Australian ITER Forum Website News Update 3/18

B.J.Green (16/3/18)

1. NEWS RELEASE

http://investors.cray.com/phoenix.zhtml?c=98390&p=irol-newsArticle&ID=2338097

CRAY TAPPED TO DELIVER LARGEST SUPERCOMPUTER DEDICATED TO FUSION SCIENCE IN JAPAN BY NATIONAL INSTITUTES FOR QUANTUM AND RADIOLOGICAL SCIENCE AND TECHNOLOGY

SEATTLE, March 14, 2018 (GLOBE NEWSWIRE) -- Global supercomputer leader Cray Inc. (Nasdaq:CRAY) today announced that the National Institutes for Quantum and Radiological Science and Technology (QST) selected a Cray XC50™ supercomputer to be its new flagship supercomputing system. The new system is expected to deliver peak performance of over 4 petaflops, an increase of more than 2 times the system it is replacing. It will support QST in powering complex calculations for plasma physics (turbulence, edge physics, integrated modeling) and fusion technology, and will be the largest supercomputer used specifically for nuclear fusion science in Japan.

The Cray XC50 supercomputer will be installed at the Rokkasho Fusion Institute in Japan. The Cray supercomputer will replace Helios, the Institute's prior supercomputer used for the Broader Approach project between the European Atomic Energy Community (Euratom) and Japan. The supercomputer will accelerate the realization of fusion energy through R&D and advanced technologies project and will complement the ITER project, a worldwide collaboration designed to demonstrate the scientific feasibility of fusion power as an environmentally responsible energy source.

“We’re looking forward to delivering a supercomputer for QST that will further the Institute’s work in discovering opportunities for fusion power as a reliable energy source,” said Mamoru Nakano, president of Cray Japan. “The speed and integrated software environment of the Cray XC50 will enhance QST’s infrastructure and allow researchers to speed time to discovery.”

QST will be providing more than 1,000 European and Japanese fusion researchers with the high-performance computing technology required to advance game-changing research in fusion power. The Cray system will provide the performance and scale necessary to support QST researchers in running complex plasma calculations as part of the ITER project.

The Cray XC series of supercomputers are designed to handle the most challenging workloads requiring sustained multi-petaflop performance. The Cray XC supercomputers incorporate the Aries high-performance network interconnect for low latency and scalable global bandwidth, the HPC-optimized Cray Linux Environment, the Cray programming environment consisting of powerful tools for application developers, as well as the latest Intel® processors and NVIDIA® GPU accelerators. The Cray XC supercomputers deliver on Cray’s commitment to performance supercomputing with an architecture and tightly-integrated software environment that provides extreme scalability and sustained performance.

The system is expected to be put into production in 2018.

For more information on the Cray XC™ supercomputers, please visit the Cray website at www.cray.com.

About Cray Inc.

Global supercomputing leader Cray Inc. (Nasdaq:CRAY) provides innovative systems and solutions enabling scientists and engineers in industry, academia and government to meet existing and future simulation and analytics challenges. Leveraging more than 40 years of experience in developing and servicing the world’s most advanced supercomputers, Cray offers a comprehensive portfolio of supercomputers and big data storage and analytics solutions delivering unrivaled performance, efficiency and scalability. Cray’s Adaptive Supercomputing vision is focused on delivering innovative next-generation products that integrate diverse processing technologies into a unified architecture, allowing customers to meet the market's continued demand for realized performance. Go to www.cray.com for more information.

Safe Harbor Statement

This press release contains forward-looking statements within the meaning of Section 21E of the Securities Exchange Act of 1934 and Section 27A of the Securities Act of 1933, including, but not limited to, statements related to the timing and delivery of the system ordered by QST and Cray's ability to deliver a system that meets QST's requirements. These statements involve current expectations, forecasts of future events and other statements that are not historical facts. Inaccurate assumptions and known and unknown risks and uncertainties can affect the accuracy of forward-looking statements and cause actual results to differ materially from those anticipated by these forward-looking statements. Factors that could affect actual future events or results include, but are not limited to, the risk that the system required by QST is not delivered in a timely fashion or does not perform as expected and such other risks as identified in the Company's annual quarterly on Form 10-K for the year ended December 31, 2017, and from time to time in other reports filed by Cray with the U.S. Securities and Exchange Commission. You should not rely unduly on these forward-looking statements, which apply only as of the date of this release. Cray undertakes no duty to publicly announce or report revisions to these statements as new information becomes available that may change the Company's expectations.

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Cray Inc

2. The Guardian view on nuclear fusion: a moment of truth

Editorial

https://www.theguardian.com/commentisfree/2018/mar/12/the-guardian-view-on-nuclear-fusion-a-moment-of-truth

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ne of the cliches of nuclear power research is that a commercial fusion reactor is only ever a few decades away – and always will be. So claims that the technology is on the "brink of being realised" by scientists at the Massachusetts Institute of Technology and a private company should be viewed sceptically. The MIT-led team say they have the "science, speed and scale" for a viable fusion reactor and believe it could be up and running within 15 years, just in time to combat climate change. The MIT scientists are all serious people and perhaps they are within spitting distance of one of science's holy grails. But no one should hold their breath. Fusion technology promises an inexhaustible supply of clean, safe power. If it all sounds too good to be true, that's because it is. For decades scientists struggled to recreate a working sun in their laboratories – little surprise perhaps as they were attempting to fuse atomic nuclei in a superheated soup. Commercial fusion remains a dream. Yet in recent years the impossible became merely improbable and then, it felt almost overnight, technically feasible. For the last decade there has been a flurry of interest –and not a little incredulity –about claims, often made by companies backed by billionaires and run by bold physicists, that market-ready fusion reactors were just around the corner.

There are reasons to want to believe that fusion will one day be powering our lives. The main fuel is a heavy isotope of hydrogen called deuterium which can be extracted from water and therefore is in limitless supply – unlike the uranium used in nuclear fission reactors. But fusion's science is tricky and the breakthroughs rare. So far there has been no nuclear fusion reaction that has been triggered, continued and self-sustained. Neither has the plasma soup that exists at temperatures found in the stars been magnetically contained. Nor has any research group sparked a fusion reaction that has released more energy than it consumed, one of the main attractions of the technology. Perhaps the most successful fusion reactor has been the JET experiment, so far Europe's largest fusion device, which ended up in the UK after the SAS stormed a hijacked German airliner in 1977 and Bonn backed the then prime minister Jim Callaghan's request to host it. JET hasn't even managed to break even, energy-wise. Its best ever result, in 1997, remains the gold standard for fusion power – but it achieved just 16 MW of output for 25 MW of input.

Hopes for fusion now rest with the International Thermonuclear Experimental Reactor (Iter), a multi-national $20bn effort in France to show that the science can be made to work. Within a decade Iter aims to control a hydrogen bomb-sized atomic reaction for a few minutes. It is a vast undertaking. At its heart is a doughnut-shaped device known as a tokamak that weighs as much as three Eiffel towers. Iter's size raises a question of how large a "carbon footprint" the site will leave. Like JET, Iter uses a fusion fuel which is a 50-50 mixture of deuterium and a rare hydrogen isotope known as tritium. To make Iter self-sustaining it will have to prove that tritium can be "bred", a not inconsiderable feat. Iter will also test how "clean" a technology fusion really is. About 80% of a fusion reaction's energy is released as subatomic particles known as neutrons, which will smash into the exposed reactor components and leave tonnes of radioactive waste. Just how much will be crucial in assessing whether fusion is a dirty process or not.
Iter's worth is that it is a facility in the real world, where fusion's promise can be tested. If it turns out to be

better than expected then private investment is going to be needed to commercialise a fusion reactor. If it falls short then there must be a realistic rethink of fusion's potential. After all, the money that has been poured into it could have been spent on cheap solar technology which would allow humanity to be powered by a fusion reactor that's 150m kilometres away, called the sun.

3. Science Committee Seeks Renewed Commitment to Fusion Research

Publication date:
9 March 2018

https://www.aip.org/fyi/2018/science-committee-seeks-renewed-commitment-fusion-research

A House Science Committee hearing this week showcased committee members' ongoing support for fusion energy research and U.S. participation in the France-based ITER project currently under construction. The committee also discussed the consequences of proposed cuts to the budget for inertial confinement fusion research.

On March 6, the Energy Subcommittee of the House Science Committee welcomedfour leaders from the nuclear fusion research community: Bernard Bigot, the director-general of the France-based ITER project; James Van Dam, acting head of the Department of Energy Fusion Energy Sciences program; Mickey Wade, director of advanced fusion systems at General Atomics; and Mark Herrmann, director of the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory.

In recent years, the committee has shown strong, bipartisan support for fusion energy research. In his opening statement, Committee Chair Lamar Smith (R-TX) lauded fusion's potential to *"reduce carbon emissions by a huge amount with major implications for climate change."* Although Smith has strongly criticizedclimate science, he often promotes technology as a means of achieving environmental goals without new regulation. He went on, *"While we cannot predict when fusion will be a viable part of our energy portfolio, it is clear that this is critical basic science that could benefit future generations."*

Much of the hearing was dedicated to the prospects of current fusion programs. However, Van Dam noted that DOE is also planning future research directions based on a variety of strategic exercises. These, he reported, will include the National Academies strategic planning study on burning plasma currently underway and a decadal survey for plasma science that will launch soon with the aim of releasing its report in 2020.

Wade testified that U.S. leadership in fusion science is in danger as other nations increase their emphasis on the area. He said the U.S. needs a comprehensive strategic plan to capitalize on current work and set the nation on an *"aggressive, distinctive pathway to fusion energy,"* which would include investment in *"world-class research capabilities."*

A primary focus of the hearing was U.S. participation in the France-based ITER magnetic confinement fusion (MCF) project, which aims to produce fusion reactions at full power in 2035.

The last time the Science Committee addressed fusion research, in March 2016, U.S. participation in ITER was in doubt due to concerns about its management. Shortly thereafter, DOE recommended continued support through fiscal year 2018 and to reassess the situation before the fiscal year 2019 budget request. Meanwhile, spurred by skeptical Senate appropriators, Congress took even stronger steps, withholding U.S. cash contributions to the project (but not in-kind contributions of equipment), beginning with fiscal year 2016 appropriations.

The issue of U.S. participation remains unresolved. Currently, the Trump administration is proposing to provide $75 million in in-kind contributions for fiscal year 2019. It is leaving a decision on U.S. participation beyond that to a comprehensive review of civil nuclear activities currently underway.

