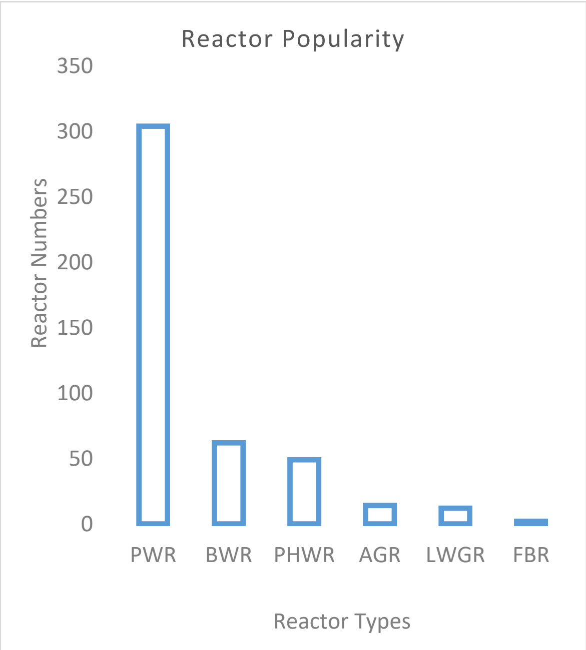
$${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3{}_{0}n^{1} + \text{Energy}$$

Types of reactors

Most of the nuclear reactors present have been created between *1970* and *1985* due to new trend in nuclear technology and the “*Atomic Age*”. During and before this age, many models of nuclear reactors have been proposed out of which 6 main types have been launched commercially. These 6 types of reactors include:

1. PWR: *Pressurized Water Reactor*
2. BWR: *Boiling water reactor*
3. Magnox
4. CANDU: *Canada Deuterium Uranium*
5. RBMK: *Reaktor Bolshoy Moschnosty Kanaly* (*High Power Channel Reactor*)
6. AGR: *Advanced Gas cooled Reactor*

Out of these, the most popular reactor is the *PWR* due to cost and simplicity.



PWR

The PWR is fuelled by *Uranium oxide (UO_2)* pellets that are put into 200-300 rods in the main reactor core. This in all would make up for 80-100 tonnes of uranium. Along with the rods, there is the *moderator and coolant* (which is the same in case of PWR) in the reactor core.

The moderator is a fluid present in the reactor core that moderates and slows down the reaction of neutrons (The part of nuclear fission). The coolant is a fluid that helps in heat transfer. It can either control the heat generated or aid in heat transfer depending on the requirement. In case of PWRs, the moderator and coolant is the same: water i.e. H_2O.

Water in the moderator/coolant is kept at *150 atm* (150 times higher than normal pressure of approx. 72 mg of Hg) to prevent boiling as the temperature of the core reaches to about 600K (325℃). Inside the core, when the nuclear reaction is triggered, multiple neutron beams are aimed at the uranium pellets. The incident neutrons hit multiple uranium atoms, starting the process of nuclear fission. Initialisation of this process causes the uranium to break apart to form smaller atoms, while other neutron beams hit other nuclei. This process (nuclear fission) generates extreme amounts of heat that heats the water to 590K (317℃). The heated water enters the *steam generator* where another source of water (at 1 atm) is boiled by this hot water at higher pressure. The other source of water is converted into steam that in turn drives the turbine that produces electrical energy.

The steam is then condensed in the condenser and returned to the steam generator once in liquid state; the process is then repeated. The moderator/coolant water is again pumped into the core.

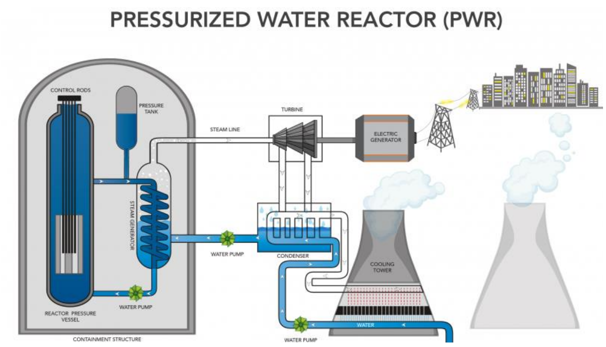


Fig 1

The idea of the PWR is rather simple, requiring relatively lesser resources (both monetary and other) hence, the popularity.

BWR Working

The working of the BWR is similar to that of PWR. Unlike PWR, BWR directly boils its water (at normal pressure) that produces steam in the reaction chamber. The generated steam is then directed towards the turbine and used to generate electricity.

