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Nuclear Fission and Fusion: A Cleaner and Greener Perspective: A Theoretical Approach

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Abstract—*The concept of atom has existed for many centuries, however the enormous potential of the tiny mass has been realised recently. Atom have a large amount of energy which is required to hold the nuclei together. Certain isotopes of some element can be split up and in turn they will release a part of the energy as heat. This entire process is referred to as fission. The heat released in this process can be easily used to generate electricity in power plants.*
Uranium -235 (U-235) is one of the isotopes that can be fissioned very easily. During fission, U-235 atoms absorb loose neutrons and it becomes unstable and split into light atoms called fission products. The combined mass of the fission products is less than original U-235. The reduction in the mass occurs because some of the matter changes into energy. This energy is subsequently released as heat. Two or three neutrons are also released along with the heat. Its a common trend that these neutrons may hit other atoms, thereby causing more fission. Subsequently this series of fission is referred to as the chain reaction. If a considerable amount of uranium is brought together under the right condition, a continuous chain reaction will occur. This is called as the self sustaining chain reaction. A self sustaining chain reaction creates a great deal of heat, which can be used judiciously to generate electricity.
Nuclear energy is a clean, safe, reliable and competitive energy source. It is the only source of energy that can replace a significant percentage of fossil fuels (coal, oil and gas) which pollute the atmosphere and contribute to the green-house effect.
The present study is an effort towards the theoretical investigation of the generation of nuclear power and thereby, realising the astonishing potential of the Nuclear Energy.

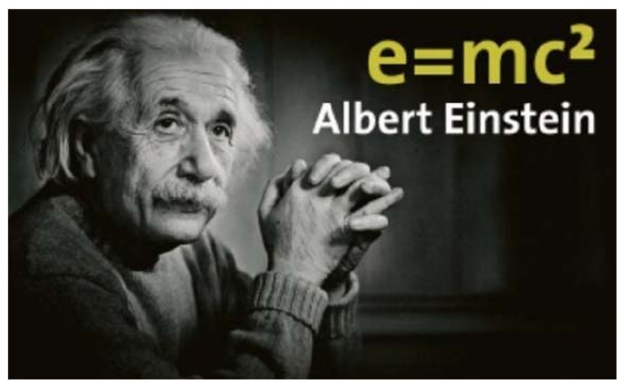
Keywords*: Nuclear Energy, Reactors, Moderator, Nuclear Power Plant, Uranium-235 Isotope*

1. INTRODUCTION

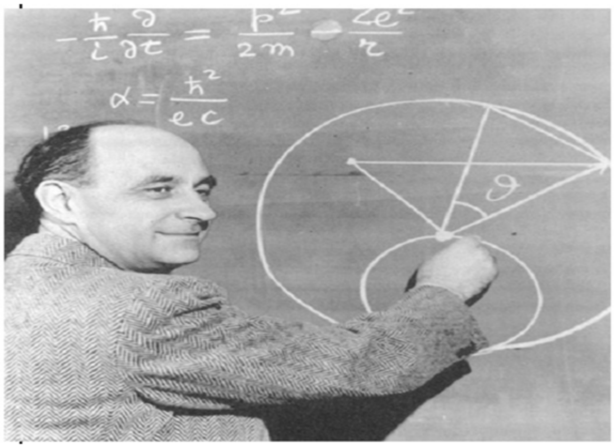
It is human mature to observe and to dream. The history of Nuclear Energy is the story of a centuries old dream becoming a reality.

Ancient Greek philosophers first developed the idea that all matter is composed of invisible particles called atoms. The word atom comes from the Greek word **atomos**, which means invisible. Scientists in the 18^{th} and 19^{th} century revised the concepts based on the experiment. By 1900, physicists knew the concept that the atom contain large quantities of energy. British physicist Ernest Rutherford was called the father of the Nuclear Science because of his contribution to the theory of atomic structure.

Albert Einstein developed his theory of the relationship between mass and energy one year later. The mathematical formula referred to as $E=mc^2$ or energy equal mass times the speed of light squared. It took almost 35 year for someone to prove Einstein's theory.



