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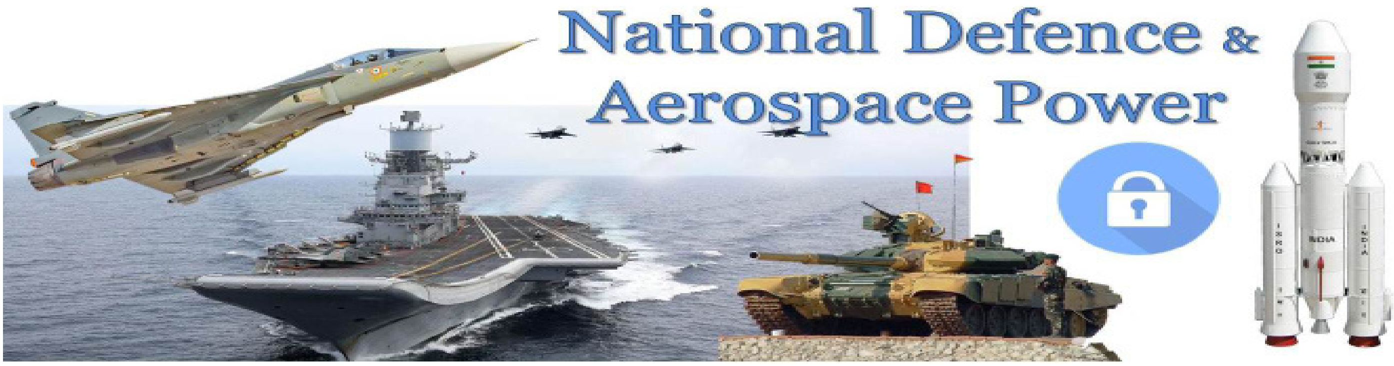

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NUCLEAR ENERGY BREAKTHROUGHS AND INDIA'S CONTRIBUTIONS

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> **The major difference between weapons and nuclear power comes from controlling the fission reaction. Controlled fission eventually led to the commercialization of nuclear power in 1957.**

There is a saying that nuclear fusion is 30 years away and will always be! But it may be time to refute that. A quantum leap in the field of nuclear energy took place in the first quarter of 2022. Scientists at the Joint European Torus (JET) located in south Oxfordshire, and the Oxford-based First Light Fusion (FLF), a British start-up backed by China's Tencent, were successful in generating nuclear energy breakthroughs with two different approaches to the same principle. The JET, which was created in the Soviet Union in the 1960s, is the world's largest and most sophisticated tokamak-fusion reactor. It managed to generate 59 megajoules of sustained energy for 5 seconds. Operated by the Culham Centre for Fusion Energy (CCFE), JET is the focus of the European fusion research program. Although quite advanced, the JET tokamak is the testbed for the world's largest nuclear experiment — the International Thermonuclear Experimental Reactor (ITER), which is also the world's largest tokamak. On the other hand, the FLF uses a bombardment mechanism called the projectile fusion technology, which it has been developing since 2011. Unlike JET, which generates a plasma medium to fuse deuterium and tritium to generate energy, FLF uses a high-velocity gas gun to launch a projectile at the target by amplifying the energy, which forces deuterium fuel, (an isotope of hydrogen used in fusion) to fuse and generate energy in the process. These methods are based on the same principles that power the sun and other stars, and were developed to demonstrate the possibility of fusion as a large-scale carbon-free energy source.[1]

What is nuclear fusion and why does it matter?

The recent experiments by JET and FLF are being considered as nuclear energy breakthroughs. If successfully accomplished, it holds ample potential to generate limitless amounts of energy. The scientists working on the JET in Oxfordshire managed to produce the largest amount of energy generated so far from a nuclear fusion reactor. Though not much, it is an important proof of the principles of fusion.

At present, nuclear energy generated is primarily produced from a fission reaction. In a fission reaction, the neutrons are projected onto the nucleus of a heavier atom, splitting the latter into lighter elements. This process releases two or more neutrons, thus enabling a chain reaction. Similar nuclear reactions formed the basis of the wartime atomic program. The major difference between weapons and nuclear power comes from controlling the fission reaction. Controlled fission eventually led to the commercialization of nuclear power in 1957.