At the hearing, Smith reiterated his support for full participation. He noted that under the U.S. commitment to fund 9 percent of ITER's costs, DOE is supposed to provide $163 million in in-kind contributions and $50 million in cash contributions in fiscal year 2019. He warned that falling short would lead to construction delays and cost increases and it could also jeopardize other scientific collaborations and damage the position of U.S. research. He said,

With countries like India, Japan, China, and Russia partnering through ITER to produce and share cutting-edge fusion research, we cannot afford to lose our seat at the table. In addition, we cannot expect to receive international support for our domestically hosted global research projects, like the high-priority Long-Baseline Neutrino Facility at Fermilab, if we do not honor our international obligations.

Subcommittee Chair Randy Weber (R-TX) asked Bigot about the impacts of the U.S. failing to meet its commitments. Bigot replied that U.S. cash contributions are needed to keep the project on budget and particularly stressed the importance of U.S. in-kind contributions, saying that *"if a component is not on-site and under specification, on time, it will stop the whole project."*

Aside from testifying at the hearing, Bigot has been visiting U.S. stakeholders, warning that if DOE does not uphold its commitments, ITER might have to announce a delay as early as June, which would raise costs for other partner nations. In his written testimony and in an exchange with Rep. Bill Foster (D-IL), Bigot sought to assure the committee that management reforms he had undertaken after taking over ITER in 2015 had placed the project on a sound footing.

Rep. Zoe Lofgren (D-CA), sitting in as subcommittee ranking member, argued it is no longer justifiable to withhold contributions, saying,

Given the remarkably impressive progress made by Dr. Bigot and his team in getting this project back on track, [the president's] budget request now essentially undermines all of our prior efforts and could end up causing the problems that we worked so hard to resolve.

Except for Rep. Dana Rohrabacher (R-CA), no committee member questioned whether ITER would fulfill its promise as a crucial step to realizing fusion energy. Asked by Rep. Neal Dunn (R-FL) why scientists are confident in ITER, Wade replied that the high level of confidence is rooted in research done to date. He remarked, *I have worked in this field a long time and I have watched the progression of our understanding. And I believe our understanding is sufficient to have high confidence if ITER with its systems can deliver the technical capability, the physics will be there to deliver the power that is projected.*

Consequences of cuts to inertial confinement fusion explored

Another focus of the hearing was inertial confinement fusion (ICF), which uses high-energy lasers to compress thermonuclear fuel pellets so that the nuclei of their constituent atoms fuse together. Currently, NIF is the world's leading institution for ICF research.

The Trump administration is proposing to cut the budget of the National Nuclear Security Administration's ICF program by over $100 million, or 20 percent. Within that, the budget for efforts to achieve ignition, a self-sustained thermonuclear reaction, would be cut by over 70 percent, from $78 million to $22 million. Support for academic research in high energy density laboratory plasmas would be eliminated, and NNSA would begin a three-year withdrawal of funding for the Laboratory for Laser Energetics (LLE) at the University of Rochester.

Herrmann said the proposed cuts would disrupt the progress of NIF experiments necessary for NNSA's Stockpile Stewardship Program and shut down the pipeline of students and early-career researchers that replenishes the ICF workforce.

He also advocated for vigorously pursuing ignition, not only because of its usefulness in stockpile stewardship but also because of ICF's potential as an energy source. While noting that NNSA does not pursue energy R&D, he pointed to a conclusion of a 2013 National Academies report that the appropriate time to initiate a large-scale inertial fusion energy program would be once ignition is achieved. A 2016 NNSA report suggested NIF might never be able to achieve ignition and set a goal of 2020 to assess the facility's efficacy for doing so. Herrmann said NIF remains on track to meet that goal and expressed optimism that ignition would ultimately prove feasible.*

Lofgren, whose district is close to Livermore, recounted her 25-year interest in fusion energy and NIF, and expressed support for pursuing both ICF and MCF as paths to fusion energy.

Rep. Paul Tonko (D-NY), the only committee member from New York, spoke in favor of LLE and asked the witnesses if they knew the rationale for shutting it down. Herrmann replied that the budget request indicated there are *"higher priorities"* but said he had heard no further details in his communications with DOE.

***Correction:** This sentence originally incorrectly stated that Herrmann said NIF is on track to achieve ignition by 2020.

4. The New Atomic Age: Nuclear Fusion And Beyond

By Gary Norman - Mar 10, 2018, 2:00 PM CST

https://oilprice.com/Alternative-Energy/Nuclear-Power/The-New-Atomic-Age-Nuclear-Fusion-And-Beyond.html

The energy market is undoubtedly in a state of flux. The current power play between the U.S., OPEC and Russia is symptomatic of the changing geopolitical and economic dynamics of the entire market, U.S. tight oil seems set to completely upset the apple cart, and rapid technological advances are putting hitherto unattainable reserves within our reach. These are just a few of the factors that are currently calling to question everything we know about the market, but perhaps the biggest paradigm shift is still on the horizon - the shift from fossil fuels to clean energy.

When we think of clean energy we usually discuss wind, solar, hydro and geothermal. Hydro and geothermal are extremely good sources of reliable energy, but they are of course location specific, meaning you either have access to it or you don't. Another type of clean energy that has enormous potential is wave, or ocean energy. However, as of writing, this potential is yet to be cost effectively harnessed. Although we are making great strides in this field, we can hardly include it as an energy game changer until we see much more substantial progress.

That leaves us with solar and wind energy. Solar can be split into several types, most notably photovoltaic solar energy and solar hot water. Aside from issues with efficiency, wind and solar share a common problem - availability. We can only generate power when the sun is shining or the wind is blowing, and that means that we cannot rely on them as a primary power source. Efficiency is constantly being improved in both areas, and breakthroughs in energy storage mean that both systems are on their way to usurping the dominance of fossil fuels. That day is still a long way off, so for now at least, it seems fossil fuels are in complete control. But what about atomic power? What happened to the promise of clean, inexpensive and abundant energy that so many households in the 50s were seduced by?
While some may argue that nuclear fission is vastly cleaner than the burning of fossil fuels, incidents like Chernobyl and Fukushima are still very fresh in our minds. Indeed it is Fukushima that led to a dramatic shift in German energy policy which has set them on a path to completely phase out its nuclear reactors by 2022. Germany is certainly not alone in this decision, and with phasing out being the rule rather than the exception, we appearto be at the end of the era of atomic power.
Related: Saudi Arabia Plans Its Own Shale Revolution
This is where another player steps in - nuclear fusion. Nuclear fission generates energy by the splitting of large and unstable isotopes (atoms with the same number of protons but different number of neutrons) into smaller ones, which in turn go on to create a chain reaction. Fusion occurs when 2 light isotopes are combined to create a single heavier isotope, and a much vaster amount of energy. The major disadvantages of fission are the byproduct of radioactive waste, and the potential for the failure of containment of the chain reaction, such as happened in Chernobyl.

The reason it has taken us so long to turn to fusion is the extremely high temperatures and pressures involved. In order to successfully create a fusion reactor we need to heat and pressurize plasma to equal those found on the surface of the sun. Perhaps surprisingly, it is not achieving this heat that is the challenge, it is sustaining it.

Now it seems that feat is within our grasp. Scientists from 35 nations are currently building the International Thermonuclear Experimental Reactor (Iter) in Southern France. This vast and extremely complex undertaking is currently at around 50 percent completion, putting the team on course for their initial firing, when they will generate 'first plasma'. This plasma will reach 150,000,000?C, which is ten times hotter than the sun, and then be contained in giant magnets that are cooled to -269?C. Should this test be successful, the team anticipate that we could see our first fusion reactors coming online by 2040.

Director general of ITER, Dr Bernard Bigot talked with no uncertainty about fusion being a viable energy source that will replace fossil fuels, going on to say that "[p]roviding clean, abundant, safe, economic energy will be a miracle for our planet." This may sound very familiar to those that were sold on the idea of nuclear fission, but we will soon see whether the new atomic age can deliver where the previous one failed.
By Gary Norman for Oilprice.com

5. Halfway to reality

7 March 2018

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Ten years after its inception, the international Iter project has passed the halfway mark. Judith Perera reviews the progress.

http://www.neimagazine.com/features/featurehalfway-to-reality-6074991/

THE ITER ORGANISATION CELEBRATED ITS 10th anniversary in 2017 after what it described as "a very significant year." The project, which is being built in Cadarache, southern France by a scientific partnership of 35 countries also passed the halfway mark towards first plasma. It will be the world's largest experimental tokamak fusion facility. Europe contributes almost half of the construction costs (45.6%), while the other six members – China, India, Japan, South Korea, Russia and the United States – contribute equally to the rest (9.1% each).
All the milestones set by the Iter Council were met in 2017. Preparation for machine assembly has begun and the cryoplant, the twin magnet power conversion buildings, and the cooling tower zone have received their first equipment. In factories on three continents, Iter members continued to manufacture strategic Iter components that were delivered to the site as planned. In the Poloidal Field Coil Winding Facility, Europe began manufacturing the fifth poloidal field coil. Nearby in the Cryostat Workshop, Indian contractors started work on a second cryostat section—the lower cylinder—and continued to advance welding and nondestructive examination testing of the cryostat base.
When the Iter project was formally launched in 2007 the estimated cost was €5bn. Construction began in 2010 but there have been delays. First plasma, originally scheduled for 2018, and the start of deuterium-tritium operation for 2026 were deferred until November 2019 and March 2027, respectively. By 2011, the budget forecast had risen to about €16bn and in May 2016 newly appointed Iter chief Bernard Bigot said the project would be delayed by more than a decade and incur cost overruns of another €4bn, estimating the overall cost to commissioning to be at least €18bn ($22bn).
More than 80% of the cost of Iter is contributed as components manufactured by the partners. Many of these massive components of the Iter machine must be precisely fitted—for example, 17-metre-high magnets with less than a millimetre of tolerance. Each component must be ready on time to fit into the Master Schedule for machine assembly. Members asked for this arrangement for three reasons. First, most of the Iter costs paid by any member are paid to that member's companies, which means the funding stays in-country. Second, the companies involved build new industrial expertise in major fields—such as electromagnetism, cryogenics, robotics, and materials science. Third, this new expertise leads to innovation and spin-offs in other fields.

Iter meets its milestones

"For the past two years, we have met every agreed project milestone. This has not happened easily," said Bigot in an end-of-year statement. "A project of this complexity is full of risks; and our schedule to first plasma in 2025 is set with no 'float' or contingency. Effective risk management is a daily discipline at Iter."
Bigot said the design has taken advantage of the best expertise of every member's scientific and industrial base. "No country could do this alone. We are all learning from each other, for the world's mutual benefit. Looking ahead, we will need the commitment and support of every member to maintain this performance."

Plans for 2018 include starting integrated commissioning of an ion source test bed by March. At the PRIMA neutral beam test facility in Padua, Italy, the key technologies of Iter's powerful heating neutral beam system will be tested and qualified on two test beds. The first of these, SPIDER (for Source for the Production of Ions of Deuterium Extracted from a Radio frequency plasma) will be ready for integrated testing during the first quarter of 2018.

