

The ITER project — the road to fusion power

Le projet ITER – La route vers la fusion

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Abstract

Commercial fusion power promises safe, CO₂-free, environmentally benign, large-scale energy production, with abundant and widely available fuels. Fusion researchers are ready to take the next step towards this goal, with the construction of ITER, which should demonstrate the technical and scientific feasibility of fusion power production. The signing, by seven Parties representing more than half of humanity, of the ITER Joint Implementation Agreement on 21 November 2006, established the ITER Organization (pending ratification by some of the ITER Parties), and opens the way to the construction phase of the project. This paper describes the history of the project, its objectives, schedule and organization, and its place on the road to the realisation of commercial fusion power.

Abstract (french)

La fusion est considérée comme une source potentielle d'énergie de base qui devrait offrir une grande sûreté d'exploitation, avec un faible impact sur l'environnement (pas d'émission de gaz à effet de serre, pas de production de déchets radioactifs à vie longue). Les réserves de combustible sont abondantes et bien réparties sur tous les continents. ITER a pour objectif de démontrer la faisabilité scientifique et technique de la production d'énergie de fusion. Le 21 novembre 2006, les sept partenaires d'ITER, représentant plus de la moitié de l'humanité, ont signé le "ITER Joint Implementation Agreement", qui devrait être prochainement ratifié. Cette signature établit l'organisation ITER, et ouvre le chemin à la construction du projet. La présentation décrira l'historique du projet, ses objectifs, son programme et son organisation.

1. Introduction

Fusion, the process in which two light atomic nuclei combine to form a heavier one, is the energy source of the sun and the stars. The long-term objective of fusion research is to harness this energy source to help meet humankind's future energy needs, as it has the potential to deliver large-scale, environmentally acceptable, safe energy, with abundant and widely available fuel resources.

Fusion research, which is carried out by scientists from all over the world, has made tremendous scientific progress over the last decades. The fusion community is now ready to take the next step, and have together designed the ITER experiment (figure 1). The aim of ITER is to show fusion could be used to generate electrical power, and to gain the necessary data to design and operate the first electricity-producing plant.

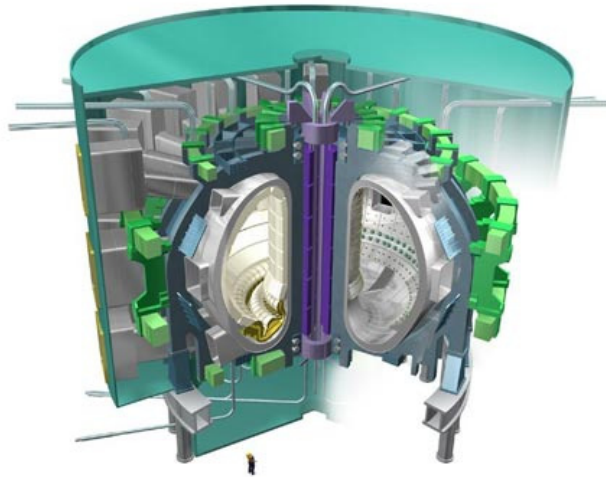


Figure 1: The ITER machine. The man in the bottom shows the scale.

In ITER, scientists will study plasmas in conditions similar to those expected in a electricity-generating fusion power plant. It will generate 500 MW of fusion power for extended periods of time, ten times more than the energy input needed to keep the plasma at the right temperature. It will therefore be the first fusion experiment to produce net power. It will also test the key technologies, including the heating, control, diagnostic and remote maintenance that will be needed for a real fusion power station.

The current participants in the project are the European Union (represented by Euratom), Japan, the People's Republic of China, the Republic of India, the Republic of Korea, the Russian Federation and the USA.

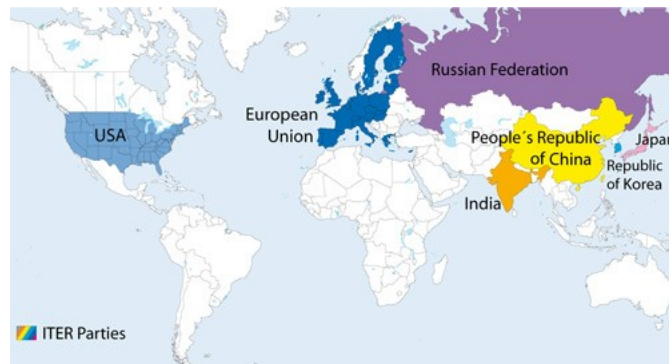


Figure 2: Countries participating in the ITER project.

