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A Technology Review of Electricity Generation from Nuclear Fusion Reaction in Future

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Abstract: *In this review paper, we have tried to revisit the basic concept of nuclear fusion and the recent thrust that has been witnessed in the recent times towards power generation from it . In fusion we get the energy when two atoms fused together to form one atoms. With current technology the reaction most readily feasible is between the nuclei of the deuterium (D) and tritium (T). Each D-T releases 17.6 MeV of energy. The use of nuclear fusion plant will substantially will reduce the environmental impacts of increasing world electricity demands. Fusion power offers the prospect of an almost inexhaustible source of energy for future generation but it also presents so far insurmountable scientific and engineering challenges.*

Keywords: *Deuterium, Nuclear fusion, ITER, Plasma Confinement, Tokamak Reactor, etc*

I. INTRODUCTION

In the present scenario of world, each day need of electricity is increasing day by day. We found out different methods to generate electricity. But due to large population of the world the present sources are not that much sufficient. Also there is some pollution problems related with present electricity generation techniques. Therefore, as a long term research and experimental solution of this problem, ITER has been developed to generate the power from nuclear fusion. In fusion reaction, two nuclei joins together to form bigger nuclei along with this large amount of energy is liberated. Then this energy can be used to rotate the turbine and can eventually possible to generate electricity. The process of nuclear fusion will takes place between the nuclei of deuterium and tritium.

Research in fields of nuclear fusion has been pursued in various countries for decades. The efforts include the JT-60, which has provided important results for improving plasma confinement; the D-IIID Tokamak experiment, which has achieved record values of plasma pressure relative to the magnetic field pressure; and the Tokamak Fusion Test Reactor (TFTR), which has generated 10 million Watts of thermal power from fusion. The Joint European Torus (JET) is expected to approach breakeven Conditions, where the fusion power generated exceeds the input power. Unresolved physics Issues, such as plasma purity, disruptions, and sustainment of current, should be resolved by the International Thermonuclear Experimental Reactor (ITER).This is being designed by experts of the European Community, Japan, Russian Federation, and the United States.

II. SCIENCE BEHIND FUSION ENERGY

For some decades, people have looked to the process powering the sun – nuclear fusion –as an answer to energy problem on the earth. Nuclear fusion is the process of binding nuclei together to form heaver nuclei with release of large amount of energy. It is the process that powers the star and of course our own sun. In the process of fusion, atomic nuclei do not stick together easily. It is because there is electromagnetic force present between the two nuclei. . However, at distances of 10^{15} m there is an attractive force which acts on the nuclei to keep them together and it is much stronger than the electromagnetic force. Appropriately, this force is called the Strong force.

Over such short distances the strong force wins over the electromagnetic force and so the nuclei stay together. To create a situation where the nuclei have sufficient energy to overcome the electromagnetic force requires the nuclei to have extremely high kinetic energy and therefore, a high temperature. We can estimate the temperature required to initiate fusion by calculating the Coulomb barrier which opposes the protons coming together. The magnitude of the force between protons is given by:

$F= (k\, q_1\, q_2)/r^2$; $k=1/(4\pi\varepsilon_0)$ is the Coulomb constant = 8.988×10^9 m/F

The work done, U in moving the two protons together until they are attracted by the strong force is given by:

$U=\int \mathbf{F}.d\mathbf{r}= (k\, q_1\, q_2)/r_0$; the limits on the integration are $-\infty$ and r_0

The Coulomb barrier increases with increasing atomic number:
$U= (k\, Z_1\, Z_2\, q^2)/r_0$. ; Z_1 and Z_2 are the proton numbers of the nuclei being fused.

$$U= (8.988 \times 10^9 \times 1 \times 1 \times (1.6 \times 10^{-19})^2)/(1 \times 10^{-15}) = 2.298 \times 10^{-13}\ \text{J}$$

The kinetic energy of the nuclei is related to the temperature by: $0.5\, mv^2 = (3/2)\, k_B T$

By equating the average thermal energy to the Coulomb barrier height and solving for T, gives a value for the temperature of around 1.1×10^{10} K. In practice, this simple calculation overestimates the temperature. The temperature of critical ignition should be lower because there will be some nuclei with higher energies than average; however the temperature requirement is still too high for even these high energy nuclei. This treatment using classic physics does not take into consideration the effect of tunneling, which predicts there will be a small probability that the potential barrier will be overcome by nuclei 'leaking' through it.

