We're a step closer to taming the Sun

(Filed: 06/07/2005)

An experimental thermonuclear reactor will show whether fusion power can ever be a reality, says Roger Highfield

Since those heady, optimistic days in the 1950s when scientists first dreamt of taming the Sun, tens of billions have been spent on the quest.

The effort by thousands of scientists around the world has been inspired by the thought that fusion - the source of the Sun's power - could solve the world's future energy needs by generating vast amounts of electricity from water, without carbon dioxide emissions and with relatively little nuclear waste.

Last week, the latest effort to realise this dream was announced. Called Iter, or the International Thermonuclear Experimental Reactor (iter is Latin for "the way"), the experimental fusion reactor will take another £7 billion and the efforts of around 10,000 workers to build and run for at least three decades.

Environmentalists cringe at the effort and expense of attempts to tether a star and draw energy from it. Earth-bound sceptics point out that fusion power has been 20 years over the horizon for the past half century. However, many leading scientists believe that this is one energy bet that must pay off.

The Government's Chief Scientist, Sir David King, believes that it could unlock a relatively pollution-free source of energy. "If successful, Iter will deliver what could be the world's most important energy source over the next millennium. Its impact will be bigger than landing the first man on the Moon," he said. "The lithium from one laptop battery and deuterium from a bath of water would generate enough energy to cover the needs of a UK citizen for 30 years."

Iter marks the last milestone before the construction of a true prototype fusion reactor. But while the physics of nuclear fusion has long been understood, the engineering required to control it remains difficult, and the political nuances lie far beyond the understanding of many of the scientists involved in the six-member international consortium.

The project began in 1988 but became bogged down in bickering four years later over where to put the reactor's design team. A compromise split the team between Japan, the United States and Germany.

Then, in 2001, the partners started to argue over where Iter would be built. Canada, Spain, France and Japan were originally in contention, but a December 2003 ministerial meeting that had hoped to pick a winner ended in a deadlock, with the US, Japan and South Korea backing the Japanese site and the other three consortium members pushing for France.

After guarantees of Japanese jobs and a promise that a £550 million materials testing centre and the real prize - the first real prototype commercial fusion plant - would be built in Japan, Iter itself went to Cadarache in France. After last week's announcement, the consortium can now draft a deal on the construction of the reactor. The accord should be signed by the end of this year, allowing construction to begin.

The Germany-based interim project leader of Iter, Dr Yasuo Shimomura, and the head of design integration division, Dr Pietro Barabaschi, can now focus on how to get the reactor in operation by 2016. Under them, a team of 100, including 70 designers, has already outlined the basic design of Iter in the heart of a computer, and hundreds more will now be drafted in to flesh out the details.

The consortium has also spent £400 million on scale models of the reactor's key components, Dr Shimomura said. The major components, with long lead times, such as the building, are already finished. Detailed technical specifications for components and issuing of contracts to manufacturers will follow. "It is a real nuclear device, so quality control will be very important," he said.

The German-born physicist Hans A Bethe, who died earlier this year, figured out in the late 1930s how the Sun shines, earning him the Nobel prize. In principle, using fusion to mint energy is easy: take hydrogen atoms and squash them together to form helium.

The helium is a fraction lighter than its atomic ingredients, and by Einstein's famous equation - energy is equal to mass times the speed of light squared (a huge number) - that tiny loss of mass results in a colossal release of energy.

The problem is that researchers must first find a way to squeeze atomic nuclei together, overcoming their tendency to repulse (positively charged nuclei repel each other) and bring the nuclei close enough so that pairs of them can fuse.

Within our local star, heat does the squeezing. At the Sun's heart, where temperatures reach nearly 15 million degrees C, hydrogen atoms are pushed together at ultra-high pressures to generate the light and heat of fusion over timescales of millions of years (Bethe showed that, in reality, it is more complex than this). But turning fusion into a viable source of energy requires figuring out how to recreate these stellar conditions on Earth.

The trick has been managed to destructive effect in the hydrogen bomb, but it has proved harder to control fusion so that energy can be extracted. One can heat up isotopes of hydrogen such as deuterium and tritium (the most easily fused) so they bash together in a plasma, a form of matter where atoms fall apart into their constituents. But then the problem is how to bottle this super-hot plasma, at 100 million degrees C, for long enough for the nuclei to collide and fuse.

