

ITER Forum website Update 1/17

B.J.Green (17/1/17)

1. China one step closer to harnessing clean, limitless energy from nuclear fusion

China acknowledged as global leader in the field and world's only nation increasing funding into research to draw energy from 'artificial sun'

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Stephen Chen

On a quiet, scenic peninsula jutting out into Hefei's Dongpu Reservoir, physicists recently set a world record, creating hydrogen plasma, hotter than the core of the sun, that burned steadily for more than a minute. The nuclear fusion researchers kept the ionised gas burning steadily for twice as long as the previous record, set four years ago at the same reactor on Science Island, home to some of China's largest research facilities.

Professor Luo Guangnan, deputy director of the Experimental Advanced Superconducting Tokamak (EAST) facility in Anhui's provincial capital said some previous fusion experiments had lasted for more than 100 seconds, but they were like "like riding a bucking bronco", with plasma that was volatile and difficult to control.

However, the experiment conducted at EAST in August was more like a dressage event, with the plasma tamed in a high-performance steady state, known as H-mode, in a donut-shaped chamber shielded by an extremely strong electromagnetic field.

"It is a milestone event, a confidence boost for humanity to harness energy from fusion," Luo told the South China Morning Post.

Physicists view H-mode as an optimal working scenario for a future fusion power plant, and the one-minute breakthrough owed a great deal to the Chinese government's heavy investment on fusion research in recent years.

While still a long way short of the duration required to make

commercialisation of the technology possible – which would be measured in decades, not minutes – scientists say the breakthrough shows the pace of development on fusion research in China is leaving other nations in the dust.

It could also help accelerate government approval of construction of the world's first fusion power plant, the proposed Chinese Fusion Engineering Test Reactor (CFETR).

Fusion occurs when two hydrogen nuclei merge to form an atom of helium. During the process, a small amount of mass is converted into an enormous amount of heat. The challenge is to bring that energy under control.

Many fusion research facilities have been set up around the world in attempts to solve the fusion-control problem, with the largest facility under construction, the International Thermonuclear Experimental Reactor (ITER) in France, expected to fire its first pulse of plasma by 2025.

But all such facilities are relatively primitive, with none able to turn fusion power to electricity.

The CFETR proposal sees the reactor going into operation in 2030, generating 200 megawatts of power initially, before an upgrade in the following decade that would ramp up output to around a gigawatt, more than is produced by each of the commercial fission reactors at Daya Bay.

“It is hoped that the proposal for CFETR construction can be approved by the government within the next five years,” Wan Yuanxi, a leading fusion research scientist with the Chinese Academy of Sciences, told an international fusion science conference in Kyoto, Japan, last month. Luo, who is also involved in the CFETR project, said China's commitment to fusion research stood out when compared to other countries.

“China is the only nation in the world increasing its budget for fusion research,” he said. “The funding in Europe has been dwindling, a proposal for the construction of new research facilities in the US was rejected by Congress, and progress in Japan has also stagnated.”

The one-minute H-mode breakthrough at EAST was made possible by financial support from the central government, which allowed the EAST team to undertake a series of major upgrades in the past few years.

In contrast, the Alcator C-Mod tokamak nuclear fusion reactor at America's Massachusetts Institute of Technology, which set many world records in 23 years of service, shut down in September due to federal government budget cuts in the United States. It set its last world record, for the highest plasma pressure, on its final day of operation.

The funding and opportunities available in China have attracted fusion scientists from around the world, eager to solve the world's energy shortage and environmental pollution problems once and for all.

Many American researchers were involved in EAST's one-minute H-mode experiment.

"In each of our experiments in recent years, the number of foreign participants easily exceeded 100," Luo said, acknowledging that the progress in China would not have been so fast without a collective effort by international community.

The rapid pace of development in China has, however, led to concerns in other countries, worried that if China is the first to commercialise fusion technology it will gain the upper hand economically and geopolitically.

There was even discussion among the other six ITER members – Japan, South Korea, Russia, the US, India and the European Union – about kicking China out of the project because of concerns it would use knowledge gained from ITER to accelerate construction of CFETR.

But ITER, plagued by years of delay and way over budget, would not survive without China's support, and the country's influence in the project has grown significantly in recent years. The number of ITER employees from China has gone from last place among its seven members to second, trailing only the EU.

Professor Steven Cowley, president of Corpus Christi College, Oxford, and former head of Britain's Culham Centre for Fusion Energy, said the best choice for other countries was to embrace, and even support, China's leadership in fusion research.

"I think that CFETR is a bold and important move – not just for China but for the world," Cowley said. "It will not undermine ITER but rather move on rapidly from ITER towards full commercial fusion power.

"If China is first that is great since it will really benefit everyone. I would like to see us all help China to accelerate the pace of fusion development. Certainly the EU would also like to be first to commercial fusion power – but the most important thing is that someone does it as soon as possible."

But the Chinese government might have other considerations. While budget estimates for the CFETR project have not been publicly released, a fusion reactor is likely to cost much more than a commercial fission reactor, and many technological hurdles remain unsolved.

The recent EAST experiment, for instance, had to be terminated because the researchers were afraid that letting it run for longer might damage the facility beyond repair.

China has also embarked on the world's most ambitious conventional nuclear power plant construction programme and that heavy investment

might leave less funding available for large, experimental projects like CFETR.

Then there's also the question of whether large, government-funded fusion projects will be able to reach the stage of commercialisation faster than smaller projects carried out by private companies funded by venture capital. In recent years, several start-ups have been established in the US to approach fusion with technology different from the donut-shaped tokamak, an old design proposed by former Soviet scientists more than 50 years ago.

But some scientists from private companies overseas are also working in Chinese facilities. Wan told the conference in Kyoto that the CFETR project had participants from General Atomics, a defence contractor headquartered in San Diego, California, that specialises in nuclear physics, as well as others from the US Department of Energy's Princeton Plasma Physics Laboratory.

"I have a dream, to see a light bulb lit by the power of fusion within my lifetime," Li Jiangang, a leading Chinese fusion scientist, said in a programme on China Central Television in April. "This light bulb will be, and has to be, in China."

2. China fires up Hineg generator in Hefei city with goal of making world's strongest neutron beam using nuclear fusion technology

Research team hopes to hit target within a few years, could be put to civilian use or facilitate downsizing of future nuclear weapons

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Stephen Chen

China has fired up its most powerful neutron generator as it aims to produce the world's strongest neutron beam using nuclear fusion technology within the next few years.

The technology is expected to have a range of applications from scientific research to the development of military weapons.

The High Intensity D-T fusion Neutron Generator (Hineg) at the Chinese Academy of Sciences' Institute of Physical Science in Hefei, the capital city of China's eastern Anhui province, generated more than 1 trillion neutrons per second during its maiden test run on Saturday, according

to an announcement on the institute's website on Wednesday.

A team of nuclear physicists led by Prof Wu Yican fired deuterium, a heavy and stable isotope of hydrogen, on to a target board made of tritium - another hydrogen isotope that is also highly radioactive.

The two isotopes fused to form helium while releasing a neutron with large amounts of kinetic energy. As the fusion reaction continued, a steady beam of high-energy neutrons was produced.

A neutron generator is a critical component of modern-day nuclear weapons. It creates a fast stream of neutrons to kickstart the chain reaction of fission or fusion materials in a thermal nuclear warhead. An advanced generator can significantly reduce the size and weight of a conventional nuclear weapon.

Moreover, this kind of technology can also be used as a weapon in its own right.

Neutron bombs developed by China and other countries generate powerful neutron beams that can kill all life within a several-kilometre radius while leaving hardware such as buildings and tanks intact. This is because accelerated neutrons can penetrate many inorganic materials. Moreover, they create scant radioactive fallout, which means they don't poison the environment for a long time afterwards.

But the powerful neutrons generated at the Hefei facility were mainly intended for civilian use, according to the research team.

Wu's team said the beam would be used to test the decay of special metals that China developed for future nuclear fusion reactors.

The generator, which harvests neutrons from the fusion of deuterium and tritium particles, can simulate the harsh environment inside a fusion reactor, the team said.

This could make it easier for scientists to find the alloy most capable of withstanding the bombardment of high-energy neutrons that are produced when a fusion reactor works its magic, the research team said.

But the neutron beam generated by Hineg looks weak in comparison to some of its international rivals. Similar facilities in Europe, Russia and Japan have produced beams ten times as strong.

Wu's team said this was expected because tests are still at an early stage. The next step will be boosting Hineg's power output 100-fold over the next few years to make it the world's most powerful fusion neutron source, they added.

However there are still some technical hurdles to surmount.

One of the biggest challenges is how to effectively cool the tritium target board, which is roughly the size of a large coin and can easily overheat. When a rapid deuterium stream hits this target, an enormous amount of heat is generated that can melt the board if it is not cooled efficiently.

The research team did not give a precise estimate of when the project

would be completed or their targets met.

Dr Li Yuan, an associate professor of physics at Peking University in Beijing who has conducted research with neutron beams but was not involved in this project, said China was still years behind advanced Western nations in terms of neutron generator technology.

“Many experiments requiring a powerful neutron source must be conducted overseas due to the inadequate hardware conditions in China,” he said.

Li said that Hineg’s test run was an important step forward that will help China narrow the gap with other countries such as the United States in the coming years.

