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The Fusion Energy Breakthrough:
Announced By US Scientists

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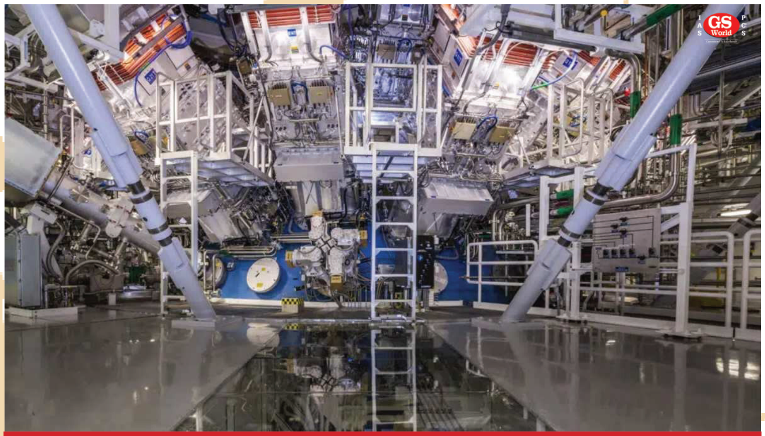
❖ **Use of the fusion process for generating electricity at a commercial scale is decades away, but the latest experiment by US scientists is still a big deal. How is their method different from the one being used by ITER, of which India is a partner?**

Scientists in the United States have, for the first time, achieved a net gain in energy from a nuclear fusion reaction, seen as a big step forward in the decades-old endeavour to master a technology that is considered the most dependable source of energy in future. Fusion is a different, but more powerful, way of harnessing the immense energy trapped in the nucleus of an atom. This is the process that makes the Sun and all other stars shine and radiate energy. Attempts to master the fusion process have been going on at least since the 1950s, but it is incredibly difficult and is still at an experimental stage.



The Lawrence Livermore National Laboratory shows the NIF Target Bay in Livermore, California

The system uses 192 laser beams converging at the centre of this giant sphere to make a tiny hydrogen fuel pellet implode

Fusion And Fission Of Atomic Nuclei

The nuclear energy currently in use across the world comes from the fission process, in which the nucleus of a heavier element is split into those of lighter elements in a controlled manner. In fusion, nuclei of two lighter elements are made to fuse together to form the nucleus of a heavier atom. A large amount of energy is released in both these processes, but substantially more in fusion than fission. For example, the fusion of two nuclei of a heavier isotope of hydrogen, called tritium, produces at least four times as much energy as the fission of a uranium atom which is the normal process of generating electricity in a nuclear reactor.

Net Energy Gain

When the energy produced is more than the energy used, it is called fusion energy gain or net energy gain.

Besides greater energy yield, fusion is also a carbon-free source of energy, and has negligible radiation risks.

But fusion reactions happen only at very high temperatures, 10 times the temperature that exists at the core of the Sun, and creating such an extreme environment in a laboratory requires huge amounts of energy. So far, the energy released in such experimental fusion reactions have been lower than what is consumed to create the enabling high temperatures. At best, some of these reactions have produced ‘near break-even’ energies. That is why the latest experiment conducted at the Lawrence Livermore National Laboratory in California is being considered a big deal.

Fusion Still Far From Reality

Significant though the achievement is, it does little to bring the goal of producing electricity from fusion reactions any closer to reality. By all estimates, use of the fusion process for generating electricity at a commercial scale is still two to three decades away. The technology used in the US experiment might take even longer to get deployed.

There are at least two different ways in which fusion reactions are being experimented with. These differ mainly in the way the input energy is supplied to create the extreme heat to enable fusion, but that also results in differences in design and capabilities. At the Lawrence Livermore facility, scientists use high-energy laser beams to achieve those temperatures, also called ‘inertial fusion’. At some other places, including the international collaborative

Current Status

All nuclear power plants in the world use fission reactors to generate electricity. France, where ITER is located, gets 70% of its energy from nuclear fission. However, it is not a popular source of fuel due to public fear of harmful radiation in most countries, affected by accidents such as the Chornobyl disaster, the meltdown at Fukushima, and the US Three Mile Island partial meltdown. The "switching off" of the plasma under unfavorable conditions also means that if any instability occurs the reaction is stopped. Hence it makes fusion much safer than fission.

The "Green" Advantage

Nuclear fusion, in addition to being highly efficient, nuclear power can dramatically reduce our dependence on fossil fuels. Nuclear power itself is considered a carbon-free alternative to fossil fuels because its manufacture does not emit greenhouse gases – its major byproduct is helium, an inert, non-toxic gas. Furthermore, deuterium is abundant in seawater, and scientists are trying to produce tritium using lithium in situ. Renewable energy sources such as wind and solar alone cannot meet global basic energy needs. Nuclear fusion, if successful, could provide much more than that.

Plasma "Switching Off"

A technological breakthrough in plasma physics is needed for fusion to become a reality. The sunlight and heat we feel on Earth are the results of fusion, a process that occurs naturally at the center of the Sun under extreme temperatures and pressures. To achieve fusion on Earth, the gases need to be heated to extremely high temperatures of around 150 million °C (270 million °F), which is about 10 times the temperature of the Sun's core. At this point, the gases become plasma, which is about a million times lighter than the air we breathe. All the protons, neutrons, and electrons that make it up get ripped apart. Fusion researchers have established that creating a plasma by heating a mixture of deuterium and tritium is the easiest way to obtain an atmosphere to fuse and generate energy. At ITER, an instrument called a tokamak uses a strong magnetic field to confine the plasma used for fusion experiments. In these extreme conditions, the particles of this plasma collide rapidly, generating heat. But paradoxically, as the temperature rises even further, the collision rate – and the heating effect – drops. it's like the plasma shuts off beyond a certain point.

project in southern France called ITER in which India is a partner, very strong magnetic fields are used for the same purpose.

