Australian ITER Forum Website News Update 5/18

B.J.Green (23/5/18)

1. Will China beat the world to nuclear fusion and clean energy?

By Stephen McDonell
BBC News, Anhui Province

- 18 April 2018
- http://www.bbc.com/news/blogs-china-blog-43792655

- **In a world with an ever-increasing demand for electricity and a deteriorating environment, Chinese scientists are leading the charge to develop what some see as the holy grail of energy.**
- **The BBC's Stephen McDonell was given rare access to their facility in Anhui province.**
- Imagine limitless energy with virtually no waste at all: this is the lofty promise of nuclear fusion.
- On Science Island in Eastern China's Anhui Province, there is a large gleaming metal doughnut encased in an enormous shiny, round box about as big as a two-storey apartment. This is the Experimental Advanced Superconducting Tokamak (or EAST).
- Inside, hydrogen atoms fuse and become helium which can generate heat at several times the temperature of the sun's core.
- Powerful magnets then control the reaction, which could one day produce vast amounts of electricity if maintained.
- Around the globe, they are trying to master nuclear fusion - in the United States, Japan, Korea, Brazil and European Union - but none can hold it steady for as long as the team in Anhui.
- Right now that's 100 seconds and it gets longer every year. Here they're already talking about goals which are 10 times as long, at temperatures of 100 million degrees Celsius.

- But there's a reason why fusion has eluded scientists and engineers since the early advances in the Soviet Union in the 1950s.

- It is really difficult.

- ## Safe nuclear energy

- Maintaining a limited fusion reaction in a controlled environment has been possible for more than 50 years and yet the duration is still a long way short of what would be needed to capture this vast heat and convert it to electricity.

- The EAST system is a souped-up version of the original Russian design.

- On the day we visit we watch a lively debate unfold in the control room. There are leakage problems - not material getting out but air being sucked into the vacuum within - and they need to find a solution.

- A separate group is in walkie-talkie contact with the control room. They move around the configuration of pipes, electricity housing and stepladders surrounding the Tokamak, looking to patch the leak.

- When Xi Jinping visited here he wanted to know about the dangers of this technology, so we asked what they told China's president.

- "A fusion reactor is quite safe compared with fission reactor," says Song Yuntao, deputy director at EAST.

- "Magnetic confinement is controllable fusion. I can shut down the power supply and it's perfectly safe. There won't be any nuclear disaster."

- Current nuclear reactors rely on fission and the splitting of an atom which leaves toxic waste that must be safely stored for potentially tens of thousands of years.

- A nuclear fusion power plant would instead stem from the joining of two nuclei to make a single nucleus and then magnets inside the internal wall of the doughnut contain the reaction (called the plasma) inside the huge tube.

- Crucially, we're told, this leaves almost no waste.

- ## A hefty price tag

- However the technology is not cheap.

- It costs $15,000 a day just to turn on the machine and that's without the wages of hundreds of specialists, the construction of buildings and the like.

- And yet the Chinese government is digging into its deep pockets to fund the project in the full knowledge that it could be decades before fusion is lighting up major cities.

- "Fusion is going to require huge breakthroughs from scientists and engineers as well as a lot of financial backing from the government," Mr Song says.
- "It's a project which costs so much but personally I think it's going to be great for the sustainable development of mankind."
- Because it carries such a hefty price tag and because it is so hard, the pursuit of fusion is seeing a fair amount of international collaboration.
- For example, China is one of the countries contributing to the ambitious International Thermonuclear Experimental Reactor (ITER) project in southern France which - apart from European nations - draws in India, Japan, Russia, South Korean and the United States. It is expected to start testing in 2025.
- In the meantime China is also making leaps and bounds on its own.
- The proposed next step for this team is to design a fully-fledged nuclear fusion test reactor capable of generating electricity. To eventually work properly it would have to be much bigger than what we've seen and able to contain a plasma reaction indefinitely rather than for a minute-and-a-half.
- "The demand for energy is huge in every country and China has a roadmap for fusion-generated power," says Mr Song. "We want to complete the design for a test fusion reactor within five years. If we succeed it will be the world's first fusion reactor."
- The eventual hope is that fusion might produce electricity in volumes beyond mankind's wildest dreams.
- It may be some way off but Beijing is taking the challenge very seriously meaning that, if it can get it to work, China could end up having the edge over all others when it comes to the power generation of the future.

- 2. DOI:10.1063/PT.6.2.20180416a

16 Apr 2018 in Politics & Policy

ITER disputes DOE's cost estimate of fusion project

The leader of the international collaboration challenges a DOE undersecretary's claim that the price tag will be tens of billions of dollars higher than official estimates.

David Kramer

https://physicstoday.scitation.org/do/10.1063/PT.6.2.20180416a/full/

The US Department of Energy has nearly tripled its cost estimate for ITER, the fusion test reactor in France that's being constructed by a seven-party international collaboration, to $65 billion. ITER headquarters is pushing back, sticking by its figure of $22 billion. Though DOE has maintained in the past that the US contribution could balloon, this marks the first time the agency has publicly challenged the ITER Organization's overall cost assessment.

Paul Dabbar, DOE undersecretary for science, provided the estimate to the Senate Appropriations subcommittee on energy and water development on 11 April. The $65 billion covers construction alone, he said; annual operating costs once experimental operations begin in 2025 aren't included. Yet Dabbar seemed to confuse matters by telling senators that ITER's cost estimates are "reasonable."

ITER director general Bernard Bigot said there's no reason to deviate from the $22 billion construction cost estimate he provided to a House of Representatives hearing in 2016. DOE's "figures are not endorsed by the ITER Organization," he said in a statement. "The cost has not gone up; we continue to adhere to the cost projections defined in 2016, when the new ITER baseline was agreed ad referendum by the ITER Council," the project's governing board.

According to a DOE spokesperson, the agency's estimate is based on extrapolating from $6.4 billion, the high end of the anticipated US contribution as determined by a 2013 review committee and confirmed in a January 2017 report. The spokesperson adds that ITER doesn't provide an official estimate of construction costs because the participating countries have different methods of pricing out their in-kind contributions—mostly in the form of fabricated reactor components—and those estimates are not reported to the ITER Organization.

Bigot noted that the day after Dabbar's testimony, the European Union Council of Ministers endorsed ITER's nearly two-year-old baseline estimate, which covers construction from 2007 to full completion in 2035. Including a 10% contingency to account for overruns, ITER's cost to EU members is €11.7 billion ($14.5 billion). As host, the EU is paying 46% of ITER's cost, five times the share of each of the other six partners: China, India, Japan, Russia, South Korea, and the US.

Based on the EU's share of the total cost and industrial procurement rates, total construction costs could be extrapolated to €25.6 billion, including a contingency. Bigot said the actual price tag is likely to be lower than that because procurement costs in India, China, South Korea, and Russia, which are collectively picking up 36% of the cost, are 15–20% lower, on average, than those in Europe.

In any case, cost estimates for the project are fraught because most of the partners' contributions are in-kind, and accounting practices, including the use and size of the contingency, vary widely. For example, DOE adds a contingency of nearly 50%, but South Korea, China, and Japan do not include any contingency.