Access to the Tokamak assembly area depends on the maturity of Tokamak Building civil works. The target is to finish the bioshield and the concrete crown by the second quarter of 2018 to allow access for the first components to be installed.

The first toroidal field coil is expected to arrive from Japan in the third quarter of 2018. Weighing 310t each, and measuring 9x17m, the toroidal field coils are among the largest components of the Iter machine. Nine will be produced in Japan and ten in Europe (18 and one spare).

The first vacuum vessel sector, measuring over 14m and weighing 440t, is expected to arrive from Korea in the fourth quarter of 2018. Nine sectors in all, supported by the overhead in-pit assembly tool, will be aligned and welded together in the Tokamak assembly pit. Fifty-three port structures will also be welded into place during the assembly of the vacuum vessel.

The final goal is not just circulating plasma [scheduled for 2025], but fusing deuterium and tritium to create a 'burning' plasma that generates significantly more energy than it uses.

Iter's successor, the Demonstration Fusion Power Reactor, or DEMO, will aim to demonstrate the continuous output of energy, supplying electricity to the grid. According to Eurofusion, DEMO is expected to follow Iter by 2050. Currently in the design stages, DEMO must have linear dimensions about 15% larger than Iter and an about 30% greater plasma density.

Work continues at JET

Meanwhile, the UK's Culham Centre for Fusion Energy (CCFE) and the Joint European Torus (JET) have continued experimental work as the precursor to Iter, despite growing concerns about how Brexit may affect the project. JET is operated by the CCFE under a contract between the European Commission and the UKAEA. It is used by all European fusion laboratories in the Eurofusion consortium. The peaceful use of nuclear energy within the EU is governed by the 1957 Euratom Treaty. The UK government has said it intends to leave Euratom as part of the Brexit process, but officials have tried to reassure the nuclear industry that the effect will be minimal. "There is political commitment right across the British government to ensure as much continuity as possible for the nuclear industry," David Wagstaff, deputy director of the Euratom exit at the Department for Business, Energy and Industrial Strategy (BEIS), told delegates at the UK Nuclear Industry Association's annual conference in London in December. BEIS is working "very closely and collaboratively", he said, with the Department for Exiting the European Union.

In December, the UK government announced investment of £86m to fund the building and operation of a National Fusion Technology Platform (NaFTeP) at Culham, which is expected to open in 2020. BEIS said the new funding is part of a series of measures to support the development of 'next-generation nuclear technology', following publication of the government's Industrial Strategy white paper in November. NaFTeP comprises two new centres of excellence: Hydrogen-3 Advanced Technology (H3AT), which will research how to process and store tritium, one of the fuels that will power commercial fusion reactors; and Fusion Technology Facilities (FTF), which will carry out thermal, mechanical, hydraulic and electromagnetic tests on prototype components under the conditions experienced inside fusion reactors. NaFTeP will "provide a powerful signal of the UK's intent to continue its participation in international science collaboration after leaving the European Union", UKAEA said.

UKAEA said the new facilities will help to secure around £1bn ($1.35bn) in contracts from Iter. So far, 38 UK companies have won contracts totalling more than €500m from Iter. Looking ahead, UKAEA said the facilities will enable development of technology for the first nuclear fusion power plants and put UK industry in a strong position to exploit their commercialisation. H3AT and FTF will work closely with the industrial supply chain to create knowledge to position them for the next phase of Iter procurements in areas including the tritium plant, hot cells, measurement systems, assembly, maintenance and reactor materials, UKAEA said. NaFTeP is expected to create around 100 jobs at Culham and many more in the wider nuclear industry supply chain.

Progress in Korea and China

A number of other fusion projects worldwide announced progress during 2017.

The Korean Superconducting Tokamak Advanced Research (KSTAR), a tokamak nuclear fusion reactor, which achieved 70 seconds in high-performance plasma operation at the end of 2016 at South Korea's National Fusion Research Institute (NFRI), has now significantly improved the stability of the elongated plasma in the facility. A team of US and Korean researchers, led by physicist Dennis Mueller of the US Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL), has now sharply improved the stability of the elongated plasma in KSTAR, successfully demonstrating a method to control the vertical instability of the plasma. "As the plasma got taller it moved away from stable operation," Mueller told the 59th annual meeting of the American Physical Society Division of Plasma Physics in October. "The new correction method stops the plasma from bouncing up and down by stabilizing the vertical centre of the plasma. Control of the vertical instability has allowed for taller plasmas in KSTAR than the original design specifications." This was achieved In China, researchers at the Experimental Advanced Superconducting Tokamak (EAST) at the Hefei-based Institute of Plasma Physics announced in July that they had set a world record by achieving 101.2 seconds of steady- state H-mode operation of the tokamak. In 2016, the EAST team achieved over 60 seconds of steady-state long-pulse H-mode discharge of the device. Similar experiments in other countries have created plasmas that lasted longer but were less stable and difficult to control for the purpose of power generation.

In December, the Chinese central government announced it was backing the project for the next-step experimental fusion power station, DEMO, launching a competition among cities in China to host the project. Hefei is hoping to be selected. According to a timetable posted by the Chinese Academy of Sciences, design work on DEMO will continue, and construction will start in 2021. The reactor will be built in parallel with Iter rather than waiting for results from Iter, expected in 2025.

Other technologies

Progress has also been reported from Wendelstein 7-X (W7-X), the world's largest stellarator, which began operating in 2015 at the Max Planck Institute of Plasma Physics in Greifswald, Germany, and is seen as a competitor to tokamak technology. Stellerators also use magnetic confinement, but are designed differently. The W7-X was intended to show that the earlier weaknesses in the stellarator fusion concept had been addressed. In September, experiments resumed at the reactor after a 15-month break. A recent upgrade means it is now capable of higher heat and longer pulses. The device was also fitted with measuring instruments that allowed scientists to track the turbulence in the plasma. "We shall be able for the first time to check whether the promising predictions of theory for a completely optimised stellarator are correct," said project head Thomas Klinger.

An alternative fusion technology to the magnetic confinement technology of the tokamak and stellerator is inertial confinement fusion (ICF) which aims to initiate nuclear fusion reactions by heating and compressing a fuel target using a powerful laser. The largest operational ICF experiment is the National Ignition Facility (NIF) in the USA, which typically uses a pellet containing a mixture of deuterium and tritium as the target. A similar large-scale device in France, Laser Mégajoule, was officially inaugurated in October 2014. However, progress is slow.

Hydrogen-boron fusion might be a faster alternative. In December, in a paper in Laser and Particle Beams, Heinrich Hora from the University of New South Wales (UNSW) in Sydney and international colleagues proposed a new design for ICF using a target of hydrogen-boron. "I think this puts our approach ahead of all other fusion energy technologies," said Hora, an emeritus professor of theoretical physics at UNSW, who predicted in the 1970s that fusing hydrogen and boron might be possible without the need for thermal equilibrium. Hydrogen-boron fusion is achieved using two powerful lasers in rapid bursts, which apply precise non-linear forces to compress the nuclei together and create the fusion reaction.

Hydrogen-boron fusion produces no neutrons and, therefore, no radioactivity in its primary reaction. Dramatic advances in laser technology are close to making the two-laser approach feasible, according to UNSW, and a spate of recent experiments around the world indicate that an 'avalanche' fusion reaction could be triggered in the trillionth-of-a-second blast from a petawatt-scale laser pulse, whose fleeting bursts pack a quadrillion watts of power. If scientists could exploit this avalanche, Hora said, a breakthrough in proton-boron fusion was imminent.

An Australian spin-off company, HB11 Energy, holds the patents for Hora's hydrogen-boron fusion process. "If the next few years of research don't uncover any major engineering hurdles, we could have prototype reactor within a decade," said Warren McKenzie, managing director of HB11. "From an engineering perspective, our approach will be a much simpler project because the fuels and waste are safe, the reactor won't need a heat exchanger and steam turbine generator, and the lasers we need can be bought off the shelf," he added.

6. PowerPost

The Energy 202: Trump administration must decide whether to back the biggest nuclear fusion project ever

By Dino Grandoni March 7

https://www.washingtonpost.com/news/powerpost/paloma/the-energy-202/2018/03/07/the-energy-202-trump-administration-must-decide-whether-to-back-the-biggest-nuclear-fusion-project-ever/5a9f075e30fb047655a06b37/?utm_term=.5c4859c18b28

The House Science, Space and Technology Committee is known for its partisan bickering. Under Chairman Lamar Smith (R-Tex.), Republicans opened probes into federally funded climate scientists that Democrats have derided as politically motivated witch hunts.

But the panel showed a rare bit of bipartisanship during a hearingTuesday with Democrats and Republicans generally uniting **in opposition to a Trump administration proposal to cut funding for a high-risk, high-reward international research project into a carbon-free form of energy — nuclear fusion.**

The United States is collaborating with five nations and the European Union to conduct the largest fusion experiment ever, agreeing to pay for one-eleventh of the cost of a fusion reactor being built in southern France called the **International Thermonuclear Experimental Reactor**.

But the White House's proposal of $75 million to fund the megaproject in fiscal 2019 falls far short of that pledge.

The United States needs to spend at least $213 million in cash and equipment to maintain the scheduled contributions to ITER, Smith said Tuesday. ITER spokesman Laban Coblentz said by email that figure “corresponds to the projected needs.”

“Reducing annual funding will only delay ITER instruments being built here in the U.S. and cause construction delays that increase overall project cost,” Smith said.

Even with House backing, **the fate of U.S. funding for ITER remains uncertain.** While in years past House Republicans and the Obama administration supported funding ITER even as it faced cost overruns and schedule delays, Senate appropriators, led by Lamar Alexander (R–Tenn.), agitated to terminate funding.

The difference now is President Trump, whose administration will have to decide whether to back this energy-related international agreement, unlike it did with the Paris climate accord. **Currently, the Trump team is reviewing all civil nuclear energy activities, including ITER.**

Over the past half-century, the Energy Department has poured billions of dollars into nuclear fusion research, all without yet producing a reactor that put out more energy than it put in.

The prospect sounds like it’s from science fiction: With the new technology, someday theoretically we’ll be able to power cities with miniaturized suns. Made hot enough for long enough, hydrogen atoms can fuse together to form helium, like in the center of stars, releasing in the process a tremendous amount of energy.

Yet the huge magnetic containers and superpowered lasers necessary to bring hydrogen to that state are expensive. Energy efforts at fusion research are littered with half-done studies and never-realized schemes, constrained by budget cuts during President Ronald Reagan's tenure and former speaker Newt Gingrich's (R-Ga.) time running the House.

The upside, if the technology works: Fusion could provide nearly unlimited power from a plentiful fuel with little or no nuclear waste and zero atmosphere-warning emissions.