At sufficiently high temperature, nearly all light nuclei undergo fusion reactions and could in principle be used to fuel a fusion power plant. However, technical difficulties increase rapidly with the nuclear charge of the reacting isotopes. For this reason, only deuterium, tritium and isotopes of helium, lithium, and boron have been proposed in practice. The first generation of fusion power plants will very likely use deuterium-tritium (DT) fuel because it is the easiest to ignite. The main reaction product, helium-4, does not pose a health hazard. The principal energy output from a DT fusion event is a 14 Mev neutron. Neutron reactions in DT fusion reactors will inevitably create radioisotopes. The principal radioactive materials present in a DT fusion reactor will therefore be tritium and neutron activated structural materials surrounding the reaction volume. Following fig shows that how nuclear fusion reaction takes place between deuterium and tritium

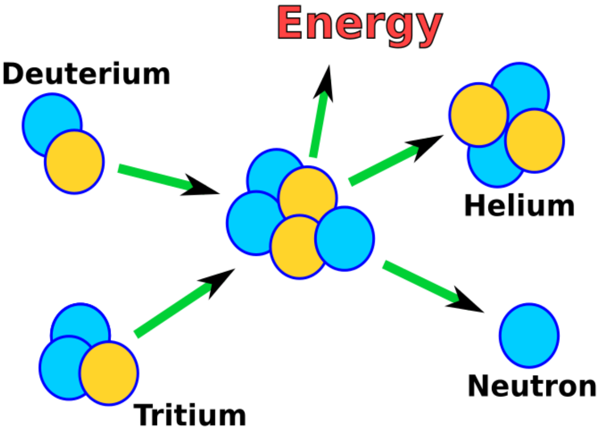

Figure 1- fusion reaction between deuterium and tritium [ ]

III. CONDITIONS FOR FUSION REACTION

When hydrogen atoms fuse, the nuclei must come together. However, the protons in each nucleus will tend to repel each other because they have the same charge (positive). If you've ever tried to place two magnets together and felt them push apart from each other, you've experienced this principle first-hand. To achieve fusion, you need to create special conditions to overcome this tendency. Here are the conditions that make fusion possible.

High temperature

The high temperature gives the hydrogen atoms enough energy to overcome the electrical repulsion between the protons. Fusion requires temperatures about 100 million Kelvin (approximately six times hotter than the sun's core). At these temperatures, hydrogen is plasma, not a gas. Plasma is a high-energy state of matter in which all the electrons are stripped from atoms and move freely about.

High pressure

Pressure squeezes the hydrogen atoms together. They must be within $1\text{x}10^{-15}$ meters of each other to fuse. The sun uses its mass and the force of gravity to squeeze hydrogen atoms together in its core. We must squeeze hydrogen atoms together by using intense magnetic fields, powerful lasers or ion beams.

With current technology, we can only achieve the temperatures and pressures necessary to make deuterium-tritium fusion possible. Deuterium-deuterium fusion requires higher temperatures that may be possible in the future. Ultimately, deuterium-deuterium fusion will be better because it is easier to extract deuterium from seawater than to make tritium from lithium. Also, deuterium is not radioactive, and deuterium-deuterium reactions will yield more energy.

IV. CASE-STUDY OF ITER

In 1985, the Soviet Union suggested building a next generation Tokamak with Europe, Japan and the USA. Collaboration was established under the auspices of the International Atomic Energy Agency (IAEA). Between 1988 and 1990, the initial designs were drawn up for an International Thermonuclear Experimental Reactor with the aim of proving that fusion could produce useful energy. Then the USA decided pull out of the project, forcing a 50% reduction in costs and a redesign. The result was the ITER – Fusion Energy Advanced Tokomak (ITER-FEAT) – expected to cost $3 billion but still achieve the targets of a self-sustaining reaction and a net energy gain.