Dabbar's testimony came in front of a subcommittee whose chair, Lamar Alexander (R-TN), and ranking member, Dianne Feinstein (D-CA), have tried to zero out the ITER budget in three separate appropriations bills. Each time, funding was restored in conference with the House. The fiscal year 2018 omnibus appropriations act signed into law in March provides $122 million for ITER. Through FY 2017, the US has contributed approximately $1.1

billion to the project, $975 million in-kind and $145 million in cash. The US is currently in arrears for $65 million in cash.

The Trump administration is reviewing ongoing US participation in ITER as part of a broader examination of DOE's range of nuclear energy activities. Dabbar indicated that review won't be completed prior to the Appropriations subcommittee's markup of the FY 2019 budget in the coming weeks. In the meantime, the agency has requested $75 million for the project next year, which includes continued funding for the construction of ITER's central solenoid at General Atomics in San Diego.

Although initial plasma experiments with deuterium are scheduled to begin at ITER in 2025, construction will continue through 2035, the planned date for the first ignition experiments using tritium.

3. INDIA

APRIL 14, 2018 / 1:51 AM / A MONTH AGO

Massive Chinese fusion reactor parts end journey in France

https://www.reuters.com/article/nuclear-iter/massive-chinese-fusion-reactor-parts-end-journey-in-france-idUSL8N1RQ5G9

SAINT-PAUL-LES-DURANCE, France, April 13 (Reuters) - Four massive parts for an international nuclear fusion project arrived in southern France on Friday after a four-month journey from their production site on the Yangtse river in China.

The four vapour suppression tanks, each weighing about 100 tonnes and measuring eight by nine metres, were delivered to the International Thermonuclear Experimental Reactor (ITER) site in Saint-Paul-lez-Durance, French authorities said.

They will be used to build a prototype fusion reactor to generate electricity in a process similar to the nuclear fusion that powers the sun. The project is more than halfway towards the first test of its super-heated plasma by 2025 and first full-power fusion by 2035.

The ITER project is a cooperation between Europe, the United States, China, India, Japan, Russia and South Korea with an estimated cost of about 20 billion euros ($25 billion).

Member countries contribute the lion’s share of the ITER budget my manufacturing components in their own factories and then shipping them to France where they are assembled.

Some of the 250 ultra-heavy components, which travel by sea, canal and road, are so large that France had to spend 110 million euros adapting roads to accommodate them.

The biggest components, some of which weigh nearly 600 tonnes, will be shipped to ITER in 2019-20. (Reporting by Jean-François Rosnoblet Writing by Geert De Clercq Editing by Alexander Smith)

4.

Europe's investment in the ITER fusion project: mastering the power of the sun and the stars

https://ec.europa.eu/info/news/looking-back-europes-contribution-iter-over-last-ten-years-2018-apr-12_en

The EU is a strong advocate for sustainability. For years it has been taking action to cut down the emission of greenhouse gases, fighting climate change and trying to make Europe more self- sufficient in the field of energy, given the fact that its import dependency is particularly high for crude oil (90%) and natural gas (69%). Half of the energy we consume is imported at a cost of 1 billion EUR per day. So how can we reconcile our potential to grow without putting at risk our planet's well-being?

The answer lies in the energy mix of the future. And fusion can be part of it. The power of the sun and stars has several merits worth considering. Its fuel- isotopes of hydrogen- is abundant and with just small amounts we can release a lot of energy. Hydrogen the size of a pineapple can offer as much fusion energy as 10 000 tonnes of coal. The fusion reaction is inherently safe and poses no risk of a meltdown. There are no greenhouse gases and no long-lasting waste for the future generations. For this reason, the EU has invested in ITER, the biggest scientific collaboration that will test the feasibility of fusion power.

ITER brings together the countries of EURATOM (EU-28 plus Switzerland), China, Japan, India, the Republic of Korea, Russia and the US. The Parties represent 80% of the global GDP and half of the world's population. Scientists all over the world are involved in R&D activities linked to the project and companies are manufacturing millions of components that will be assembled in Cadarache, south of France, where the project is located.

Europe, being the host of the biggest fusion experiment, is financing nearly half of it. Fusion for Energy (F4E), the EU body which was set up ten years ago to manage the European contribution to ITER, counts with approximately 450 members of staff working in Barcelona (Spain), Cadarache (France) and Garching (Germany). Since its establishment, F4E has invested in Europe's economy 4 billion EUR by awarding more than 900 contracts to 440 companies, research organisations, and to 1500 of their subcontractors, working for the ITER project. Its impact in making Europe more competitive can be widely felt in the socio-economic fabric of our continent. Think of the creation of new jobs and skills, partnerships between big and smaller companies, and the transfer of know-how to develop new applications which could enter into new markets. To find out more about Europe's business potential in ITER and to read the views of some of our contractors click here.

In December 2017, ITER celebrated an important milestone having reached 50% completion of the total construction work needed for the first operation stage – so called First Plasma. The progress on the ITER construction site, which consists of 39 buildings and infrastructures under Europe's responsibility, has been impressive. Nearly 2000 people are working daily on a platform that is nearly 42 hectares. Click here to fly over the site and become familiar with the works carried out. The main building (Tokamak Complex) where the ITER machine will be installed is reaching its final level (fourth floor), and the progress of various auxiliary buildings such as the Cryoplant, which will generate the cold temperatures needed, and the Magnets Power Coversion building, which will energise the powerful magnets that will confine the super-hot plasma, are advancing. More equipment has started arriving on-site. For example, the first tooling has been delivered to the Assembly Hall, and the first Cryoplant tank has been installed.

In terms of manufacturing, Europe has celebrated a fair share of achievements. In the Spring of 2017, the most high-tech magnet in history was unveiled before going through the final stages of production. ITER will require powerful magnets to confine the hot plasma and control its shape and stability. Europe will have to deliver ten Toroidal Field coils and five Poloidal field coils. Works have also been advancing with the production of the vacuum vessel, the “metallic shell” which will host the fusion reaction. Europe is responsible for the fabrication of five sectors entrusted to a consortium of companies. Last but not least, in collaboration with the ITER Organization and Consortium RFX, F4E has invested in a Neutral Beam Test Facility to develop powerful heating systems that will eventually be used to raise the temperature of ITER’s plasma. The most powerful negative ion beam source to date has already been installed in its vacuum vessel and first operations are expected to start in summer.

ITER can be described as a big technology puzzle which will push forward our knowledge frontiers. It will give us the answer regarding the feasibility of fusion energy, its cost and financial return. Ultimately, however, it will help policy-makers take an informed decision on the energy scenarios of the future. Europe’s commitment to see this project through offers our industry and scientific community an unparalleled opportunity to demonstrate its strength, to grow and to learn how to deliver the energy of the future. The challenges we currently face require the broadest possible energy alliance to guarantee our citizens access to safe, sufficient and sustainable power supply. Let’s work together to deliver it!

To keep up to date with the progress of Europe’s contribution to ITER subscribe to F4E News and visit regularly F4E’s website.

5. DOE SCIENCE NEWS SOURCE

The DOE Science News Source is a Newswise initiative to promote research news from the Office of Science of the DOE to the public and news media.

