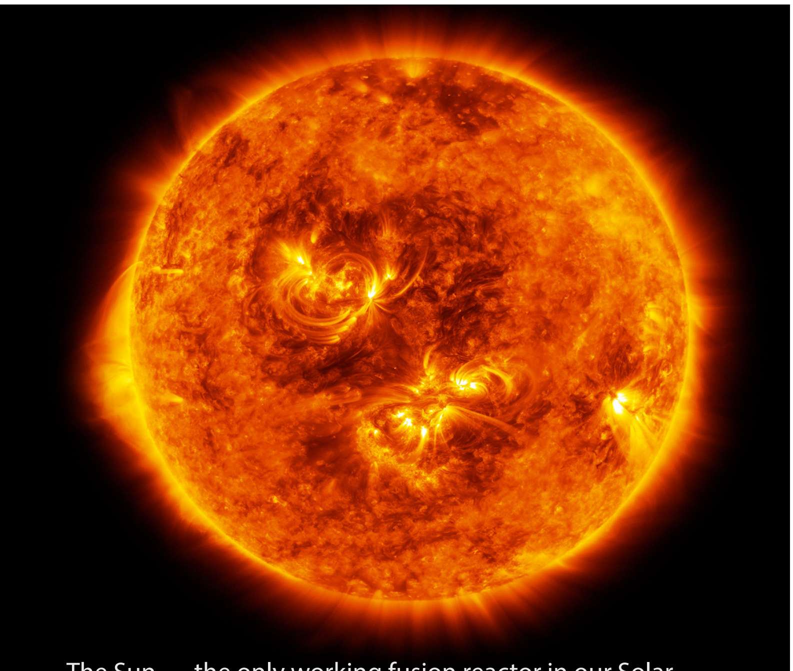
Nuclear Science & Technology

Harnessing Energy from Nuclear Fusion

What should I know?

Providing energy from nuclear fusion is widely regarded as the grand engineering challenge in the energy field. Many researchers and engineers across the world are focusing on ways to produce this energy by recreating on earth the conditions, such as density and temperature, that naturally occur in stars.

Unlike nuclear fission, where atoms are split to produce energy, in fusion, lighter nuclei are joined together to create heavier nuclei, resulting in the release of energy. This is how stars convert tiny amounts of mass into vast amounts of energy. Life on earth would not be possible without the nuclear fusion reactions that power the sun.



The Sun — the only working fusion reactor in our Solar system at the moment — produces mostly all of the energy that we use in our life.

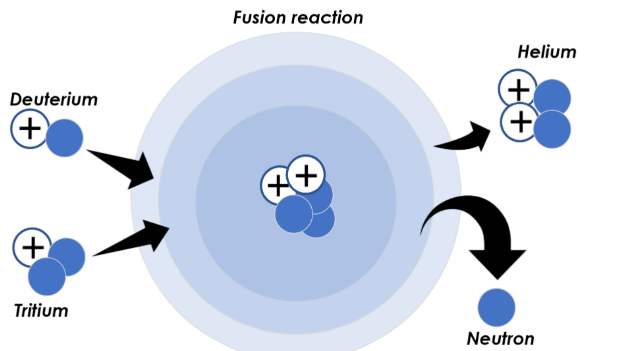
(Image: NASA/SDO/AIA)

Despite the expected benefits of generating energy from fusion for society, such as the abundance and accessibility of fuel, the carbon-free footprint and the absence of high level radioactive waste, putting fusion into practice remains one of the most challenging areas of experimental physics and engineering today; controlling a fusion reaction at over 100 million degrees Celsius is a complex and challenging undertaking.

Once this challenge is overcome, fusion energy can become a virtually inexhaustible, safe, environmentally friendly and universally available energy source capable of meeting global energy needs.