Chernobyl Case Study

Introduction

The Chernobyl incident in 1986 was a disaster on a scale that is still under research. It could have wiped out half of Europe.

After the Second World War, the Soviet Union and neighbouring countries started investing into nuclear energy. A lot of Nuclear reactors were built, one of them being the Chernobyl Nuclear Reactor in Ukraine, 1977.

April, 1986. This night a few workers miscalculated few safety precautions causing multiple electrical surges in one of the reactor, which blew up the concrete and steel lids spewing out tons of radioactive material around and in the air.

Chernobyl Nuclear Power Plant

The Chernobyl nuclear power plant had 4 units that were finished in construction by 1983. All were RBMK type. The RBMK-1000 was built by the soviets. It worked by creating pressure on water using 2% uranium-235 dioxide fuel that boiled it. This steam was used to generate electricity like a boiling water reactor (check the earlier section).

Accident

25 April, 1986, a crew was testing a few procedures for the unit 4 reactor when they violated several safety protocols. The fuel was already pressurized above the limit. This extremely hot uranium fuel met the cooling water in an uncontrolled situation. This caused rapid expansion in volume of the gas leading to immense pressure in reaction chamber of the unit 4 reactor.

The pressure generated was higher than the steel and concrete layers of walls could handle. The lid of the reactor broke. Several tons of radioactive material along with outbursts of explosions were witnessed in a large area around the Chernobyl power plant.

Impact

This surge of radioactive material in the air was caught by Sweden. Firemen, workers and other people present at the plant were either immediately dead or faced severe injuries in the first few hours of the incident. Thousands of civilians in neighbouring countries were dead in the course of few years after the incident. Indirect deaths due to this disaster is still unknown. Several thousand adolescents were diagnosed with thyroid cancer across Europe as a direct result of airborne radioactive material.

Commercial Safety

Introduction

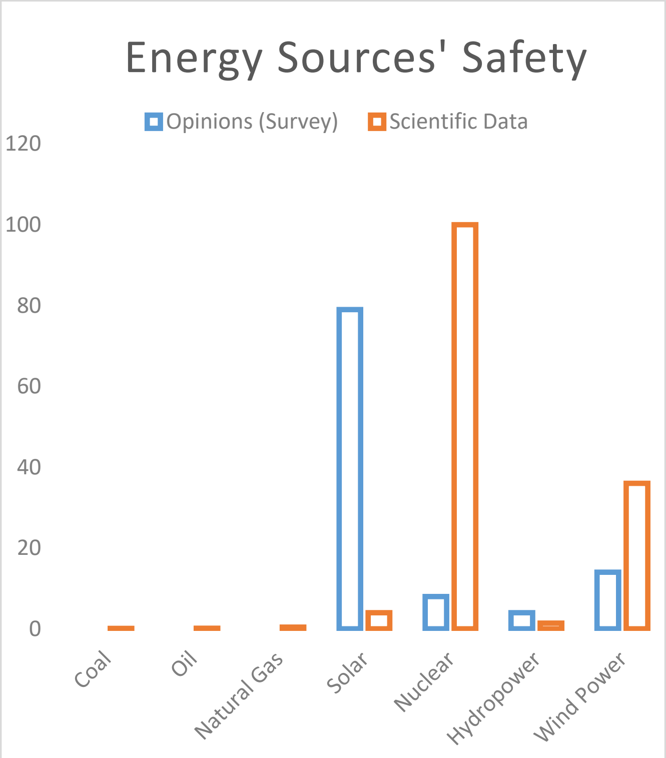
The Chernobyl nuclear blast is what started this chain reaction of false claims and accusations against harnessing nuclear power for the betterment of human society and mother earth. Chernobyl was one example among the handful of incidents that have taken place half a century ago.

Many new technologies since then have arrived including multiple safety levels and trained-certified individuals. All of these points along with many other to be mentioned further, have led to a standpoint that proves, that not only is nuclear energy much safer to obtain, but also among the safest ways to obtain energy both at a commercial and environmental level.

Data Analysis

Here is a dataset comparison plot. It compares results on the number of annual death percentage due to popular energy sources. The comparison is between a survey taken and scientific data taken from *Statista*.

This dataset shows us the massive gap that lies between opinion and truth. According to the survey Nuclear Energy ranks among the lowest in terms of safety on basis of worker mortality rate. Solar is considered safest. On the other hand, according to actual scientific data, nuclear energy is the safest as opposed to its counterpart. Solar energy is much less safer than seen in the survey.