3. Financial crisis brings meltdown in Toshiba’s nuclear power plans

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The News That Matters about the Nuclear Industry

<https://nuclear-news.net/2016/12/30/financial-crisis-brings-meltdown-in-toshibas-nuclear-power-plans/>

Toshiba’s nuclear power hopes in meltdown The

Australian, REBECCA SMITH, KOSAKU NARIOKA, The Wall

Street Journal, December 30, 2016 Toshiba seemed poised to profit from a global nuclear power revival when it paid \$US5.4 billion to win a bidding war for Westinghouse Electric in 2006.

Today, that bet threatens to sink the venerable Japanese conglomerate, as cost overruns and missed deadlines on nuclear-reactor projects around the world have forced it to warn investors that it may soon have to report billions of dollars in losses.

Toshiba lost a fifth of its market value on Wednesday and its stock fell another 15 per cent early yesterday in Tokyo as panicked investors rushed to sell shares. The news of the nuclear writedowns came just as Toshiba was beginning to emerge from an earlier accounting scandal.....

Westinghouse’s woes help explain why the nuclear industry has seen its dreams of global growth sputter. Until recently, the company was regarded as the industry’s front-runner, the only nuclear supplier to have landed contracts for its next-generation reactor in both the US and China.

But a series of missteps and unexpected problems have snarled nuclear projects by Westinghouse and rivals including Areva and General Electric.

Fifty-four reactors are under construction in 13 nations, and 33 are badly delayed, according to the World Nuclear Industry Status Report, an

independent annual assessment. Blunders have afflicted projects regardless of location, reactor design or construction consortiums. To lower costs and speed construction times, Westinghouse and its competitors came up with cookie-cutter plant designs in which major sections would be built as modules in factories and then hauled to plant sites for final assembly. Gone was the customisation that added expense.

But the strategy appears to have backfired. "Supply-chain issues just moved from the plant sites to the factories. It didn't solve the basic issue of quality control," said Mycle Schneider, a nuclear expert based in Paris. And cookie-cutter designs meant flaws got replicated.

In France, Areva is trying to get to the bottom of a scandal involving falsified records for critical components that have wound up in nuclear plants there and in other countries, including the US. The problems appear to stretch back decades and to have gone unnoticed despite supposedly strict government supervision. Areva has said it is co-operating with investigators from France and other nations.

"There's a world-wide problem with managing these megaprojects," said Edwin Lyman, senior scientist for the Union of Concerned Scientists in Washington, DC. "Managers grossly underestimated the time and cost of construction."

It isn't clear if Toshiba's difficulties would have an impact on the eight reactors it is trying to complete in the US and China, but its disclosure suggests the situation is worse than previously understood.

In the US, Westinghouse was providing reactor components for nuclear plants in Georgia and South Carolina being built by utilities Southern and SCANA.

At the site of Southern's Vogtle 3&4 reactors going up in rural Georgia, there have been rumours of financial problems for months, said Will Salters, business manager for the union IBEW Local 1579.

He said the site now employs about 500 of his electricians but the union recently received notice that there would be a hiring freeze pending a review.

"We've been hearing for months they were broke and had to meet certain milestones by Southern to get paid," Mr Salters said.....

Toshiba is already on a Tokyo Stock Exchange watchlist because of the accounting scandal that forced it to take a \$US1.3bn writedown for its nuclear business in November 2015.

At the time, it acknowledged that it had overstated its profit for seven years.

4. First plasma for WEST fusion reactor

19 December 2016

<http://www.world-nuclear-news.org/NN-First-plasma-for-WEST-fusion-reactor-1912161.html>

WEST is the new name for Tore Supra, a plasma facility near Cadarache in southern France, which has been upgraded to undertake research towards the Iter fusion project. The reactor celebrated its first plasma on 14 December.

Tokamak fusion reactors feature a divertor structure to remove any unwanted atoms from the plasma chamber, including the helium produced by fusion itself. All of these elements are flung by centrifugal force into an absorber material, which naturally heats up tremendously. WEST is designed to test prototype components and accelerate their development for Iter, which will be by far the world's most powerful fusion reactor when it starts up, hopefully in 2025. The name WEST stands for 'W' Environment in a Steady-state Tokamak, where W is the chemical symbol for tungsten, the material that will be used for the Iter divertor.

France's nuclear and renewable research agency CEA owns WEST and will use it to minimise the cost and schedule risks of industrialising Iter's components by testing prototypes. It will also give initial findings on the functioning of the divertor and test the durability and ageing of tungsten materials.

Transforming Tore Supra into WEST required an extensive refit, beginning in 2013. The previously uniform plasma was changed to focus energy on the divertor by installing new poloidal field magnetic coils in the vacuum vessel. A new cooling system was been installed, including active cooling for the divertor, and all plasma-facing components are now metal to allow for more experiments to take place.

*Researched and written
by World Nuclear News*

5. Tokamak is ready to test ITER's internal components

December 16, 2016

<http://phys.org/news/2016-12-tokamak-ready-iter-internal-components.html>

On 14 December 2016, the WEST tokamak produced its first plasma, reflecting the success of the operations carried out since 2013 on the CEA nuclear fusion reactor. Now that this major milestone has been passed, preparation of the machine is continuing for a first experimental campaign in spring 2017. WEST will enable the CEA and its national and international partners to qualify technological "bricks" for the ITER project. Since its construction in the 1980s, the Tore Supra tokamak has continued to evolve in order to improve plasma performances, even

setting a world record with a stationary plasma lasting over six minutes for an extracted energy of 1 gigajoule (GJ). The WEST project - Tungsten (W) Environment in Steady-state Tokamak - aims to transform Tore Supra into a test bed for ITER or, more precisely, to test a "divertor" using ITER technology. The divertor, which is situated on the floor of the vacuum chamber, is a fundamental component as it receives most of the heat and particle fluxes coming from the central plasma. Its function is to extract the "ash" (helium) and part of the heat produced by the fusion reaction, whilst minimising the contamination of the plasma by the other impurities.

WEST makes it possible to:

- minimise risks (costs and deadlines) linked to the industrialisation of the high-tech components of the ITER divertor. Prototypes produced by the suppliers selected for the manufacture of the ITER divertor are already in place, and industrial pre-series are under preparation;

- to obtain initial experimental findings on the functioning of this divertor and to prepare the teams for its scientific exploitation in ITER;

- to test, in an accelerated manner, the durability and ageing of this plasma-facing component during extended discharges.

The challenges of plasma control

Plasma is a fourth state of matter after gas form, obtained by heating a gas to several million degrees. Plasma can be compared to a "soup" where nuclei and electrons are no longer linked and move around freely. When two "light" nuclei collide at high speed they can fuse, forming a heavier nucleus: that is nuclear fusion. The quantities of energy released are very significant, leading scientists to seek a way to exploit this reaction as a new source of sustainable energy; however, for this they need to be capable of creating, maintaining and controlling this plasma.

6. CHALLENGES ON THE ROAD

TOWARDS FUSION ELECTRICITY | Tony Donne´ –

I EUROfusion Programme Management Unit, Boltzmannstraße 2, 85748 Garching bei Mu´nchen, Germany

<http://www.europhysicsnews.org/articles/e pn/pdf/2016/05/e pn2016475-6p20.pdf>

The ultimate aim of fusion research is to generate electricity by fusing light atoms into heavier ones, thereby converting mass into

energy. The most efficient fusion reaction is based on merging the hydrogenic neutron which releases 17.6 MeV in the form of kinetic energy of the reaction products.

The helium particle carries 20% of the reaction energy which is used for heating the plasma. The neutron with 80% of the energy is not confined by the magnetic field and will penetrate into the blanket surrounding the plasma. There it deposits its energy, leading to a temperature rise of the blanket coolant, which will drive electric turbines. In the blanket it also converts ${}^6\text{Li}$ into ${}^3\text{T}$, and ${}^4\text{He}$; the ${}^3\text{T}$ is subsequently used as fuel.

The two main strategies to achieve fusion on earth are based on magnetic confinement and inertial confinement. In *magnetic* confinement, a gas is heated to temperatures in the order of $1\text{-}1.5 \times 10^8$ K. At these high temperatures the gas is transformed into a plasma, consisting of charged particles with sufficiently high energy to overcome the Coulomb potential and to fuse.

Magnetic fields are used to confine the plasma and keep it away from any material surfaces. In *inertial* fusion a small pellet of solid deuterium-tritium is quickly and strongly compressed by powerful laser or particle beams, leading to sufficiently high densities and temperatures for fusion.

Magnetic Confinement Fusion

European fusion research is largely concentrated on magnetic confinement fusion, as it is the most promising concept to deliver fusion electricity. In the range of magnetic confinement devices that have been studied over the last decades, the tokamak has reached the best performance. In a tokamak, the plasma is confined by a magnetic field that is a superposition of a field generated by external magnetic coils (yielding a field in the toroidal direction) and an internal poloidal field generated by a toroidal current through the plasma which is induced by a transformer (see Figure 1).

Hitherto, the highest fusion performance (16 MW) has been achieved in the Joint European Torus, JET, world's largest tokamak (see article by L.Horton). Also the international ITER experiment (see article by D. Campbell) – a collaboration of China, Europe, India, Japan, Russia, South-Korea and the United States – is based on the tokamak concept. ITER is expected to have first plasma around the middle of the next decade and is designed to achieve fusion power generation of about 500 MW, using 50 MW of external input power. ITER will not deliver any

fusion electricity and will therefore be succeeded by DEMO, the first Demonstration Fusion Power Plant (see article by D. Ward).