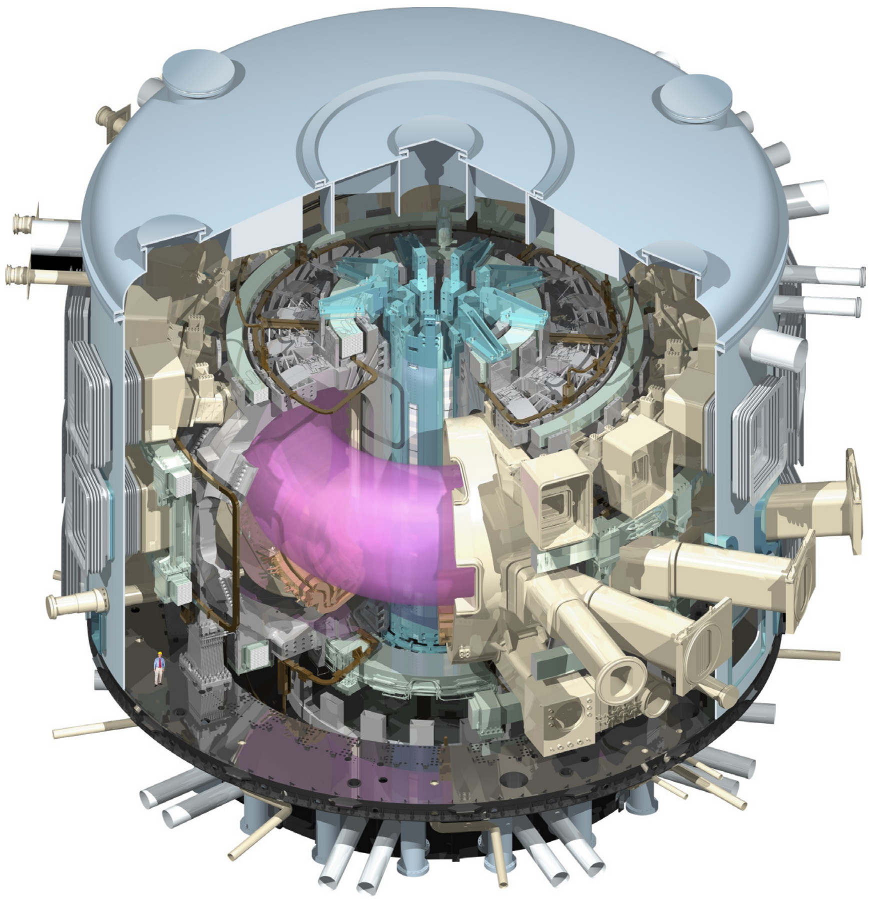
How does fusion work?

At the core of a star, fusion reactions between hydrogen atoms take place within dense plasma, with temperatures exceeding 10 million degrees Celsius. Plasma is the fourth state of matter and has unique properties, distinct from solids, liquids and gases. It consists of freely moving, charged particles and is formed at high temperatures when electrons are removed from neutral atoms. As we currently



A mixture of Deuterium and Tritium — two Hydrogen isotopes — will be used to fuel future fusion power plants. Inside the reactor, Deuterium and Tritium nuclei collide and fuse, releasing Helium and neutrons.

(Image: IAEA/M. Barbarino)



The ITER Tokamak will be nearly 30 metres tall, and weigh 23,000 tonnes. The very small man dressed in blue (bottom left) gives some idea of the machine's scale. The ITER Tokamak is made up of an estimated one million parts.

(Image: US ITER)

understand, more than 99 percent of the universe exists as plasma, including interstellar matter and stars, such as our sun.

In a controlled nuclear fusion power plant, three conditions must be fulfilled:

1. Very high temperature (over 100 million degrees Celsius) to provoke collisions of highly energetic particles;
2. Sufficient particle density in the plasma — where the reaction takes place — to increase the probability of these collisions; and
3. Sufficient confinement to hold the plasma and enable the fusion reactions to take place on an ongoing basis.

To date, the confinement concept with the best results has been the tokamak (coined from a Russian acronym that stands for "toroidal chamber with magnetic coils"), a doughnut-shaped configuration first invented in the 1950s, which uses powerful magnets to contain the plasma. Tokamak machines can already provide the essential conditions for fusion, in terms of both plasma density and the required temperature, and fusion reactions can therefore be generated. What is still missing to ensure the production of net power is better and longer confinement, which is a measure of how good the magnetic field is at maintaining the plasma energy over time.

