ITER: the search for an inexhaustible form of energy

The world's first global laboratory

Deep in the Durance valley, with the foothills of the Alps a distant backdrop, you turn off the pine-tree lined road that leads up to Vinon-sur-Verdon. Take a dirt track as far as you can, walk the last kilometer through an oak forest and, turning a corner around a hill, you come upon the site - 70 hectares of a lunar landscape, where the trees, their roots, and all the scrub around them have been dug up. It is here, in the heart of Provence, that the ITER project, the world's biggest scientific laboratory, will be set up in the years to come.

By Yves de Saint Jacob and Jean-Luc Crozel

ITER is a joint international research and development project that aims to demonstrate the scientific and technical feasibility of fusion power. Whether it turns out to be a success, providing a practically unlimited source of energy by the middle of the 21st century, or yet another costly failure - for the next 20 years, the region will be home to the largest international scientific community in the world.

The laboratory is a ground-breaking project, crossing international boundaries, with a supranational statute, a sort of world power in microcosm, uniting the developed world (Europe, Russia, the United States, Japan and South Korea) and the main emerging countries (India and China) in a research project that is vital to the future of mankind.

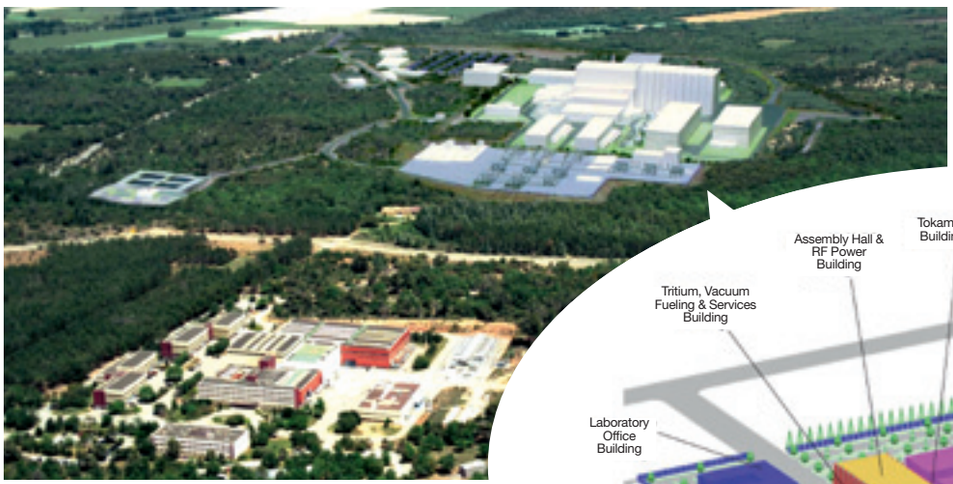
More than 300 people of a dozen nationalities are already involved in the preparatory work and have set up home in the region along with their families. By the time the laboratory is fully up and running, more than 3,000 will be on site and an international school in Manosque will open for 1,000 pupils in the autumn of 2009.

Cadarache, a hamlet in the area of Saint Paul lès Durance, is best known as the home of the research centre of the French nuclear authority, the CEA. The experimental nuclear reactors are hidden by vegetation, protected by electrified fences. The ITER site is not within this heavily-protected enclave, but nearby. The first section of land to be cleared is part of a total area of 180 ha, which will be given over to the bulldozers around the middle of 2008.

