(TFR-1) Thermonuclear Fusion Reactor: Theoretical Construction and Application

Reyes - Mora, J.

Mentor: Dr. Chawdhury, A.

Introduction

- **A Brief History Of Fusion:**

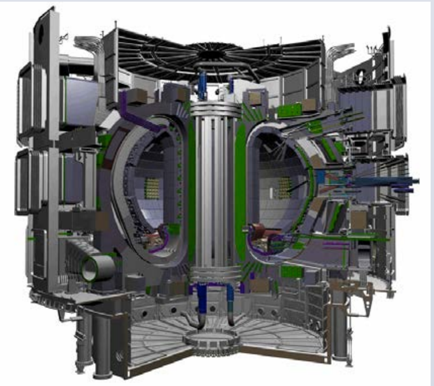
The article, “A Brief History of Fusion” by the European Commission of Research and Innovation, provides us with some interesting information about how the roots of fusion started. In 1905, the first ideas about how the sun works were defined by Albert Einstein in the development of the famous relativity equation (E=MC^2). This equation declares that with a minimum amount of mass one could create a huge amount of energy with the conversion factor being the speed of light, but no one was able to find any connection or any importance for the development of fusion energy. No one until Francis William Aston, who in 1920 took measurements of the masses of atoms. Such work was seized upon by Sir Arthur Eddington, a British astrophysicist, who realized that by burning hydrogen into helium, the Sun would release around 0.7 % of mass into energy. In 1939, German physicist Hans Bethe completed the picture with a quantitative theory explaining the generation of fusion energy in stars.

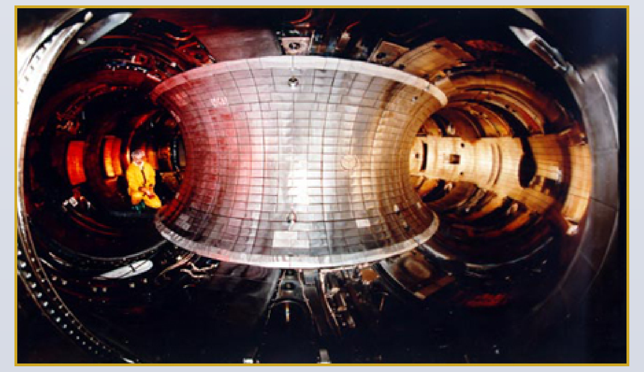
However, it wasn’t until the end of World War II that the first legitimate fusion energy experiments were created. The original large-scale experimental fusion device was built in the late 1940s and early 1950s at Harwell in the U.K. The Zero Energy Toroidal Assembly (ZETA) worked from 1954 to 1958, showing initial promise and producing useful results for later devices. Research on fusion quickly became an international area of science with experimental devices developed in France, Germany, the Soviet Union, and the U.S. Even during the depth of the Cold War, scientific exchange on fusion was encouraged. In 1958, an Atoms for Peace conference in Geneva formally sealed the start of truly international collaboration that would in time lead to today's ITER experiment in southern France.

- **Types of Fusion:**

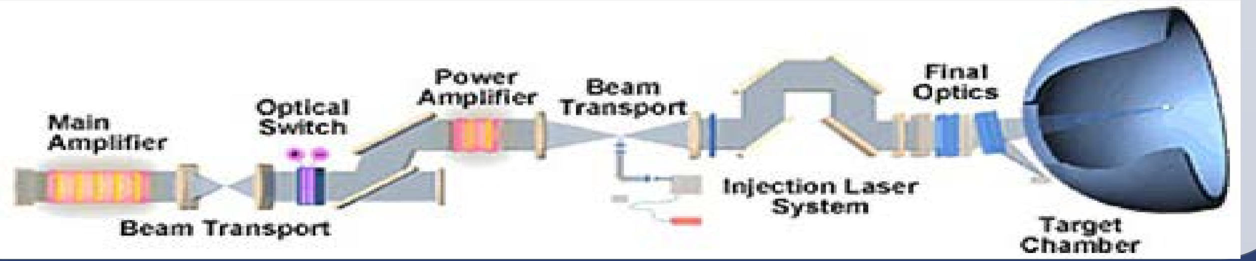
There are three known types of fusion experiments which have been recreated on Earth. Only two of them with energy harvesting purposes.