Or as Rep. Randy Weber (R-Tex.) put it Tuesday: “The potential benefits to society from a fusion reactor are beyond calculation.”

Rep. Zoe Lofgren of California, the No. 2 Democrat on the committee, echoed that sentiment. “Given the huge potential benefits of developing a viable approach to fusion energy, I believe this is an area where we should strongly investing in,” Lofgren said. “Unfortunately, that’s not what we’re seeing in the Department of Energy’s recent budget request.”

After the United States signed a pact to start ITER in 2006 under President George W. Bush, some members of Congress worried other countries would back out of their commitments to fund the project.

A dozen years later under another Republican president, it’s the United States that is in danger of reneging on its pledge.

“A shortfall in contribution of any single member,” Bernard Bigot, director-general of ITER, told Congress, **“will have a cascading, strong effect in delays [and] cost.”**

Bigot said later in an interview with The Washington Post that unless the United States ponies up by June, he will have to inform the other member nations that ITER will be delayed again.

"Clearly, we put the project in danger," he said. "Everybody has to understand, if the U.S. doesn't comply, it will be all the other six members which will be blocked, with overcosts for them." ITER is scheduled to produce its first plasma by 2025.

The ITER leader raced through Washington this week on a whirlwind lobbying tour, speaking to officials at the Energy and State departments and at the White House’s Office of Science and Technology Policy (which still has no leader) in addition to testifying before the Science Committee. Bigot said he was optimistic after talking with the Trump administration officials.

Concern about ITER, which is plagued with the ballooning costs and delayed schedules that have afflicted other fusion projects and caught the eye of auditors at the U.S. Government Accountability Office in 2014, colors some on both the left and right sides of the political spectrum.
“Controlled fusion to produce electricity has been an elusive goal sought for 50 years,” said Matthew McKinzie, a senior scientist at the Natural Resources Defense Council, an environmental nonprofit group. “While ITER may have promise as a plasma science research facility, it isn't plausible as an economic energy source that can scale up to address climate change.”

“I’d love to believe in the dream of fusion energy. I’d love to believe that,” said Rep. Dana Rohrabacher (R-Calif.), the only member of the House science panel to voice frustration over the United States funding ITER. “But we know with the expenditure of that kind of money that we’ve spent on fusion energy, we could have developed fission energy alternatives that are for sure — not just computer models.”

And crucially, **Alexander, chair of the Senate appropriations subcommittee on energy and water development, has unsuccessfully moved to pull the United States out of ITER at least twice before,** even though Oak Ridge National Laboratory in his state of Tennessee hosts the U.S. ITER office.
In the past, House lawmakers had the Obama administration on their side, even if the United States over the past three years has actually been short on its ITER contributions. James W. Van Dam, acting associate director of the Energy's Office of Fusion Energy Sciences, told the House science panel project is currently under review in the Trump administration, but that the project **"has the potential to contribute to American energy dominance."**

Van Dam, a career official, added: "I think we need to stay in the ITER project."

7. BUSINESS NEWS
MARCH 7, 2018 / 8:25 AM / 9 DAYS AGO

International nuclear fusion project seeks reversal of Trump budget cuts

https://www.reuters.com/article/us-nuclearpower-fusion-project/international-nuclear-fusion-project-seeks-reversal-of-trump-budget-cuts-idUSKCN1GJ021?utm_campaign=trueAnthem:+Trending+Content&utm_content=5a9f535a04d3016b6b256fcf&utm_medium=trueAnthem&utm_

Timothy Gardner

WASHINGTON (Reuters) - An international project to build a nuclear fusion reactor in France that would start generating electricity in 17 years will face delays if Trump administration cuts are not reversed in a few months, the head of the venture said on Tuesday.

Bernard Bigot, director-general of the International Thermonuclear Experimental Reactor project, or ITER, said the administration's budget cuts would reduce the U.S. contribution to the project and lead to construction delays.

"It's not a question of capability, it's a question of political will," Bigot said in a telephone interview while he was in Washington to meet with U.S. officials.

The Energy Department did not immediately respond to a request for comment.

ITER, launched 10 years ago by seven partners: the European Union, the United States, China, India, Japan, Russia and South Korea, would generate electricity from a process similar to the nuclear fusion that powers the sun.

Conventional reactors split atoms to generate power and create poisonous nuclear waste, for which there is no permanent disposal site in the United States.

The cost of the experimental project, which its partners hope will reach its first full-power fusion by 2035 is $21 billion to $26 billion.

The United States has given about $1 billion to ITER so far, and had been planning to contribute an additional $500 million through 2025.

But with U.S. President Donald Trump's proposed budget cuts, Washington's contribution for 2019 would drop to $75 million from $165 million. Last year, the administration cut the 2018 U.S. contribution to $63 million from a planned $120 million.

Bigot said he told officials from the Energy Department, the White House's office of science and technology policy and the State Department, that the project will face delays unless Washington promises by June to fund the original amounts.

If the United States, which provides 9 percent of ITER's funding, does not contribute the planned tens of millions of dollars on time, contracts for assembling large parts of the project will be delayed, he said.

In December Shaylyn Hynes, an energy department spokeswoman, said that the administration is reviewing civilian nuclear policy, including research and development, which will influence its policy toward ITER going forward.

Reporting by Timothy Gardner; Editing by Peter Szekely and Grant McCool
Our Standards:[The Thomson Reuters Trust Principles.](#)

8. 'The pathway to commercial fusion is the adventure which drives us all' - Howard Wilson on his return to Culham | 05/03/2018
http://www.ccfe.ac.uk/news_detail.aspx?id=446

Professor Howard Wilson returned to Culham as Programme Director at the start of October. He spoke to us about what has changed since he worked here previously, and his hopes for research towards the first demonstration fusion reactors. As well as his CCFE role, Howard is Chair at the University of York as Director of the **York Plasma Institute** and the **EPSRC Fusion Centre for Doctoral Training**.

“It's essential we find a solution to the energy problem and it's hard not to be enthusiastic about that working back here at Culham,” Howard Wilson stated. “But what is fantastic is that nuclear fusion research is much more of a national programme than it was when I left back in 2005. Back then Culham had relatively few collaborations with UK universities. Now we see many different link ups with a wider range of universities, increasingly integrated into the national programme.”

Howard, a leading theoretical plasma physicist, returned to Culham in October 2017. The place itself hasn't changed drastically whilst he has been away, but what is different is the wider appreciation of the vital work done at Culham.

Having left to establish an academic fusion energy research and training programme that grew into the York Plasma Institute at the University of York, he has now returned part-time and is seeking to combine both roles to encourage wider involvement in fusion energy, and working towards its successful commercialisation.

Perception of fusion is good – but we must keep up the good work

“Public perception of fusion is generally good, and rightly so, but it is vitally important that we maintain this by effective communication about our progress and the importance of world class research and development to address the remaining challenges.

“Other sustainable energy technologies can demonstrate progress through steadily increasing the fraction of power they deliver onto the grid as advances are made. Although this fraction is still relatively small, it is measureable progress that is clear to all.

"The situation for fusion is different – we have to achieve certain conditions to generate any fusion power which, we expect, will then be abundant. In the meantime, our achievements are measured in terms of proximity to these conditions, and even though there has been great progress, this can be difficult to quantify and explain to those outside the field.“

Howard first joined Culham's theory department in 1988 as a research scientist. Having completed his PhD in particle physics at Cambridge, his first stint here involved him developing theories of plasma instabilities, including the so-called “peeling-ballooning” model for ELMs (Edge Localised Modes). He co-led (in collaboration with General Atomics in the US) on the development of the ELITE code (Edge Localised Instabilities in Tokamak Experiments) to provide quantitative predictions of the plasma stability in the insulating layer - called “the pedestal”. This code is now used for analysing the pedestal stability to understand how and when the ELM is triggered on tokamaks worldwide.

He also led the development of the plasma physics basis for compact fusion reactor designs based on the spherical tokamak, including an electricity-producing power plant and a small reactor for components testing.

Student world increasingly engaged with fusion

It was his passion for enabling future generations to be informed about nuclear fusion that led to him taking up his post at the University of York 13 years ago.

“At the time UK fusion research was predominantly done at Culham, and university research programmes were limited to a few excellent individuals around the country. The University of York was seeking to expand its plasma physics group and I saw the

opportunity to establish a fusion plasma physics programme there.
“For me, it's important that young people are aware of the opportunities that fusion research offers, and also gain a knowledge of what fusion research is about – knowledge that they will carry through whatever career path they choose. One way to ensure this is obviously to be involved in the education of those people, and to get fusion further embedded in some of the undergraduate and postgraduate programmes.

“Seeing first-hand how enthusiastic students are about this is extremely fulfilling. It is my privilege to lead the Fusion Centre for Doctoral Training, which has over 60 PhD students at any time. Half stay in the field after qualifying, and half choose careers elsewhere. It's vital there are people with an understanding of fusion in all sectors, whether that be politics, media or other research fields.”

He added: “I hope that (and expect) the 50 per cent who follow other careers can be just as important to fusion as those who stay directly in the field – it is stimulating to see the range of careers that a fusion education prepares our students for.”

The current stats at York are certainly impressive. As many as 60 undergraduates choose the final year Plasma Physics and Fusion course. Added to this are another 20 students undertaking the York Masters in fusion energy and a further 15 PhD students in each year group. “Of course this isn't all down to me,” Howard said. “It is the team of academic and support staff at York and our partner universities which ensure that it works so well.”

“Coming back, one sees the evolution of the programme here at Culham in terms of technology, materials science, plasma physics, and engineering. There is strength in all of these, but the real power of the programme will come from an integration of these capabilities.”

Fusion of the future

“One of the areas that most excites me is to bring the combined strengths of Culham across these disciplines to look for a more compact route to fusion power. Perhaps even a smaller demonstration fusion reactor than is currently being considered.

“You see, at the moment the DEMO design is broadly based on a scaled-up version of the **ITER project**, so it is a fairly big beast with a high capital cost. The spherical tokamak, such as the newly-built **MAST Upgrade experiment** at CCFE, offers the potential for a more compact route to fusion. However, we cannot know whether this is viable yet because our knowledge of spherical tokamaks is still at a relatively early stage.

"MAST Upgrade is exciting because it will help us achieve the fusion objectives of ITER, as well as providing a possible answer for how to control the exhaust power of DEMO. It may also point the way to a more compact route to DEMO. Add to that the unique capabilities of JET and the eagerly anticipated fusion power experiments with the deuterium-tritium fuel mix and it is easy to see why Culham is one of the most exciting places to do fusion research in the world.

So what does a typical working week look like?

