

In this issue

- 35 nations, 40 languages... which culture? Page 2
- Pulling together for ITER Page 3

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1

Hotter than the Sun

Editorial

ITER isn't only a groundbreaking scientific experiment with the potential to open the way to a new form of energy. It's also a community of men and women from 35 nations that are working shoulder to shoulder to realize a common goal: building one of the most complex machines in the history of science and technology.

This month's *ITER Mag* invites you to discover both aspects of the Project – the technological and the human. With the international flavour that is uniquely ITER ...

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Warm concrete in the chilly dawn

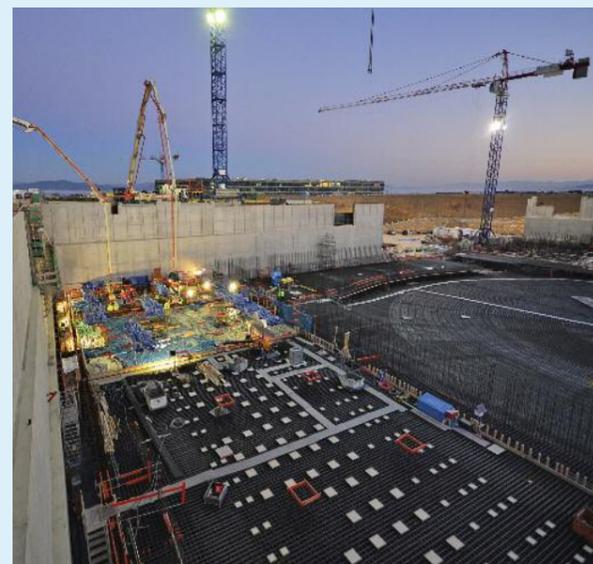
Well before dawn on 11 December 2013, the first cubic metres of concrete were poured for the Tokamak Complex basemat (the "B2 slab").

On an ordinary worksite the operation would have been rather unremarkable. But for ITER, the activity that morning had important symbolic value. What was taking shape in the pre-dawn cold under the bright light of the projectors was the 1.5-metre-thick floor of the Tokamak Complex, a three-building edifice at the heart of the ITER scientific facility that will weigh more than 360,000 tons.

For approximately ten hours a continuous flow of concrete poured from two long-armed pumps – 800 cubic metres in all for a corner of the basemat that measures 21 x 26 metres.

"The concrete qualified for the B2 basemat has been the object of particular care," specifies Laurent Patisson, head of the Nuclear Buildings Section at ITER, "having to answer to the rigorous requirements of a nuclear facility in terms of stability, water permeability and gas confinement." Pouring at such early hours, and during the winter months, required special measures to maintain the temperature of the concrete at a minimum level – such as heated water and gravel at the concrete batching plant and tents and hot air blowers at the worksite.

Pouring continued on 22 January and 13 February to complete the southern portion of the basemat. Work will continue throughout the summer to complete the Tokamak Complex slab; in all, 15 individual segments and approximately 15,000 cubic metres of concrete.



On the banks of the Durance River, halfway between Aix-en-Provence and Manosque, a unique community has taken root – some 500 people from 35 countries who have arrived with their languages, cultural references, traditions and work habits.

Some are physicists. Others are secretaries, engineers, accountants, administrators or specialists in a multitude of areas. Many come to ITER from the research laboratories of the ITER Member states ... others from industry or international organizations.

While the oldest have been working for the last 30 years toward fusion energy, the youngest were just coming into the world when the ITER Project was officially launched at the end of 1985.

English – the official working language of the ITER Organization – is the native language of just 15% of staff. But to truly understand one another, a common working language is not sufficient. That's the difficulty – and the beauty – of multiculturalism at ITER.

With the exception of the United Nations such a diversity of languages, origins and cultures is not easy to find. And there's an important difference. Staff at the UN work for the country they represent, whereas at ITER, whatever the country of origin, every person is mobilized toward the same objective.

"To work at ITER is to be confronted daily with the "difference" of the person across the hallway," explains Shawn Simpson, who organizes workshops, seminars and events dedicated to "interculturality" within the Organization. "And the pitfalls ... both linguistic and cultural ... are numerous."

Translated into the *lingua franca* of ITER, a "yes" or "no," or a simple "I would like, please" can be quite heavy with meaning and expectation depending on

whether the words were pronounced by someone from Japan, China, the United States, India, Russia, Korea, or southern or northern Europe.

A friendly gesture from one person may be construed as overly familiar by another. The raising of one's voice – a common occurrence in one part of the world – may be felt by members of another culture as aggressive and intolerable.

And as for emails (tens of thousands are exchanged each day within the Organization), they can also be a mirror of cultural values and traditions and, as such, the cause of serious misunderstanding. Take the formal, polite formulations that are *de rigueur* at the beginning and ends of emails in some cultures. For some, this is an indispensable sign of respect; for others, such elaborate formulations are seen as superfluous and long-winded.