In 1934, physicist Enrico Fermi conducted experiments in Rome that showed neutrons could split into many kinds of atoms. The result surprised even Fermi himself. When he bombarded uranium with neutrons, he did not get the elements he expected. The elements were much lighter than uranium.



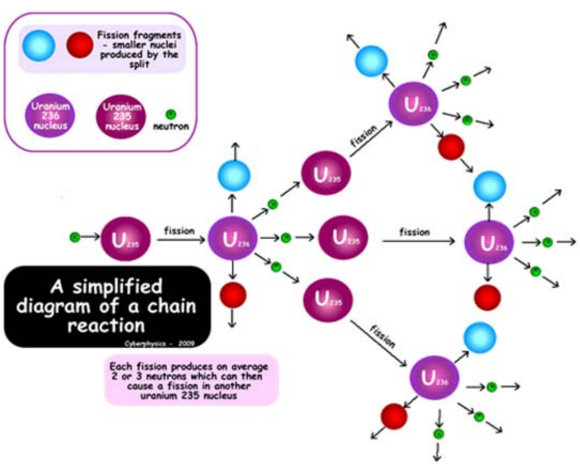
Enrico Fermi, an Italian physicist, led the team of scientists who created the first self sustaining nuclear chain reaction

2. HISTORY OF NUCLEAR POWER GENERATION

In the fall of 1938, German Scientists Otto Hahn and Fritz Strassman fired neutrons from a source containing the elements Radium and Beryllium into Uranium (atomic number-92). They were surprised to find lighter elements, such as Barium (atomic number-56) in the left over material.

These elements had a about half the atomic mass of uranium. In previous experiment, the left over material were only slightly lighter than uranium.

3. THE FIRST SELF SUSTAINING CHAIN REACTION

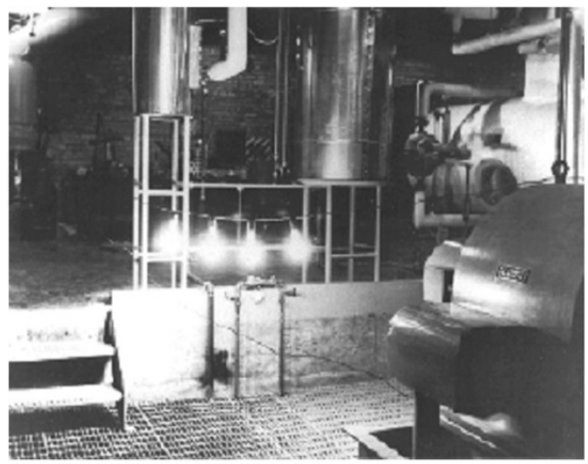


In 1939, Bohr came to America. He shared with Einstein the Hahn-Strassman-Meitner discoveries. Bohr also met Fermi at a conference on theoretical physics in Washington D.C. They discussed the exciting possibility of a self-sustaining chain reaction. In such a process atoms could be split to release large amount of energy.

Scientist throughout the world began to believe a self-sustaining chain reaction might be possible. It would happened if enough uranium could be brought together under proper conditions. The amount of uranium needed to make a self-sustaining chain reaction is called a critical mass.

Fermi and his associate, Leo Szilard suggested a possible design for uranium chain reactor in 1941. Their model consisted of uranium placed in a stack of graphite to make a cube like frame of fissionable material.

Earlier in 1942, a group of scientist led by Fermi gathered at the University of Chicago to develop their theories. By November 1942, they were ready for construction to begin on the world's first nuclear reactor, which came to be known as Chicago Pile-1. The pile was erected on the floor of a squash court beneath the University of Chicago's Athletic stadium. In addition to uranium and graphite, it also contained control rods made of cadmium. Cadmium is a metallic element that absorb neutrons. When the rods were in the pile, there were fewer neutrons to fission uranium atoms. This slowed the chain reaction. When the rods were pulled out, more neutrons were available to spilt atoms. The chain reaction sped up.