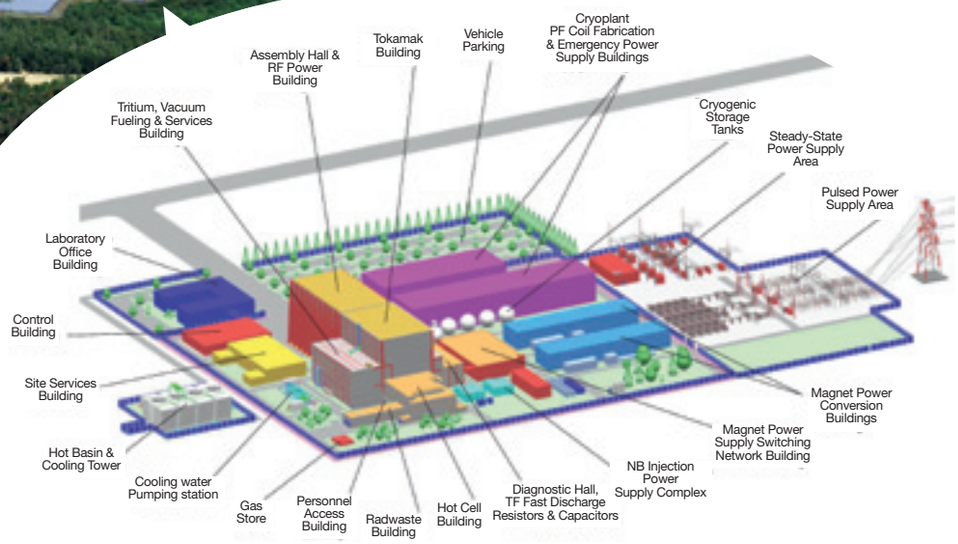
Between now and then, the 100 km of road, which will allow materials to be transported from the port of Fos-Marseille to Cadarache, will be reinforced to allow 100 or so abnormally heavy convoys of trucks to gain access to the site. The heaviest component will weigh 900 tons, making it impossible for it to be transported by airship or giant helicopter, as had once been intended.

The route has been chosen to cause minimum disruption to the 16 Provencal villages along the way or to motorway traffic. The only difficulty lies in the approach to Cadarache, where traffic has to cross the river Durance on a narrow road, near a place called Mirabeau, which has to be widened.

None of this appears to worry the inhabitants of the country above Aix-en-Provence, who, like the rest of the region, from Marseille to Nice as far up as Briançon, supported Cadarache's candidature to host the ITER project.



Construction site at Cadarache.
Photo: ITER



And as certain anti-nuclear groups have demonstrated in Marseille and Aix-en-Provence, the overriding feeling is that the region has everything to gain in terms of employment and an increase in land value. A clear-minded confidence in the future seems to triumph over a short-sighted refusal that would bring no benefits.

The choice of Cadarache was made in 2005 after protracted negotiations with the Japanese, who also wanted to house the project. The Japanese gained various concessions, notably in being able to appoint the Director General of the project (currently Kaname Ikeda). Spain was also a candidate and as a sweetener it was allotted the ITER European agency in Barcelona. The European Union and Switzerland are both represented in the project through Euratom.

ITER was first conceived in 1985 as the brainchild of the then Soviet leader Mikhail Gorbachev, who convinced his US counterpart Ronald Reagan and other world leaders of the feasibility of the project. But it has been a long road from conception to reality, with Canada falling by the wayside and the United States initially abandoning the project and then returning to the fold.

The ITER project is first and foremost a scientific and technological experiment, which will start around 2016 when the construction is completed. Its aim is to demonstrate the feasibility of fusion to generate electrical power under controlled conditions. That day in 2016 will be as historic an occasion as the Fermi experiment in 1942 with the first atomic batteries, says Bertrand Barre, Chairman of the INSC (International Nuclear Societies Council).

This will be followed by an exploitation phase lasting about 20 years, with involvement from experimental physicists and engineers worldwide, leading to a prototype power station, DEMO. Some have suggested that the plant might be operational before the tests are completed, but Operations Manager Norbert Holtkamp (see interview) does not agree.

Doomed to fail

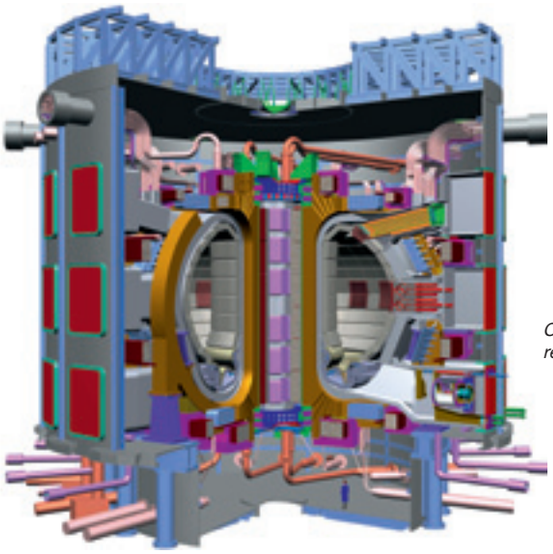
With so many delays and such an ambitious project, it is inevitable that doubts are raised.