- The International Thermonuclear Energy Reactor (ITER) is based on the 'tokamak' concept of magnetic confinement, in which the plasma is contained in a doughnut-shaped vacuum vessel. The fuel—a mixture of deuterium and tritium, two isotopes of hydrogen—is heated to temperatures in excess of 150 million, forming a hot plasma. Strong magnetic fields are used to keep the plasma away from the walls; these are produced by superconducting coils surrounding the vessel, and by an electrical current driven through the plasma.(ITER 2013)



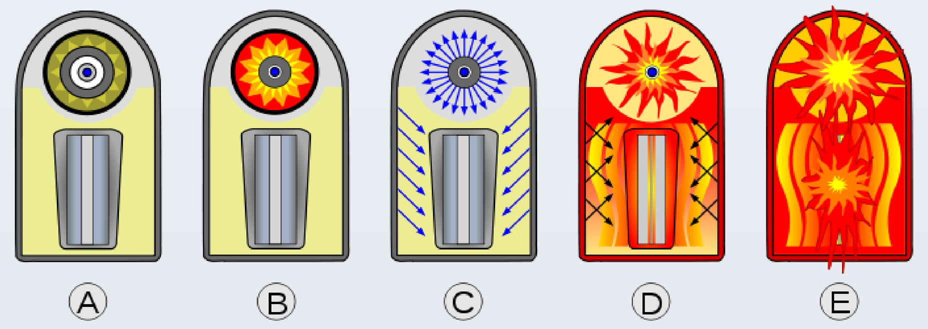


- The National Ignition Facility (NIF)'s 192 laser beams travel a long path, about 1,500 meters, from their birth at the master oscillator to the center of the target chamber. As the beams move through NIF's amplifiers, their energy increases exponentially. From beginning to end, the beams' total energy grows from one-billionth of a joule to four million joules, a factor of more than a quadrillion—and it all happens in about five millionths of a second. Every NIF beam starts at the master oscillator. The low-energy beam is amplified in the preamplifier module and then in the power amplifier, the main amplifier, and again in the power amplifier before the beam is run through the switchyard and into the target chamber.(NNSA 2013)



- The other way in which nuclear fusion has been achieved on the earth is in the device commonly known as the hydrogen bomb. At the high temperatures produced in a fission reaction, nuclei of isotopes of hydrogen undergo fusion with the liberation of energy. In these circumstances, the nuclear reactions are propagated so rapidly that the energy is released in an uncontrolled (or explosive) manner. It seems reasonable to hope that, somewhere between the trivial production of fusion energy achieved by means of accelerated particles, on the one hand, and its release in an explosive manner, on the other hand, controlled nuclear fusion will be possible. In essence, a controlled fusion reactor would be a device in which appropriate isotopes of hydrogen combine, the end result being the production and extraction, in a manner that can be regulated at will, of useful quantities of energy in excess of the amount required to operate the device.

Diagram of a Thermonuclear Fusion Bomb:



Objectives

The goals for the undergraduate research process would concentrate on measurement of specific characteristics of the device; such as released radiation, materials, efficiency, possible hazardous situations, and others. In order to recreate Fusion, a model was suggested. With the implementation of models of previously made thermonuclear fusion devices an adaptation of the model was proposed. Reducing the size of the yield of the reaction would make it safe enough for experimentation and future reproduction. Several measurements and calculations have been estimated based on the research theory mentioned below. For undergraduate research, a final sketch and blue prints will be proposed, as well as detailed instructions of construction. The TFR-1 construction process is estimated to take around four to eight years after the theoretical considerations are completed, a two to four year endeavor.