Safety Regulations: India

Nuclear power plants and reactors are made and operated only if they are licensed by international and national organizations in terms of safety majorly.

Several Layers of protection in the reactor core ensure that there is no radiation leak that might harm neighbouring vicinities.

The nuclear safety regulatory authority bill was passed in 2011. According to this bill, all nuclear activities pertaining to obtaining of nuclear energy would be thoroughly monitored and safety aspects would be looked upon by the Nuclear Safety Regulatory Authority (NRSA) in India.

This bill also established the Council of Nuclear Safety to review nuclear safety policies from time to time. Any nuclear safety violations would be penalised with at least 5 years imprisonment.

AERB and NSRA Laws

Here are a few laws (in brief) as mentioned in the Radiation Protection Rules 2004 by AERB (Atomic Energy Regulatory Board) and NSRA:

1. No nuclear activities shall take place without a government issued licence
2. Inappropriate disposal of any material emitting radiation above the radiation emission mark set by the government shall lead to severe penalisation.
3. No modification of radiation installation or change in working condition from what is issued in the licence receipt is permitted
4. Mandatory restrictions on use of sources of which details are not specified in the licence
5. Restriction on addition of radioactive material in commodity items
6. Application and maintenance of Radiation symbol or Warning sign in specified places is mandatory.

… And many more laws (Check bibliography for detailed report link).

Environmental Safety

Since commercial safety is also discussed, only one major form safety is left to be discussed i.e. Safety of nuclear energy for the environment. Whether and exactly how it affects the environment.

Furthermore, 5 major factors of nuclear environmental safety will be discussed; impact on the atmosphere, impact on hydrosphere, impact on lithosphere, nuclear fuel and nuclear waste.

Impact on the Atmosphere

Effect of any form of obtaining of energy on the atmosphere occurs due to emission of gaseous components that might interfere with the balance of the gases that are already present.

Unlike in fossil fuel generation, where tons of carbon dioxide and other greenhouse gases are emitted and generated, in Nuclear reactors the only form of gas generated is water vapour.

Not only is water vapour absolutely harmless, it is also generated and recycled within the facility several hundred times.

Hence, replacement of other energy sources with nuclear energy can potentially help solve air pollution and global warming by reducing greenhouse gas emissions.

Impact on Hydrosphere

Working of the nuclear reactors might hint at a possible water pollution event. Even though it might seem that the pressurized water in a

PWR reactor comes in contact with the uranium itself, it is not the case.

Multiple layers of protection prevent direct contact and contamination of water due to radioactive fuel.

Impact on lithosphere

Nuclear Energy takes much less land per terawatt generation as compared to other renewable forms of energy.

While solar and wind energy generation farms can take huge land areas for minimal energy generation, nuclear energy generates much more energy within minimal land usage.

Nuclear Fuel

The resources (in term of raw input) is shockingly low in nuclear energy as compared to other sources. Yet having the highest energy generation capacity.

This is due to the energy density of nuclear energy.

To put things in perspective, I uranium pellet can generate as much energy as 120 gallons of oil or 1 ton of coal.

Nuclear Waste

Nuclear waste might also be a concern for some as it is highly toxic to any form of life.

Nevertheless, nuclear waste generation is very minimal. All the nuclear waste generated by the US in the past 60 years can be fit in a football field. This statement gives us an idea on how less waste is generated. This waste is safely stored in government facilities where it loses its radioactivity through radiation emission over thousands of years.

New designs for nuclear reactors are also coming up that can reuse nuclear waste within.

The nuclear waste that is generated can also be recycled externally.

German Nuclear Situation

First: Expansion

As already discussed, during the 1950s and 60s, peaceful use of nuclear energy was highly encouraged and implemented by most nation around the world. Germany was also among them.

They built about 26 nuclear reactors.

First wave of conflict

The following decades saw a shift in public interest regarding the nuclear power plants. The Three Mile Island nuclear disaster in 1976 and Chernobyl disaster in 1986 led a lot of German citizens to believe worse of nuclear power and expansion of nuclear energy.

This protest continued until only a while after the Chernobyl blast.

Nuclear Phasing-out Policies

In 1998, when the elections took place, a new government was appointed which amended a few policies regarding nuclear power plants.

The main policy was to phase-out all nuclear operations and power plants which brought the number down from 26 to 17. At this point a survey showed that only 13% Germans favoured this policy.