Opponents of the project claim it is doomed to fail as it has so many hurdles to overcome.

The first hurdle is that of scientific feasibility. The forces put to work are too great in an overheated environment. The bombardment of neutrons will be so violent that no material would be able to withstand it long enough to become a regular source of energy. To harness the energy 24 hours a day, seven days a week, as required by any service industry, appears to be an unattainable goal at present.

The second hurdle is the astronomical cost, estimated to be €10 billion (in 2000 value), 5 billion for the construction and a further 5 billion for the operational phase. Part of these sums will be paid 'in kind'. That is to say, the members will be providing most of the components themselves rather than just putting up the money. 'We already know that the Americans will not allow the project to go over time or over budget', says Jean-Pierre Perves, former manager of the French Saclay plant, who is involved in safety plans for ITER. A guarantee of rigor perhaps, but also a warning that certain partners in the project may not be prepared to see it through to the end - no matter what the cost.

Jacques Foos, Professor of nuclear physics at the Conservatoire des Arts et Metiers in Paris, is not hostile to the ITER project.



Cutaway of the ITER fusion reactor. Illustration: ITER

However, as Europe is heavily committed to the project because it is financing 45% of the costs, the other partners contribute around 9% each, he fears that Europe could be forced to go it alone. It would have to put up more money to stave off failure and the research budget would be swallowed up into a single punitively expensive project.

The third hurdle is the economic viability of the project, which is also the biggest hurdle to be surmounted. The cost of the power plant will be exorbitant, the critics claim. The debate has never focused on the exact figures, as it will be impossible to set a cost until 2050, so any estimate is little more than crystal-ball gazing. However, everyone involved agrees that a fusion reactor would be in direct competition with the future fission reactors (Next Generation Nuclear Plant - NGNP) as an alternative source of power. Bernard Barre says, 'I see them in parallel, I don't see fusion replacing fission in the way oil replaced coal. We will be happy to have both.'
The two "durable" plants - fission and fusion - will not have to worry about exhausting the supply of fuel, but Norbert Holtkamp believes that the cost of a fusion reactor will have to be equivalent to that of the largest fission reactor or fusion will be forced out of the market.

Jean-Pierre Perves highlights another argument in favor of fusion: 'A fusion reactor will be more expensive to build than a fission reactor', he says. 'But in traditional reactors the extraction of uranium, the production of fuel, and the waste treatment are very expensive. In a fusion reactor, those processes will cost almost nothing. You have to compare the respective costs right down the line.'
Clearly the debate has only just begun. ■

Domesticating the energy from the sun

More than 4,500 years ago, ancient civilizations worshipped the sun. In Peru, they still celebrate the festival of the sun on June 24 by using a mirror directed towards a sacred star to light a fire. With the ITER project, scientists are given 30 years to domesticate the energy that makes it shine.

In the stars' centers, the hydrogen cores collide and fuse together under the pressure of gravity, and release a formidable energy. This is called thermonuclear fusion, a physical process very different from fission, which divides the core of a heavy atom into several lighter fragments and which is used in current nuclear power plants.

Domesticating fusion has many advantages - a fusion power plant would not emit any greenhouse gas and would produce little radioactive waste; it would not present any risk of a runaway chain reaction (contrary to fission power stations); the fuels required for fusion, deuterium and tritium (two isotopes of hydrogen), are found in the seas in virtually unlimited quantities; and finally, there would be fantastic operational savings in the long term - a coal power plant of 1 gigawatt burns 10,000 tons of coal per day, whereas a fusion power plant with the same power would require only 1 kilogram of deuterium-tritium.

The ITER project, carried out by an international collaboration of developed countries (Europe, Russia, the United States, Japan, Korea) and the large emerging countries (China and India), aims to prove the feasibility of such a fusion power plant. The construction of this experimental station should begin in the next weeks and the first tests are set to commence in 2016.