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Fusion Research Ignites Innovation

How technologies developed for fusion have taken on second lives in industry.

If you're heating something to 100 million degrees — three times hotter than the core of the sun — oven mitts and aprons aren't going to cut it. But researchers investigating how to produce fusion energy tackle this challenge every day. Fusion involves combining nuclei from two atoms into one, resulting in a small amount of mass transforming into a staggering amount of energy. Getting that reaction started and containing it requires some of the most high-tech equipment in science.

While sustained fusion power is still years away, several technologies that scientists have developed to research it have already moved beyond the lab. From enabling smartphones to scanning for radioactive materials, technologies originally produced for fusion research supported by the Department of Energy's (DOE) Office of Science are keeping us safe, secure, and connected.

Enabling Improvements in Semiconductors

When manufacturers needed to make electronics increasingly smaller in the 1990s, turning to fusion researchers may not have been the first thing on their minds. To make electronics smaller, faster, and more powerful, they needed to make semiconductors much smaller as well. The grooves and lines in semiconductors and other components needed to be at the atomic level, more than 100 times smaller than a human hair.

But fusion researchers at DOE's Oak Ridge National Laboratory (ORNL) knew something industry didn't — how to control plasma. A separate state of matter from solids, liquids, or gases, plasma is a collection of particles with positive and negative electric charges. It occurs when high amounts of power run through a gas. As it's chemically very reactive, it interacts readily with almost anything you put it in contact with.

The semiconductor industry wanted to put materials into chambers filled with plasma and use the resulting chemical reactions to strip off or add atoms. In theory, this process would give them the level of control they needed to make miniscule grooves and lines.

Unfortunately, the companies had unpredictable results when they used radio frequency (RF) waves to create the plasma.

"Mother Nature was not kind. It turns out that there are very complex connections between different frequencies of voltages," said Mark Kushner, a University of Michigan professor and director of the DOE Plasma Science Center there.

Because testing the RF power levels by hand was too complex and time-consuming, they sought outside expertise.

Fortunately, ORNL scientists had been using RF waves to heat up fuel for fusion for more than a decade.

"The government's here to help you; they can actually help you!" laughed ORNL's Gary Bell, recalling how manufacturers felt. "We got a big kick out of that."

Partnering with a consortium of semiconductor manufacturers and suppliers, ORNL researchers evaluated a number of RF power delivery systems and controls. Using knowledge and tools from fusion research, ORNL scientists helped companies reposition components and reprogram controls. They also helped build testing equipment and developed technician training.

"A lot of expertise that came in was developed through magnetic fusion energy research, through the people and understanding of plasma science," said Amy Wendt, a professor at the University of Wisconsin-Madison and a member of DOE's Fusion Energy Sciences Advisory Committee.

Modifying how they produced semiconductors allowed manufacturers to fit more components onto computer chips than ever before. Those improvements and others using plasma made it possible for companies to build smaller, lighter, more efficient cell phones, tablets, and computers.

Launching Jets From Aircraft Carriers

While smartphone components are some of our smallest technologies, fusion research has also set the stage for improving some of the world's biggest ones: aircraft carriers.

In the 1990s, the Department of Defense (DOD) realized that they could do better than the steam and hydraulic-powered catapults on aircraft carriers in use at the time. So they released a request for proposals for a technology that could store a huge amount of energy and release it almost instantaneously — over and over again.

Researchers at the DIII-D National Fusion Facility, an Office of Science user facility run by General Atomics (GA), were familiar with those challenges. In fact, they had to solve a similar problem back in 1978 before they could get a new iteration of their reactor up and running.

“GA is in a unique position to drive technology innovations, given its long history of using scientific research results to develop cross-cutting practical applications,” said John Rawls, chief scientist at GA.

To control the 100-million-degree plasma inside of it, the DIII-D reactor produces huge magnetic fields. The machine creates and maintains these fields by running tremendous amounts of energy through giant magnets. When GA scientists designed the machine with funding from the Office of Science’s predecessor in the 1970s, they developed the controls and inverters to release and control those bursts of energy.

Based on that expertise and existing technology, DOD chose GA to develop the Electromagnetic Aircraft Launch System (EMALS). This system speeds an aircraft down the deck of a carrier using a linear induction motor coupled to the same type of inverters that provided such precise electrical and magnetic control at DIII-D. The performance of the induction motor can be finely controlled to deliver the precise amount of acceleration and velocity necessary to launch an aircraft of a specific size and weight. Because it’s much more precise than previous systems, EMALS minimizes the physical stress put on the aircraft, increasing their lifespans, and reducing costs.

Today, the U.S. Navy is using EMALS on the USS Gerald R. Ford (CVN 78). It is also installing EMALS on all future Ford-class aircraft carriers.

“We were able to advance numerous first-of-kind technologies, including the creation of the world’s most powerful linear motor and new inverter drives, to produce an integrated EMALS system that has a smaller footprint, greater efficiency, and requires less manning and maintenance to help save costs and improve reliability,” said Scott Forney, president of General Atomics Electromagnetic Systems. “To top it off, we offer a flexible design that has the potential for installation on other platforms requiring different catapult configurations and aircraft support.”

Developing New Materials for Extreme Conditions

Fusion reactions create some of the most high-stress environments in the universe. The materials used in reactors must withstand staggeringly high pressures, temperatures, and radiation.

“We’re taking materials outside their usual comfort zone,” said Steven Zinkle, a University of Tennessee professor with a joint appointment at ORNL.

The plasma bombarding a fusion reactor’s walls can remove and re-deposit a single atom a billion times a year. Through it all, the walls need to stay tough, maintain stability, and absorb as little radiation as possible in a very stressful environment for building materials.

“If you’re going to make a fusion reactor work, it’s all about the materials,” said Bell.

To build a better reactor, ORNL researchers helped develop a new type of stainless steel that could resist temperatures up to 1560 degrees F.

It turns out that fusion researchers weren't the only ones who needed steel that could withstand extremely high temperatures. Because advanced diesel engines run hotter than conventional ones, they needed advanced materials to match. ORNL's materials group realized that this new steel could meet that challenge. After the Office of Science's fusion group completed the basic research, DOE's Vehicle Technologies Office took it over, supporting an agreement between ORNL and equipment manufacturer Caterpillar to adapt the material for vehicles. In 2007, Caterpillar started using it in all of their heavy-duty highway truck engines. Since then, the material has generated millions of dollars of revenue.

Even the best steel isn't tough enough for fusion reactors' inner walls. To provide further protection, ORNL developed radiation-tolerant silicon carbide ceramic composites. These composites can survive temperatures of up to 2700 degrees F.

Recognizing the potential of this material, NASA and other agencies supported further design and processing research on these composites. In rocket nozzles, thrusters, gas turbines, and even conventional nuclear reactors, this material can now simplify components and increase efficiency.