The Experimental Breeder Reactor I generated electricity to light four 200-watt bulbs on December 20, 1951. This milestone symbolized the beginning of the nuclear power industry.

On the morning of 2nd December 1942, the scientist were ready to begin a demonstration of Chicago Pile-1. Fermi ordered the control rods to be withdrawn a few inches at a time during the next several hours. Finally at 3:25 pm, Chicago time, the Nuclear reaction became self-sustaining. Fermi and his group had successful transformed scientific theory into technological reality. **The world had entered Nuclear Age.**

4. HOW NUCLEAR POWER PLANTS GENERATES ELECTRICITY

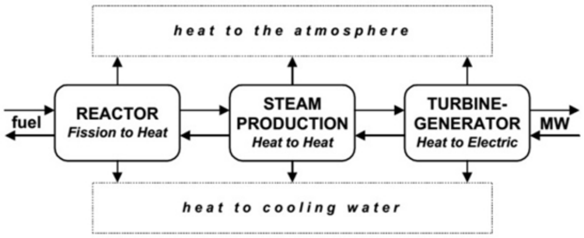
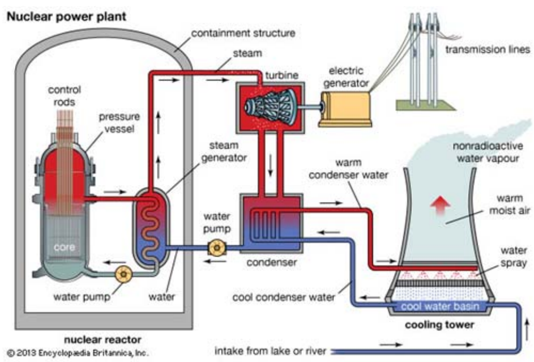
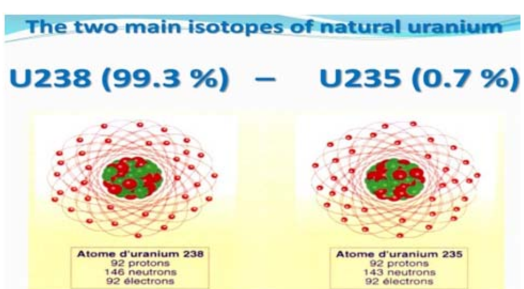


Figure: Basic Flow Of Energy In A Nuclear Power Plant:



Nuclear Power Plants generate electricity in the same way as that of the other Thermal Power Plants. The combustion of a fuel is used to generate heat, the heat is used to create the steam and the steam is used to spin turbines, which in turn generate electricity. The difference with the Nuclear Power Plants is that instead of using the combustion of a fuel to generate heat, they use Nuclear Fission to generate heat. Nuclear Fission in simple terms is splitting of large atoms into smaller atoms, this process releases vast amounts of energy.



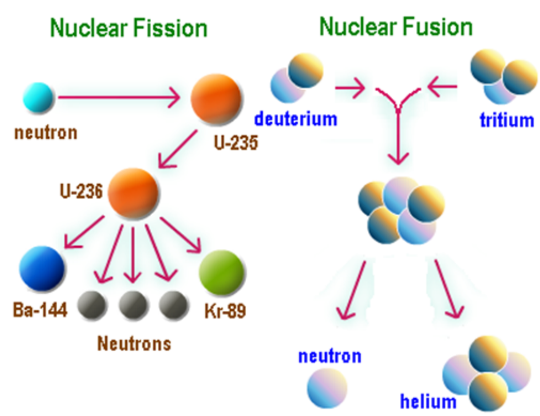
Radioactive Decay

Nuclear Fission can occur either naturally or be induced. When it happened naturally, the process is called as the Radioactive decay and it is a common process. The elements in which this process occurs naturally are known as Radioactive-isotopes.