TFR-1 Theory

According to Samuel Glasstone and Ralph H. Lovberg’s Research on Controlled Thermonuclear Reactions, Both acceleration and heating methods have been proposed for conferring energy upon deuterium nuclei in order to bring about controlled fusion reactions. It seems fairly certain, however, when acceleration is used, it would be advantageous if the directed motion of the accelerated nuclei were converted into random motion with a distribution of energies. This means that, if controlled fusion can be achieved on a sufficient scale to be of practical value, it will probably be by way of reactions which are essentially thermonuclear in nature.

Many reactions involving the combination of nuclei of low atomic number, e.g., isotopes of hydrogen, helium, and lithium, are accompanied by a liberation of energy. Such reactions are therefore of possible interest in connection with the production of fusion power. Since atomic nuclei are positively charged, when two nuclei are brought together as a, preliminary to combination (or fusion), there is an increasing force of electrostatic (or Coulomb) repulsion of their positive charges. At a certain distance apart, however, the short-range nuclear attractive forces just exceed the long-range forces of repulsion. At this point, fusion of the nuclei becomes possible. The variation in the potential energy of the system of two nuclei, with their distance apart, is shown in the image bellow; a negative slope of the potential energy curve indicates net repulsion whereas a positive slope implies net attraction. According to classical theory, the energy which must be supplied to the nuclei to surmount the Coulomb barrier, i.e., the energy required to overcome the electrostatic repulsion so that fusion can occur, is given by :

$$\text{Energy to surmount Coulomb barrier} = \frac{Z_1 Z_2 e^2}{R_0},$$

where Z_1 and Z_2 are the respective charges (or atomic numbers) of the interacting nuclei, e is the unit (or electronic) charge, and R_0 is the distance between the centers of the nuclei at which the attractive forces become dominant.

Because of the increased height of the Coulomb energy barrier with increasing atomic number, it is generally true that, at a given temperature, reactions involving the nuclei of hydrogen isotopes take place more readily than do analogous reactions with heavier nuclei. In view of the great abundance of the lightest isotope of hydrogen, with mass number 1, it is natural to see if nuclear fusion reactions involving this isotope could be used for the release of energy. It is unfortunate, however, that the three possible reactions between H nuclei alone or with deuterium (D) or tritium (T) nuclei, i.e.,

$${}_1H^1 + {}_1H^1 \rightarrow {}_1D^2 + {}_1e^0$$
$${}_1H^1 + {}_1D^2 \rightarrow {}_2He^3 + \gamma$$
$${}_1H^1 + {}_1T^3 \rightarrow {}_2He^4 + \gamma,$$

are known to have cross sections that are too small to permit a net gain of energy at temperatures which may be regarded as attainable. Consequently, recourse must be had to the next most abundant isotope, i.e., deuterium, and here two reactions, which occur at approximately the same rate over a considerable range of energies, are of interest; these are the D-D reactions

$${}_1D^2 + {}_1D^2 \rightarrow {}_2He^3 + {}_0n^1 + 3.27\ \text{Mev}$$
$${}_1D^2 + {}_1D^2 \rightarrow {}_1T^3 + {}_1H^1 + 4.03\ \text{Mev},$$

called the "neutron branch" and the "proton branch," respectively. The tritium produced in the proton branch or obtained in another way, as explained below, can then react, at a considerably faster rate, with deuterium nuclei in the D-T reaction