EUROfusion and the European Fusion Roadmap

Europe has drafted an elaborate plan to achieve the milestone of fusion electricity demonstration in DEMO by the middle of the century. In this so-called Fusion Roadmap, eight important missions have been defined, which can be grouped into:

- 1. Risk mitigation for ITER**
- 2. (Pre-) Conceptual Design of DEMO**
- 3. The stellarator as back-up strategy**

Fusion research in Europe is coordinated by EUROfusion, a consortium of 29 National Fusion Laboratories from 27 countries, plus Switzerland and – from 2017 onwards - Ukraine, along with over 100 Universities, groups and industries that are acting as Linked Third Parties to the National labs (see Fig. 2).

The fusion community is confident that ITER will work and reach its full performance and all of its objectives. However, there are open research issues that, if better understood, can help ITER to optimise its research plan. It is no surprise that there are even more open issues with respect to the design of the DEMO reactor. These are largely related to the very hostile environment with strong plasma-wall interaction and high fluxes and fluences of neutrons and gammas emerging from the hot plasma. In the remainder of this paper and the following ones of this special issue the reader will be guided through a few of the main physics challenges in the fusion roadmap.

The choice has been made to focus on items 1 and 3 above. Item 2 is linked to the DEMO design and preparation, and is more technology-oriented than the other two items, although it comprises challenging and interesting issues such as developing neutron-resistant materials, achieving tritium self-sufficiency, intrinsic safety, integrated DEMO design and competitive cost of electricity (see article by D. Ward).

Risk mitigation for ITER (and DEMO)

The temperature of the fusion plasma in ITER (and also in DEMO) must be about 10-20 times higher than that in the core of the Sun, for colliding particles to have sufficient energy to fuse. Because there are strong temperature-, density- and current density gradients, the plasma is prone to develop microscopic instabilities (turbulence) as well as

macroscopic magnetohydrodynamic instabilities, which degrade the plasma performance. The macroscopic instabilities can potentially completely destabilise a tokamak plasma which can end the plasma state. This process - called disruption - leads to strong forces onto the surrounding vacuum vessel due to induced halo currents. So plasma scenarios need to be developed in which the performance is ramped up in a controlled way and in which instabilities are actively controlled. An excellent external 'knob' to control magneto-hydrodynamic instabilities is the injection of radio waves at the place of the instability. The radio frequency waves injected are either resonant with the local electron or ion cyclotron frequency or one of its higher harmonics. This stabilisation method can act either on the electrons or on the ions in the plasma. Another possibility to act on the plasma is the injection of powerful beams of neutral particles (typical energies in ITER ~1 MeV).

ITER will bring fusion physics into a new regime: The alpha particles carry 20% of the generated fusion power, which implies that at the highest ITER performance (fusion power/input power = 10), the self-heating by the alpha particles is twice the external input power. This has a large effect on the way the plasma can be controlled. Only localized heating methods, with a high power density, like cyclotron heating can outweigh the alpha particle heating, and can therefore be used for efficient plasma control. Additionally, new effects can occur as the energetic alpha particles can interact with instabilities, which might lead to intolerable losses of fast particles. Many of these effects can be studied already in present devices by mimicking alpha particles by fast ions that are externally injected, but the ultimate understanding of alpha-particle physics needs to come from ITER.

Achieving a high performance plasma is not the only challenge. By far the largest quest for the fusion researchers is to solve the heat exhaust problem. Namely, the power generated in the core of the plasma needs to be exhausted in a small part of the reaction chamber called the divertor. In ITER, the neutrons, deposit a total of 400 MW more or less uniformly into the blanket structure surrounding the vacuum chamber. But about 90% of the remaining exhaust power of about 100 MW is convected towards the divertor, leading to a steady state heat load on the divertor components in ITER with peak values of 10-20 MW/m².

These are power densities that are close to those at the surface of the Sun! The challenge of finding a proper solution beyond ITER is largely

going into two directions: development of (new) plasma-facing materials that are more robust against the plasma-wall interactions as well as

developing new magnetic geometries for the divertor in which the peak heat load is distributed over a larger surface. With respect to the latter direction: options that are being studied in Europe are the snowflake divertor in the Swiss TCV tokamak, the Super-X divertor in the British MAST-Upgrade tokamak and liquid materials divertors in a number of specific experiments.

Plasma regimes of operation (mission 1) and Heat-exhaust systems (mission 2) in the fusion roadmap are tightly interlinked. This is illustrated by the following. Originally most tokamaks in the world utilised carbon tiles as main plasma-facing components and carbon-fibre composites (CFC) in the divertor, as this material is very strong and can withstand high temperatures up to about 1200°C.

Carbon is also a relatively light atom and does not pollute the plasma too much when it enters (since the plasma is quasi-neutral, each impurity ion with charge number Z pushes out Z hydrogenic ions, leading to fuel dilution). However, carbon has two important drawbacks: 1) it forms dust, and 2) it binds with hydrogen. The effect of both is that in a machine operating with 3T (like ITER) after a short time the whole tritium

inventory is immobile due to retention in the carbon dust and carbon plasma-facing components. This implies opening and cleaning the machine and subsequently separating the tritium from the dust. It is for this reason that about 10-15 years ago a deliberate choice has been made in Europe to switch to full metal machines. The German ASDEX-Upgrade, has gradually changed the wall material from full carbon to full tungsten. JET has been modified in a single shut-down from a carbon machine to a device with beryllium walls and a tungsten divertor (exactly the same materials as will be employed in ITER, see the following papers). The Tore Supra superconducting tokamak in France is presently being changed into WEST, a full tungsten device able to run long plasma pulses. Tungsten has a high melting point of 3422°C, but recrystallisation becomes important above 1200°C. The result of a few years of operation of ASDEX-Upgrade with a full tungsten wall and JET with the ITER-like wall is that the hydrogen retention has been reduced by a factor of ~15, which is sufficiently good for ITER. However, it turned out to be much more challenging to achieve a high plasma performance due to influx and accumulation of tungsten in the plasma core, which – as sketched above – leads to considerable fuel dilution. This can be

avoided by using special tricks as central plasma heating (with radio frequency waves), surrounding the plasma by a seeding gas and controlling instabilities at the plasma edge to purge the tungsten out of the plasma. This shows the rather intricate interplay between reaching a high plasma performance and finding proper solutions for the plasma heat exhaust geometry and material choices.

Apart from the integrated research of plasma-wall interaction in tokamaks, new materials are constantly being developed and tested in linear plasma devices, like MAG- NUM-PSI and Pilot-PSI in The Netherlands and JULE-PSI in Germany, in which the materials can be exposed to plasma fluxes and fluences that are reminiscent to those in ITER.

The stellarator as back up strategy

Undoubtedly, the tokamak has the simplest design of the relevant confinement devices. Because it also has the best performance, international research has largely concentrated on this line since the 1970's. Besides its scientific successes, the tokamak has a number of drawbacks. Firstly, it is a pulsed device due to the fact that the plasma current is induced by a transformer. Secondly, the tokamak is prone to current-driven instabilities and disruptions that necessitate active control tools for a stable operation, as outlined above.

There is a second magnetic confinement device in which the confining magnetic field is completely generated by external field coils: the stellarator. The stellarator is in principle net current free and, hence, the device is intrinsically more stable. But every advantage comes with a disadvantage: the design and construction of the stellarator is much more complex (see Fig. 3), and this is the main reason why it is generally lagging behind the tokamak.

Nevertheless, stellarator research has entered a new era: On 10 December 2015, the super-conducting Wendelstein 7-X device with its optimised magnetic configuration, located in Greifswald, Germany, and with a diameter of 16 m (see Fig. 5) has been taken into operation. Angela Merkel initiated on 3 February 2016 the first hydrogen plasma, which had already an electron temperature of 8 keV. Research in Wendelstein 7-X will show the viability of this concept and its potential for a future fusion power plant.

Concluding remarks

In this brief paper it has only been possible to describe a small fraction of the European research in nuclear fusion, and in doing that even only the tip of the iceberg could be discussed. There are still many scientific and technological challenges in fusion research, ranging from a very fundamental nature to more applied issues. More technical information is provided in the following papers of this special issue. Apart from that it is a very interesting and rewarding discipline to work in, it has the additional prospect that it is contributing towards a solution to the world energy and climate problem.

About the Author

Tony Donn  is Programme Manager of the EUROfusion consortium, a position he has held since June 2014. He obtained his PhD degree (1985) at the Free University of Amsterdam. Most of his scientific career was devoted to research in the field of high-temperature plasma diagnostics. From 2009 – 2014 he was heading the fusion research department of the Dutch Institute for Fundamental Energy Research.