“Firstly, I don't really have a normal week. In terms of when I am here at Culham, my role is about understanding what the different programmes are doing, and working with the programme teams to decide priorities alongside the European and international fusion

programmes, the overall UKAEA and EPSRC strategies and, of course, the Government's Industrial Strategy.
“Another integral part is to continue to integrate Culham's programme with the wider academic community, and keeping aware of the mutually beneficial opportunities there as we plan our own programme.
“We are building an exciting vision for UK fusion and the pathway to commercial fusion energy; there are challenges ahead but it is those challenges that stimulate us and the adventure of the journey to fusion power that drives us. It is great to be a part of it.”
What is certain is that Howard is extremely focused and driven, as well as incredibly busy. So how does he switch off when the chance comes?
“I love to cycle and to run, as well as winter hill walking – ideal ways to counter the effects of my passion for a pint or two. I enjoy DIY, and get plenty of practice with our 250 year old house in York and my old Range Rover – but it is probably best if I'm not allowed to approach a tokamak with a spanner in my hand.”

9. Oxfordshire Guardian

Brexit threat to future of fusion

Posted By: George Welchon: March 02, 2018

http://www.oxfordshireguardian.co.uk/brexit-threat-to-future-of-fusion/

An MEP concerned with the future of a ‘world-leading’ nuclear power project near Abingdon has called on the government to be ‘very clear’ about its commitment to the multi-million pound scheme.
John Howarth believes Theresa May’s ‘off-the-cuff commitment’ to leave an EU-wide treaty promoting nuclear research “threatens the future of fusion research in which Britain has led the way”.
The EU covers £60million – or 88 per cent – of the running costs at the Joint European Torus (JET) project, which employs 1,300 workers at its Culham Science Centre base, but the UK’s contract to host the facility ends in December.
The complications of Brexit negotiations have raised major questions over the future of the world’s largest current fusion experiment.
“If the Conservative government gets Brexit wrong it will seriously affect Britain’s world-leading scientific reputation,” said Labour MEP Mr Howarth, who last week hosted an event in Culham with nuclear experts to discuss challenges ahead.
“Fusion research is far too complex for any one country to pursue on its own. These projects hinge on cross-border collaboration and involve scientists from every EU member state and beyond.”
The theory is that fusion will provide plentiful clean energy when developed on a commercial scale, with the first successful proof of concept experiments being carried out at Culham.
Mr Howarth added: “The government needs to be very clear about its future commitment to the project.”

Ian Chapman, CEO of the UK Atomic Energy Authority, the parent company of Culham Science Centre, also told the Guardian that finding a way to continue JET is 'hugely important for the UK, Europe and the world'.
He added that fusion is about to "enter the delivery era" – and that JET "has a pivotal role to play on the path to delivering fusion power to the grid".
The government has drawn fire for the decision to leave Euratom as it will have to negotiate new treaties with third party countries.
Abingdon MP Layla Moran accused the government of 'saying warm words about funding replacements' but has 'yet to demonstrate how everything will operate in practice'.

10. Fusion breakthroughs among highlights of the Department of Energy's research milestones during the past 40 years

By
John Greenwald
February 16, 2018

https://www.pppl.gov/news/2018/02/fusion-breakthroughs-among-highlights-department-energy's-research-milestones-during

he U.S. Department of Energy's (DOE) Office of Science, the largest U.S. supporter of basic research in the physical sciences, celebrated the 40th anniversary of its founding in 2017. To mark the 40th anniversary of Office of Science support for the country's national laboratories and basic research at universities and private industry, the DOE has compiled 40 milestone papers(link is external) that represent what the Department calls "a cream-of-the crop selection that has changed the face of science."

Among the 40 Office of Science milestones: four landmark papers are on breakthroughs in the development of fusion energy. Two are from PPPL, one is from the DIII-D National Fusion Facility with which PPPL collaborates, and one is by Nat Fisch, a PPPL physicist and Princeton University professor, who based the paper on his doctoral dissertation at MIT.

"These papers highlight the substantial progress in fusion energy and plasma physics in the DOE program," said Michael Zarnstorff, deputy director for research at PPPL. "This research has advanced our fundamental understanding and established the path to make fusion energy a reality."

Here are the four major papers, which represent 10 percent of the DOE's "40 Years of Research Milestones," in reverse chronological order:

1994 – PPPL physicists report the successful first use (link is external) of a high-power mix of deuterium and tritium to produce fusion energy on the Tokamak Fusion Test Reactor (TFTR). Shortly after the paper appeared, the reactor produced an unprecedented 10.7 megawatts of fusion power. The deuterium-tritium mix will serve as fuel for future tokamaks including ITER, the international experiment under construction in France to demonstrate the practicality of fusion power.
1990 – For fusion to take place in tokamaks, researchers must calm the randomly fluctuating turbulence produced by plasma that is far hotter than the core of the sun.At DIII-D, which General Atomics operates for the DOE in California, physicists discover that changing the shearing of the flow(link is external) in the plasma can break up turbulent eddies that cause heat and particles to leak out. The discovery produced agreement between experiments and key theoretical predictions and allows plasmas to reach the superhot temperatures that fusion requires and that will be crucial for the success of ITER.

1989 – Research conducted on the Princeton Beta Experiment (PBX-M) at PPPL demonstrates how to measure the helical magnetic field(link is external) that confines the plasma during fusion experiments. The magnetic field is given helical form by current induced in the plasma. Researchers measured the helical angle inside the hot plasma by interpreting the light emitted by atoms injected into the plasma. Today, the technique allows physicists to tailor the magnetic field to maximize fusion performance.

1978 – The current that creates the helical magnetic field in tokamaks must be sustained during experiments. In the early days of tokamaks, the current could only be sustained for short time periods. In his landmark paper, Nat Fisch, drawing on his dissertation(link is external) as a doctoral student at MIT and overturning the conventional thinking of power dissipation in plasma, suggested an energy-efficient method for maintaining this current using radio frequency waves. Fisch, now a professor in the Princeton University Department of Astrophysical Sciences, is director of graduate studies for the Program in Plasma Physics that brings graduate students to study and work with scientists at PPPL.

PPPL, on Princeton University's Forrestal Campus in Plainsboro, N.J., is devoted to creating new knowledge about the physics of plasmas — ultra-hot, charged gases — and to developing practical solutions for the creation of fusion energy. The Laboratory is managed by the University for the U.S. Department of Energy's Office of Science, which is the largest single supporter of basic research in the physical sciences in the United States, and is working to address some of the most pressing challenges of our time. For more information, please visit science.energy.gov(link is external).

11. Tale of the atom tamers

Tushna Commissariat reviews *Let There Be Light: the 100 Year Journey to Fusion* by Mila Aung-Thwin

http://live.iop-pp01.agh.sleek.net/2018/02/22/tale-of-the-atom-tamers/

"Imagine putting the Sun in a bottle...that's what we're trying to do." As an opening line in a film it's a powerful one. Nuclear fusion is often sold as a panacea, and while it would indeed be a clean and seemingly endless source of energy, achieving and sustaining fusion in lab conditions is no mean feat. Written and directed by film-maker Mila Aung-Thwin, *Let There Be Light: the 100 Year Journey to Fusion* tells the story of our ongoing quest for fusion here on Earth, with a prominent focus on the science and the scientists behind ITER – the International Thermonuclear Experimental Reactor – based in France, as well as a few other fusion companies too.

ITER was first proposed in 1985, as the first inkling of such technology was shared during the Cold War, when the Soviet Union's Mikhail Gorbachev and US president Ronald Reagan agreed to collaborate "in obtaining this source of energy, which is essentially inexhaustible, for the benefit for all mankind". Today, ITER encompasses not only the US and Russia but China, the European Union, India, Japan and Korea too.

Before going further into the film, I must point out a pet peeve of mine in documentaries, which is not knowing who is speaking for vast chunks of the film. As a viewer I dislike hearing a disembodied voice with no knowledge of who it is (as this often means a loss of context), and this was the case for the first 10 minutes or so of *Let There Be Light*. Apart from that small misgiving, I enjoyed the mix of artistic visuals, footage from ITER, on-screen graphics and schematics, and animated historical scenes. One of the first actual faces we meet in the film is Michel Laberge, founder and chief inventor of the private Canadian company General Fusion. He explains nuclear fission and fusion, succinctly wrapping up the whole fusion story by saying "The aim of the game is to get more energy out than you put in."

The film also does a good job of explaining the basics of the science involved, from tokamak technology, to the toroidal magnets needed to hold the 150 million kelvin plasma, to how a gyrotron (the part that heats up the plasma) functions. This scene was particularly charming as ITER physicist Mark Henderson attempts to explain how the device works, using an analogy of creating resonance by blowing across the top of a Coke bottle. To better illustrate this fact, he sends a colleague off to buy a bottle only for the colleague to return with a (useless) can. "Man... you call yourself a physicist!" Henderson exclaims.

Ken Blackler, who oversees assembly and operations at the experiment, says that "ITER is going to be built from a million pieces so it's a real nightmare to know where pieces are." He goes on to explain that a tokamak is built bottom up and so it is crucial that each piece is available at the right time – this involves a considerable planning effort with all of ITER's member states, who provide different bits. Indeed, one of the big challenges that ITER faces is its complex organizational politics. Others are its ability to receive continued funding (the project in its entirety will likely cost tens of billions of euros) and the need to stay on schedule. Indeed, ITER was supposed to achieve its "first plasma" in 2016; that date has been pushed multiple times and is now likely to be 2025, as it struggles to make sure that fusion doesn't become one of the most "expensive failures in scientific history".

Just as I was beginning to bemoan the lack of a single woman on screen, Sabina Griffith – ITER's communications manager – pops up, lamenting the public's lack of awareness when it comes to ITER. She rightly points out that taxpayers around the globe allow this project to move forward, and so ITER maintains a very "transparent" communications strategy. It's interesting to watch Griffith coach Henderson on what to say, and not to say, when it comes to funding (or the lack thereof) from its members, especially the US. She advises that instead of complaining in official reports about how funding has decreased since the 1970s, they should instead say that "it is difficult" and remind people that to achieve fusion by the middle of this century, continued funding is key. Griffith points out that if ITER does not succeed, then "fusion will be dead, forever or at least for a very very long…nobody will bet on fusion for a long time".