The goal of ITER is to generate energy from thermonuclear fusion by maintaining low-density plasma at very high temperatures, confined in a vast vacuum vessel in the shape of a torus, called a "tokamak". This type of machine is not new - a dozen tokamaks have been manufactured since the fifties. The largest of them, the Joint European Torus (JET) in the United Kingdom, managed to "break even" - i.e. to produce as much energy as it consumed - but only for a few seconds.

Many other technological challenges await the scientists, and the most sceptical of them joke that 'fusion is the power of the future and always will be'. Indeed, they will have to find a material that is capable of resisting intense heat to cover the walls of the torus. They will also have to prevent the development of instabilities within the plasma that are likely to stop the fusion process (to date, the record of duration of such a process is 6 minutes!), in order to produce a source of continuous energy that feeds a city 24/7. Another challenge will be to maintain the temperature of the plasma with the heat emitted by the fusion reaction, which has never been done before and which could hold many surprises.

If the ITER experiment is a success, it could lead to the construction of a commercial-plant prototype, DEMO, between 2025 and 2035... just 500 years after the fall of the Inca empire in 1533.

Interview
Norbert Holtkamp, project leader ITER

Born in Furstenau, Germany, Norbert Holtkamp studied physics at the University of Berlin, and gained his doctorate at the Technical University of Darmstadt. Since 2001, he has been Director of the Accelerator Systems Division, Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. He was nominated as ITER Principal Deputy Director-General and Project Construction Leader in April 2006.

The first meeting of the ITER Council was held in Cadarache at the end of November. Has the timetable for the project been confirmed?
The ITER agreement is very specific on this issue. The agreement between the seven parties spells out the costs, human and financial resources, the money committed by the members, and the schedule that we are supposed to achieve, i.e. the construction time. It began with the foundation of the organization in January 2007. The transition into operation or finishing the construction is to be completed by 2016.

Are you afraid of the "red tape" of French public inquiries?
[laughs] No, actually, I'm originally from Germany, and I worked in the United States for quite some time. Given what I know about licensing processes in Germany and the US, the French system and the people seem quite reasonable to me.

Would 2009 be the beginning of the construction of the core of the ITER device?
That's the plan. I don't see why we can't achieve that - we are very much on track. The site has been given to us by the state of France, and the agency that was created, Agence de France, is actively preparing and clearing the site. The contract to level the site and to prepare the platform has been signed, and the work will start in March 2008.

Is the 2016 date confirmed for the end of the construction and the beginning of the operations?
I wouldn't bet my life on it right now, I think that would be a little too optimistic. I would say that the 2016 date is a commitment by everybody to achieve as much as possible, but that is not fully within our control. ITER is a very unique project in that 90% of the components come from outside. At a political level we can agree on 2016 as the date, but the material has to arrive… However I do believe there is a commitment and a strong push by everybody to achieve the date as much as possible. That is very clear.

Are the financial contributions confirmed?
It was confirmed, and I believe it is beyond questioning - it's 45% for Europe and approximately 9% for the other six partners.

Only part of the budget is in cash and the rest is "in kind", which is that hardware procurements are provided mostly by the parties. The calculations are not very easy...
Yes, but the distribution has been agreed upfront, so there is no discussion now. The cash contribution is for the center of the organization, for R&D, and for some activities that will happen on site. But the majority of the funds stays in the domestic programs and is spent in each country's own program.

ITER is the first experiment of world governance - it involves developed countries as well as emerging countries, such as China and India. Is it easily manageable, and do you have a philosophy for governance?
Is it easily manageable? I think you can answer that question. I would say it's likely to be manageable, but of course there's no proof because we haven't done

View of the ITER site in Cadarache.
Photo: ITER

it yet. There is worldwide pressure on energy resources, and therefore pressure on us, and on the members to deliver. ITER is the first and a unique, one-of-a-kind experiment; if it fails, it's a failure not only for the project, but it could become an excuse to avoid international collaboration on any large projects in future. What's my management approach? Like an old friend of mine used to say, "Equal distribution of pain!" This quip seems to hold true - if everybody feels equally cheated, you have reached a good compromise.

Do you feel pressure from the governments, or do you think it's a question of individual management?
There are clearly different mentalities, cultures, and individual personalities that clash. The individuals sitting around the table are all bound by their cultural backgrounds.

But no direct pressure from their governments?
No, I don't think so. Not between each other and not in that sense.