7. THE FIRST FUSION REACTOR: ITER

**I D.J. Campbell – DOI: <http://dx.doi.org/10.1051/e pn/2016504>
I on behalf of the ITER Organization, Domestic Agencies and ITER Collaborators
I ITER Organization, Route de Vinon-sur-Verdon, CS90 046, 13067 St-Paul-lez-Durance Cedex, France**

<http://www.europhysicsnews.org/articles/e pn/pdf/2016/05/e pn2016475-6p28.pdf>

Established by the signature of the ITER Agreement in November 2006 and currently under construction at St Paul-lez-Durance in southern France, the ITER project [1,2] involves the European Union (including Switzerland), China, India, Japan, the Russian Federation, South Korea and the United States. ITER ('the way' in Latin) is a critical step in the development of fusion energy. Its role is to provide an integrated demonstration of the physics and technology required for a fusion power plant based on magnetic confinement.

In practical terms, the project's goal is to construct and operate a tokamak experiment which can confine a deuterium-tritium plasma in which the α -particle heating dominates all other forms of plasma heating.

Formally, the primary mission of the ITER project is to demonstrate sustainment of a DT plasma producing ~500 MW of fusion power for durations of 300 - 500 s with a ratio of fusion output power to input heating power, Q , of at least 10. ITER is also designed to explore the physics basis for continuous operation of fusion power plants by investigating 'steady-state' plasma operation by means of non-inductive current drive for periods of up to several thousand seconds while maintaining a fusion gain, Q , of ~5. If plasma confinement characteristics are favourable, ITER would also be capable of exploring the 'controlled ignition' regime of tokamak operation (with $Q \sim 30$) in which power plant plasmas are expected to operate. The project's technical goals encompass significant technological demonstrations to prepare the design basis for a fusion power plant.

The unique nature of the ITER international collaboration is reflected in the scheme by which the components for the tokamak and auxiliary plant are being constructed. The ITER Organization (IO-CT) in France is responsible for design integration, procurement of components amounting to about 10% of the project's capital construction cost, management of the on-site installation of the tokamak and plant, and, ultimately, for the operation of the facility. The seven ITER partners have each established Domestic Agencies (IO-DAs) through which 90% of the facility's components are being procured 'in-kind' and supplied to the IO-CT for integration into the ITER facility.

ITER Design, Manufacturing and Construction

The engineering design for ITER has been developed around a long-pulse tokamak with an elongated plasma shape and a single-null poloidal divertor. The design has been validated by wide-ranging physics and engineering R&D: it is based on scientific understanding and extrapolations derived from extensive experimental studies in tokamaks in the international fusion research programme spanning several decades (e.g. [3]) and on the technical know-how flowing from the fusion technology R&D programmes in the ITER Members (e.g. [4]). A schematic of the ITER tokamak is shown in Fig. 1 and the principal parameters are listed in Table 1.

TABLE 1. MAIN PARAMETERS OF THE ITER TOKAMAK

Plasma Current	15 MA
Toroidal Field (at $R = 6.2$ m)	
Major/minor radius	6.2/2 m
Plasma elongation/triangularity	1.85/0.49
Installed auxiliary heating power	73 MW
Fusion power (at $Q = 10$)	500 MW
Pulse duration (at $Q = 10$)	≈ 400 s

ITER is a superconducting device with several major magnet systems [5]: the 18 toroidal field (TF) coils and 6 central solenoid (CS) modules are fabricated from Nb₃Sn superconductor due to the high fields required, e.g. 13 T in the centre of the CS. The 6 poloidal field (PF) magnets use NbTi superconductor, as do the 18 correction coils (CC). The international collaboration formed around the production of superconducting magnets for the ITER tokamak has produced over 600 t of Nb₃Sn (increasing annual world production by approximately a factor of 10) and almost 250 t of NbTi superconducting strand. Over 80% of the superconductors required for the ITER magnets are now complete, and coil fabrication activities are underway in 6 of the 7 partners' factories. Series production of the high temperature superconducting current leads will be launched during 2016. Operation of the magnet systems, which are cooled by supercritical helium, will be supported by the world's largest single-platform cryogenic plant. Fabrication of the vacuum vessel, a double-walled stainless-steel toroidal chamber with an outside diameter of ~19.5 m and a height of ~11.5 m, is advancing, with structures being produced under the responsibility of four Domestic Agencies. The first elements of the cryostat (~29 m diameter × ~29 m height – the largest stainless-steel high vacuum pressure vessel in existence when complete) have been delivered to the ITER site. In-vessel components such as the stainless-steel divertor cassettes (54 make up the entire divertor structure), stainless-steel shielding blanket modules (440 cover almost the entire first wall) and the associated (tungsten) divertor and (beryllium) first wall plasma facing components (PFCs) are undergoing prototyping and, in the case of the PFCs, high heat flux testing to their rated performance. ITER will be equipped with a significant heating and current drive (H&CD) capability. This will consist initially of 33 MW of (negative ion based) neutral beam injection using 1 MeV deuterium, 20 MW of electron cyclotron resonance heating operating at 170 GHz, and 20 MW of ion cyclotron radiofrequency heating operating in the range 40-55 MHz. These systems are required for plasma initiation, heating of the plasma to temperatures at which fusion reactions can be initiated, controlling the fusion burn, provision of a substantial fraction of the non-inductive current drive for steady-state operation, control of the plasma current profile to avoid magnetohydrodynamic (MHD) instabilities and direct suppression of growing plasma instabilities. An extensive diagnostic capability consisting of about 50 large-scale systems will provide plasma measurements for control, investment protection and physics studies of burning plasmas, while a sophisticated control, data acquisition and command system will support all aspects of facility operation and protection.

Physics challenges for burning plasma studies in ITER

Successful operation of ITER will open new frontiers in fusion research involving the influence of a significant α -particle population on plasma heating, transport processes and stability. Moreover, to sustain high fusion power, it will be critical to control the exhaust of power and particles from the plasma to prevent overheating of plasma facing surfaces.

ITER operation will evolve through several stages (e.g. [6]): a period of hydrogen and helium operation will be used to commission all tokamak and auxiliary systems; this will be followed by a short period of deuterium operation to approach thermonuclear conditions more closely and to phase gradually into full DT operation, which will then provide access to significant levels of fusion power and α -particle heating.

Three 'design basis' scenarios have been assembled from the physics basis developed by the international fusion research community in recent decades. These reference scenarios provided a conceptual basis for the ITER design and form idealized targets for the various modes of plasma operation which will be explored in ITER. Their basic parameters are summarized in Table 2. The inductive scenario is expected to provide the simplest route towards the achievement of high fusion power and to allow the first studies of substantial α -particle heating. The 'hybrid' scenario provides a relatively simple basis for technology testing under long-pulse stationary conditions. Fully non-inductive operation is an altogether more complex plasma regime in which the total plasma current is driven by a combination of auxiliary heating systems and internal processes (bootstrap current). While the basic principles of operation in this regime have been understood for the past 20 years, and experimental demonstrations of candidate modes of operation have been made for periods of several seconds, considerable research is required, both in existing devices and, eventually, in ITER, to establish an operational mode in which all requirements of plasma confinement and stability are satisfied.

Like JET and all relevant fusion devices, ITER will also be equipped with a divertor, located in the lower region of the vacuum vessel. The material and geometry of the divertor surfaces are designed to handle high heat fluxes while allowing extraction of helium 'ash' produced by DT fusion reactions. The operational functions of the divertor are well-established in existing experiments, but the critical step that ITER will make is to integrate this power-handling strategy with a burning plasma core in such a way that the core and edge plasmas perform as intended, in benign coexistence.

A key aspect of this solution to the power and particle exhaust challenge is the choice of plasma facing materials. Two metals, beryllium and tungsten, have been chosen, with the former lining the first wall of the main plasma chamber and the latter covering the divertor surfaces. This material combination has been tested on JET in the frame of the ITER-like wall (see article by L. Horton).

Fusion Technology at ITER

The development and testing of key 'fusion' technologies required for construction of a fusion power plant is a principal mission goal of the ITER project. A significant element of this research is the Test Blanket Module (TBM) Programme [7], which will involve the construction and testing, by exposure to ITER plasmas, of 6 different concepts of tritium breeding module. The breeding of tritium, by reactions between neutrons emitted from the plasma and lithium contained in either ceramics or (Li-Pb) eutectics within blanket modules lining the reactor wall, is fundamental to the fuel cycle in a fusion power plant burning deuterium and tritium. While ITER can be fuelled by tritium from external sources in the fission programme, it is designed to conduct the first tests of concepts for tritium breeding, which could be applied in a DEMO reactor. The primary research goal will be to confirm the rate at which tritium can be produced: in DEMO, the 'tritium breeding ratio', defined as the ratio at which tritium is bred against the tritium burn rate, must certainly exceed unity. ITER tests will allow the first studies of the tritium production and extraction rates which can be achieved in a practical design.

Once ITER makes the transition to routine DT operation, the fusion power level, burn duration and duty cycle required will necessitate real-time reprocessing of the tokamak exhaust gas stream to provide DT fuel at an adequate rate to sustain the planned experimental programme.

While a significant quantity of tritium can be stored on the ITER site, this inventory will be recycled, resulting in as much as 25 times this amount of tritium being reprocessed annually to maintain the ITER experimental programme at the required performance level. This will require a tritium processing plant of unprecedented scale, and its operation will establish the technical basis for tritium reprocessing in fusion power plants.

The development and application of remote handling technology for ITER will also provide a substantial basis for the future application of this technology in the fusion environment. Soon after the transition to DT operation, activation of the ITER tokamak due to the interaction of 14 MeV neutrons with the reactor structure will require that all maintenance, repair and upgrade work in the tokamak core be carried out using remote handling methods.