Constructing and operating ITER is the essential step to determining whether magnetic confinement of plasma can be usefully employed by humankind for large-scale energy generation. This paper describes the history of the project, its objectives, schedule and organization, and its place on the road to the realisation of commercial fusion power.

2. Organization

The ITER project brings together the most advanced nations in the world to co-operate in the development of a major new technology that will benefit everyone. The challenges of the ITER project require the best technological and scientific expertise, which can best be harnessed by pooling resources globally.

The ITER project is being undertaken by a new international organisation: the ITER Organization, with headquarters in Cadarache, France. The ITER Organization is responsible for all aspects of the project: the licensing procedure, hardware procurements mostly provided through the Parties, the twenty-year operation period, and ultimately for decommissioning of ITER at the end of its lifetime. This organisation was established by the ITER Joint Implementation Agreement, which covers the entire life of the project.

ITER started out during the cold war era as an initiative of the then Soviet Union to engage in a high technology enterprise with the west. From then until the recent ITER Agreement, development of ITER has taken place under the auspices of the United Nations International Atomic Energy Authority (IAEA), with the major fusion programmes worldwide contributing the resources. The ITER Agreement, for which the IAEA now acts as Depository, moves the development onto a new legal footing by the creation of a truly international legal entity to be responsible for construction, operation and decommissioning. This agreement will be open for accession by or co-operation with other countries who have demonstrated a capacity for specific technologies and knowledge and are ready to contribute to the project.

The members of the Organisation (the Parties to the Agreement) will bear the costs of ITER. The construction costs of ITER are estimated at 5 billion Euro, to be spread over about ten years. A similar amount is foreseen for the twenty-year operation lifetime of ITER, which will follow the construction period. The EU will contribute almost half of the costs of ITER, the other partners will share the remaining part equally. During the construction of the ITER device, most of the components will be contributed by the members in kind, meaning that they will contribute the components themselves, rather than paying the project to procure for them.

Europe will contribute in proportion up to half of the construction costs and the other six parties will each contribute up to 10%. Thus there is a 10% contingency within the present funding.

In order to manage and provide their contribution to the ITER project, each of the partners needs to establish its own Domestic Agency, which is responsible for the delivery of the components to ITER.

In the first months of 2006, the top management team of ITER has been named. The Director-General of the project will be Kaname Ikeda, formerly Ambassador for Japan in Croatia. The Project Construction Leader will be Dr. Norbert Holtkamp, a German, and former Director of Accelerator Systems at the Spallation Neutron Source in Oak Ridge, USA.

3. Objectives of the ITER project

ITER is a tokamak, in which strong magnetic fields confine a torus-shaped fusion plasma. The goal of ITER is "to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes". Part of this general goal are a number of specific technical objectives, all concerned with developing a viable fusion power reactor.

First of all, ITER should produce more power than it consumes. This is expressed in the value of Q , which represents the amount of thermal energy that is generated by the fusion reactions, divided by the amount of external heating required to keep them going. A value of Q smaller than 1 means that more power is needed to heat the plasma than is generated by fusion. JET, presently the largest tokamak in the world, has reached $Q=0.65$, near the point of "break even" ($Q=1$). ITER has to be able to produce $Q=10$ for pulses of several hundred seconds, and Q larger than 5 during for pulses of up to an hour. In both these cases, most of the heating in the plasma comes from the fusion reactions themselves. Secondly, ITER should implement

and test the main technologies and processes needed for future fusion power plants - including superconducting magnets and remote handling (maintenance by robots). Lastly, ITER should test and develop concepts for breeding sufficient tritium from lithium inside the blanket surrounding the plasma.

Compared with current conceptual designs for future fusion power plants, ITER will include most of the necessary technology, but will be of slightly smaller dimensions and will operate at about one-sixth of the power output level. It will not be a producer of electricity.

4. Schedule

After increasingly detailed phases, the design of ITER was sufficiently complete in 2001 for the potential future Parties to be able to discuss the sharing of hardware construction costs.

The design is currently being developed in finer detail to allow procurement of hardware to start as soon as possible, now that the ITER Organization has started its operation.

Detailed plans exist for the construction, operation and decommissioning of ITER. Construction of the ITER complex is planned to begin in 2008, while assembly of the tokamak itself is scheduled to begin in the year 2011. The first plasma is expected to be produced in 2016.