$${}_1D^2 + {}_1T^3 \rightarrow {}_2He^4 + {}_0n^1 + 17.6\ \text{Mev}.$$

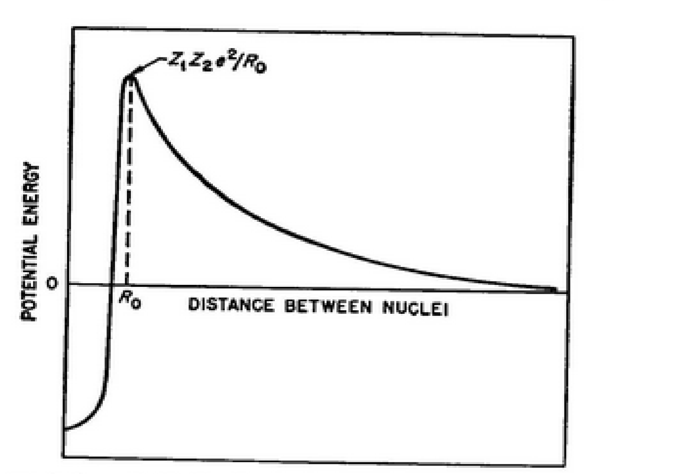
The He^3 formed in the first reaction can also react with deuterium; thus,

$${}_1D^2 + {}_2He^3 \rightarrow {}_2He^4 + {}_1H^1 + 18.3\ \text{Mev}.$$

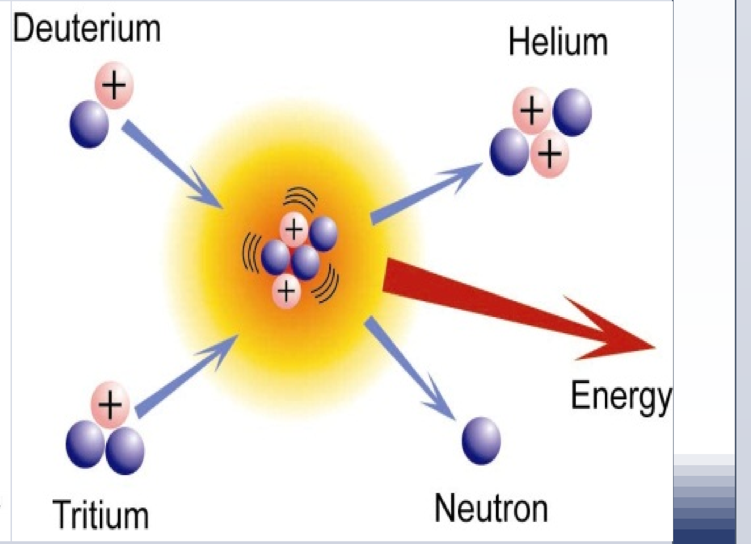
This reaction is of interest because, as in the D-T reaction, there is a large energy release; the D-He^3 reaction is, however, slower than the others at low thermonuclear temperatures, but its rate approaches that of the D-D reactions at 100 kev . In the methods currently being considered for the production of useful thermonuclear power, the fast neutrons produced in the neutron branch of the D-D reaction and also in the D-T reaction would probably escape from the immediate reaction environment. It is to be expected that these neutrons will be slowed down in a suitable moderator, e.g., water, lithium, or beryllium, with the liberation of their kinetic energy as heat which can be utilized. The slow neutrons can then be captured in lithium-6, which constitutes 7.5 atomic per-cent of natural lithium, by the reaction

$${}_3Li^6 + {}_0n^1 \rightarrow {}_2He^4 + {}_1T^3 + 4.6\ \text{Mev}$$

leading to the production of tritium. The energy released can be used as heat, and the tritium can, in principle, be transferred to the thermonuclear system to react with deuterium.



Variation of Coulomb potential energy with distance between nuclei.