These Radioactive-isotopes are the atoms that have an unstable Nucleus because the Nucleus has an excess amount of energy. The instability will cause them to spontaneously decay or split into two smaller atoms. These newly formed atoms will be of different elements from the original Radioactive-isotope and their nuclei will be more stable. It is not possible to predict when a specific Radioactive-isotope will decay, however the average rate at which it will decay is known, this rate is referred to as the Half Life. Half Life is referred to the amount of time for a specific quantity of a decaying substance to be reduced by half. Half lives can vary greatly and range from mere seconds to millions of years. One example of naturally occurring Radioactive decay is that of Carbon -14. Carbon-14 occurs naturally in the atmosphere and it is present in living things at a very specific proportion. Carbon-14 is used to estimate the age of organic remain by measuring the amount of Carbon-14 remaining in a fossil and comparing it to the amount that it would have had at the time of death. Since, the half life of Carbon-14 is known, by knowing how much Carbon-14 has decayed, an estimate of how much time it would have taken far that to happen can be made.

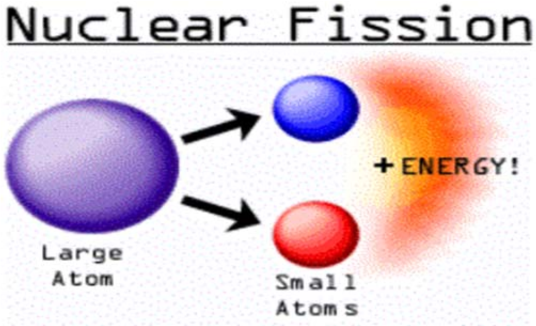
5. NUCLEAR REACTION

The other type of nuclear decay called fission is a man-made nuclear reaction.



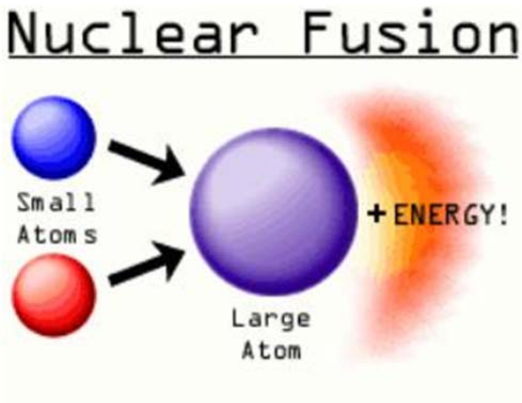
This reaction occurs inside the nuclear reactor and generates the heat to produces electricity. A Nuclear reactor is the steel vessel where the nuclear fuel is contained. A Nuclear reaction occurs when an atom is induced to split or fission and as a consequence, it release a large amount of energy substances that are able to be induced to split are known as fissile materials and it is out of fissile materials that Nuclear fuel is made. The Nuclear fuel, most commonly used for commercial Nuclear Power Plants is uranium. Uranium is metallic chemical element commonly found on the earth's crust. Naturally occurring uranium come in three different varieties or isotopes. All uranium isotopes contain 92 protons in their Nucleus; the differences between the isotopes is the number of Neutrons in the Nucleus. Naturally occurring uranium include

U-234 with 142 Neutrons and U-235 with 143 Neutrons and U-238 with 146 Neutrons.



In nature 99.3% of uranium is U-238, 0.7% is U-235 and less than 0.01% is U-234.

U-235 is the only fissile naturally occurring uranium isotope and it is therefore the most commonly used nuclear fuel.



A Nuclear reaction starts with a U-235 atom that is induced to split by shooting a neutron at it. When the U-235 atom absorb the Neutron it momentarily becomes a U-236 atom. The Nucleus of the U-236 atom is relatively unstable and it quickly breaks up into two different atoms and releases two or three free neutrons in the process. The newly formed atoms are known as fission products and they will roughly be half the size of the original atom. Fission Products will vary with each Fission reaction and will range from elements with atomic number 30 (Zinc) to atomic number 71 (Lutetium).