The process of nuclear fusion is the opposite of this. To release energy, lighter atoms are fused to generate heavier atoms. In a nutshell, nuclear fusion is a thermo-nuclear process wherein the atoms are stripped of their electrons due to extreme heat in the plasma, the fourth state of matter, where nuclei and electrons are suspended freely. Since nuclei are positively charged, they repel each other. To overcome this repulsion, the nuclei move at a fast rate and at high temperatures, amounting to millions of degrees. The pressure causes the nuclei to fuse until they merge, creating a heavier nucleus and releasing energy in the process. This energy is then harnessed through a new generation of power plants, the fusion reactor.

The difficulty of attaining a controlled fusion reaction has made the recent event in Oxfordshire a nuclear energy breakthrough. If done right, the fusion reaction would be more powerful and sustainable than the fission reaction.

First light fusion, with its projectile mechanism, made a wildcard entry into an otherwise enclosed field of fusion energy. Projectile fusion technology, which began its genesis only in the last decade, has managed to come to fruition. This technology launches a projectile with a hypervelocity gas gun at a speed of 6.5 km per second.[2] By intensifying the impact of the projectile, energy is generated by forcing the hydrogen isotope to fuse. The speed of the hyper-velocity gas gun is 10 times faster than that of a rifle bullet. The target enclosing the deuterium fuel is a clear cube enclosing two spherical fuel capsules, which is a centimetre wide and is the key technology of the mechanism. The company wants to produce and sell the targets to future power plants (designed to its specifications) that would need to vaporise one every 30 seconds to maintain power generation. Each target could generate enough energy to power an average UK home for two years. Although on a smaller scale as compared to the energy generation capacity of a tokamak, the projectile fusion mechanism could be a cheaper, easier, and a faster route to commercial energy generation. Since it is a start-up backed by private entities, the technology is being kept confidential and is closely guarded by the company. Nicholas Hawker, Chief Executive of FLF, in his statement to the Financial Times in 2021, called it "the ultimate espresso capsule."[3] The project has been approved by the United Kingdom Atomic Energy Authority (UKAEA), a research organization of the government of the UK, which is responsible for the development of fusion energy. UKAEA has also hosted the JET at the Culham facility since the inception of its design in 1973.

By 2025, the ITER is expected to be ready for its first experimental run. This accounts for a contribution of 2.2 billion dollars on the part of India. In return for its investment, India will get access to 100 per cent of the intellectual property rights, which opens the pathways for the construction of fusion reactors in India in the future.

Traditionally, there are two possible ways of achieving nuclear fusion: inertial confinement and magnetic confinement. In inertial confinement, brief but powerful laser pulses are used to compress the fuel and start the fusion reaction, while in magnetic confinement, powerful magnets are used to confine the plasma for long periods of time. The magnetic confinement strategy has been the chosen route for energy generation due to higher development possibilities. Tokamaks, where the plasma is constrained by a strong magnetic field, are the subject of the great bulk of magnetic confinement research.

ITER is a demonstration reactor that uses the Tokamak configuration and is currently being built in southern France. It will be the "world's largest fusion reactor, the first fusion device to maintain fusion for long periods and the first to test integrated technologies, materials, and physics regimes necessary for the commercial production of fusion-based electricity."[4] The ITER tokamak will be a unique experimental tool aiming to contain ten times the plasma volume of the largest machine operating today. Furthermore, the machine has been designed to produce 500 MW of fusion power from 50 MW of input heating power, demonstrate the integrated operation of technologies for a fusion power plant, achieve a deuterium-tritium plasma with internal heating, and demonstrate the safety characteristics of the fusion device.[5]

India and ITER

India is one of the seven partner nations that are cooperatively working on the ITER project. These countries have engaged in 35 years of collaboration to build and operate the ITER experimental device.[6] The countries are India, the USA, China, Russia, South Korea, Japan, and the EU. India is tasked with the manufacturing and is responsible for the "delivery of cryostat, in-wall shielding, cooling water system, cryogenic system, heating systems, diagnostic neutral beam system, power supplies, and some diagnostic."[7] The 3,800 tonne cryostat is the largest stainless steel vacuum vessel, and all the superconducting magnets within ensure an ultra-cool, protective environment necessary for magnetic confinement. By 2025, the ITER is expected to be ready for its first experimental run. The reactor is likely to cost and the rest over 20 billion Euros. As the reactor is being constructed in Europe, the EU will be taking care of 45 per cent of the entire cost and the rest of the members will bear 9.1 per cent each.[8] This accounts for a contribution of 2.2 billion dollars on India's part.[9] In return for its investment, India will get access to 100 per cent of the intellectual property rights which opens the pathways for the construction of fusion reactors in India in the future.