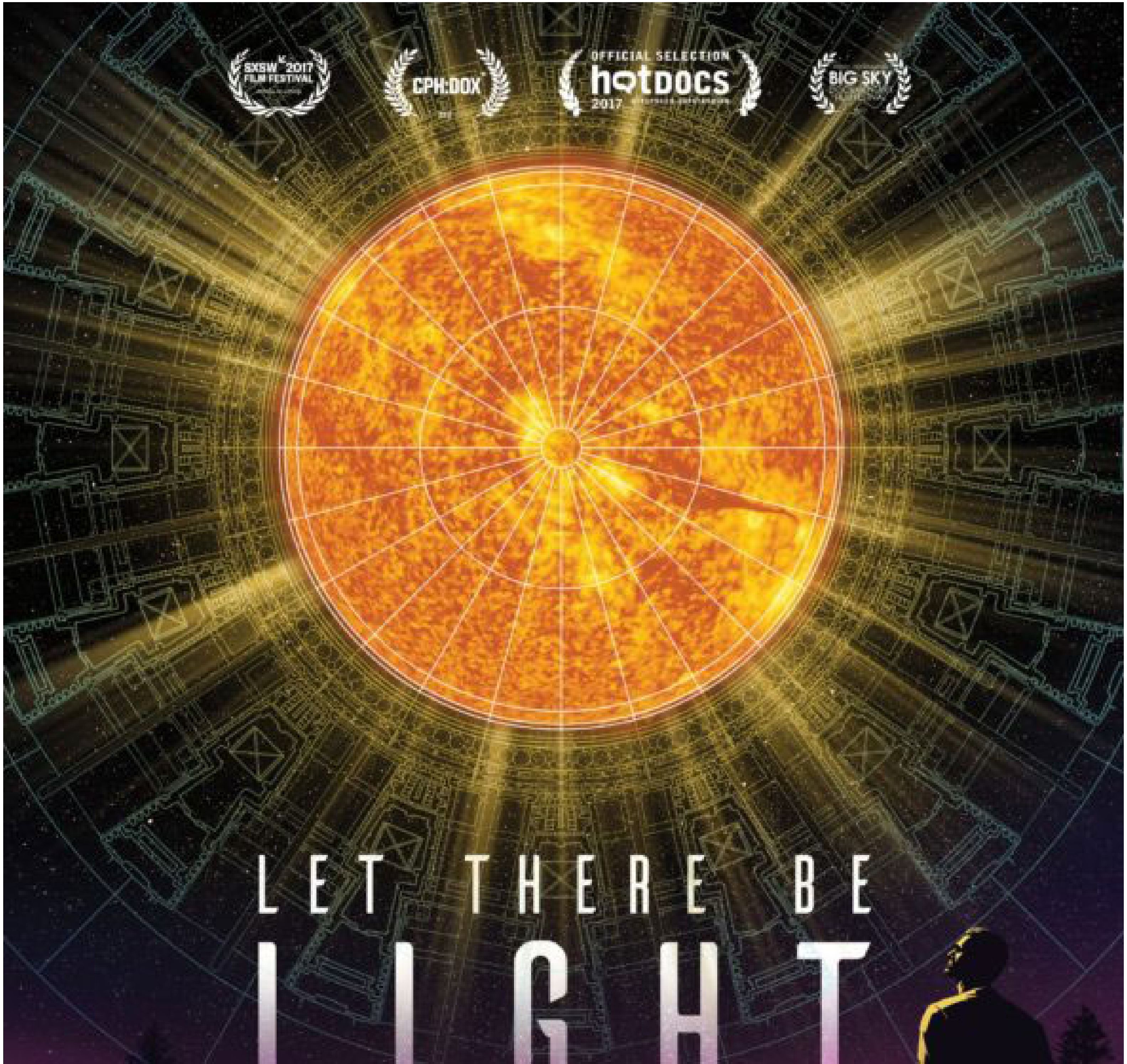
Towards the end of the film, we join Henderson as he visits the tokamak pit for the first time, and chats to some of the construction workers on site, asking if they know what they are building. "The molecules and what they do is not really our department…our job is making the structure," says one of workmen. After a quick explanation, Henderson tells them this has been his dream since he was 14 and they are helping to make it a reality. As they say their goodbyes and thank-yous, one of the workmen adds that "My dream would be that all countries in the world can benefit…that's my dream."

I must admit that despite writing about physics for the last seven years, I've never been completely clear on ITER and what goes into making fusion energy a reality. While it's not the most slick or engaging science documentary I've watched, *Let There*

Be Light goes a long way to shedding light on this epic scientific endeavour. Laberge complains that there still isn't enough excitement about fusion, and that people don't mention fusion when talking about alternate energy sources – "windmills, tide, solar, chicken shit, whatever… but never fusion" he grumbles. But not before adding that he will "work on this all my life until this works".

Available worldwide for rent or purchase on the Vimeo platform, in English and French.

Tushna Commissariat is reviews and careers editor of *Physics World*


SXSW 2017
FILM FESTIVAL
CPH:DOX
OFFICIAL SELECTION
hotdocs
2017
BIG SKY
LET THERE BE
LIGHT

Let There Be Light: the 100 Year Journey to Fusion
Dir. Mila Aung-Thwin
2017 EyeSteelFilm

12. Nuclear Fusion Powered by the Moon Could Solve Earth's Energy Problems

David Nabhan
https://www.newsmax.com/davidnabhan/nuclear-fusion-iter-moon-energy/2018/02/21/id/844640/

Wednesday, 21 Feb 2018 01:01 PM

Last December Dr. Bernard Bigot, the Director-General of the International Thermonuclear Experimental Reactor (ITER) in France, declared the project 50 percent complete. This may be a watershed in the decades-long effort by all the major powers to get the first fusion reactor up and running. Futurists today — seemingly so certain of tomorrow's energy needs relying upon wind, solar, and geothermal power — may be surprised by the actual events to come, taken unawares by a future moved forward not by sunlight, gusts of breezes, or steam pouring forth from geysers but by one of the most powerful forces in the cosmos: fusion.

A fusion reactor would leave our current fission models in the dust, not unlike comparing a uranium fission bomb to the overwhelmingly explosive force of thermonuclear fusion devices such as the Soviet Union's fifty-five megaton Tsar Bomba — over 4,000 times more powerful than the Little Boy bomb used over Hiroshima. Fission involves splitting an atom while fusion requires that two atoms be squeezed into one. In effect, a fusion reactor would be a mini-sun built here on Earth, turning isotopes of hydrogen into helium, creating blistering heat in the process, using that heat to flash water into steam to spin turbines that in turn would churn out vast amounts of electricity. There is just one small problem to solve in order to create a man-made star: mind-boggling heat is required.

Atom smashers have recorded temperatures in the trillions of degrees — a quarter million times hotter than the center of the Sun — but only for infinitesimal durations and heating volumes smaller than an atom, useless for producing a single watt of electricity. A tokamak, however, is a machine built to really do the job and the progress being made here is simply astonishing. ITER, the world's largest tokamak, will need to sustain temperatures on the order of 150 million degrees centigrade, holding the broiling plasma to be fused in the only way possible — by not actually allowing it to touch anything. Magnetic confinement is utilized to keep materials ten times hotter than the core of Sun within the "walls" of invisible magnetic fields. The hydrogen isotopes found in "heavy water" — deuterium and tritium — are the fuels for fusion reactors and are to be found in plain sea water all over the surface of the Earth.

Once reactors are a reality, mankind's energy larder could be as vast as the oceans from which heavy water will be extracted to power civilization. To be sure, inexpensive and profuse energy is a sure path to a more bountiful and more peaceful world; currently over half of the planet's entire gross world product evaporates without electricity and that astounding figure can only be expected to rise in the future. ITER expects full power production sometime around 2035, and there are other consortiums working toward the same goal: Lockheed Martin in the United States, the Wendelstein 7-X fusion reactor in Germany, the United Kingdom's ST40, etc.

China is being drawn to the Moon in part by the lure of fusion reactors and a potential superior fuel for the process: helium-3. This isotope, delivered via the solar wind, is exceedingly rare on the Earth due to the planet's magnetic shield which prevents it from being deposited on the surface. The Moon, however, possessing no such defense, has been bombarded by helium-3 nuclei stripped of their electrons for the last four billion years. The Chinese estimate that there's around 1.2 million tons of the stuff infused into the first few centimeters of the lunar surface. Helium-3 comes into the picture for good reason. If helium-3 replaces one of the heavy water components — tritium — its fusion with deuterium might be more efficient, would generate no radiation, and most importantly should produce no radioactive waste materials. One can imagine the hosannas to be sung, and for good reason, should clean, abundant, cheap energy burst forth from fusion reactors with the good housekeeping seal attesting to all three.

China is far along in its plans to establish a permanent base on the Moon in the near future. They're not going simply to leave footprints and outdo a rival as with space races of prior eras. It should surprise few if the Chinese have a much more practical purpose in mind: surveying our satellite for the best areas in which to extract helium-3 and initiating mining operations at those sites.

It may turn out that the greatest treasure ever discovered in history will cause the silver deposits of pre-Columbian South America, the gold rushes of California and the Klondike, and the diamond fields of South Africa and Canada to pale in comparison. It might be on the Moon where the most valuable mother lode is waiting to be tapped.

David Nabhan is a science writer, the author of "Earthquake Prediction: Dawn of the New Seismology" (2017) and three previous books on earthquakes. Nabhan is also a science fiction writer ("Pilots of Borealis," 2015) and the author of many scores of newspaper and magazine op-eds. Nabhan has been featured on television and talk radio all over the world. His website is www.earthquakepredictors.com.

Read Newsmax Article: **Nuclear Fusion Powered by the Moon Could Solve Earth's Energy Problems | Newsmax.com**

13. SPIN-OUT OF FUSION ROBOTICS TO HEALTH CARE AND INDUSTRY

February 19th 2018

https://www.differ.nl/news/spinout-remote-handling-study-center

On Tuesday 20 February, the Dutch Remote Handling Study Center (RHSC) for research into remotely controlled robots has spun out to became an independent entity. RHSC was founded within the Dutch Institute for Fundamental Energy Research DIFFER in collaboration with Heemskerk Innovative Technology and developed maintenance techniques for future fusion reactors such as ITER. The spin-out enables RHSC to broaden its scope to include industrial maintenance and even health care.

The Remote Handling Study Center RHSC couples human insight and natural motor skills to remotely operated robots, using advanced computer assistance. This allows operators to safely perform tasks in sensitive or inaccessible environments that are too complex for a computer controlled system. Operators in the study center can use force feedback to experiment with maintenance procedures in a lifelike simulation, avoiding the costly and time-consuming manufacture of prototype systems. The spin-out of the center allows for application of its experience in fields beyond its current focus on fusion energy, opening up opportunities in health care but also maintenance for the European Spallation Source ESS.

REMOTE HANDLING FOR THE ITER FUSION PROJECT

The Remote Handling Study Center was founded in 2011 to research remote maintenance technology for the international nuclear fusion project ITER . In this worldwide collaboration, researchers and industrial partners are building the first fusion experiment to produce more power from nuclear fusion than is needed to drive and control the reaction. ITER is the last experiment on the way to realizing a safe, clean and sustainable for of concentrated power production.

RHSC-founders Heemskerk Innovative Technology (HIT) and the Dutch Institute for Fundamental Energy Research DIFFER used the study center to develop maintenance procedures for ITER using remotely controlled robots. Their work contributed to the maintainability of the reactor, which will become activated by neutrons from the fusion reaction during operation.