While national laboratories often develop these innovative materials, they also provide equipment and expertise that enable private companies to do so as well. Using tools developed for fusion research at DOE's Princeton Plasma Physics Laboratory (PPPL), Lenore Rasmussen found a way to use plasma to improve the attachment of her Synthetic Muscle™ technology to metal electrodes. She also used the laboratory's resources to test the material's resistance to extreme temperatures and radiation. Since then, NASA has tested how well the material resists radiation on the International Space Station. Rasmussen is now working to commercialize the technology. In the future, companies may use it in prosthetic limbs and robotics.

Detecting Radioactive Materials for Security

Building a fusion reactor is hard enough. Retiring it can be even tougher. Charles Gentile and his colleagues at PPPL faced this dilemma in 1999. They needed to decommission the lab's Tokamak Fusion Test Reactor that had been running for more than a decade.

Staff first needed to identify radioactive elements in the vacuum vessel, the container that housed the fusion reactions. So they created a portable detection unit to collect data, as well as software to process that data. After they finished disassembling the reactor, the technology sat on the shelf.

But in 2001, they saw the opportunity for their invention to have a second life. The federal government had put out a call for technologies that could have applications in homeland security. The team determined that their device had the potential to accurately identify in real time radionuclides that might be used in "dirty" bombs. With a $400,000 grant from the U.S. Army, PPPL staff adapted their technology. They revised it so it could run in any weather, be used by non-nuclear scientists, and detect a wider array of radioactive substances.

Now, the Miniature Integrated Nuclear Detection System is a combination hardware and software system that's the size of a thermos. In one second, it can sense one-billionth of the material needed to build a credible dirty bomb. It can scan moving vehicles, luggage, packages, and cargo for more than 20 different types of radioactive substances. So far, security firms have used it at a major bus and commuter rail center as well as major U.S. ports.

As fusion technology advances, the work that goes into it will continue to yield unexpected benefits.

As Gentile said, “It’s nice that we do have these technologies that come out of the laboratory that can help people in other areas.”

The Office of Science is the single largest supporter of basic energy 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 https://science.energy.gov.

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6.

Bulletin of the Atomic Scientists

ANALYSIS
9 APRIL 2018

Why fusion?

Robert J. Goldston

The 2014 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report included publication on the web of a wide range of scenarios for the future, produced by energy and environment modelers from all over the world. If we select an internationally coordinated set of scenarios that are consistent with a temperature rise of less than 2 degrees Celsius (3.6 degrees Fahrenheit) above the pre-industrial era—the upper-limit goal of the Paris Climate Accords—and average their projections, we find the projection for future electricity production in the table below, shown in units of annually averaged gigawatts electrical <GWe>.

IPCC Projected Worldwide Annually Averaged Electrical Power Production <GWe>

	2020	**2050**	**2100**
Solar	30	650	3720
Nuclear	400	1120	2230
Wind	150	930	2170
Biomass	40	540	1500
Hydro	410	640	850
Coal + Oil	920	860	770
Gas	780	980	620
Geothermal	30	84	100
Total	2770	5800	11900

This IPCC-based mean scenario relies heavily on solar and wind, which vary strongly on a daily and seasonal basis. By the time these intermittent energy sources become dominant, later in the century, we may well have developed the capability to mitigate their daily variation using energy storage. Seasonal variation, however, is hundreds of times harder to compensate, and it is difficult to imagine how this can be done effectively. As solar and wind grow in scale they will need to occupy sites with higher variability, and when they become a large fraction of the energy supply, later in the century, the costs associated with their variability will grow.

The IPCC scenario also relies heavily on nuclear fission power, which carries with it well-known risks associated with safety, waste storage, and nuclear weapons proliferation. By later in the century, this scenario burns all of the world's reported identified, predicted, and speculative uranium resources. While other resources may become available, the scale of this uranium use, coupled with its uneven distribution, is likely to cause growth in the use of reprocessing technology and plutonium fuel, significantly increasing proliferation risks. Another concern is the implied requirement for geological waste storage in the absence of reprocessing, expected to be about 50 facilities with the capacity of Yucca Mountain.

Biomass, while somewhat smaller than the others listed above it, is equally important because it is assumed to provide a net sink of carbon dioxide. Vegetation extracts carbon from the atmosphere as it grows, and if much of the CO2 produced from its combustion can be captured and stored, then the overall system forms a net sink. The biomass in the IPCC scenario, however, requires using land equal to about 75 percent of all the land that is currently employed by agriculture, at a time when world food consumption is projected to more than double and the competition for water grows. The very large scale of the biomass CO2 that would need to be sequestered from the environment—for hundreds of years, in varying geological conditions—is far beyond our experience. The possibility of burning coal, oil, and gas into the future also depends on carbon capture and storage on a massive scale, in a broad range of geologies.

Consequently, solar and wind have a common limitation in most parts of the globe: seasonal variability. Meanwhile, biomass, coal, oil, and gas share a common risk—the practicality of very large-scale carbon storage worldwide. And nuclear fission introduces risks associated with safety, radioactive waste, and nuclear proliferation. These energy sources all need to be pursued vigorously to determine the degree to which their limitations, risks, and problems can be overcome at the unprecedented scale required.

In contrast, fusion energy can offer an attractive alternative. Fusion is a continuous energy source; it does not face the same safety, waste, and proliferation issues as fission; it does not require disproportionate land use; and it does not depend on the success of carbon capture and storage. Fusion can come on line later in the century, as electric power needs double between 2050 and 2100, and as the scale of electricity production puts strong pressure on the issues for other energy sources.

What sets the timescale for fusion development? Until recently, the answer has been the science. The very hot gas, called plasma, that supports fusion is tricky, and it has taken time for scientists to understand its behavior. In that time we have made immense strides. We are now able to accurately calculate, predict, and control key aspects of the behavior of fusion plasmas. We know how to heat plasmas to fusion temperature, we know how plasmas confine the heat put into them, and we know how the heat flows out. We also know how the precious tritium that is used to fuel a fusion power system circulates, and we have demonstrated that fusion devices with metallic walls retain very little of it.

There is room for innovation and improvement, but the basic outlines of how a fusion power system can work are now well-known. We have already made plasmas where we pour in 25 million watts of heating power, and an additional 16 million watts of heat from fusion pours out. An international coalition comprised of China, Europe, India, Japan, Russia, South Korea, and the United States is building the ITER project in southern France, whose goal is to produce 500 million watts of fusion heat, ten times its input of only 50 million watts of heating power. For a practical fusion power system, this ratio needs to be increased from 10 to about 25, due to the inefficiencies of turning electricity into plasma heating, and then fusion heat into electricity. That step is left for the first fusion pilot plants to follow ITER.

It is fair to ask, why can’t we have fusion sooner? The answer is that these systems are intrinsically large; you cannot test the physics and technology of fusion on a lab bench and then mass-produce fusion systems, as you can solar cells. Consequently, as we are now approaching systems on the scale of power plants, they are large, first-of-a-kind facilities, and they take time to construct. The only way that we have been able to assemble the financial resources to construct the ITER project is through international collaboration. But after ITER, the next facilities will likely be national fusion pilot plants, which will use the physics and technology developed from ITER to put net electricity onto the grid (subtracting out the energy required to operate the plant). China, Europe, and South Korea each have well-developed plans to do this. The United States should as well. Such plans put fusion on the path to supporting the continuing growth in world electricity supply as it is needed.