Hierarchical relationships also vary from one culture to another – flexible and friendly for some ... more rigid and formal for others.

"Mutual understanding in an organization like ITER is only possible if each person is willing to regularly question his or her own values," says Shawn, an American born in Vietnam and raised in (among other places) France, Nigeria and Australia. "When problems occur, it's always a question of ego, irrespective of nationality."

Despite what she calls the "minefields" that are a regular part of intercultural life, the men and women of ITER understand one another. Better still, each person can be enriched by the differences encountered. "We are

constantly learning from one another and, as a result, we are learning about ourselves. It's an extraordinary thing to be part of such a rich environment ..."

From the moment the first ITER Organization employees settled into temporary offices on the CEA research centre site in 2006, an "ITER culture" began to take root, enriched naturally by every newly recruited staff member from the ITER Member nations. "When today I see Americans attending a performance of traditional Japanese dance here in the south of France, I think to myself – interculturality truly works at ITER!"

The grandest human enterprises, scientific or otherwise, will all be founded in the future on broad international collaboration. What men and women are inventing daily at ITER may be too young yet to be considered a model. But it's an experience that is sufficiently enriching and unique to already be the object of interest on the part of other international organizations.



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The Tore Supra tokamak at the French research centre CEA Cadarache is undergoing a profound transformation to become a test bed for the ITER tungsten divertor.

Pulling together for ITER

In its quest for fusion energy, ITER is not striving alone. Tokamaks in Europe, the United States, Korea and Japan have been the front-runners, exploring the road that ITER will begin to experiment in less than ten years.

Although each experimental machine is unique in its conception and its size, all of these machines have oriented their scientific programs or modified their technical characteristics in the last years to reinvent themselves – either partially or totally – as test beds for ITER.

Next door, at the French research centre CEA Cadarache, the Tore Supra tokamak is undergoing a profound transformation. In operation since 1988, the CEA-Euratom machine will be altered ⁽¹⁾ to test the ITER tungsten divertor – one of the critical ITER components that will be exposed to some of the highest thermal and particle loads during operation.

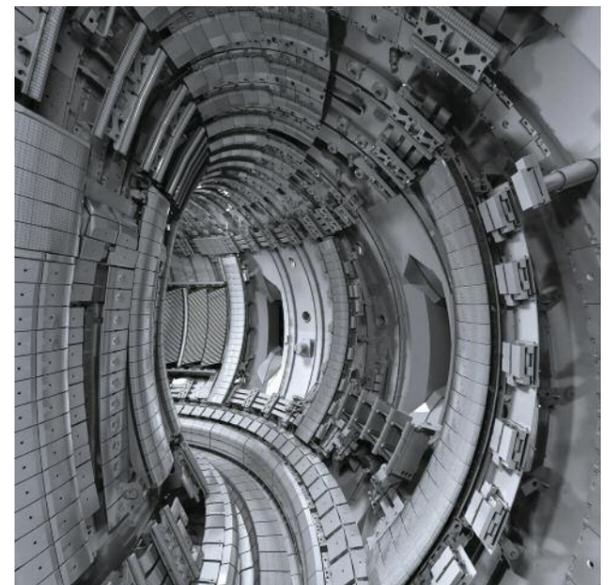
Started just a few weeks ago, the “stripping down” of the vacuum vessel is now complete. From the huge heating antennas to the smallest elements of piping,

some 1,500 elements – 65 tons in total – were dismantled, carefully indexed, and stored.

In the newly liberated space, the physicists at Tore Supra plan to recreate part of the ITER environment on a smaller scale. Supplementary magnetic coils will allow operators to create a D-shaped, ITER-like plasma. And thermal load studies will be run on the new ITER-like tungsten divertor – a strategic component facing loads as high as those of a (hypothetical) spaceship near the surface of the Sun.

The world’s tokamaks are not all undergoing such radical transformation. But all have been mobilized to anticipate, and help resolve, the scientific and technological challenges that the ITER Tokamak will face.

(1) The alterations are part of the WEST program, for *W Environment in Steady-state Tokamak* (W is the chemical symbol for tungsten.)



The inner wall of the European tokamak JET has been fitted with new beryllium and tungsten tiles – the same material that will be used for ITER’s plasma-facing elements. © EFDA



Visits on the rise: 15,000 in 2013

More than 15,000 visitors have been welcomed to the ITER site in 2013. Visits are organized by both the ITER Organization Visit Team (general public) and Agence Iter France (students).

While the ITER website has often been the first point of contact for the public and the fusion community, it is during an ITER visit that visitors get a chance to put a “face” to the Project. The purpose of the visits is to educate the public on fusion basics, acquaint them with the current status of the Project and take them on a tour of the construction site.

The ITER Visit Team welcomes visitors of all backgrounds – from fusion experts to professionals, government delegations and the general public – drawing on the participation of many ITER staff members who volunteer their time as well as logistics support from Agence Iter France and Fusion for Energy.