The study center won tenders to analyse the design and maintainability of several ITER components, such as some of the meters long port plugs which contain complex diagnostics and control systems to measure and optimise the state of the fusion reactor. The study center won tenders to analyse the design and maintainability of several ITER components, such as the meters long port plugs, complex diagnostical and control systems that regulate the fusion reaction. These tasks from Fusion for Energy, the European tendering organization for ITER, will be continued after the spin-out of the Remote Handling Study Center.

14. Culham is key partner in new £1.2M ‘virtual qualification’ EPSRC Manufacturing Fellowship | 20/02/2018

Researchers at Culham have developed novel virtual engineering techniques over the years – and one of the latest initiatives being pursued by staff is virtual qualification.
http://www.ccfe.ac.uk/news_detail.aspx?id=443

The initiative is led by Dr Llion Evans, a researcher in Culham's Technology Department, as part of his role at CCFE and as a EUROfusion research fellow.
Experimental testing is currently essential to ensure the quality of new components in high-value manufacturing (HVM). This is particularly true when component failure might be challenging or even impossible to rectify, such as in a satellite or nuclear reactor. Unfortunately, testing can often be prohibitively expensive, ineffective when it is not able to recreate in-service conditions or only capable of giving unspecific pass/fail results.
Virtual qualification uses 3D X-ray imaging to create micro-accurate digital replicas for part-specific simulations. This has the potential to replace costly and time-consuming experimental testing and improve on pass/fail testing by assessing defects for performance impact.
Now the **UK's Engineering & Physical Sciences Research Council (EPSRC)** has identified the area of virtual qualification as being of strategic importance to the UK manufacturing sector – awarding Dr Evans a five-year research fellowship to further explore his vision of seeing image-based modelling transforming the way HVM component qualification is performed.
The technique currently requires significant manual interaction over a timescale of weeks per component. Production line manufacturing is well suited to automation of virtual qualification but challenges remain, particularly regarding automated 3D X-ray image processing.
Image-based modelling accounts for deviations caused by manufacturing processes not considered by design-based simulations, for example due to tolerancing or micro-defects. This has applications in advanced manufacturing wherever there is variability from one component to another, e.g. joining, additive manufacturing or composites. Thus it is of interest to aerospace and the wider energy sector outside fusion.
The team is led by Dr Llion Evans and based at Swansea University – an institution established by Prof Olek Zienkiewicz as a birthplace for finite element analysis (vital to this technique) and is now recognised as a leading research centre in the field.
Culham will be a leading partner on the £1.2m fellowship acting as an end-user for the technique. This will entail working on a case-study to showcase the capabilities of virtual qualification on a batch of heat exchange components. This activity will closely align with aims of the **newly-announced Fusion Technology Facilities (FTF) at Culham** that will support industry with a range of test and design capabilities, preparing them to bid for forthcoming major ITER contracts.

The interest in the potential of this research is such that the list of collaborators also includes Nikon Metrology Ltd., Diamond Light Source, Synopsys Inc., University of Manchester, TWI and Airbus.
Dr Evans said: “My main motivation in my research is to develop technologies that will contribute towards reducing environmental impact, particularly ones facilitating the realisation of fusion energy. My aim in leading this fellowship is to have a key role in knowledge transfer between academia and industry."

15. UK firm sees year-end launch of pulsed power device

15 March 2018

First Light Fusion (FLF) is investing GBP3.6 million (USD5.0 million) building what it says will be the only pulsed power machine of its scale in the world dedicated to researching fusion energy. The Oxford, England-based company said on 12 March it expects to commission the device - Machine 3 - by the end of this year.

http://www.world-nuclear-news.org/NN-UK-firm-sees-year-end-launch-of-pulsed-power-device-15031801.html

FLF aims to achieve 'gain' before seeking to demonstrate the commercial viability of the technology to produce safe, efficient and environmentally friendly baseload energy around the world. The fusion energy gain factor, usually expressed with the symbol Q, is the ratio of fusion power produced in a nuclear fusion reactor to the power required to maintain the plasma in steady state.
"The pressures and velocities that we will be able to access with this machine will massively extend the development of our fusion target designs," Nicholas Hawker, Founder and CEO of FLF said.
"We are confident that we will reach our present goal of demonstrating fusion. Beyond that, the experimental platform that we can build with this machine will give us critical insights into the next step, which is to demonstrate gain."
Machine 3 will be capable of discharging up to 200,000 volts and in excess of 14 million ampere - the equivalent of nearly 500 simultaneous lightning strikes - within two microseconds, the company said. It will use some 3km of high voltage cables and another 10km of diagnostic cables.
Machine 3 will be used to further research FLF's technology as the company seeks to achieve first fusion. The next step in the technological development will be to achieve gain, whereby the amount of energy created outstrips that used to spark the reaction, it said.
It uses a high-velocity projectile to create a shockwave to collapse a cavity containing plasma inside a 'target'. The design of these targets is the company’s "technical USP", FLF said.
The only example of inertial confinement found on Earth is the pistol shrimp, which clicks its claw to produce a shockwave that stuns its prey, the company said. The only other naturally occurring inertial confinement phenomenon is a supernova. The reaction created by the collapsing cavity is what creates energy, which can then be captured and used, it added.
Fusion has already been demonstrated by other approaches, FLF noted. The two most advanced are the tokamak and laser-driven inertial fusion.

ITER, being built in the south of France, will be the world's largest tokamak, aiming to demonstrate gain. The National Ignition Facility in California is the world's most energetic laser and is also aiming to demonstrate gain.
Both these projects have encountered "substantial difficulties", FLF said, both relating to the fusion process itself but also the complexity of the engineering required. FLF must demonstrate fusion before then undertaking an equivalent gain-scale experiment, it added.
If First Light succeeds in the fundamental demonstration of fusion, however, the pathway to gain and a power plant is "potentially much simpler, quicker and cheaper than these mainstream approaches", it said.
Hawker said FLF looked forward to welcoming its collaborators from the high energy density physics community to work with it on its experiments.
"All of this has been achieved at a drastically reduced cost when compared with other alternative technology choices," he said.
FLF Ltd, which researches energy generation via inertial confinement fusion, was spun out from the University of Oxford in July 2011, with seed capital from the IP Group plc, Parkwalk Advisors Ltd and a number of Angel investors. Until May 2014, the company was named Oxyntix Ltd.

Researched and written
by World Nuclear News

16. Ohi 3 reaches critical milestone in restart

15 March 2018

Unit 3 of the Ohi nuclear power plant in Japan's Fukui Prefecture reached criticality this morning, operator Kansai Electric Power Company announced. The reactor - the sixth to be restarted after clearing the country's revised safety regulations - is expected to resume commercial operation early next month.

http://www.world-nuclear-news.org/C-Ohi-3-reaches-critical-milestone-in-restart-1503184.html

Following the shutdown of all of Japan's reactors after the March 2011 accident at the Fukushima Daiichi plant, Ohi 3 and 4 were given permission to resume operation in August 2012. However, the two 1180 MWe pressurised water reactors (PWRs) were taken offline again for Nuclear Regulation Authority (NRA) inspections in September 2013.
The NRA announced in May 2017 that the two units meet safety standards introduced in July 2013. The NRA approved Kansai's plan for strengthening the units in August last year. The regulator subsequently conducted pre-operation inspections of the units to confirm that the safety countermeasure equipment complies with the approved construction plan at the plant.
The governor of Fukui Prefecture approved the restart of Ohi units 3 and 4 in November.
Kansai began loading the 193 fuel assemblies into the core of unit 3 on 9 February, completing the process on 13 February.
The reactor was restarted at 5.00pm yesterday. Kansai said Ohi 3 attained criticality - a sustained chain reaction - at 3.00am today.

On 13 March, Kansai said: "After reaching criticality, the plant will start power control operation on 16 March 2018 as the final stage of the periodic outage inspection following various types of tests." It added, "In early April, the plant will restart full-scale operation after the completion of the comprehensive inspection performed by the Nuclear Regulation Authority."
Kansai earlier said it expects to refuel Ohi 4 in mid-April, restart it around mid-May, with commercial operation expected to resume in early June.
In December, Kansai said it will not seek permission to restart Ohi units 1 and 2, which have been offline since July 2011 and December 2011, respectively. The company announced on 1 March that it had applied to Japan's Ministry of Economy, Trade and Industry for approval to decommission the two 1175 MWe PWRs, which are approaching 40 years old.
Ohi 3 is the sixth of Japan's 42 operable reactors which have so far cleared inspections confirming they meet the new regulatory safety standards and have resumed operation. The others are: Kyushu's Sendai units 1 and 2; Shikoku's Ikata unit 3; and Kansai's Takahama units 3 and 4. Another 18 reactors have applied to restart.
Kyushu Electric Power Company expects to restart both units 3 and 4 at its Genkai nuclear power plant in Saga prefecture later this year.
Nuclear energy is expected to account for 20-22% of Japan's power generation in 2030, with a similar portion coming from renewable sources. The remainder of the country's power generation will be met by coal (26%), LNG (27%) and oil (3%), according to Japan's latest energy policy. That policy supports "utilizing nuclear power generation whose safety is confirmed".
Researched and written
by World Nuclear News

17. Drifting and bouncing particles can help maintain stability in fusion plasmas

By
Raphael Rosen
March 12, 2018
https://www.pppl.gov/news/2018/03/drifting-and-bouncing-particles-can-help-maintain-stability-fusion-plasmas

A key challenge in fusion research is maintaining the stability of the hot, charged plasma that fuels fusion reactions inside doughnut-shaped facilities called “tokamaks.” Physicists at the U.S. Department of Energy’s (DOE) Princeton Plasma Physics Laboratory (PPPL), have recently found that drifting particles in the plasma, which consists of free electrons and atomic nuclei, can forestall instabilities that reduce the pressure crucial to high-performance fusion reactions inside these facilities.

Fusion, the power that drives the sun and other stars, is the fusing of light elements in the form of plasma that produces massive amounts of energy. PPPL scientists seek to study and replicate fusion by heating the plasma to superhot temperatures inside a tokamak and confining it under pressure in spiraling, magnetic fields. Physicists use the term “beta” to characterize how the pressure of the heat produced by a tokamak compares with the pressure of the magnetic field used to contain the plasma.

Research led by Zhirui Wang used data from the National Spherical Torus Experiment (NSTX), a spherical tokamak at PPPL shaped like a cored apple that produces high-beta plasmas. Findings of the study explain how particles that drift and bounce within the fields can stabilize high-pressure and high-performing plasmas.

Such particles become trapped and bounce back and forth within a limited portion of the magnetic fields instead of traversing their entire circumference around the machine. The portions themselves can drift around the machine. The bouncing and drifting can dissipate energy that might otherwise destabilize the plasma and interfere with fusion reactions, the physicists found.