What is ITER and why it is so important?

ITER ('International Thermonuclear Experimental Reactor'), a collaboration between 35 countries, will be the largest fusion experiment on earth. It is under construction in Saint-Paul-lez-Durance, France, and is scheduled to become operational at the end of 2025.

The impetus to establish ITER in 2007 came from discussions at IAEA forums that covered several initiatives for collaboration on international fusion research and technology development. The IAEA Director General is the depository of the ITER Agreement.

ITER is designed to demonstrate much higher gains in fusion power than other fusion experiments conducted to date. Following the injection of 50 MW of heating power, it aims to produce 500 MW of thermal power for long pulses of 400 to 600 seconds. Even though ITER will not capture the power it produces as electricity, it will pave the way for a machine that can.

The next stage after ITER, converting heat into electricity, will be addressed by a demonstration fusion power plant known as DEMO. DEMO is expected to explore and demonstrate continuous or near-continuous operation, fuel self-sufficiency, and the large-scale production of energy, including its conversion to electricity, and could be connected to the power grid by approximately 2050.

Does fusion produce radioactive waste in the same way as nuclear fission?

The easiest fusion process to achieve involves two isotopes of hydrogen: deuterium and tritium. Tritium is radioactive, but its half life is short (12.32 years). It is only used in relatively low amounts, so, unlike long lived radioactive nuclei, it does not present any serious danger.

This deuterium–tritium reaction yields a helium atom (an inert gas) and a neutron, whose energies can be harvested for powering the reactor and producing electricity, respectively. Therefore, fusion reactions do not create long lived radioactive waste.

However, fusion will result in the generation of neutron-activated materials surrounding the plasma. In other words, when neutrons (as a result of fusion reaction) collide with the reactor walls, its structures and components become radioactive. Therefore, one of the important challenges when building future fusion power plants is to optimize the construction design in order to minimize this neutron-induced radioactivity and resulting radioactive waste volumes.

What is the IAEA's role in fusion plasma and fusion technology?

Since its inception in 1957, the IAEA has supported nuclear fusion research. The IAEA undertakes numerous nuclear fusion activities, under the guidance of the International Fusion Research Council, an IAEA advisory body with members from around the world.