A final significant facet of the ITER nuclear R&D programme, and a key ITER mission, will be the demonstration of the environmental and safety

advantages of fusion energy. After the submission of the formal application documents and an extensive interaction between the ITER Organization and the French nuclear regulatory authorities, the French Government granted the Decree of Authorization of a nuclear facility to the ITER Organization in November 2012. ITER is now established as Basic Nuclear Installation 174 (INB-174) within the French regulatory framework.

Towards ITER Operation

Construction of the ITER facility is now moving forward rapidly and the ITER partners have recently agreed to work together towards a First Plasma date of December 2025. DT operation is expected to begin about 10 years later. The research programme under development will establish the major lines of research within the ITER experimental plan in order to optimize the fusion performance of the device and to exploit the opportunities, which ITER offers for studies in burning plasma research at the reactor scale.

Acknowledgments

This report represents the work of the staff of the ITER Organization, the Domestic Agencies and many collaborators in the Members' fusion communities. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

About the Author

David Campbell spent 14 years at JET, Europe's major fusion experiment, followed by 10 years leading the EU's physics and plasma engineering R&D activities for ITER. He joined the ITER Organization in 2007 and is currently

Director of the Science and Operations Department, which is responsible for developing the ITER facility's central control systems, for conducting the project's fusion physics research and for preparing the framework for ITER operations.

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8. First Hualong One dome takes shape

06 January 2017

Assembly of the containment building dome for unit 5 of the Fuqing nuclear power plant has been completed. The unit - the first of two demonstration Hualong One units being built at the site in China's Fujian province - is expected to start up in 2019.

<http://www.world-nuclear-news.org/NN-First-Hualong-One-dome-takes-shape-0601175.html>

China National Nuclear Corporation (CNNC) announced today the main assembly work for the dome had been completed on 3 January.

The hemispherical structure, weighing about 305 tonnes and with a diameter of some 45 meters, will later be placed upon the walls of the unit's containment structure - a major component for protecting the reactor and preventing the release of radioactive materials into the environment in the event of a serious accident.

In November 2014, CNNC announced that the fifth and sixth units at Fuqing will use the domestically-developed Hualong One reactor design, marking its first deployment. The company had previously expected to use the ACP1000 design for those units, but plans were revised in line with a re-organisation of the Chinese nuclear industry. China's State Council gave final approval for construction of Fuqing units 5 and 6 in mid-April 2015.

The pouring of first concrete for Fuqing 5 began in May 2015, marking the official start of construction of the unit. The first steel lining module for the containment building of the unit was installed three months later. Construction of unit 6 began in December 2015. The units are scheduled to be completed in 2019 and 2020.

Construction of two Hualong One units is also under way at China General Nuclear's Fangchenggang plant in Guangxi province. Those units are also expected to start up in 2019 and 2020, respectively.

Researched and written

by World Nuclear News

9. Construction milestones at new Chinese units

05 January 2017

Installation of the fourth and final reactor coolant pump at the Sanmen 2 AP1000 was completed yesterday, China National Nuclear Corporation (CNNC) announced. Meanwhile, the boron injection tank has been installed at the second demonstration Hualong One unit being constructed at the Fuqing plant.

<http://www.world-nuclear-news.org/NN-Construction-milestones-at-new-Chinese-units-0501175.html>

Each AP1000 employs four main reactor coolant pumps - each almost seven metres tall and 1.5 metres wide and weighing some 91 tonnes - which circulate reactor coolant through the core, loop piping and steam

generators.

Westinghouse is currently constructing four AP1000 units in China, two each at Sanmen in Zhejiang province and Haiyang in Shandong. US manufacturer Curtiss-Wright was awarded a contract by Westinghouse to produce 16 reactor coolant pumps for the units in 2007.

Sanmen unit 1, construction of which began in April 2009, is expected to be the first AP1000 to begin operating. First concrete for Sanmen 2 was poured in December 2009. All four Chinese AP1000s are scheduled to be in operation by the end of this year.

Four AP1000 reactors are currently being built in the USA - two each at Vogtle and Summer - while three AP1000s are also proposed for the Moorside site in the UK.

Progress at Fuqing 6

The boron injection tank was also installed yesterday at Fuqing 6 - the second Hualong One unit under construction at the site in China's Fujian province.

The boron injection tank - weighing almost 20 tonnes - will contain a boric acid solution that can be injected into the reactor in the event of a severe accident to shut down the chain reaction in case the control rods are not capable of being inserted into the core.

China's State Council gave final approval for construction of Fuqing units 5 and 6 in April 2016. The pouring of first concrete for the reactor basemats for Fuqing 5 and 6 - marking the official start of construction of the units - took place in May and December 2015, respectively. Fuqing 5 and 6 are scheduled to be completed in 2019 and 2020.

Construction of two Hualong One units is also under way at China General Nuclear's Fangchenggang plant in Guangxi province.

Researched and written

by World Nuclear News

10. OPG submits geologic repository studies

05 January 2017

This story has been updated to include information on the review and public comment process.

Ontario Power Generation (OPG) has submitted further information on its proposed deep geologic repository for low- and intermediate-level waste to Canadian regulators. The studies, carried out in response to a ministerial request, show that relocating the repository from OPG's proposed site at Bruce to one of two alternative locations would increase environmental effects and costs.

<http://www.world-nuclear-news.org/WR-OPG-submits-geologic-repository-studies-0501177.html>

The proposed repository would provide permanent storage for low- and intermediate-level waste from the Bruce, Pickering and Darlington nuclear power plants. A federally appointed panel in 2015 approved OPG's environmental assessment for the proposed repository at its Bruce site, but in February 2016 Canada's minister of the environment and climate change asked OPG to carry out three further studies: an assessment of the environmental effects of two technical and economically alternative locations for the project, including incremental off-site and transportation costs; an updated analysis of the cumulative environmental effects of the project, if a separate repository for used nuclear fuel were to be built nearby; and a review of OPG's mitigation commitments and actions.

OPG's proposed site at Bruce would see the repository built 680 metres under the existing nuclear site, in impermeable limestone. The alternative locations - a crystalline granite location in central-to-northern Ontario, and a sedimentary location in the southwest of the province - both met OPG's criteria for technical and economic feasibility. OPG's studies showed that the DGR's primary objectives of public health and safety, worker health and safety and environmental protection could be achieved at any of the three locations.

However, the studies concluded that the environmental effects of a repository at either of the two locations would be greater than the Bruce site due to the environmental impacts of additional waste transportations, as well as effects on land use, vegetation and wildlife from the establishment of a new site.

The study found that an additional 22,000 shipments would be required to move the waste - currently in storage at Western Waste Management's surface storage facility at Bruce - on public roads. This would cause a "small but incremental" risk of radiation exposure to the public and transportation workers as well as creating an incremental risk of conventional transport accidents over the decades that would be required to complete the additional shipments.

Incremental costs of using an alternate location were found to range from about CAD 1.2 billion to CAD 3.5 billion (\$0.9 billion to \$2.6 billion). Additional costs would come from activities including the redesign and implementation of a site selection process; acquisition of land for the facility; development and implementation of support services; repackaging and transportation; and restarting the licensing process for the new location.

"The studies show that relocating the [repository] to an alternate location would result in increased environmental effects and significant

incremental costs, with no assurance of increased safety to workers and the public, or protection of the environment," OPG said yesterday. "Based on the findings, OPG maintains that a [deep geologic repository] is the right answer for its low- and intermediate-level waste, and that the current proposed Bruce nuclear site is the right location."

Cumulative update

The ministerial request also saw OPG update its assessment of cumulative environmental effects at the Bruce site to determine whether combined effects could occur if the same region were to host two different repositories in close proximity.

Canada's Nuclear Waste Management Organization (NWMO) is in the process of selecting a site for a repository for the country's used nuclear fuel, through a long-term program called Adaptive Phased Management. Nine out of an original 21 communities that expressed an interest in the NWMO repository are still involved in the process, but no site has yet been selected.

OPG said the conclusions on cumulative effects presented in its environmental impact statement for the Bruce repository remained valid. The updated analysis showed no potential for likely adverse cumulative effects, and also showed cumulative effects as a result of malfunctions, accidents, and malevolent acts related to both repository projects would be unlikely, it added.

The Canadian Nuclear Safety Commission is assisting the Canadian Environmental Assessment Agency (CEAA) in its review of the additional information that is due for completion by 16 January. They aim to determine whether OPG's information is complete and conforms to the ministerial request. CEAA will then open OPG's additional information for public comment. The agency expects to submit its final report to the minister this autumn and a decision on the environmental assessment for the repository will be made at the ministerial level.

*Researched and written
by World Nuclear News*

11. China agrees further Russian fuel reloads for fast reactor

04 January 2017

Russian nuclear fuel manufacturer TVEL has signed a contract with the China Institute of Atomic Energy (CIEA) for the supply of fuel to the Chinese Experimental Fast Reactor (CEFR).

<http://www.world-nuclear-news.org/NN-China-agrees-further-Russian-fuel-reloads-for-fast-reactor-04011701.html>

The sodium-cooled, pool-type fast reactor was constructed with Russian assistance at CIEA, which undertakes fundamental research on nuclear science and technology. The reactor has a thermal capacity of 65 MW and can produce 20 MW in electrical power. The CEFR was built by Russia's OKBM Afrikantov in collaboration with OKB Hidrogress, NIKIET and Kurchatov Institute.