Researchers first noticed discrepancies between the NSTX data and simulation predictions. Modifying the code to take the trapped particles into account improved the agreement by producing simulations suggesting that the plasma would remain stable longer under high pressure, as the NSTX experiments showed. "We found that tokamaks can go to a higher beta because the plasma will be stabilized by these kinetic effects," said Wang, lead author of a paper describing the results in the journal *Nuclear Fusion*.

Improved kinetic simulations could also lead to better predictions and control of plasma instabilities known as edge-localized modes (ELMs), which appear at the edge of high-confinement plasmas and by unleashing large amounts of energy to the wall can significantly damage plasma-facing components in a fusion reactor. Better predictions would allow scientists to foresee when an ELM is about to occur and adjust magnetic controls so the instability is either mitigated or completely suppressed before it erodes the materials surrounding the fusion plasma.

Overall findings of this research could lead to improved achievement of high-performance fusion plasmas in present day tokamaks and in ITER, the international experiment under construction in France to demonstrate the feasibility of fusion power.

Participants in this research and coauthors of the paper included PPPL physicists Jong-Kyu Park, Jonathan Menard, Stanley Kaye, and Stefan Gerhardt, as well as General Atomics physicist Yueqiang Liu. Support for this research was provided by the DOE Office of Science.

PPPL, on Princeton University's Forrestal Campus in Plainsboro, N.J., is devoted to creating new knowledge about the physics of plasmas — ultra-hot, charged gases — and to developing practical solutions for the creation of fusion energy. The Laboratory is managed by the University for the U.S. Department of Energy's Office of Science, which is the largest single supporter of basic research in the physical sciences in the United States, and is working to address some of the most pressing challenges of our time. For more information, please visit science.energy.gov

18. Big steps toward control of production of tiny building blocks

By
John Greenwald
March 6, 2018

Nanoparticles, superstrong and flexible structures such as carbon nanotubes that are measured in billionths of a meter — a diameter thousands of times thinner than a human hair — are used in everything from microchips to sporting goods to pharmaceutical products. But large-scale production of high-quality particles faces challenges ranging from improving the selectivity of the synthesis that creates them and the quality of the synthesized material to the development of economical and reliable synthesis processes.

However, this situation could change as a result of research at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL), where scientists have developed the diagnostic tools that are being used to advance an improved and integrated understanding of plasma-based synthesis — a widely used but poorly understood tool for creating nanostructures. PPPL scientists and collaborators outline, in several published papers, recent research that could help to develop controllable and selective fabrication of nanomaterials with prescribed structures. Such basic research could pave the way toward manufacturing advances in a variety of industries.

Unique observations
The papers report unique observations of the synthesis in carbon plasma generated by an electric arc *in situ*, or as the process unfolds. Researchers create the plasma arc between two carbon electrodes, producing a hot carbon vapor composed of atomic nuclei and molecules that cool and synthesize — or condense — into particles that grow into nanostructures by bunching together.

Direct observation has produced "a big step forward in understanding how carbon nanoparticles grow in plasma generated by arc," said physicist Yevgeny Raitses, head of the Laboratory for Plasma Nanosynthesis at PPPL. "The idea now is to combine experimental results with computer modeling for improved control of the process and to apply what we learn to other types of nanomaterials and nanomaterial synthesis."

Following is a look at three papers that break new ground in unraveling the poorly understood arc synthesis process. Support for this work comes from the DOE Office of Science.

• **Spotting precursors that become nanotubes.** Missing from today's knowledge is a detailed understanding of the precursors of nanotubes that are formed from the vapor during synthesis. This poses a key challenge for predicting the mechanism for nanosynthesis with a carbon plasma arc.
Shedding light on this process are new discoveries at PPPL. Research led by physicist Vladislav Vekselman and reported in the journal Plasma Sources Science and Technology(link is external)shows that what governs the synthesis of carbon nanotubes in a purely carbon electric arc is molecular precursors that include "dimers" — molecules formed by two carbon atoms.

This finding opens the door to improved predictive modeling of nanosynthesis in carbon arcs. "This is the first time that a laser-induced diagnostic technique has been applied to this type of synthesis," Vekselman said. "We now know where and how much precursor is formed in carbon arc material."

Supporting these findings are simulations of carbon arc synthesis conducted by PPPL physicist Alexander Khrabry. "Our models are based on the underlying physics of vaporization, condensation and the formation of nanostructures," said physicist Igor Kaganovich, deputy head of the PPPL Theory Department. "We apply this to results of the *in situ* experiments to develop predictions that can be tested with further experiments."
Such predictive models have begun to make progress. "Having *in situ* measurements while synthesis takes place is a very valuable aid to understanding and modeling," said Brent Stratton, head of the diagnostics division of PPPL and deputy director of the Plasma Science and Technology (PS&T) Department that houses the nanosynthesis laboratory. "What this project shows is the combined value of experiments and modeling for deepening understanding of plasma arc synthesis."
• **Detecting nanoparticle growth.** To further such understanding, researchers must monitor the production of particles in sizes ranging from nanometers all the way down to the atomic scale. PPPL research has now built and demonstrated a unique table-top laser technique for *in situ* detection of nanoparticle growth. "This custom-made diagnostic helps piece together the puzzle of plasma arc nanosynthesis," said physicist Alexandros Gerakis of PPPL, who designed the technique and is lead author of its description in the journal Physical Review Applied(link is external). "There had previously been no good way to monitor the process."
The novel method, derived from a prediction by Mikhail Shneider of Princeton University, detects particles that flow within and from the electric arc. The technique observes particles some five nanometers in size, and could be used to measure materials created by other forms of nanosynthesis as well. Such *in situ* measurement of nanoparticles during large-volume synthesis could advance understanding of the mechanisms behind nanoparticle growth.
• **Why some synthesis goes wrong.** Among the most promising types of nanomaterials are single-wall carbon nanotubes that carbon arc discharges can produce on an industrial scale. But a key drawback to this method is the impurity of much of the synthesized nanomaterial, which includes a mix of nanotubes, carbon soot and random carbon particles
A chief source of these drawbacks is the unstable behavior of carbon arcs, PPPL has found. Such behavior creates two modes of production, which the laboratory calls "synthesis-on," for pure nanotube fabrication, and "synthesis-off," for impure results. "The synthesis in plasma arcs is 20 percent on and 80 percent off," said physicist Shurik Yatom, lead author of the results published in the journal Carbon(link is external).

In these experiments, Yatom used a conventional arc synthesis technique and filled one of the two electrodes — called an "anode" — with graphite powder and a catalyst and found that the synthesis was erratic, switching between the dominant synthesis-off mode and the far less common synthesis-on mode. Fast-camera images, electric characteristics and emission spectra showed that the arc engaged the contents of the anode directly in the synthesis-on mode, but oscillated around the hollow anode in the synthesis-off mode and was unable to interact with the powdered graphite and catalyst inside.

The team also constructed a probing device to selectively collect the synthesized product between the two modes. Evaluating the synthesized nanomaterials was Rachel Selinsky of Princeton University, who found that the vast majority of nanotubes were collected during the "synthesis-on" mode.

The findings revealed the need for stabilizing the arc so that it constantly engaged the graphite and catalyst for the continuous production of single-wall carbon nanotubes. The paper proposes several pathways going forward, ranging from the use of thinner-walled to solid composite anodes for producing nanotubes in a continuous manner with fewer unwanted byproducts.

Finally, understanding the cause of such impurities is crucial for future research at PPPL and elsewhere. As scientists continue to develop methods of *in situ* characterization for nanostructures, they must monitor the arc behavior and distinguish between results obtained in the synthesis-on and synthesis-off modes.
Going forward, PPPL conducts *in situ* measurements of plasma nanotubes synthesized from boron nitride, a promising material with aerospace and electronics applications. Collaborating on this work are professors Roberto Car of Princeton University, Predrag Kristic of the State University of New York at Stony Brook, and Bruce Koel of Princeton.

Overseeing PPPL nanosynthesis projects is Phil Efthimion, head of the PS&T Department. Following are coauthors of the papers. Nanoparticle precursors: Vladislav Vekselman, Alexander Khrabry, Igor Kaganovich, Brent Stratton and Yevgeny Raitses of PPPL, and Rachel Selinsky of Princeton University. Detecting nanoparticle growth: Alexandros Gerakis, James Mitrani, Brent Stratton, and Yevgeny Raitses of PPPL, Yao-Wen Yeh and Mikhail Schneider of Princeton University. Synthesis on and synthesis off: Shurik Yatom and Yevgeny Raitses of PPPL, Rachel Selinsky and Bruce Koel of Princeton University.

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19. Meetings and Workshops

LLNL Hosts Joint Working Group Meeting

https://lasers.llnl.gov/news/meetings-workshops

The Laboratory was host to a week-long U.S.-United Kingdom Joint Working Group (JOWOG) meeting on plasma physics and high energy density (HED) physics from March 5 to 9. JOWOGs enable technical exchanges between UK and U.S. collaborators via the two nations' 1958 Mutual Defense Agreement, which was reaffirmed by the signing of a new Statutory Determination.
The partnership covers experiments and simulations in support of the National Nuclear Security Administration (NNSA)'s Stockpile Stewardship Program (SSP) at HED research facilities. JOWOG37 provides a forum for the presentation and exchange of information on topics such as radiation transport and hydrodynamics, radiation sources and effects, material properties (equation of state, material strength, and opacity), nuclear boost/burn physics, and atomic physics in the HED regime.

Much of the data are obtained on large laser facilities such as NIF, the Omega Laser Facility at the University of Rochester, the Z Facility at Sandia National Laboratories (SNL), and the Atomic Weapons Establishment (AWE)'s Orion Laser Facility in Aldermaston, UK.

The 140 attendees and presenters at the meeting were from LLNL, Los Alamos National Laboratory (LANL), SNL, AWE, General Atomics, the U.S. Naval Research Laboratory, the Laboratory for Laser Energetics at the University of Rochester, the Nevada National Security Site, and NNSA.

The technical agenda included oral and poster sessions on HED and inertial confinement fusion results from various experiments. A side session and poster session covered a variety of topics on target fabrication at LLNL, AWE, General Atomics, and LANL, including opacity and double-shell targets, advanced foam technologies, aerogels, and robotic target assembly.

“I was delighted to host such an important meeting,” said NIF & Photon Science researcher Hye-Sook Park. “The scientific and technical presentations were excellent, truly representing cutting-edge science in the high energy density physics area. The NIF results were remarkable in terms of scientific quality and importance to the SSP programs. The interactions between the UK and U.S. teams and between the U.S. institutions were very dynamic and positive. Many attendees praised the high-quality scientific program. The fact that this JOWOG was so well received tells us that the NIF results are important to both the NNSA and UK programs.”