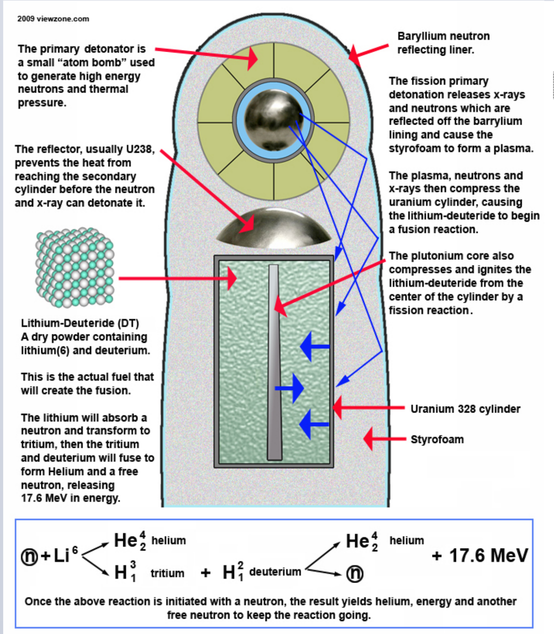
TFR-1: Application of Theory

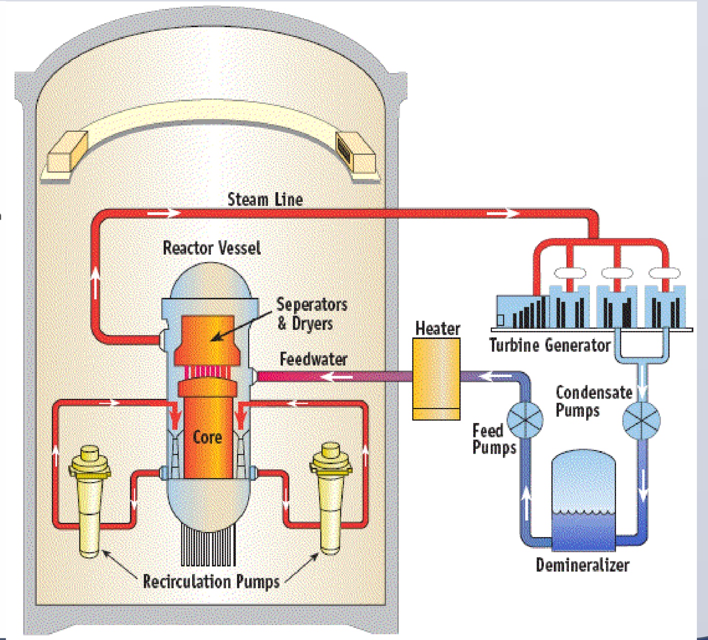
The TFR-1 would integrate a new system and theory to produce thermonuclear reactions which are based on thermonuclear fusion explosive devices, originally created for defense purposes. The increment of yield and destructive power of the device has been considered more important than the energy that could be harvested from it. The TFR-1 would test the power of a thermonuclear fusion device on a small scale, enough to reduce the amount of destruction and obtain just the necessary yield to harvest energy without destroying the reactor. A constant flow of small explosions would create the necessary heat to create enough steam to power electric turbines at a constant flow, and for long periods of time. The TFR-1 is a very challenging and time-consuming project. Work is currently being done on the physical design of the reactor as well as some of the theory. Including previous research done in theoretical fusion by Samuel Glasstone and Ralph Lovberg. References from Dr. Robert E.H. Clark, and Dr. William Allis. Assistance and mentorship have been provided by the former Chair of the University of Alaska Physics Department, Dr. Ataur Chowdhury.

As pointed out above, in order to bring about fusion reactions it is necessary that the interacting nuclei collide with sufficient energy to overcome the forces of electrostatic repulsion which tend to keep them apart. It is known that this energy can be supplied, under laboratory conditions, by means of a charged-particle accelerator. Alternatively, the interacting nuclei may acquire the necessary energy if they are part of a system at sufficiently high temperatures, as is the case in the sun and stars. The two situations are, how-ever, different in an important respect. Accelerated particles all have essentially the same energy and move in the same direction, but when the energy is acquired as a result of raising the temperature the particles exhibit random motion combined with a wide distribution of energies. The TFR-1 will overcome such repulsion with the high accelerating particles of explosive that would penetrate the Coulomb barrier and generate a Fusion Reaction.