The only bottle that can contain such a plasma is one made from magnetic fields. At the Culham Laboratory, near Oxford, the Joint European Torus (Jet) is in its 21st year of operation. Built at a cost of £175 million (in 1983 prices), Jet is a refinement of one type of magnetic bottle, known as a tokamak, first developed in the Soviet Union.

The magnetic field inside a tokamak resembles a twisted ribbon that closes round on itself. The plasma is confined inside a doughnut-shaped vacuum chamber, the torus. Looping around this, through the centre of the doughnut- ring, are a series of large magnetic coils. These generate a field running in the direction of the doughnut. The twist is provided by a second magnetic field created by inducing an electric current in the plasma.

Iter would be far and away the largest ever tokamak. Jet has produced 16 megawatts of fusion power, for a few seconds, although 25 megawatts were invested for this return. Iter, at 10 storeys high, will be twice as big as Jet, but should produce a near-continuous 500 megawatts of power, 10 times the amount of power put in, the sort of ratio needed for a viable power plant.

The Iter plasma torus itself would be 16 metres across and would be nested in a tangle of machinery and electronics rising 30 metres high.

The key components to contain the nuclear fire have already been designed, said Dr Shimomura, notably the stainless steel interior of the tokamak and the coils that will produce the giant magnetic fields using material - niobium-tin alloy - that loses all resistance to electricity by being chilled to 4.5 degrees above absolute zero with liquid helium.

These superchilled magnets will generate 12 Tesla, a magnetic field 240,000 times more powerful than the Earth's, to bottle up the fusing plasma.

The 500 megawatt fusion reaction will heat the reactor's stainless steel heart and it is likely that water will be used to cool it, to a couple of hundred degrees C, so that power can be extracted as steam and hot water.

Dr Barabaschi said there are more exotic plans to siphon energy from the plasma, which can be tested with Iter. "There are a lot of ideas of how to do this efficiently," he said. "But it is premature to discuss them now."

In order to succeed, the Iter project must also demonstrate that it can produce excess tritium, the reactor's fuel, from a "blanket'' of lithium lining the reactor chamber. As neutrons thrown off from the fusion reaction strike the lithium atoms, they produce fuel. For the reactor to be viable, the reactor must produce more tritium than it consumes.

Then there is the problem of how the stainless steel in the blanket will absorb neutrons. Some thought must be given to materials to withstand this bombardment, how to deal with the resulting radioactive waste and perhaps recycle it.

The International Fusion Materials Irradiation Facility, now to be located in Japan, will study whether it would be better to use expensive materials such as silicon carbide, which will become less contaminated. All the while, there will be an intense effort to design robots and remotely controlled machines to service the reactor.

Does nuclear fusion pose the same risks as conventional (fission) nuclear power? "You cannot get a runaway reaction in a fusion reactor," said Dr Shimomura. Close off the fuel and the reaction stops. If the temperature soars, the magnetic bottle fails and the fusion reaction falters. Iter would also be exhaustively tested with hydrogen gas, which will not produce fusion energy, before real fusion fuel is used.

Like any megascience project, Iter has critics. Some would prefer to explore novel magnetic configurations whose superior confinement properties - if they could be maintained for longer than the transient bursts so far achieved in tokamaks - might lead to a less expensive reactor.

Results from two fusion experiments, one in the US and one in the UK, suggest that making a tokamak spherical with a hole through the middle - like a cored apple - may be more efficient.

But Iter's supporters believe that these are risky diversions from the path to a working reactor. A larger demonstration project is envisaged to begin operating around 2030, and a commercial fusion reactor would follow around 2050.

Iter will show whether, after half a century of tantalising promise, scientists are at last about to catch up with the receding horizon of fusion expectations.

Iter [International Thermonuclear Experimental Reactor] http://www.iter.org
Jet [Joint European Torus] http://www.jet.efda.org

http://www.telegraph.co.uk/connected/main.jhtml?xml=/connected/2005/07/06/ecfsun06.xml&sSheet=/connected/2005/07/06/ixconnrite.html