"It is relatively easier to attain break-even energy levels through inertial fusion compared to magnetic fusion. Obtaining net energy gain is a very important step, but we are still far away from reactor grade fusion reactions. There are many many challenges to be overcome before the potential of fusion reaction is realised," Dr Indranil Bandyopadhyay, Group Leader, Council Support and Knowledge Management, ITER India, said.

According to current timelines, the ITER project is expected to demonstrate the viability of a commercially scalable nuclear fusion reactor between 2035 and 2040. The actual deployment of a fusion reactor for generating electricity could take another decade after that. Several countries, like China, Japan, UK and South Korea, are working on this technology separately as well, apart from collaborating at ITER. Bandopadhyay said it is the magnetic fusion that is expected to deliver the fusion reactors first.

Still, the United States, also a partner at ITER, and some other countries including China, are trying the laser-based inertial fusion as well. This is mainly because this technology can also be used to develop fusion-based nuclear weapons that would be far more powerful and devastating than the current nuclear weapons.

Incremental Progress

In December last year, UK-based JET laboratory, which uses magnetic fusion, had improved its own previous record for the amount of energy produced from a

Tokamak (TOKAMACA)

It is the name of a special method and device designed for the confinement of hot plasma. It was first developed by Russian scientists in the year 1950. Today many tokamaks are in operation including India, Japan, Russia, France, the UK, the USA, and Germany. It is necessary for the construction of a 'fusion reactor'. With its help, a toroidal magnetic field is created. In India, two tokamaks, Aditya and SST-1 are in operation at the Institute for Plasma Research in Gandhinagar. In China, the China Fusion Engineering Test Reactor (CFETR) is a proposed tokamak fusion reactor, which uses a magnetic field to confine the plasma and generate energy. Large Hadron Collider (LHC)

The Large Hadron Collider (LHC) is a particle accelerator that accelerates protons or ions to near the speed of light. It consists of a 27-kilometer ring of superconducting magnets with a variety of accelerating structures that boost the energy of the particles. The word "Large" refers to its size, which is approximately 27 kilometers in circumference. km's "Hadron" because it accelerates protons or ions, which belong to a group of particles called hadrons. "Collider" because the particles create two beams traveling in opposite directions, which collide at four points around the machine. are made for

CERN

It is actually known as European Council for Nuclear Research and it is known as European Nuclear Research Organization in Hindi, but the most popular name is 'CERN'. CERN, the world's largest particle physics laboratory, is located in the northwestern city of Geneva, on the border between France and Switzerland. CERN consists of 22 member countries and currently employs about 8,000 scientists and engineers from hundreds of universities in 70 countries around the world. In the year 2002, India was given the status of observer member of CERN. However, India has been contributing to CERN since the 1960s. It is to be noted that very concrete indications of the existence of Higgs boson particles (commonly called God particles) were obtained by a mega experiment led by the scientists of CERN.

fusion reaction. The reaction had run for five seconds and produced 59 megajoules of energy, more than double the previous record.

The fusion reactions currently being run in labs last for barely a few seconds. Those based on laser beams run for even shorter times. It is difficult to sustain such extreme high temperatures for prolonged periods. Bandopadhyay said the ITER project was being designed to run for 3,000 seconds. At its full power, it was expected to produce five times more energy than it would consume. However, when run for shorter time periods, about 300-500 seconds, it could release10 times the energy consumed.

ITER and India : Future of Fusion Energy

ITER, when operational, would become the biggest machine anywhere in the world, more complex than the Large Hadron Collider at CERN, or the LIGO project to detect gravitational waves. Right now, the ITER reactor is in the machine assembly phase. Over 10 million parts, being manufactured and tested in the seven member countries, have to be transported, assembled and integrated.

India joined the ITER project in 2005. The Institute for Plasma Research in Ahmedabad, a laboratory under the Department of Atomic Energy, is the lead institution from the Indian side participating in the project. As a member country, India is building several components of the ITER reactor, while also carrying out a number of experiments and R&D activities related to the project.

Expected Question

Que. Consider the following statements-

1. In India, two Tokamak named Aditya and SST-1 (Steady State Superconducting Tokamak-1) are working at the Plasma Research Institute in Gandhinagar (Gujarat).
2. India joined the ITER (International Thermonuclear Experimental Reactor) project in 2005.

Which of the statements given above is/are correct?

(a) Only 1 (b) Only 2

(c) Both 1 and 2 (d) Neither 1 nor 2

Answer : C

Mains Expected Question & Format

Que.: For energy, what do you understand by nuclear fusion and fission process? Highlight the global efforts on nuclear fusion as the energy of the future.

Answer Format :

- ❖ Explain the process of nuclear fusion and fission.
- ❖ Describe the global efforts on nuclear fusion as the energy of the future.
- ❖ Give a balanced conclusion.

Note: - The question of the main examination given for practice is designed keeping in mind the upcoming UPSC mains examination. Therefore, to get an answer to this question, you can take the help of this source as well as other sources related to this topic.