The critics of the project argue that its scientific success is far from certain. For example, they say that building a fusion reactor that generates more energy than it consumes is very difficult. So far, all experimental fusion reactors could hardly break even. Why would ITER succeed?
Well, ITER is a straight extrapolation of JET, and JET managed to break even, if only for a few seconds. (See the sidebar 'Domesticating the energy from the sun', editor.) We can have doubts about the Q of 10 (Q is the amount of thermal energy that is generated by the fusion reactions, divided by the amount of external heating; break even is Q=1 and ITER has the aim of producing Q=10, editor), about the viability of 24/7 operations, 12 months a year; that's something we can argue about, but not about the general objective of making a device like ITER go beyond "break even". That is beyond question.
ITER is supposed to be a step between the scientific program and an industrial plant, and that's where we can have some questions. I think some of the difficulties in making that move can be resolved. But I think ITER will certainly demonstrate the industrial viability - that is the challenge of ITER and that is why it's being built.

Do you confirm that the tests are planned to last at least 20 years, and that the next step is the construction of DEMO, the prototype power plant?
Yes, that's correct. This 20-year period will be necessary to get everything in order to the point of allowing operations. Some people are even talking about doing DEMO before ITER is finished. That seems a little crazy to me, but…

Adversaries of the project argue that a fusion power plant will not be economically viable. What would the economic cost of the future plant be and what is the cost of the energy it will produce?
That is a very good question. First of all, let's talk about the world energy market; I don't know the exact numbers, but I believe the last one I heard was $3 trillion a year. So, measured against that, experiments that open up potential, like ITER, are really peanuts. It should be done, it has to be done, and it would be unforgivable if we don't do it. That's pretty clear.

Another point - looking at the curve of the price per barrel of oil, it doubled between 1 January 2007 and today. I am not sure how much it will increase in the future, but I think we are all agreed that it will go up. It is just a question of time when the cost of nuclear energy - fission or fusion, or anything else - will become viable.
I don't want to scare anybody about the lights going out in the next 20, 50, or 100 years, but oil will run out.

The construction costs of ITER are about 5 billion euros, but what would the cost of a future plant itself be?
It's hard to measure, but in a competitive environment it has to be on the same scale as the investment for a large power plant. Look at the power plants today - they're a few billion euros or dollars. I think ITER has a real fair chance to be in that ballpark once we begin to build a fusion device.
It will be fair to compare the cost of the first large-scale fission power plant to the first fusion power plant like ITER. If the cost is not equivalent, nobody will do it. That's economics, and it's very simple.

If fusion energy is a success, do you think that it will eventually replace or complement fission energy?
If I had a crystal ball, I could tell you. By mid-21st century, every source of energy (wind, water, coal, fission - fusion would not be ready yet) we have will be in use. I'm sure that fusion could play a tremendous role, certainly in large, centralized energy sources. One of the real advantages of fusion is that the fuel is available to everyone. That's not quite true for fission, unless you make breeders and fast breeders, but that technology has its own difficulties and applications because it produces very long-lived isotopes.

'If we fail, it will be a failure of international collaboration'

Let's examine the safety questions. Should we fear another Chernobyl?
No, there is no risk in fusion devices such as ITER. The accident scenarios that can breach the vessel and lead to exposure are externally-driven accidents - a bomb, a plane crash. Internal disruption demonstrates the safety of the device because it stops the operation of the device and prevents a chain reaction. Chernobyl is an internally-driven scenario in which a core reactor became too hot and out of control, reaching a temperature that went beyond the melting temperature of its surrounding vessel. The situation of Chernobyl or Three Mile Island was a runaway situation in a fission reactor.

Does the fusion process produce less nuclear waste?
The question is not so much of less or more - given the size of the facility, the total waste is probably in terms of tons. The point is the type of waste produced - short-lived isotopes, which are short-lived in the sense of a hundred or two hundred years. This is different in a breeding reactor or other reactors where we talk about high-level, highly contaminated waste, sometimes with lifetimes of tens of thousands of years.

Do you feel that the local population of Cadarache accepts the project?
They do. The general acceptance - not only of ITER and nuclear devices - and the positive attitude towards technology are pretty amazing. ■