This number only kept growing again, to result in the second wave against nuclear energy in Germany. In 2007, 34% favoured the phasing out of nuclear operations.

Since the majority still wanted nuclear energy to continue, in 2009, all phasing-out policies were cancelled.

The 2011 Fukushima incident turned the numbers completely. A 2011 survey showed that about 90% Germans now supported phasing out of nuclear operations, so the policies were reintroduced.

About 8 nuclear power plants were immediately shut down.

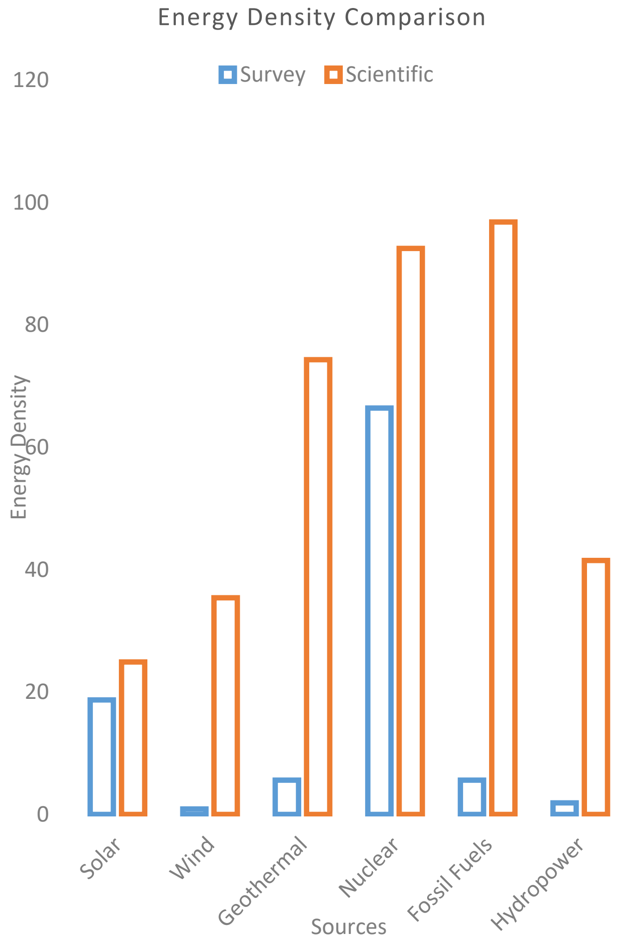
Currently, only 6 nuclear reactors are under operation.

Overall Analysis

As seen in the previous sections, nuclear power and fission is used for high density energy generation. While a lot of it may seem bad or good about it, both pros and cons are to be considered before actually implementing it.

Energy

Energy generation by nuclear power plants is extremely high as compared to other energy sources. This is both scientifically and commercially known as shown in the dataset given below.



How much energy is generated per amount of fuel/input is called energy density of an energy source. Nuclear Energy is among the highest energy density sources. About 2 million times higher than chemical based energy sources.

From the plot itself we can conclude that Nuclear energy has the highest energy density.

Maintenance

Nuclear Power plants comparatively require less maintenance as compared to other energy sources.

On average a nuclear reactor can operate for 1.5 to 2 years before refuelling it again.

Cost

Typically, nuclear energy can be a bit costly when compared to other sources of energy. This is also one of the major drawbacks of this form of energy. While the fuel itself might not be very expensive, building the nuclear plant (also known as capital cost) is generally quite expensive.

Conclusion

We have discussed most of the important aspects of nuclear energy along with 2 short case studies (Chernobyl and Germany).

When it comes to nuclear energy on a commercial scale, it has its benefits and drawbacks. A lot of uneducated claims regarding nuclear energy have also been made that falsify a lot of its benefits, like in Germany. As of the safety concerns, multiple research studies by different institutions have showed that nuclear energy is not only safe but also among the safest forms of energy extraction in the world in both commercial and environmental terms. Accidents that took place in 1976 (Three-mile island), 1986 (Chernobyl) and 2011 (Fukushima) have all been due to lack of safety measures, which, as already proven is under thorough check by multiple institutions.

Even though the nuclear industry has highly advanced technology to ensure safety, accidents might still occur, is what one might argue. The simple answer to this would be the frequency of occurrence of such a disaster is almost negligible.

Finally, safety, energy density and environmental impact of nuclear energy clearly out-weigh the cost drawback, making it the best option out there as an energy source.

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