Details of Model

The system design is very similar to a standard Fission Power plant, however, there are some major differences. The core will be replaced with a Thermonuclear Core. Which would work by replaceable “Reaction Packs” which would contain the necessary materials for the reaction, The remaining contents of the pack would adhere to the walls of the shield, reducing the need of cleaning and improving the shield’s blocking ability as time passes. The heater showed in the diagram would be removed. The materials of the reactor core will be composed of several coats of top quality steel, as well as carbon fiber, grapheme and thin coats of diamond dust. The shield must be impenetrable. The rest of the reactor would look and work very similarly to most of the coal and fission reactors in current production and use. Another major difference is the size of the recirculation pumps. A thermonuclear fusion reaction would generate more pressure power, heat and electricity than the average fission generator. Therefore, the recirculation pumps must be larger.





Possible Results

The possible outcome estimated with the consulted information projects a possibility of a future completion and mass production of the project. There are many calculations yet to make, but the theory points in a positive direction. The previously proposed thermonuclear fusion method, which would be implemented on the TFR-1, has been the only method of fusion experimentation with a positive and desired outcome. With the complete measurement calculations and specific reductions necessary to complete an experimentation sketch, the TFR-1 might be the first reactor with a possibility of fusion power harvest.

Following up on Glasstone and Lovberg’s research, another way of emphasizing the vast amounts of energy that might be realized by controlled fusion is to state that 1 gram of deuterium could yield a maximum of something like 8×10^{10} calories. To produce this quantity of deuterium requires about 8 gallons of water, so that 1 gallon of water has a fusion energy equivalent of 10^{10} calories. The combustion of 1 gallon of gasoline yields a little more than 3×10^{7} calories. Hence, the nuclear fusion energy that could, in theory, be obtained from 1 gallon of water would be equivalent to over 300 gallons of gasoline. In spite of the fact that the nuclear energy potential of a gram of deuterium is equivalent to the combustion energy of more than 2500 gallons of gasoline or to the explosive energy of some 80 tons of TNT, a fusion reactor may be expected to be completely safe. It appears that there would be absolutely no danger of a destructive runaway if there were a loss of control due to an accident or to earthquake, lightning, or other natural phenomenon. The reason is that the reactor would operate at a very low gas density, and so the total energy density would not exceed 20 calories/cm^3. The disruption of a reactor having a volume of 1500 liters would thus release no more energy than is produced by the combustion of a gallon of gasoline. It is probable, therefore, that there would be no serious danger of explosion in the operation of a controlled fusion reactor. In connection with the hazard problem, it may be noted that, in contrast to the fission process, no appreciable amount of radioactive material would result from the reactions occurring in a fusion reactor. There would thus be no problem of the disposal of radioactive waste and no danger of the contamination of the surrounding area in the event of an accident leading to disruption of the reactor. However, like a fission reactor, a fusion device would require considerable shielding to prevent the escape of neutrons and various harmful radiations.

Cited Work

Glasstone, Samuel. Controlled Thermonuclear Reactions, an Introduction to

Theory and Experiment. Los Alamos, NM: Van Nostrand, 1960. Print.

Willis, B. (2007,). Nuclear Fusion. Retrieved from Worsley School Online

website: http://www.worsleyschool.net/science/files/fusion/nuclearfusion.html

Various. (2006,). *What is Fusion?* Retrieved from International Thermonuclear Experimental Reactor website: http://www.iter.org/

Various. (2003,). *Laser Inertial Fusion Energy*. Retrieved from National Ignition Facility website: https://lasers.llnl.gov/

Willis, B. (2007,). *Nuclear Fusion*. Retrieved from Worsley School Online website: http://www.worsleyschool.net/science/files/fusion/nuclearfusion.html

Various, Authors. "A Brief History of Fusion Energy." *Research And Innovation*. European Commission, n.d. Web.

Shultis, J Kenneth., and Richard E. Faw. *Fundamentals of Nuclear Science and Engineering.* CRC Press, 2002. *Google Books*. Web.