From the 10 year old hearing about fusion for the first time, to the fusion experts finally seeing their research come to fruition, each ITER visit is specially tailored. Common questions range from “When will we have commercial fusion reactors?” and “How much does the ITER Project cost?” to “Where do we get tritium?” and “Why do we need it?”

The number of visitors has been steadily increasing since 2007, with over 67,000 cumulative visitors to the site. School visits accounted for 53 percent of the visits in 2013, with the general public coming in at 21 percent and professionals making up the third largest category of visitors at 9 percent.

To reserve your visit at ITER, please visit www.iter.org/visit or email visit@iter.org.

Hotter than the Sun

The ITER plasma will be ten times hotter than the centre of the Sun. How will the machine's operators produce such a blistering environment? And what physical enclosure can contain it?

In the heart of the Korean tokamak KSTAR, in operation since 2008, a plasma pulse burns brightly. But don't be fooled – the brightest areas of the photo are in fact the coolest. At 150 million °C (the temperature in the centre), the plasma doesn't emit in the spectrum of visible light. © National Fusion Research Institute, Korea

In the depths of the Sun where fusion reactions produce the energy that we perceive as light and heat, temperatures reach 15 million °C. In the centre of the ITER plasma temperatures will soar to between 150 and 300 million °C. How is such an environment possible? And what type of container will be host to an environment that is ten to twenty times hotter than the centre of the Sun?

To answer these questions it is first necessary to ask ourselves about the nature of temperature. For a physicist, temperature is not only an indication of "cold" or "hot"; it also describes the energy of the particles that make up an object or a particular environment such as a plasma. The motion of particles such as nuclei, atoms and molecules (and the speed at which they travel) determine their energy.

For example, particles in ice (a solid) are tightly bound to one another and cannot move about at all. But as temperature rises, the agitation of the particles increases and the solid ice becomes water. At even higher temperatures, with particles moving at ever faster speeds, water becomes a gas (vapour).

"Temperature" is not the same as "heat." Let's take the example of a fluorescent tube, which contains a gas such as neon, argon or mercury vapour that has been energized by an electrical discharge. Inside of the tube the temperature of the gas is elevated (on the order of 10,000 to 15,000 °C) but the tube can be touched without harm.

This paradox can be explained by the very low density of the gas within. Density is needed to transmit heat from an object to your skin (the higher the density, the more heat is transferred). An iron rod exposed to the Sun for an afternoon becomes scorching hot, whereas a

piece of wood under the same conditions would never be too hot to touch due to its lower density.

Now let's return to ITER and to its plasma temperatures of 150 to 300 million °C. Plasmas are very tenuous environments, nearly one million times less dense than the air we breathe. The plasma particles are heated – that is, sped up – by different types of auxiliary heating methods until they are possessed of a formidable amount of energy. When they collide, the shock is such that the electromagnetic barrier that surrounds them is overcome, and the fusion of the nuclei can take place.

Despite its tenuousness, no physical cage can contain a plasma heated to temperatures of at least 150 million °C. If any part of the plasma were to come into contact with the surrounding wall, surface damage would result. But there would be even a graver consequence for ITER and for fusion: the plasma, despite the extraordinarily high temperatures at its core, would cool practically instantaneously in contact with the relatively cold vessel walls, stopping the fusion reactions immediately.

The solution physicists have found is to "imprison" the plasma inside a magnetic field – this is the concept of the "magnetic bottle" that was developed in the early 1950s and from which all present-day fusion machines derive. In a tokamak like ITER the hot plasma's charged particles are contained in the centre of the vacuum vessel by intense magnetic field and kept from physical contact with the interior walls of the machine.

Within the ITER machine, physicists and engineers are preparing to reproduce the physical reaction that, by fuelling the energy of the Sun, has maintained life on our planet for billions of years. In this very reaction is perhaps the solution for centuries of human development ahead – an energy source that is unlimited, clean and safe.

How to obtain fusion reactions

To initiate fusion reactions, a small quantity of gaseous fuel composed of equal parts of hydrogen isotopes (deuterium and tritium) is injected into the vacuum vessel. By applying a powerful electrical current to this mixture the gas is transformed into a plasma – electrons are stripped from the nuclei and the tenuous mixture turns into a conducting environment.

An electrical current circulating through the plasma augments the temperature of the plasma progressively. On the same principle as a toaster or an electric radiator, "Ohmic (or resistance) heating" will bring the plasma to approximately 10 million °C.

To surpass this limit, other techniques are needed. Two auxiliary methods will be used on the ITER machine: radiofrequency microwaves (the ITER systems will be 25,000 times more powerful than an average microwave and are effective at different wavelengths); and the injection of high-energy particles that transfer their energy to the heart of the plasma.

Each of these auxiliary methods is capable on its own of bringing the ITER plasma to the required temperatures. As an experimental machine, ITER will test both to determine which is better adapted for future industrial fusion devices.