India's contribution to ITER

India is contributing to the project in three ways: material (in-kind) contributions; cash contributions; and human resources. India has been steadfast in meeting the deadlines for material contributions. It has supplied the crucial 3800-ton cryostat. A crucial part of the tokamak, the cryostat, was made by L&T in Gujarat and was then shipped to France. Bernard Bigot, the Director General of ITER, has called this an unprecedented engineering challenge and an achievement.[10] India has also delivered the components needed for ITER's secondary cooling water system and has nearly completed the delivery and installation of cryolines and other piping for the cryogenics system.[11] However, India is defaulting on its cash contribution and the lack of supply of human resources has also created an unprecedented challenge concerning India's commitment to ITER.

India's financial commitment to ITER has not been fulfilled. By the mid of 2021, India had majorly defaulted on this front.[12] DG-ITER says that other member states of the project were not happy with India as it has been unable to fulfil its cash contribution since 2017. The outstanding amount is now to the tune of Rs 1000 crore. Because of India's default on cash contribution, other nations have come forward and helped pay for the labour cost. The DG has expressed concern about the lack of funding from India and has reiterated the danger ITER could face in the long run.

Another concern for India is its dismal allocation of human resources to the reactor site. According to the agreement signed by the participating countries, each country can provide up to 9 per cent of the total required staff. As a result, India can send around 86 scientists and engineers to work at ITER.[13] While ITER does not have a quota, there exists a cap on the number of international staff members at 1050. According to ITER records, only 25 Indians worked there in 2020, and the numbers have been disappointing.[14] The core staff sent to ITER are obligated to bring their fusion expertise back to India so that India can set up its own commercially viable nuclear fusion plant in the future. India has allowed countries like China to fill in the gaps left by not completing its complete roster. The reason for India's inability to fulfil its roster is that, according to a general circular by the Department of Personnel and Training (DoPT), government staff are not to be posted overseas for more than two years. The ITER project has a gestation period of more than three decades. Such short tenures with a 'one size fits all' policy are detrimental to the project's expertise and are counter-productive. India has to reform its domestic laws to allow for more individuals to participate in the project.

Nuclear fusion provides an alternative way of generating power with clean baseload energy and zero carbon emissions, helping us bypass the environmentally disastrous side effects of existent energy sources. It produces tremendous amounts of energy as compared to nuclear fission.

Why is nuclear fusion important?

11 per cent of the world's total energy comes from 450 nuclear reactors around the world that function primarily on the principle of nuclear fission. Often termed as a rather environment-friendly alternative and a green solution to the rapidly changing energy discourse, disasters like Chernobyl and Fukushima, along with the looming reality of radioactive waste piling up, have made it clear that fission-based power has its limitations. These concerns have made many countries rethink their course on nuclear energy, as is evident from the nuclear withdrawing countries of Europe. Portrayed as strong alternatives to pollution-intensive fossil fuels, renewable energy sources are plagued by the issue of being intermittent. Emerging technologies and large-scale electrification of appliances would mean an exponential increase in energy demands. This coupled with net zero emission goals, calls for a rethinking on the energy front.

Nuclear fusion provides an alternative way of generating power with clean baseload energy and zero carbon emissions, helping us bypass the environmentally disastrous side effects of existent energy sources. It produces tremendous amounts of energy as compared to nuclear fission. It is also a safer process as the radioactive waste generated by the fusion process is short-lived and in small amounts, and therefore not as dangerous as that generated by nuclear fission. Fusion techniques, be it using either a tokamak or a projectile, use different approaches to the same principle. With the advancement and such breakthroughs, our quest for nuclear energy generation has sped up considerably.

While fusion energy with its perks seems great, the difficulties in the process could mean that it would be available to us only in the second half of the 21st century. While there is no silver bullet for the climate crisis, nuclear fusion may be the closest thing to it.

Notes:

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[14] Ibid.

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