is Fusion the Future?

The ITER Project is banking on it. 10 billion Euros worth.

by Mark Westra

Fusion—the process by 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 process to help meet mankind's future energy needs. It has the potential to deliver large-scale, environmentally benign, safe energy, with abundant and widely available fuel resources.

Fusion research, carried out by scientists from all over the world, has made tremendous progress over the last decades. The fusion community is now ready to take the next step, and has designed the international ITER experiment. The aim of ITER is to show that fusion could be used to generate energy and to gain the necessary data to design and operate the first electricity-producing plant. The participants in the project — the ITER Parties — are the European Union (including Switzerland and represented by Euratom), Japan, China, India, the Republic of Korea, the Russian Federation, and the USA.

Constructing and operating ITER is the essential step to determining whether fusion can be usefully employed by humankind for large-scale energy generation.

An Early Start

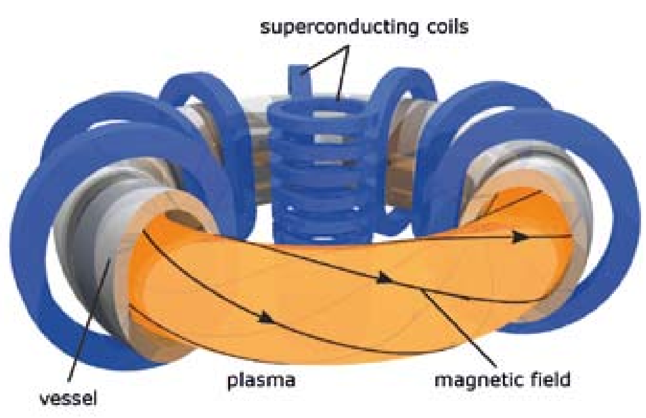
While significant progress has been made with large fusion experiments around the world, most of which were constructed in the 1980s, it has been clear from an early stage that a larger and more powerful device would be needed to create the conditions expected in a fusion reactor and to demonstrate its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

The idea for ITER originated from the Geneva superpower summit in November 1985 where Premier Gorbachev, following discussions with President Mitterrand 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.

Since its conception, ITER development has taken place under the auspices of the IAEA, who now is the depository of the ITER Joint Implementation Agreement. The IAEA has always provided active support, for example by organising the biennial Fusion Energy Conference and Technical Coordination Meetings with ITER sessions, and the publication of the ITER Project Documentation and a monthly Newsletter.

Since conceptual design work started on the ITER machine in 1998, the design has moved through various stages before arriving at the design above in 2001.

The figure of a man at the bottom shows the scale. (courtesy Eric Verdult, www.kennisinbeeld.nl).



The principle of ITER: a hot plasma (orange) is confined in a torus-shaped vessel using strong magnetic fields which are generated by superconducting coils (blue).

Extended Energy Production

The goal of ITER is "to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes". To do this, ITER will demonstrate extended energy production, essential fusion energy technologies in an integrated system and perform testing of key elements required to use fusion as a practical energy source.

Scientists will study plasmas in conditions similar to those expected in an electricity-generating fusion power plant. ITER 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 a number of key technologies, including the heating, control, diagnostic and remote maintenance that will be needed for a real fusion power station. ITER will also test and develop concepts for breeding 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. It will be of slightly smaller dimensions and will operate at about one-sixth of the power output level of these designs.

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.

A fuel mixture of two isotopes of hydrogen, tritium and deuterium, will be heated to a temperature in excess of 100 million degrees. The high temperature causes some of the fuel particles to fuse together, creating a helium atom and a neutron in each reaction. Most of the energy produced by the fusion reaction is carried to the wall by the neutrons. Inside the wall, the neutrons react with a "blanket" layer containing lithium atoms to produce the fuel tritium. The heat deposited by the neutrons as they slow down by collisions is taken away in a cooling fluid.

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 existing tokamak, the Joint European Torus (JET, located in the UK), and its fusion performance is predicted to be many times greater. These extrapolations in size and physics performance provide the major uncertainties in the design of ITER.

The ITER Organization

The ITER project will be undertaken by a new international organization: the ITER Organization, which is based in Cadarache, in the South of France. The ITER Organization will be responsible for all aspects of the project such as the licensing procedure, hardware procurements, commissioning and operation, and ultimately for the de-activation of ITER at the end of its lifetime.

This Organization was established by the ITER Joint Implementation Agreement, which was signed by the ITER Parties on 21 November 2006, and which will be ratified by the parliaments of the participating Parties (when required by local laws) in the course of 2007.

The members of the Organization will bear the costs of ITER. The construction costs of ITER are estimated at 5 billion Euros, to be spread over about ten years. A similar amount is foreseen for the twenty-year operation phase of ITER, which will follow the construction period. During the construction of the ITER device, 90% of the components by value will be contributed by the Parties *in kind*, meaning that they will contribute the components themselves, rather than paying for them. Europe will contribute up to half of the construction costs as the host Party and the other six parties will each contribute up to 10%, thus giving a 10% contingency within the present funding.

In order to manage and provide their contribution to the ITER project, each of the Parties is in the process of establishing its own Domestic Agency, which is responsible for the delivery of the Parties' components to ITER.

The process of selecting a location for ITER took a long time, and was finally successfully concluded in 2005. On 28 June 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. The construction site at Cadarache covers a total surface area of about 180 hectares.

The top management team of ITER includes as Director-General of the project Kaname Ikeda, formerly Ambassador for Japan in Croatia and Director of Japan's National Space Development Agency. The Project Construction Leader is Norbert Holtkamp, a German, and former director of accelerator systems at the Spallation Neutron Source in Oak Ridge, USA. The senior management team of department heads is in place, and the team is building up rapidly at the Cadarache site. The other joint sites where work on ITER was carried out — in Garching, Germany and Naka, Japan — were closed at the end of 2006.

Timeline: 2016 First Plasma

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 being developed in finer detail to allow procurement of hardware to start as soon as possible, now that the ITER Organization (which will own and build ITER for the Parties) has started its operation on a provisional basis. This Design Review process is scheduled to result in a new baseline design for ITER this year.

Many components and techniques that are needed for ITER have already been tested by industry, such as this section of the tokamak vessel, produced in Japan. (Courtesy JAERI).

With the establishment of the ITER Organization by the end of 2006, and the provisional application of the agreement pending ratification, 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 a view to 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 a commissioning and operational phase lasting about 20 years, and a decommissioning phase of five years.

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 development and concept improvements are necessary in order to build a commercial electricity-producing reactor. Technological progress is required especially in the qualification for nuclear use of low-activation high-temperature structural materials to enable reuse of radioactive waste from a fusion reactor within a reasonable timescale. This is planned to be implemented as part of a "broader approach", with several elements including ITER, to put fusion on as fast a track as possible to its development as a power source.

The DEMO step 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. It will lead fusion into its industrial era, and open the way towards the first commercial fusion power stations.

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