One author has questioned in these pages whether fusion can be an attractive energy source. Of course fusion will not be magical, but the questions raised by Daniel Jassby have answers. Fusion will require cooling like any heat-based energy source such as biomass, coal, and fission. Furthermore, fusion systems will use a fraction of their own energy production to sustain their operation—like any energy system equipped with carbon capture and storage, which uses a significant fraction of its power production to operate the capture and storage technologies. Some fusion power plant designs use liquid lead as a coolant, which is much more efficient than water and steam, and so requires reduced cooling to produce a given amount of electricity.

Fusion neutrons will surely damage the internal components closest to the plasma. In the first fusion pilot plants, materials in the regions with the highest neutron flux would need to be replaced every 6-to-12 months of full-power operation. There are options for new nano-structured materials that are more neutron-resistant. These can be developed and qualified for fusion application using computer simulations and small-scale tests, as well as tests in the pilot plants themselves and in follow-on fusion power sources, as was done for fission. Fusion will have nuclear waste, but the lifetime of this waste will be measured in decades, not millennia. Fusion neutrons can in principle be used to breed fuel for weapons. But because no breeding materials should be present in a fusion power plant, this will be much more straightforward to detect and deter, as compared with fission reactors where the production of large quantities of weapons-usable material is intrinsic to the process.

The first fusion power plants will be expensive, but one can expect that as the technology matures, costs will come down. The major safety issues that have driven up the cost of fission power plants over time are not present for fusion. In sum, while fusion energy is not magical, it has the potential to be an attractive energy source that can be deployed as major pressures rise on existing energy supply options.

It is encouraging that a number of start-up companies are now investing in fusion. They are looking for breakthrough paths to fusion energy, and every breakthrough—scientific or technological—is welcome, not to mention the contributions possible from the breadth of scientific enquiry they support. It is not very likely, however, that these small, high-risk private ventures will come to fruition before the work of the world’s large, open scientific research community. Venture capital firms generally make their profits by supporting multiple high payoff, but low probability, undertakings. Even so, the recently announced initiative by a private company associated with the Massachusetts Institute of Technology is potentially very helpful as it may open a path to reducing the size of fusion energy systems following on ITER’s results, through more advanced magnet technology based on new high-temperature superconductors.

So, what is the answer to "Why fusion?" The choice of the energy sources that will power human development throughout this century is extraordinarily important. And the cost of developing fusion is tiny compared to the size of the world's energy economy. It is indeed far smaller than the subsidies provided by governments for existing energy sources. Fusion should be developed as a practical and attractive alternative, to become available at scale as other energy sources face major limitations, risks, and problems that may constrain their growth. We owe our children and grandchildren both the opportunity for further human development based on access to energy, and also the same lovely, green planet we inherited from our parents and grandparents.

Editor's note: A year ago, the Bulletin *published an article about the drawbacks of fusion as an energy source,"Fusion reactors—Not what they're cracked up to be," written by a physicist who had spent 25 years at the Princeton Plasma Physics Lab studying plasma physics and neutron production related to fusion energy research and development. The article garnered more than 100 reader comments and stirred up intense debate—so much so, that we asked the author, Daniel Jassby, to revisit the topic a few weeks ago, in "ITER is a showcase... for the drawbacks of fusion energy."*

7. 18 Apr 2018 | 17:00 GMT

MIT Spin-off Faces Daunting Challenges on Path to Build a Fusion Power Plant in 15 Years

Commonwealth Fusion Systems has pledged to build a commercial fusion reactor based on new superconducting magnets

By Tracy Staedter

https://spectrum.ieee.org/energywise/energy/nuclear/fifteen-years-to-a-fusion-power-plant-might-be-a-reach

Fusion power is always two or three decades away. Dozens of experimental reactors have come and gone over the years, inching the field forward in some regard, but still falling short of their ultimate goal: producing cheap, abundant energy by fusing hydrogen nuclei together in a self-sustained fashion.

Now an MIT spin-off wants to use a new kind of high-temperature superconducting magnet to speed up development of a practical fusion reactor. The announcement, by Commonwealth Fusion Systems, based in Cambridge, Mass., caused quite a stir. CFS said it will collaborate with MIT to bring a fusion power plant online within 15 years—a timeline faster by decades than other fusion projects.

CFS, which recently received an investment of US $50 million from Eni, one of Europe's largest energy companies, says the goal is to build a commercial fusion reactor with a capacity of 200 MWe. That's a modest output compared to conventional fission power plants—a typical pressurized water reactor, or PWR, can produce upwards of 1,000 MWe—but CFS claims that smaller plants are more competitive than giant, costly ones in today's energy market.

It's certain that, between now and 2033, when CFS expects to have its reactor ready for commercialization, the company will face a host of challenges. These revolve around key milestones that include: fabricating and testing the new class of superconducting magnets, and using them to build an experimental reactor, which CFS named SPARC; figuring out how to run SPARC so that fusion reactions inside the machine can produce excess energy in a continuous manner, one of the biggest challenges in any fusion reactor; and finally, scaling up the experimental design into a larger, industrial fusion plant.

Each of these steps embodies numerous scientific and engineering quandaries that may have never been seen before or have already confounded some of the smartest physicists and nuclear engineers in the world. Can CFS and MIT finally harness fusion power? Maybe. In 15 years? Probably not.

"Fusion research remains fusion research," says Robert Rosner, a professor of physics at the University of Chicago and the former director of Argonne National Laboratory. "It's a field where getting to a practical, energy-generating reactor is not an engineering issue, but a basic science issue."

Most experimental fusion reactors are based on a Russian design called a tokamak. These machines employ a powerful magnetic field to confine a cloud of hot ionized gas, or plasma, in the shape of a donut. This creates the extreme temperatures—in excess of 100 million degrees Celsius— for hydrogen nuclei to speed around and collide, fusing into heavier elements, like helium. The process releases vast amounts of energy. (Fusion is what powers stars like our sun, with their mighty gravity squeezing the hydrogen nuclei into helium.)

CFS and MIT plan to build a tokamak with technology never before employed in fusion. It will generate a magnetic field using a relatively new high-temperature superconducting material made from steel tape that's coated in a compound called yttrium-barium-copper oxide, or YBCO. The advantage of using this material is that it can produce intense magnetic fields from a much smaller machine than those at other facilities.

CFS estimates that SPARC will be about one-fourth the size (and 1/65 the volume) of the 23,000-metric ton machine called ITER, the world's largest experimental tokamak, currently under construction in France. Yet SPARC's magnet will generate a maximum magnetic field of 22 teslas, nearly double that of ITER's 12-T magnetic field.

Although MIT has pioneered research in tokamak magnetics and has persisted in exploring the high magnetic field approach to fusion, nobody has made superconducting magnets of that size and strength from YBCO, says Tim Luce, head of operations and science at ITER. “There are a lot of technological challenges associated with that,” he says.

MIT expects it will take three years to design, fabricate, and test the magnets. For comparison, ITER’s magnets, which consist of 18 units made from niobium-tin and niobium-titanium, are still being built, with final assembly scheduled for 2022 (the ITER project began in 2007).