The new agreement, which was signed during a visit to China by a delegation from TVEL last month, covers the supply of two additional batches of fuel assemblies in 2017-2018 with loading into the reactor in 2019.

In a statement on 28 December, TVEL said the contract will enter into force on 10 January and has a value of more than \$50 million.

TVEL and CIEA have worked together since 1999 on fuel supply to the CEFR. During their meeting last month, the two sides confirmed their willingness to deepen their collaboration, TVEL said.

The Russian company has invited managers from CIEA to visit its enrichment plants in the first half of this year, while the Chinese side has invited TVEL president Yury Olenin to visit the institute in April.

The CEFR was started up in July 2010 and was successfully operated at full capacity for the first time in December 2014. Core height is 45 cm, and it has 150 kg Pu (98 kg Pu-239). Temperature reactivity and power reactivity are both negative.

The CEFR project was approved by the Chinese State Council in 1992, with final approval given in 1995. The China Experimental Fast Reactor is one of the major energy projects under the national high-tech research and development program of China's "National 863 Program". CIAE, which is based near Beijing, is the organizer of the project's construction.

*Researched and written
by World Nuclear News*

12. Worldwide nuclear capacity continues to grow in 2016

03 January 2017

Global nuclear generating capacity increased slightly in 2016 to 391.6 GWe net, up from 382.2 GWe at the end of 2015, according to data from the World Nuclear Association. Construction of three large reactor projects also started during 2016, while three units were permanently shut down.

<http://www.world-nuclear-news.org/NP-Worldwide-nuclear-capacity-continues-to-grow-in-2016-0301175.html>

Ten new nuclear power reactors with a combined generating capacity of 9479 MWe came online in 2016. Five of these - Ningde 4, Hongyanhe 4,

Changjiang 2, Fangchenggang 2 and Fuqing 3 - were in China. Unit 3 of South Korea's Shin Kori plant was also connected to the grid, as were India's Kudankulam 2, Pakistan's Chashma 3, Russia's Novovoronezh 6 and the USA's Watts Bar 2.

In 2015, 9497 MWe of new nuclear generating capacity was connected to the grid, while 4763 MWe was added in 2014.

China started construction of the 1080 MWe Tianwan 6 and the 1150 MWe Fangchenggang 4 during 2016. In addition, China General Nuclear also started construction of a 60 MWe floating nuclear power plant project.

Construction was also started last year at unit 3 of Pakistan's Karachi nuclear power plant, where work on unit 2 began in 2015.

Three power reactors with a combined capacity of 1402 MWe were officially shut down in 2016. These were Ikata 1 in Japan, Fort Calhoun in the USA and unit 3 of Russia's Novovoronezh plant. Also in Japan, the government took the formal decision that the Monju prototype fast breeder reactor would not be restarted and steps will be taken to decommission it. The Monju reactor has been offline since 2010.

At the end of 2016, there were 447 reactors operable around the world totalling 391.4 GWe net, and 60 under construction (64.5 GWe gross). This compares with 439 reactors in operation at the end of 2015, with a total 382.6 GWe.

The World Nuclear Association has developed its own vision for the future of electricity, referred to as Harmony. This is based on the International Energy Agency's 2-degree scenario which aims to avoid the most damaging consequences of climate change and requires a large increase in nuclear energy. Harmony envisages a diverse mix of low-carbon generating technologies deployed in such a manner that the benefits of each are maximised while the negative impacts are minimised. The Association's target for nuclear energy is to provide 25% of electricity in 2050, requiring roughly 1000 GWe of new nuclear capacity to be constructed.

*Researched and written
by World Nuclear News*

13. END OF BATTERIES: Huge breakthrough means you'll be able to charge your phone in SECONDS

SCIENTISTS tonight hailed one of the biggest technological advancements in years as they unveiled a revolutionary new gadget which could make batteries redundant forever.

By **NICK GUTTERIDGE**

PUBLISHED: 00:01, Tue, Dec 6, 2016 | UPDATED: 18:14, Tue, Dec 6, 2016

<http://www.express.co.uk/news/science/740174/Battery-breakthrough-supercapacitor-technology-revolutionise-mobile-phones-electric-cars>

British boffins said the futuristic system will allow people to fully charge mobile phones and laptops in seconds and could make petrol powered cars redundant within decades.

Experts predicted it will have a “seismic impact” on people’s everyday lives and said it represents the biggest leap in electrical storage since the battery was invented in 1800.

Dr Ian Hamerton, who led the team of brainboxes behind the project, declared: “We believe that this is an extremely exciting and potentially game-changing development.”

The scientists, from two leading British universities, say they have developed cutting edge high density supercapacitors which will replace the need for batteries in hundreds of everyday appliances.

The technology could rapidly revolutionise mobile phones, tablets and laptops - which are currently constrained both in terms of power and size by the need for batteries.

And it could also provide a massive breakthrough for electric cars, current models of which have failed to capture the public imagination largely because of limited ranges and long recharging times of around eight hours.

Scientists say that, using the new supercapacitors, electrically powered vehicles could travel just as far as a conventional petrol car, and be recharged in the same time it takes to fill up at the pump.

The technology could be used for public transport too. China currently has buses running on rudimentary supercapacitors but, but they are inefficient and need to recharge every two or three stops.

However, following this breakthrough experts say that would be extended to every 20-30 stops, with recharging times also drastically slashed to just a few minutes.

Supercapacitors, which store energy using electrodes and electrolytes rather than chemicals like batteries, have long been hailed as an alternative power source due to their ability to charge and discharge electricity rapidly over very large numbers of cycles.

However, the technology has been held back because of their poor energy density per kilogramme - currently just one twentieth of existing battery technology - meaning they have been unable to perform basic

tasks.

But the new supercapacitors, which have been developed using the same technology applied when making soft contact lenses, are proven to be between 1,000-10,000 times more powerful than existing batteries.

Dr Brendan Howlin from the University of Surrey, which led the research, said: “There is a global search for new energy storage technology and this new ultra capacity supercapacitor has the potential to open the door to unimaginably exciting developments.”

Meanwhile Dr Hamerton, from Bristol University’s Department of Aerospace Engineering, said the new technology had untold possibilities in the field of wearable electronics, like Apple Watch, and advanced optics, such as Google Glass.

Academics from Surrey and Bristol joined together with the private company Augmented Optics Ltd, with the research being initiated with its director Dr Donald Highgate.

Jim Heathcote, the firm’s chief executive, said the test results were so encouraging that production on the new supercapacitors could start in the “very near future”.

He added: “We are now actively seeking commercial partners in order to supply our polymers and offer assistance to build these ultra high energy density storage devices.”

Elon Musk, the billionaire founder of the Tesla electric sports car firm and SpaceX, has previously said that that supercapacitors could even be used to make electric-powered airliners in the future.

14. China Aims to Spend at Least \$360 Billion on Renewable Energy by 2020

By MICHAEL FORSYTHEJAN. 5, 2017

http://www.nytimes.com/2017/01/05/world/asia/china-renewable-energy-investment.html?rref=collection%2Ftimestopic%2FWind%20Power&action=click&contentCollection=energy-environment®ion=stream&module=stream_unit&version=latest&contentPlacement=2&pgtype=collection& r=0

[China](#) intends to spend more than \$360 billion through 2020 on renewable power sources like solar and wind, the government's energy agency [said on Thursday](#).

The country's National Energy Administration laid out a plan to dominate one of the world's fastest-growing industries, just at a time when the United States is set to take the opposite tack as [Donald J. Trump](#), a climate-change doubter, prepares to assume the presidency.

The agency said in a statement that China would create more than 13 million jobs in the renewable energy sector by 2020, curb the growth of greenhouse gasses that contribute to [global warming](#) and reduce the amount of soot that in recent days has blanketed Beijing and other Chinese cities in a [noxious cloud of smog](#).

China surpassed the United States a decade ago as the world's biggest emitter of greenhouse gasses, and now discharges about [twice as much](#). For years, its [oil](#) and coal industries prospered under powerful [political patrons](#) and the growth-above-anything mantra of the ruling Communist Party.

The result was choking pollution and the growing recognition that China, many of whose biggest cities are on the coast, will be threatened by rising sea levels.

But even disregarding the threat of climate change, China's announcement was a bold claim on leadership in the renewable energy industry, where Chinese companies, buoyed by a huge domestic market, are already among the world's dominant players. Thanks in part to Chinese manufacturing, costs in the wind and solar industries are [plummeting](#), making them increasingly competitive with power generation from fossil fuels like coal and natural gas.

Sam Geall, executive editor of [Chinadialogue](#), an English- and Chinese-language website that focuses on the environment, said that the United States, by moving away from a focus on reducing carbon emissions, risked losing out to China in the race to lead the industry.

Mr. Trump has in the past called the theory of human-caused global warming [a hoax](#) and picked a [fierce opponent](#) of President Obama's rules to reduce carbon emissions, Scott Pruitt, the Oklahoma attorney general, to lead the Environmental Protection Agency.

15. Wales' first solar village just got its first tenants

The affordable housing homes in Pembrokeshire could save tenants £2,000 a year in bills

<http://www.walesonline.co.uk/business/business-news/wales-first-solar-village-first-12408604>

The tenants of Wales' first solar powered village are getting the keys to their new homes today.