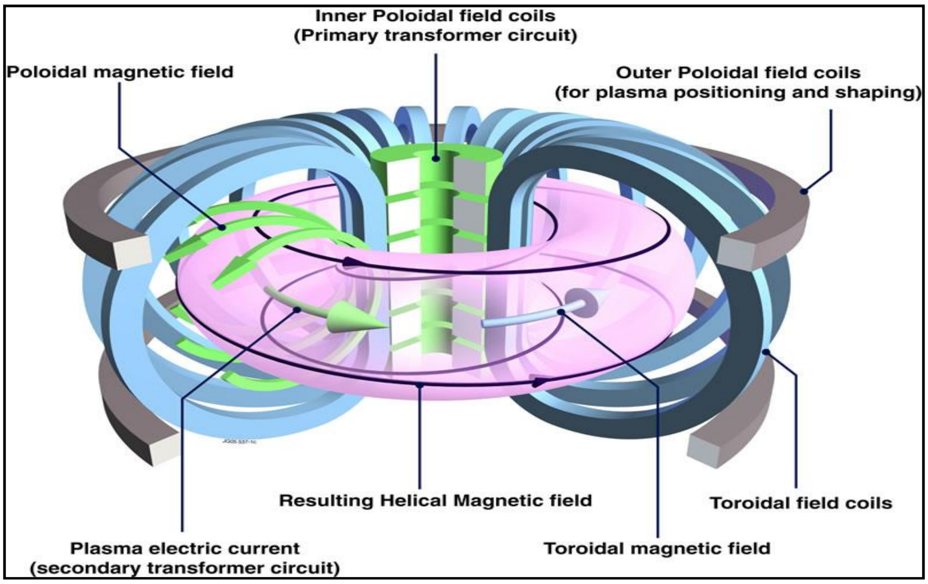

Figure 2 – Magnetic Confinement Reactor – Tokamak [ ]

After deadlocked discussion, the six partners agreed in mid-2005 to site ITER at Cadarache, in southern France. The European Union (EU) and France will contribute half of the €12.8 billion total cost, with the other partners like Japan, China, South Korea, USA and Russia – putting in 10% each. Japan will provide a lot of the high-tech components, will host an €1 billion materials testing facility – the International Fusion Materials Irradiation Facility (IFMIF) – and will have the right to host a subsequent demonstration fusion reactor. The total cost of the 500 MWt ITER comprises about half for the ten-year construction and half for 20 years of operation. India became the seventh member of the ITER consortium at the end of 2005. In November 2006, the seven members – China, India, Japan, Russia, South Korea, the USA and the European Union – signed the ITER implementing agreement. The goal of ITER is to operate at 500 MWt (for at least 400 seconds continuously) with less than 50 MW of input power, a tenfold energy gain. No electricity will be generated at ITER.

A 2 GWt Demonstration Power Plant, known as DEMO, is expected to demonstrate large-scale production of electrical power on a continual basis. The conceptual design of Demo is expected to be completed by 2017, with construction beginning in around 2024 and the first phase of operation commencing from 2033.

Fusion Reactors: Magnetic Confinement

There are two ways to achieve the temperatures and pressures necessary for hydrogen fusion to take place:

- **Magnetic confinement** uses magnetic and electric fields to heat and squeeze the hydrogen plasma
- **Inertial confinement** uses laser beams or ion beams to squeeze and heat the hydrogen plasma.

In magnetic confinement, Microwaves, electricity and neutral particle beams from accelerators heat a stream of hydrogen gas. This heating turns the gas into plasma. This plasma gets squeezed by super-conducting magnets, thereby allowing fusion to occur. The most efficient shape for the magnetically confined plasma is a donut shape (toroid).

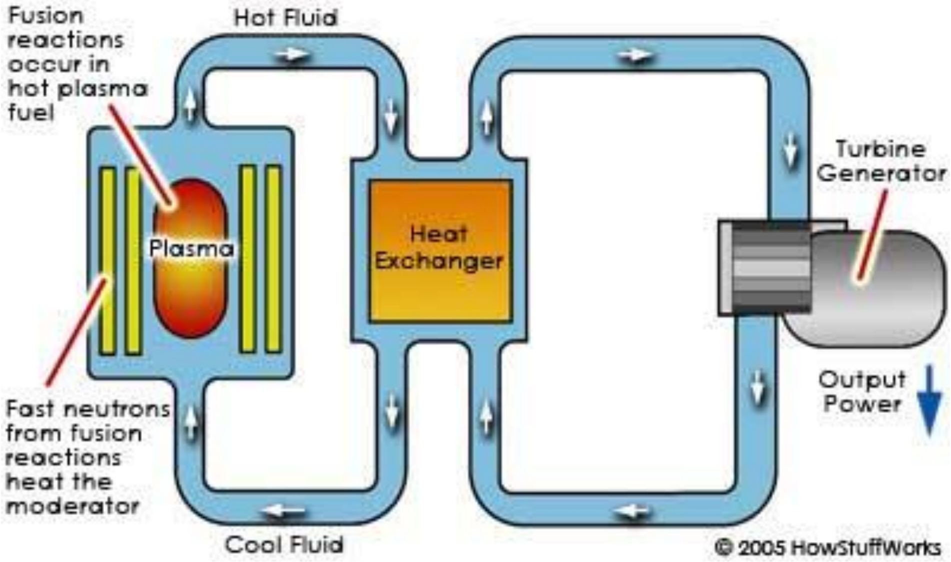

Figure 3 – The Nuclear Fusion Power Generation System [ ]