There’s also the question of fuel. The sun with its intense gravity and pressure is able to produce fusion using ordinary hydrogen. But hydrogen gas doesn’t work well in a fusion reactor because the nuclei do not collide reliably.

To improve the chances of fusion, plasma physicists prefer two gases that are isotopes of hydrogen: deuterium, which is abundant in seawater, and tritium, a form rarely found in nature because it naturally decays with a half-life of about 12 years. A deuterium-tritium mixture, called D-T, has the greatest potential in the near-term for a sustainable fusion reaction that lasts more than a few minutes. But using that mixture has a downside: It produces large amounts of free neutrons, whose lack of an electrical charge allows them to escape the tokamak’s magnetic field. This stream of neutrons reacts with the nuclei of metals in the containment vessel to form new isotopes that can produce harmful radiation or make the vessel material brittle and vulnerable to cracks.

“Any tokamak must run for years to optimize the plasma before daring to use tritium,” says Daniel Jassby, who was a principal research physicist at the Princeton Plasma Physics Laboratory until 1999.

Tokamak designers who have used D-T fuel—or plan to use it—have come up with creative solutions to deal with the neutrons. ITER engineers, for instance, are designing a water-cooled steel structure about 1-meter thick that will line the inside of the machine. Both the Tokamak Fusion Test Reactor, which the Princeton Plasma Physics Lab operated from 1982 to 1997, and the Joint European Torus, operating at Culham Centre for Fusion Energy in Oxfordshire, U.K., simply surrounded the entire machine in a thick concrete shield.

CFS and MIT want to develop a molten salt blanket that will surround the plasma and behave as a kind of neutron-absorbing lining. Although circulating molten salt has been used in fission nuclear reactors, no one has ever developed such a technology for use inside in a tokamak.

In an email to *IEEE Spectrum*, Robert Mumgaard, CEO of CFS, writes that this collaboration is different than others dominated by government funding with a focus on basic research. In this partnership, MIT will carry out the basic and applied research and CFS will work to commercialize it.

“By involving private industry focused on delivering a working product, the project and company will be able to grow and accelerate upon success, bringing more human and monetary resources to bear,” he says.

“We think that the MIT projection of 15 years to a power plant is very ambitious, if not overly ambitious,” says Luce, of ITER. “But we will celebrate any success, and we share the dream of making energy from fusion.”

8. 16 April 2018

Europe is ready to switch on SPIDER - the most powerful negative ion source experiment to date

http://fusionforenergy.europa.eu/mediacorner/newsview.aspx?content=1223

The final countdown for the operation of SPIDER has started. All its systems are connected and engineers together with scientists are getting ready to turn the switch on and start testing. It's the result of a successful international collaboration of various Parties, from inside and outside Europe, working together to bring fusion energy a step closer. The thinking behind this experiment is similar to that of ITER: various components had to be produced in different parts of the world, and subsequently they had to be assembled in a facility specifically built for it. What started as an idea on paper is now an operational state-of-the-art test bed that will improve our knowledge on ITER heating systems and help us manufacture them.

Financed mostly by F4E, and with contributions from Consorzio RFX, ITER International Organization, and India's ITER Domestic Agency, this is the first of the two experiments/test beds at ITER's Neutral Beam Test Facility located in Padua, Italy. A second one called MITICA, which will mimic the full power of the ITER injectors, also under the same roof a few metres away, will be operational in a few years from now.

SPIDER, which stands for Source for Production of Ion of Deuterium Extracted from Radio Frequency plasma, will help engineers to finalise the development of the ion sources required for the ITER Neutral Beam Injectors (NBI), and to test key aspects of the diagnostic neutral beam accelerator. This is the first full-scale ITER ion source, capable of running pulses of up to 3 600 seconds at maximum power with hydrogen or deuterium. The 6 MW beam generated for one hour by 1280 powerful beamlets are equivalent to the energy required by roughly 1 000 medium apartments in one day.

An army of F4E suppliers and subcontractors worked hard to deliver various components of the SPIDER experiment. A European consortium consisting of Thales Electron Devices SA, CECOM Srl, Galvano-T GmbH, and E.Zanon SpA has been responsible for the manufacturing of the beam source and its vacuum, which weighs about 5 t and measures 3 x 3 x 2 m, and of its vacuum vessel. Works started four and a half years ago, for value of 10 million EUR approximately, which also includes the costs for the fabrication of the vacuum vessel and handling tool. OCEM Energy Technology and COELME provided the power supplies that will energise SPIDER. The cooling plant was delivered by Delta Ti Impianti, and the vacuum and gas injection plant system by Angelantoni Test Technologies. Last but not least, URS and NIER offered valuable engineering support. ITER India collaborated with PVA Tepla for the beam dump and with ECIL for the accelerator grid power supplies. Consorzio RFX in collaboration with the Italian authorities undertook the construction costs of the buildings, and procured diagnostics and control systems which were agreed in collaboration with F4E.

To understand the importance of this milestone, which has also been highlighted by the ITER Council, the political body that brings together all ITER Parties to monitor the overall progress, we need to make sense of history. We spoke to Tullio Bonicelli, F4E's Head for Neutral Beam, Electron Cyclotron and Power Supplies Systems, who has been following the evolution of this project the last 15 years. "Early in 2000 when the fusion community was finalising ITER's engineering design activities, the conclusion was reached that specific R&D activities were required to develop the neutral beams. In 2005, J. Potočnik, European Commissioner for Research, and L. Moratti, Italy's Minister for Education, Universities and Research, reached an understanding to host in Italy the Neutral Beam Test Facility. EFDA (European Fusion Development Agreement) was asked to set the wheels in motion and Consorzio RFX, in Padua, was selected as the Host of the experiment.

As soon as F4E was established the EU responsibility of the project was transferred to us. Until the end of 2011, we were busy trying to convert the concept of the facility into a concrete project involving also ITER International Organization. In a way, it felt like putting together a mini ITER. From 2012 onwards, we opened a new chapter making this facility a reality and laying the foundations of a legal framework to channel our contribution. Thanks to a dedicated team of 20 people bringing on board their expertise from the fields of engineering, planning, quality assurance, project management, law and procurement, today F4E has honoured its contribution vis `a vis all other Parties involved in this facility. We have come a long way, if you think about it…and now the exciting part for the fusion community starts with testing".

9. PPPL physicists to create new X-ray diagnostics for the WEST fusion device in France

By
Raphael Rosen
May 11, 2018
https://www.pppl.gov/news/2018/05/pppl-physicists-create-new-x-ray-diagnostics-west-fusion-device-france

A team of scientists at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) has won a DOE Office of Science award to develop new X-ray diagnostics for WEST — the Tungsten (W) Environment in Steady-state Tokamak — in Cadarache, France. The three-year, $1-million award will support construction of two new devices at PPPL, plus collaboration with French scientists and deployment of a post-doctoral researcher to test the installed devices at CAE Laboratories, the home of the WEST facility.

"We are extremely proud that our proposal was chosen considering that there was strong competition from our community," said PPPL physicist Luis F. Delgado-Aparicio. "Developing innovative X-ray diagnostics will allow us to push technology ahead and give us a great opportunity to be part of an incredible team of French scientists and engineers at WEST." Other scientists on the team include PPPL diagnostics division head Brentley Stratton and principal research physicist Ken Hill.