The affordable housing homes, which are in Glanrhyd, Pembrokeshire, form a village called called Pentre Solar, and have accepted tenants off the council housing register in the county.

Residents of the six timber homes will enjoy smaller bills as a result of the properties having an energy rating of A++ and roof solar panels of producing 6000kWh a year.

The project, the result of a £2m investment by the company, incorporates the latest thinking on eco design from around the world. The Cabinet Secretary for Environment and Rural Affairs, Lesley Griffiths, who will officially open the village today, said that the project will provide much needed housing for local people, while also addressing other issues such as energy efficiency, fuel poverty, skills development and the use of Welsh timber.

"I'm pleased we as a Government were able to financially support the developer with the establishment of their local production facility," said Griffiths.

"I am sure the tenants will be very happy in their new homes with much lower energy and heating costs."

The CEO of Western Solar, the company behind the project, Glen Peters said: "We built this village to demonstrate to sceptical housing providers that people don't have to choose anymore between putting food on the table and keeping warm."

Together with low energy and the use of a shared electric car, tenants can expect to avoid up to £2000 per annum of living costs.

In addition to providing an innovative design the company's strategy is to build sustainably using local supply chains.

By keeping it local it means that 60p of every £1 spent goes directly into the local economy creating jobs and new skills in the area.

The Welsh Government provided the company with £141,000 of business finance to assist with the creation of their production facility

locally, which has create jobs and training opportunities.

The company has ambitious plans to build a thousand homes over the next 10 years. It is looking for partnerships with housing providers and investors to realise this ambition.

"Small businesses hold the key to providing affordable housing as it is clear the large builders have not been able to meet the huge demand for social housing", said Peters.

The homes, which have a modern contemporary design, all have:

- Fitted kitchens and white goods

- Superfast broadband, satellite and Freeview TV connections

- Landscaped gardens

- Access to a shared electric car

- Extremely low energy costs

Here's how they save energy

- They have 11" of insulation

- Use 12% of the energy of a traditional home

- Powered by solar energy

All timber construction

- A monopitch roof (single-sloping roof surface)

80% of space heating needs came from solar energy, achieved by a southerly orientation of the dwelling.

16. Stellarator to be New Face of Fusion Reactors? Physicists Test Magnetic Field Potential

By **Rhenn Anthony Taguam**

Dec 06, 2016 07:07 AM EST

<http://www.natureworldnews.com/articles/33496/20161206/stellarator-new-face-fusion-reactors-physicists-test-magnetic-field-potential.htm>

Physicists are starting to look toward stellarators as the new model of future fusion reactors by observing the potential of utilizing magnetic fields.

According to [Phys.org](#), Sam Lazerson of the U.S. Department of

Energy's Princeton Plasma Physics Laboratory (PPPL) and German scientists are experimenting with the Wendelstein 7-X (W7-X) fusion energy device called a stellarator.

The findings reveals an "error field" or a deviation from the design of less than a part in 100,000. These results can point towards the verification of just how feasible are stellarators as reactors.

[W7-X](#) is the largest and most sophisticated stellarator in the world. It was finished in 2015 by the Max Planck Institute as the vanguard for stellarator design.

Stellarators are able to confine the hot charged gas that is plasma into its twisty (or 3-D) magnetic fields. This is vastly dissimilar to the symmetrical or 2-D fields that tokamaks create.

This twisty configuration will enable stellarators to control the plasma without any need to induce the gas, unlike in tokamaks. This means stellarators run little risk of being disrupted and shut down, which commonly happens in tokamaks.

The PPPL designed and delivered five barn door-sized coils to fine-tune the magnetic fields. An electron beam is fired along the lines. Afterwards, a cross-section of the entire surface is obtained by a fluorescent rod to intersect and sweep through the lines.

This "cage" not only highlights the efficiency in design but also the cooperation of the United States to the endeavor.

The results revealed a fidelity to the design of the magnetic field. The discrepancy means the stellarator is incredibly accurate not just in the engineering of a fusion device, but in the measurement of magnetic topology as well.

The W7-X is the most recent of the stellarator concept. According to [Phys.org](#), the concept was originally designed by Lyman Spitzer from Princeton University, and also the founder of PPPL, in the 1950s. The stellarators gave way to tokamaks a decade later, as its doughnut shape is easier to design and build.

Interestingly, the interest in stellarators has developed some decades later after advancements in plasma theory. Experiments with the W7-X can finally reveal if stellarators may be the right step for fusion energy

utilization.

17. Shattering fusion records during the last months of 2016

Fusenet – The European Fusion education Network

<http://www.fusenet.eu/node/1210>

In pursuit of nuclear fusion as a viable and clean energy source for future use, scientists and engineers are continuously pushing the boundaries of science. Groundbreaking research leads to higher plasma pressures and temperatures, a better confinement and longer pulse durations. In that respect, the past couple of months have been a very successful by shattering some of the previous fusion records, making sure to end the year 2016 with a bang.

60 seconds of non-inductive H-mode confinement in EAST, China

The Experimental Advanced Superconducting Tokamak (EAST) in Hefei, China, has achieved a steady-state, non-inductive H-mode plasma discharge which lasted over a minute. This discharge, which took place in November during the 11th EAST experimental campaign, broke the world record for longest non-inductive pulse for H-mode confined plasmas. By doing so, EAST doubled the previous confinement record, which was already in the hands of EAST when the machine managed to run a 32 second discharge in 2012. In order to achieve the sustained H-mode confinement which resulted in the new record, EAST relies on its ITER-like RF heating system as well as NBI and lower hybrid current drive systems.

70 seconds of non-inductive H-mode confinement in KSTAR, Korea

The Korea Superconducting Tokamak Advanced Research (KSTAR) of the National Fusion Research Institute (NFRI) in Daejeon, South Korea, managed to raise the bar even higher by breaking the brand new confinement record within a month time. The KSTAR team succeeded to keep a high-performance H-mode plasma stable for 70 seconds. The

record-winning confinement has been achieved by operating the device in the so-called 'high poloidal beta scenario', which uses a high-power neutral beam in combination with several other techniques, including the use of a rotating 3D field to alleviate the accumulated heat fluxes on the plasma-facing components.

2 atmosphere of plasma pressure in Alcator C-Mod, USA

A high confinement is key to reach plasma ignition, but plasma pressure, which is the product of plasma temperature and density, is just as important. During its last day of operation, the [Alcator C-Mod](#) tokamak at the Massachusetts Institute of Technology (MIT) has reached a plasma pressure of roughly 2 atmosphere, breaking the previous world record of 1.77 atmospheres, which dated from 2005 and was also set by Alcator C-Mod.

The record-winning discharge was achieved by using the high-magnetic-field approach, having a central magnetic field of about 5.7 T, which is more than double the magnetic field strength that is typically being used in other machines. The resulting temperature inside the tokamak reached over 35 million degrees Celsius, which is about twice the core temperature of the sun, during a pulse lasting two full seconds.

For more information, please refer to the press releases of the involved institutes:

[IPP CAS: EAST Achieves Longest Steady-state H-mode Operations](#)

[NFRF: Unprecedented Progress in Fusion Plasma Research in KSTAR](#)

[MIT: New Record for Fusion](#)

18. Top 10 PPPL stories that you shouldn't miss

January 6th, 2017

<http://phys.org/wire-news/245161562/top-10-pppl-stories-that-you-shouldnt-miss.html>

The past year saw many firsts in experimental and theoretical research at the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL). Here, in no particular order, are 10 of the Laboratory's top findings in 2016, from the first results on the National Spherical Torus Experiment-Upgrade to a new use for Einstein's theory of special relativity to modeling the disk that feeds the supermassive black hole at the center of our galaxy.

1. First results of the National Spherical Torus Experiment-Upgrade (NSTX-U)

The NSTX-U recorded important findings during its first 10 weeks of operation, before shutting down for repairs. Results ranged from rapidly achieving high plasma confinement, a superior regime for plasma performance, to swiftly surpassing the maximum field strength of its predecessor prior to the upgrade. The nearly four-year overhaul doubled the heating capacity and field strength of the NSTX-U, making it the most powerful spherical torus device in the world.

2. Collaborating on fusion facilities around the world

PPPL contributes heavily to worldwide fusion experiments. PPPL leads all U.S. collaborators on the Wendelstein 7-X stellarator in Germany, and played a key role in confirming the accuracy of the twisty, 3D magnetic fields that distinguish stellarators from 2D tokamak devices. The Lab leads studies on avoiding disruptions on KSTAR, the major tokamak in South Korea, and heads a multi-institutional project to study plasma-material interaction on China's EAST tokamak. Domestically, PPPL collaborations on the DIII-D tokamak at General Atomics this year have ranged from analyzing the behavior of the crucial edge of fusion plasmas to coupling our flagship TRANSP fusion analysis code to a GA code to make TRANSP widely available to beginners and experts alike.

3. Unraveling the source of rapid reconnection

Scientists have puzzled for decades over what causes magnetic reconnection, a universal process that sets off solar flares, northern lights and geomagnetic storms, to develop so much faster than theory says it should. Recent findings at PPPL suggest the answer lies in electrically charged plasma sheets that break up into tiny magnetic islands called "plasmoids" that evolve from quiescent to explosive stages. This process, which roughly follows a principle laid out by 17th century mathematician Pierre de Fermat, accelerates magnetic reconnection, which occurs when the magnetic field lines in plasma converge and violently snap apart.