5. ITER – the machine

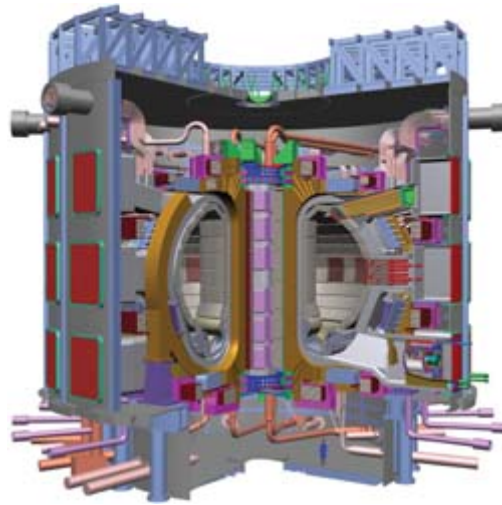


Figure 3: Design of the ITER device

ITER is based on the "tokamak" concept - a doughnut-shaped vessel surrounded by coils that produce an intense magnetic field in which the conditions needed for fusion are created and maintained. In ITER, all the magnetic coils are superconducting.

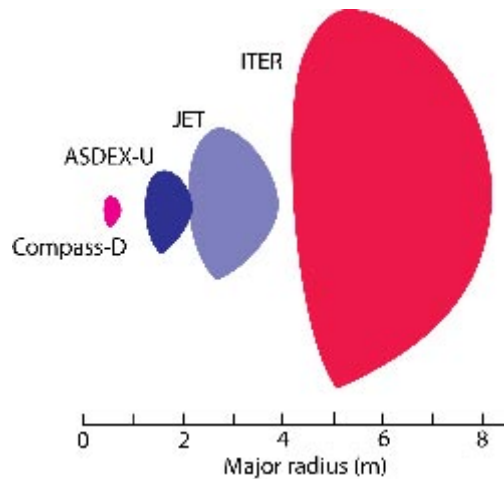


Figure 4: The size of the plasma in different fusion experiments across Europe. The ITER plasma is twice the size of JET in its linear dimensions.

In order for the confined plasma to produce more energy than is needed to heat it, it needs to be hot enough, dense enough, and contained for long enough. To meet its objectives, ITER will be twice the size of the largest tokamak yet built, JET (as shown in figure 4), and its expected fusion performance will be many times greater. These extrapolations in size and physics performance provide the major challenges to the design of ITER.

Main ITER Parameters	
Total Fusion Power (MW)	500
Q - Fusion Power/Auxiliary Heating Power	10
Average (1 MeV) neutron wall loading (MW/m ²)	0.57
Plasma major radius (m)	6.2
Plasma minor radius (m)	2.0
Plasma Current (MA)	15
Toroidal Field at 6.2 m radius (T)	5.3
Plasma Volume (m ³)	837
Installed auxiliary heating/current drive power (MW)	73

ITER will test all the main new features needed for future electricity-generating devices - high-temperature-tolerant components, large-scale reliable superconducting magnets, fuel-breeding blankets using high temperature coolants suitable for efficient electricity generation, and safe remote handling and disposal of all irradiated components. ITER's operating conditions are close to those that will be experienced in a power reactor, and will show how they can be optimised, and how hardware design margins can be reduced to increase efficiency and control cost.

6. The Cadarache site

The process of selecting a location for ITER took a long time, and was finally successfully concluded in 2005. Canada was first to offer a site in Clarington, in May 2001. Soon after, Japan proposed the Rokkasho-Mura site, Spain offered a site at Vandellòs near Barcelona, and France proposed the Cadarache site in the South of France.

Canada withdrew from the race in 2003, and Europe decided in November 2003 to concentrate its support on a single European site, for which the French site Cadarache was chosen. From that point onwards, the choice was between France and Japan. On June 28, 2005 it was officially announced that ITER will be built in the European Union, at the Cadarache site, near Aix-en-Provence in the South of France.



Figure 5: Impression of the ITER site (top). Below, the existing site of CEA is shown, which houses the Tore Supra fusion experiment.

As part of the deal over the siting, it was agreed that Japan would provide 20% of the staff for the ITER project, and Europe would make a fifth of its procurements in Japan. In addition, the head of the project would be proposed by Japan, and Japan and Europe would work together on a "broader approach" including the other programmatic items which would be necessary to build a demonstration power plant in Japan after ITER, such as materials qualification, advanced plasma experimentation, plasma simulation, and the design team itself.

The construction site at Cadarache covers a total surface area of about 40 hectares with another 30 hectares which will be used temporarily during the construction period.