WEST is an upgrade of Tore Supra, a large facility with plasma-facing components that use carbon, like those in the National Spherical Torus Experiment-Upgrade (NSTX-U) at PPPL. Researchers at WEST have replaced the carbon components with those made of tungsten, a material that can withstand the superhot temperatures of fusion plasmas without absorbing gas from the plasma; the gas can be released and degrade plasma performance.

One diagnostic, called the "Multi-Energy Hard X-ray (ME-HXR) Camera," will measure X-ray emissions over a broad energy range from the plasma that fuels fusion reactions.

Measuring the soft, or relatively low-energy, X-ray emissions will let scientists determine the plasma's temperature and electric charge. It will also enable them to figure out exactly how densely and where heavy elements that could slow the fusion reactions are scattered within the plasma. Such information could be useful for a variety of experiments.

The camera will also measure the plasma's hard, or high-energy, X-ray emissions, which stem from the collisions of background ions with high-energy electrons accelerated by a radio frequency (RF) system known as the Lower Hybrid Current Drive (LHCD). These electrons carry the current in the WEST plasma. The spectrum of the hard, non-thermal emissions will provide information about where these fast electrons absorb RF energy.

The camera will also probe X-ray emissions from the tungsten metal tiles that will cover the interior of the tokamak. That information will reveal whether the machine's extreme heat has been dislodging tungsten atoms from the tiles and propelling them into the plasma. The presence of tungsten atoms in the plasma could indicate that the tungsten components are starting to melt; monitoring the tungsten content is therefore crucial to preventing damage to the machine.

The other diagnostic, known as the "Compact X-ray Imaging Crystal Spectrometer (cXICS)," is a variation of a device that Hill and senior physicist Manfred Bitter invented for PPPL's National Spherical Torus Experiment (NSTX) and the Alcator C-Mod tokamak at the Massachusetts Institute of Technology (MIT). The cXICS device will create a low-resolution, two-dimensional cross-section image of the plasma showing the general location of impurities, including argon, molybdenum, xenon, and tungsten.

"These are two different but complementary instruments," Delgado-Aparicio said. "They will provide vital information about the plasmas in WEST — which can inform future fusion devices."

The planned design and delivery of the two new instruments "builds on long-term expertise on X-ray diagnostic development at PPPL," Stratton said. "This laboratory is known quite favorably for its X-ray diagnostics research, and we want to continue that."

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).

10. JET restart ramps up with first test plasma | 04/05/2018

http://www.ccfe.ac.uk/news_detail.aspx?id=451

The first plasma pulse for almost 18 months took place on JET last night (Thursday) – as work hots up to get the world's largest fusion machine ready for **EUROfusion's** 2018 experiments.

Although not a full fusion plasma, the 1.2 mega amp pulse is a key part of completing the JET restart and getting ready for further commissioning of the machine.

The machine has been closed for a planned engineering shutdown since November 2016, with work carried out since including repairs and improvements to the neutral beam heating system, the installation of a Shattered Pellet Injector for plasma fuelling, replacement of some of the tungsten-coated divertor tiles and work on the magnetic coils.

In addition, engineers have prepared for JET's future deuterium-tritium (DT) fusion experiments by installing tritium injection modules and tritium-compatible vacuum pumps, and by enhancing the diagnostics that view and measure the plasma.

A video showing the first pulse taken with one of the new DT-compatible camera diagnostics can be seen below, slowed by a factor of 40.

George Sips, Head of the Operation Group of the JET Exploitation Unit, said: “After four discharges, progressively reaching higher plasma current, the first shift of plasma operation reached 1.2 mega amps, achieving a plasma duration of five seconds.

“This first pulse demonstrates we have advanced the process of restarting JET. It means we are now at the stage to start plasma commissioning. Once you start this, all the technical systems must be working in harmony.”

The process of readying the machine for the scientific campaign will now continue, with the first full operations expected this summer.

11. 05.02.18

Whistling While You Work: Fusion Scientists Find Inspiration in Atmospheric Whistles

Just like lightning, fusion plasmas contain odd electromagnetic whistler waves that could control destructive electrons in fusion reactors.

https://science.energy.gov/fes/highlights/2018/fes-2018-04-b/

The Science

The challenge of fusion energy is often equated to capturing—and holding—lightning in a bottle. The analogy is apt. Lightning and a fusion energy plasma have a lot in common. Similarities include very high temperatures, massive electric charges, and extremely complex fluid dynamics. Researchers at the DIII-D National Fusion Facility found another characteristic shared between the two types of plasmas: an odd electromagnetic wave known as a whistler. If their theories are correct, the whistler discovery could help better understand runaway electrons in tokamaks. It could even help control these destructive particles.

The Impact

Runaway electrons are a significant concern for future large tokamak devices such as ITER. These electrons must be mitigated due to their potential to cause significant damage to the walls of plasma-confining tokamaks. Researchers at DIII-D and other fusion facilities are exploring approaches to controlling runaways. While much work remains to be done, the team thinks there is a way to inject whistlers into a plasma to control runaway electrons. The whistlers would bleed energy from the particles, making them less likely to run away.

Summary

For more than a century, mysterious electromagnetic waves that occur naturally in the earth’s ionosphere—generally caused by lightning—have been detected over telephone lines, antennas, and satellites. They were named *whistlers* because of their characteristic time-varying frequencies, which are unmistakable when the signals are converted into sound.

Theorists have for years predicted that whistlers could exist in a tokamak, but experimentalists were never able to directly observe the waves. Recently, however, a team at DIII-D generated extremely diffuse plasmas with a low magnetic field that yielded the characteristic whistling of the electromagnetic oscillations. That is, researchers at DIII-D were able to measure the presence of whistler waves in a tokamak for the first time. The researchers believe the whistlers are driven by runaway electrons.

Runaway electrons develop due to an unusual feature of plasmas—a collisional drag that decreases with increasing velocity. This allows energetic electrons that are in the presence of an electric field in a tokamak to freely accelerate to high energies. Runaway electrons in fusion reactors only reach a terminal velocity as they approach the speed of light, per Einstein’s theory of relativity. These electrons are thus called runaway electrons.

To illustrate the oddity of this characteristic, if skydivers experienced the same phenomenon, jumping out of an airplane would always be fatal, since the skydiver depends on increasing drag with increasing speed to provide a terminal velocity.

If large fluxes of runaways were to escape the plasma in a fusion reactor, they could cause damage to the surrounding material walls. Whistlers may play a role in regulating the generation and evolution of runaway electrons. The DIII-D experiments show that whistler waves driven by runaway electrons modify the runaways in such a way as to redirect some of their energy.

A similar idea is being explored in ionospheric studies of whistler waves. Directed energetic electron components are also present in the ionosphere and can damage satellites. Whistler waves are predicted to mitigate these effects in a manner similar to that being explored in tokamaks. Whistlers also play an important role in space weather and the regulation of earth's Van Allen belts. The DIII-D experiments provide the first direct evidence that such waves exist in a tokamak and open an exciting new field of exploration that could have critical importance to ITER and other large tokamaks.