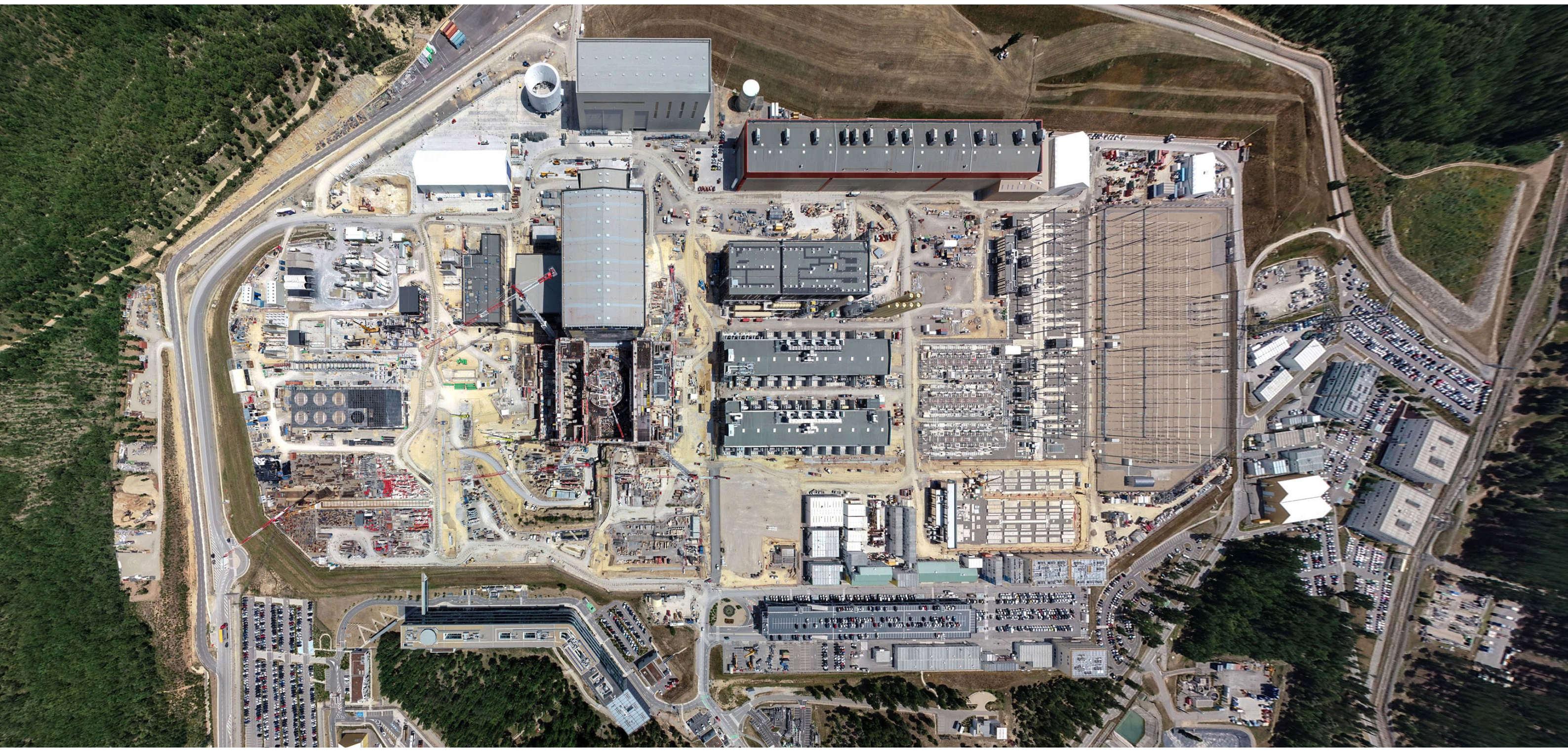
The IAEA coordinates international efforts in fusion research and technology development by involving nuclear physicists, materials scientists, nuclear data specialists, engineers and plasma experts, among others. It also organizes the Fusion Energy Conference — the world's largest international event in the field of nuclear fusion.

Through the DEMO Programme Workshop, the IAEA also acts as a central hub in developing programme plans and initiating new research and development activities, in order to formulate various concepts of demonstration fusion power reactors.

In recent years, the IAEA has been working on the production of guidelines and reference documents to be used by the fusion community. These aim to help facilitate and optimize different processes and information exchange on nuclear fusion research and development. For example, the recently published IAEA Technical Document entitled Integrated Approach to Safety Classification of Mechanical Components for Fusion Applications (IAEA TECDOC No. 1851) is the first international guidelines document related to nuclear fusion.

How does IAEA help in capacity building?

Cooperation among laboratories and facilities through the IAEA contributes significantly to the development of fusion research and technology, as well as of the necessary guidelines and related standards.



ITER site: Aerial view of the ITER construction site, June 2019.
(Photo: ITER Organization)

Through coordinated research activities, several networks of small fusion devices have been established and are being successfully used to enable an integrated approach in the quest for solutions to a number of outstanding issues. For instance, joint experiments are organized within these networks, in which experts from various institutions gather to test the capabilities of a given machine, thereby increasing intellectual diversity and maximizing the scientific output of the device. The series of Joint ICTP–IAEA College on Plasma Physics is another example of international initiative contributing to capacity building in this area.

Furthermore, the IAEA aims to broaden the education and training of the next generation of fusion scientists and engineers. This is particularly important, as fusion research and development activities increasingly require cutting-edge technologies, expanding beyond the horizon of present-day know-how.

MORE INFORMATION

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