A reactor that uses magnetic confinement to initiate fusion is called a Tokamak**.** The ITER Tokamak will be a self-contained reactor whose parts are in various cassettes. These cassettes can be easily inserted and removed without having to tear down the entire reactor for maintenance. The Tokamak will have a plasma toroid with a 2-meter inner radius and a 6.2m outer radius. "Tokamak" is a Russian acronym for "toroidal chamber with axial magnetic field." The main parts of the ITER Tokamak reactor are:

- Vacuum vessel - holds the plasma and keeps the reaction chamber in a vacuum
- Neutral beam injector (ion cyclotron system) - injects particle beams from the accelerator into the plasma to help heat the plasma to critical temperature
- Magnetic field coils (poloidal, toroidal) - super-conducting magnets that confine, shape and contain the plasma using magnetic fields
- Transformers/Central solenoid - supply electricity to the magnetic field coils
- Cooling equipment (crostat, cryo-pump) - cool the magnets
- Blanket modules - made of lithium; absorb heat and high-energy neutrons from the fusion reaction
- Diverters - exhaust the helium products of the fusion reaction

The fusion reactor will heat a stream of deuterium and tritium fuel to form high-temperature plasma. It will squeeze the plasma so that fusion can take place. The power needed to start the fusion reaction will be about 70 megawatts, but the power yield from the reaction will be about 500 megawatts. The fusion reaction will last from 300 to 500 seconds. (Eventually, there will be a sustained fusion reaction.) The lithium blankets outside the plasma reaction chamber will absorb high-energy neutrons from the fusion reaction to make more tritium fuel. The blankets will also get heated by the neutrons. The heat will be transferred by a water-cooling loop to a heat exchanger to make steam. The steam will drive electrical turbines to produce electricity. The steam will be condensed back into water to absorb more heat from the reactor in the heat exchanger. Initially, the ITER Tokamak will test the feasibility of a sustained fusion reactor and eventually will become a test fusion power plant.

V. APPLICATIONS OF FUSION

The main application for fusion is in making electricity. Nuclear fusion can provide a safe, clean energy source for future generations with several advantages over current fission reactors:

- **Abundant fuel supply** - Deuterium can be readily extracted from seawater, and excess tritium can be made in the fusion reactor itself from lithium, which is readily available in the Earth's crust. Uranium for fission is rare, and it must be mined and then enriched for use in reactors.
- **Safe** - The amounts of fuel used for fusion are small compared to fission reactors. This is so that uncontrolled releases of energy do not occur. Most fusion reactors make less radiation than the natural background radiation we live within our daily lives.

- **Clean -** No combustion occurs in nuclear power (fission or fusion), so there is no air pollution.
- **Less nuclear waste -** Fusion reactors will not produce high-level nuclear wastes like their fission counterparts, so disposal will be less of a problem. In addition, the wastes will not be of weapons-grade nuclear materials as is the case in fission reactors.

NASA is currently looking into developing small-scale fusion reactors for powering deep-space rockets. Fusion propulsion would boast an unlimited fuel supply (hydrogen) would be more efficient and would ultimately lead to faster rockets.

VI. CONCLUSION

The Thermonuclear reactor based on fusion can prove to be a huge step towards a massive source of energy, if the technologies developed for the research works practically as it is expected in this large scale and the setup handles that much energy without damaging the reactor. The ITER project has opened many areas of fundamental studies to understand fusion and controlling the same in an enclosed environment.

REFERENCES

[1] Cook, Marbach, Di Pace, Girard, Taylor, “ Safety and Environmental Impact of Fusion”, April 2001
[2] IEEE Nuclear and Plasma Sciences Society.
[3] Nuclear fusion: Targeting safety and environmental goals by Franz Nicolas Flakus, John C. Cleveland and T. J. Dolan
[4] Tokamak Reactor design as a function of aspect ratio by C.P.C. Wong and R.D. Stambaugh
[5] M.S. Tillack, “ARIES-RS Tokamak Power Plant Design, “Special Issue, Fusion Engineering and Design 38 (1997) 1–218.