Cadarache is an excellent site for ITER for various reasons:

- The site satisfies all the technical requirements specified by the international team in charge of the design of ITER.
- Cadarache already hosts what was until the recent start of the EAST experiment in China the world's largest super-conducting fusion experiment Tore-Supra at the CEA Cadarache Research Centre, one of the biggest civil nuclear research centres in Europe. Therefore the Cadarache site has existing technical support facilities and expertise.
- France has well-established regulations for licensing ground-breaking "first of a kind" facilities such as ITER.

7. A short history

While significant progress has been made with large fusion experiments around the world, most of which were constructed in the 80's, it has been clear from an early stage that a larger and more powerful device would be needed to create the conditions expected in a fusion reactor and to demonstrate its scientific and technical feasibility, and each of the fusion programmes around the world started to make their own design for it starting in the early 1980s.

The idea for ITER originated from the Geneva superpower summit in November 1985 where Premier Gorbachov, following discussions with President Mitterand of France, proposed to President Reagan that an international project be set up to develop fusion energy for peaceful purposes. The ITER-project subsequently began as a collaboration between the former Soviet Union, the USA, the European Union and Japan, and was later enlarged to China, the Republic of Korea and the Republic of India.

In 1988 the conceptual design work was started, followed in 1992 by engineering design. On July 21st, 2001, the ITER engineering design activities were successfully completed, and the final design report was approved by the ITER Parties. The design was underpinned by Research & Development work worth \$650M, which was carried out by the ITER Parties to establish the practical feasibility of the design. The design of ITER, resulting from this unique international collaboration, is the first complete design of a fusion device of conventional power station size, based on well-established and proven technology. This design provides a detailed engineering plan ready for implementation.

Negotiations on joint implementation of ITER then began between Canada, Europe, Japan, and the Russian Federation, and were joined by the People's Republic of China, the United States of America and the Republic of Korea during 2003. Canada ended its involvement at the end of 2003, and the Republic of India joined at the end of 2005. These Negotiations drew up the international agreement for construction, exploitation and decommissioning of ITER, deciding who will pay for what, and how the project will be organised and staffed.

At the end of 2003 the project entered "Transitional Arrangements" (ITA) leading up to the establishment of the ITER International Fusion Energy Organization (ITER Organization) which will build and run ITER. Technical work, conducted by the ITER International Team and the Participant Teams of each of the Negotiators, underpinned the Negotiations technically and prepared for construction by the writing of detailed technical specifications for the most urgent procurements, engaged licensing bodies, and put in place the necessary project infrastructure to embark on such a complicated multi-party construction.



Figure 6. Many components and techniques that are needed for ITER have already been tested by industry, such as this full-scale vacuum vessel sector, produced in Japan (courtesy JEARI).

The physics studies and technology developments on many fusion devices worldwide have provided a solid basis for predicting how an ITER-scale plasma should behave. During the ITER engineering phase, key prototypical high-technology equipment, such as superconducting coils, remote handling systems, and high heat tolerant components, has been

developed specifically for the purpose and manufactured by industry and is now ready for production.

Site clearance and levelling will begin in 2007, and an application for a license to construct will be made at the end of 2007. A public enquiry will take place in 2008, with the granting of a license to construct around the end of 2008. If this schedule is achieved, the construction process can begin in earnest in 2009, leading to the first plasma in 2016. This will be followed by an exploitation phase lasting about 20 years.

8. ITER on the road to fusion power

ITER is not an end in itself: it is the bridge toward a first plant that will demonstrate the large-scale production of electrical power. The long-term aim of fusion research and development is to create power station prototypes demonstrating operational safety, environmental compatibility, and economic viability. The strategy to achieve this long-term aim includes a number of different elements: first of all the construction of ITER, followed by a demonstration reactor called DEMO.

In parallel to the realisation of ITER, further technology developments and concept improvements are necessary in order to build a commercial electricity-producing reactor. Technological progress is required in several areas, especially in the development of plasma-facing materials sustaining high heat loads and of low activation and high endurance structural materials, the latter to minimize the quantity of radioactive waste from a fusion reactor. Testing has begun on these, but needs to be completed before future plants based on them can be licensed.

The subsequent step after ITER is called DEMO, which should demonstrate large-scale electrical power production and tritium fuel self-sufficiency. DEMO should come into operation 30-35 years after the start of the construction of ITER and demonstrate large-scale electrical power production and tritium fuel self-sufficiency. It will lead fusion into its industrial era, and open the way towards the first commercial fusion power stations.

More information:
www.iter.org