4. Applying Einstein and quantum mechanics to astrophysical mysteries

Pulsars, collapsed stars that orbit a cosmic companion and flash like lighthouses in the sky, have many properties that defy detailed explanation. Researchers at PPPL and Princeton have combined Albert Einstein's theory of special relativity with the theory of quantum mechanics to portray several of the qualities. The new method infers the

strength of the magnetic field and density of the plasma that surrounds pulsars with greater precision than standard approaches can show. This method, based on the complex behavior of plasma waves, can also infer such properties for the plasma created by inertial fusion, which uses lasers to vaporize a target that contains plasma fuel.

5. Delivering power and diagnostics to ITER

The United States is a key contributor to ITER, the international fusion experiment under construction in France to demonstrate the feasibility of fusion power. PPPL is an important participant in the experiment. During the past year the Laboratory completed delivery of new major components for the steady state electrical network that will power the complex plant's electrical loads, with the exception of the pulsed loads that will power the heating, current and magnetic fields inside the giant tokamak itself. PPPL also furthered development of designs for seven diagnostic instruments that the U.S. will provide to ITER to observe, record and analyze data from its experiments.

6. First steps toward a possible technique for facilitating disarmament agreements

The Laboratory and Princeton University successfully completed a novel experiment for a system that, when fully developed, could prove useful in future disarmament talks. The experiment translated a method called "zero-knowledge protocol" that is employed in cryptography into use in a physical system. The aim of this system is to determine, without tapping into classified information, whether objects to be dismantled are true nuclear warheads. The experiment successfully distinguished between "true" and "false" patterns of 2-inch steel and aluminum cubes without revealing any information about the composition and configuration of the cubes. While far more development will need to be done, the test marked a promising beginning.

7. Creating a framework for improving high-intensity particle accelerator beams

Accelerator beams consist of billions of charged particles that are used in scientific experiments to strike other particles with enormous intensity and generate subatomic particles not seen since the early universe. However, mutual repulsion of the particles and imperfections of accelerators tend to degrade the beam, so the walls of large devices are lined with high-precision magnets to control the motion. Now

researchers at PPPL, South Korea and Germany have teamed up to develop a theoretical framework for optimizing the beams. The new method contrasts with standard approaches, which treat the horizontal and vertical motions of the charged particles as uncoupled. Instead, the new system couples all forces and elements that can stabilize the beam, and the results agreed well with simulation of a German experiment that illustrated a technique for manipulating the beams of future accelerators.

8. Modeling the accretion disk that feeds the black hole at the center of our galaxy

As the accretion disk that orbits the supermassive black hole at the center of the Milky Way spirals into the hole, the plasma particles that comprise it emit far less radiation than the disks that flow into many other black holes. The question is why, since feeding black holes can create some of the brightest and most energetic radiation in the universe, and the huge Milky Way hole has four million times the mass of our sun. To help find the answer, scientists at PPPL and Princeton University have developed a rigorous new method for modeling the disk around the gigantic Milky Way hole, which is called Sagittarius A*. The particles inside this disk's plasma rarely collide, compared with the frequent collisions of particles in other disks. So tracing the movements of individual collisionless particles in Sagittarius A*, rather than relying on standard formulas that treat the plasma in collisional disks as a fluid, could produce improved predictions of how the Sagittarius A* disk will behave when compared with astrophysical observations.

9. A shot-by-shot look at what happens when plasma meets walls

Of crucial importance to the production of fusion energy is the contact during experiments—or shots—between particles of the hot plasma that fuels fusion reactions and the walls that enclose the magnetically confined gas. Such contact can erode the walls of a fusion facility and recycle the particles back into the core of the plasma, cooling it down and halting fusion reactions. At PPPL, physicists have collaborated with a consortium that includes Princeton University and the University of Illinois at Urbana-Champaign to successfully test a unique diagnostic called a Materials Analysis Particle Probe (MAPP) that swiftly analyzes what happens when plasma meets a tokamak's walls. The diagnostic, tested on a shot-by-shot basis on the NSTX-U at PPPL, could become an integral part of fusion research and lead to optimal methods of conditioning a facility's walls.

10. Gauging the speed of fusion plasma rotation

The superhot plasma that fuels fusion reactions swirls rapidly during experiments—but how fast is it spinning and why do researchers want to know? At PPPL, physicists have developed a real time velocity diagnostic that delivers crucial information about the speed of the swirl that could lead to a system for actively controlling the rapid motion. Such control can be critical for optimizing the stability of the plasma against a range of instabilities that can shut down reactions. Researchers gathered their findings by measuring just four points of the plasma during NSTX-U operations, enabling the diagnostic to swiftly calculate how the velocity evolves over time.

Provided by Princeton Plasma Physics Laboratory

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19. A new twist on fusion power could help bring limitless clean energy

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Matthew Hole Senior Research Fellow, Plasma Research Laboratory, Australian National University

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Matthew Hole receives funding from the Australian Research Council and the Australian National University. Matthew is also the inaugural Chair of the Australian ITER Forum, a consortium of over 180 scientists and engineers in support of an Australian engagement in ITER, a member of the IAEA International Fusion Research Council, and Vice Chair of the Division of Plasma Physics of the Association of Asia Pacific Physics Societies.

<http://theconversation.com/a-new-twist-on-fusion-power-could-help-bring-limitless-clean-energy-70324>

In a world struggling to kick its addiction to fossil fuels and feed its

growing appetite for energy, there's one technology in development that almost sounds too good to be true: nuclear fusion.

If it works, fusion power offers vast amounts of clean energy with a near limitless fuel source and virtually zero carbon emissions. That's if it works. But there are teams of researchers around the world and billions of dollars being spent on making sure it does.

In February last year a new chapter of fusion energy research commenced with the formal opening of [Wendelstein 7-X](#). This is an experimental €1 billion (A\$1.4bn) fusion reactor built in Greifswald, Germany, to test a reactor design called a [stellarator](#).

It is planned that by around 2021 it will be able to operate for up to 30 minutes duration, which would be [a record](#) for a fusion reactor. This is an important step en-route to demonstrating an essential feature of a future fusion power plant: continuous operation.

But the W-7X isn't the only fusion game in town. In southern France [ITER](#) is being built, a \$US20 billion (A\$26.7bn) experimental fusion reactor that uses a different design called a [tokamak](#). However, even though the W-7X and ITER employ different designs, the two projects complement each other, and innovations in one are likely to translate to an eventual working nuclear fusion power plant.

Twists and turns

Fusion energy seeks to replicate the reaction that powers our Sun, where two very light atoms, such as hydrogen or helium, are fused together. The resulting fused atom ends up slightly lighter than the original two atoms, and the difference in mass is converted to energy according to Einstein's formula $E=mc^2$.

The difficulty comes in encouraging the two atoms to fuse, which requires them to be heated to millions of degrees Celsius. Containing such a superheated fuel is no easy feat, so it's turned into a hot ionised gas – a plasma – which can be contained within a magnetic field so it doesn't actually touch the inside of the reactor.

What makes the W-7X particularly interesting is its stellarator design. It comprises a vacuum chamber embedded in a magnetic bottle created by a system of 70 superconducting magnet coils. These produce a powerful magnetic field for confining the hot plasma.

Stellarators and tokamaks are both types of toroidal (doughnut-shaped) magnetic confinement devices that are being investigated for fusion power. In these experiments a strong toroidal (or ring) magnetic field creates a magnetic bottle to confine the plasma.

However, in order for the plasma to have good confinement in the

doughnut-shaped chamber, the magnetic field needs to have a twist. In a tokamak, such as in the ITER reactor, a large current flows in the plasma to generate the required twisted path. However, the large current can drive “kink” instabilities, which can cause the plasma to become disrupted.

If the plasma is disrupted, the reactor needs to be flooded with gas to quench the plasma and prevent it from damaging the experiment.

In a stellarator, the twist in the magnetic field is obtained by twisting the entire machine itself. This removes the large toroidal current, and makes the plasma intrinsically more stable. The cost comes in the engineering complexity of the field coils and reduced confinement, meaning the plasma is less easily contained within the magnetic bubble.

Come together

While the W7-X and ITER use different approaches, most of the underlying technology is identical. They are both toroidal superconducting machines, and both use external heating systems such as radio frequency and neutral beam injection to heat the plasma, and much of the plasma diagnostic technology is in common.

In a power plant, heavy isotopes of hydrogen (deuterium and tritium) fuse to form helium along with an energetic neutron.

While the helium is contained within the plasma, the neutron is has a neutral electric charge, and shoots off into the “blanket” surrounding the plasma. This heats it up, which in turn drives a steam turbine that generates electricity.

A common feature across fusion power is the need to develop materials that can withstand the high heat and fast neutrons generated by the fusion reaction. Regardless of design, the first wall of a fusion reactor has to withstand a massive bombardment from high energy particles throughout its lifetime.

At this stage, it’s too early to tell whether the tokamak design used by ITER or the stellarator used by W-7X will be better suited for a commercial fusion power plant. But the commencement of research operation of W-7X will not only help decide which

technology might be best to pursue, but will contribute valuable knowledge to any future fusion experiments, and perhaps one day a true energy revolution.