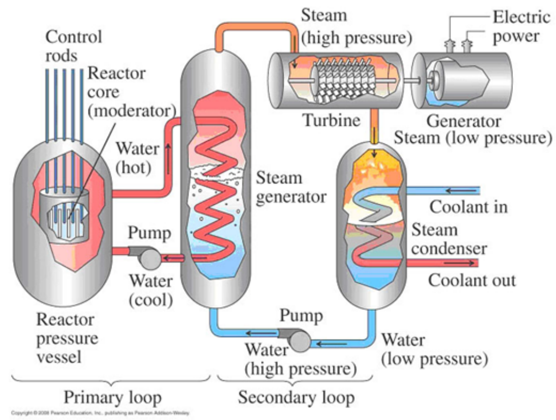
The free Neutrons that are released are very important for the continuation of the Nuclear reaction or which may also be called as the Nuclear Chain Reaction. A chain reaction occurs when the Neutrons released by the fission of a U-235 are absorbed by other U-235 atoms, causing further fission reaction, which in turn release more Neutrons and cause further fission reaction.

There are two types of Nuclear Reactors, Thermal or Slow Neutron Reactor and Fast Reactors.

6. THERMAL REACTORS

Thermal Reactors use slow Neutrons to sustain the Nuclear Chain Reaction.

The Speed at which the Neutrons are released by the fission reaction is too first to be absorbed by the other U-235 atoms.



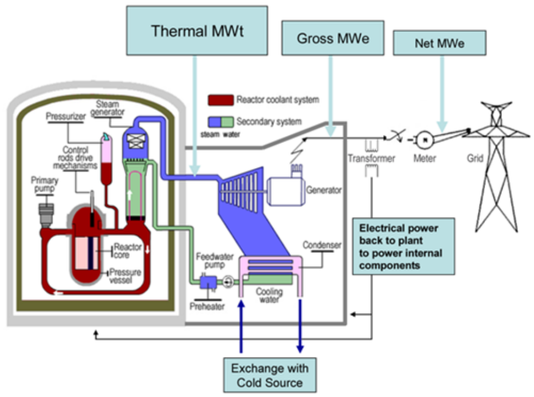
In order to slow down the Neutrons the fuel is contained within a "Moderator" so that a continuous chain reaction can be maintained. The Moderator is usually water, but heavy water (water whose hydrogen atom contain both a Proton and a Neutrons as opposed to just one proton) and graphite are also used.

In addition to serving as the moderator, water in thermal reactor also serves as the coolant. Water inside the reactor is constantly flowing to both cool the reactor and capture the thermal energy to produce electricity. Both thermal and fast reactors must constantly be cooled, even when shut down because of the heat generated by the radioactive decay of the fission product. Thermal reactors are the ones that are currently being used for commercial operation, since the technology to make fast reactors economically viable is not yet available.

7. FAST REACTORS:

As opposed to the thermal reactors, fast reactors can sustain a Nuclear Chain Reaction using the fast Neutrons, thus they have no need for a Moderator.

However in order to maintain the Nuclear Chain Reaction using fast Neutron as fuel that is richer in fissile materials is needed. Fast reactors can use either a fuel that has a higher concentration of U-235 (20% or higher as oppose to 3-5% for Thermal Reactors) or Plutonium-239 (Pu-239). Pu-239 is more suitable for fast reactors because it releases 25% more Neutrons per fission than U-235. Even though there is less Neutron absorption because of the higher speed of the Neutrons that is compensated by the higher amount of Neutrons release and the Nuclear Reaction is able to be maintained. Since fast reactors depend on fast Neutrons, in order to avoid any type of moderation, liquid metal (usually sodium) is used as the coolant instead of water and liquid metal is also more efficient medium for transferring heat.



8. CONCLUSIONS:

- Today most of the energy we use is supplied by the fossil fuels. In one hundred year coal will be the only one left and petroleum product may last for 2-3 decades.
- Fossil fuels are non-renewable. The world is using the biomass which makes only 15% of energy consumption and hydroelectric power meets 6% of the world energy needs. It is very expensive to built but cheap to maintain.
- Solar and wind energy are also available but not available all the time.
- Life on earth depends on achieving a balance between energy supply and the needs of the worlds

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