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Related Links

DIII-D National Fusion Facility: https://fusion.gat.com/global/diii-d/home

Highlight Categories

Program: FES

Performer/Facility: University, DOE Laboratory, Industry, SC User Facilities, FES User Facilities, DIII-D

12. 05.02.18

Zero Tolerance in Tokamaks: Eliminating Small Instabilities Before They Become Disruptions

Energetic ions and beam heating cause or calm instabilities, depending on the tokamak's magnetic field.

https://science.energy.gov/fes/highlights/2018/fes-2018-04-a/

The Science

One of the greatest obstacles to producing energy via fusion on earth is the formation and growth of small magnetic field imperfections in the core of experimental fusion reactors. These reactors, called tokamaks, confine hot ionized gas, or plasma. If the imperfections persist, they let the energy stored in the confined plasma leak out; if allowed to grow, they can lead to sudden termination of the plasma discharge. Recent simulations of tokamak discharges with fast, energetic ions have shown that the structure of the magnetic field can either stabilize or destabilize these magnetic imperfections, or "tearing" instabilities. The result depends on the helical structure of the field as it winds around the tokamak.

The Impact

Energetic ions, ubiquitous in fusion plasmas, can be a strong stabilizing or destabilizing force. The choice depends on the magnetic shear in the plasma. Understanding the physics driving the onset of the instabilities can lead to their avoidance, a "zero tolerance" approach, vital for ITER's stable operation. ITER is a key step between today's fusion research and tomorrow's fusion power plants. Also, the results explain many experimental observations of tearing instabilities that limit the maximum heat energy that can be contained.

Summary

Advanced tokamaks achieve high-thermal-energy plasmas by injecting beams of hot ions that collide with, and thereby heat, the background plasma. Burning plasma experiments that create energy from fusion reactions, such as ITER, will also have a significant population of hot alpha particles, the byproduct of fusion. The effects that energetic ions have on the benign instabilities, such as the sawtooth instability, which causes the temperature near the plasma core to flatten, and the toroidal Alfvén eigenmode, which intuitively is a "vibration" (wobble) of the magnetic field lines, have been known for some time. As the current and confined energy in plasmas are increased, a "stability boundary" can be crossed when the thermal pressure (that is, the heat energy) exceeds a certain fraction of the magnetic energy that comprises the magnetic bottle that confines the plasma. These "tearing" instabilities create imperfections in the magnetic field. If these imperfections grow, they can trigger a large-scale disruption, which terminates the plasma confinement and can damage the machine. Simulations of tokamak discharges with fast, energetic ions have shown the emergence of a stabilizing influence, or force, to the disruptive instabilities. Whether the force is stabilizing or destabilizing depends on the "shear," which measures how the magnetic field lines wrap around the bagel-shaped, or toroidal, plasma in the tokamak. In positive shear, the usual case, the energetic ions are stabilizing. However, the inner region of tokamaks can often have low or negative (reversed) magnetic shear, and this leads to a destabilizing force, enough to drive the tearing mode unstable, thereby possibly leading to a disruption. As we move toward controlled avoidance of disruptions in ITER, it will be critical to incorporate advanced stability models into active control strategies in order avoid unstable conditions.

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Highlight Categories

Program: FES

Performer/Facility: University, DOE Laboratory

Last modified: 5/2/2018 12:35:56 PM

13 Ghostly 'Lightning' Waves Discovered Inside a Nuclear Reactor

By Marcus Woo, Live Science Contributor | May 18, 2018 10:18am ET
https://www.livescience.com/62605-whistler-waves-nuclear-fusion-reactors.html

Editor's Note: This story was updated at 1:35 p.m. E.T.

Mysterious, ghostlike "whistler waves" that are normally created by lightning could protect nuclear fusion reactors from runaway electrons, new research suggests.

These whistler waves are naturally found high above ground in the ionosphere — a layer of Earth's atmosphere about 50 to 600 miles (80 an1000 kilometers) above the planet's surface. These ghostly whistler waves form when lightning bolts generate pulses of electromagnetic waves that travel between the Northern and Southern hemispheres. These waves change in frequency as they cross the globe, and when these light signals are converted to audio signals, they sound like whistles.

Now these whistler waves have been discovered in the hot plasma inside a tokamak — the doughnut-shaped machine where nuclear fusion reactions take place — according to a recent study published April 11 in the journal Physical Review Letters.

Because whistlers can scatter and impede high-speed electrons, they could provide a new way to prevent runaway electrons from damaging the inside of a tokamak.

Fusion power

In nuclear fusion reactions, which power the sun and stars, atoms slam together, fusing into larger atoms while releasing energy. For decades, researchers have been trying to harness fusion energy on Earth, using powerful magnetic fields inside tokamaks to corral doughnut-shaped clouds of hot plasma — a weird phase of matter that consists of electrically charged gas.
Inside the tokamak, electric fields can propel electrons faster and faster. But as these high-speed electrons fly through the plasma, they can't slow down. Normally, objects moving through a gas or liquid feel a drag force that increases with speed. The faster you drive your car, for example, the more wind resistance you run into. But in plasma, drag force decreases with speed, allowing electrons to accelerate to near light speed, damaging the tokamak.
Researchers already have a few techniques to mitigate runaways, said Don Spong, a physicist at Oak Ridge National Laboratory in Tennessee and a co-author of the new study. They can use artificial intelligence algorithms to monitor and adjust the density of the plasma to prevent electrons from accelerating too fast. If there are still runaways, they can inject pellets of frozen neon into the plasma, which increases the plasma density and slows runaway electrons.

But whistler waves could be yet another way to rein in runaway electrons. "We ideally want to avoid disruptions and runaways," Spong said. "But if they occur, we would like multiple tools available for dealing with them."

Stopping runaways

In the tokamak at the DIII-D National Fusion Facility in San Diego, Spong's research team detected, for the first time, whistler waves being produced by runaway electrons.

Plasma, he explained, is like a piece of Jell-O with many modes of vibration. If some runaway electrons have just the right velocity, they excite one of these modes and trigger whistler waves — similar to how driving an old car at just the right speed can cause the dashboard to vibrate.

"What we would like to do is reverse engineer that process and put those waves on the outside [of the plasma] to scatter the runaways," Spong said.

By better understanding how runaways create whistlers, the researchers hope they can reverse the process — using an external antenna to generate whistlers that can scatter the electrons and prevent them from getting too fast.

The researchers still need to further explore the relationship between runaways and whistlers, Spong said, for example, by identifying what frequencies and wavelengths work best to inhibit runaways and by studying what happens in the denser plasma needed for fusion reactors.

Of course, suppressing runaway electrons is just one hurdle to creating clean energy from nuclear fusion. Right now, fusion reactors require more energyto heat plasma than is produced by the fusion. To reach the breakeven point, researchers still have to figure out how to get plasma to stay hot without having to add heat.

But Spong is optimistic about fusion energy. "I'm a believer that it's achievable."

In 2025, the ITER project in southern France is slated to begin experiments. and scientists hope it will be the first fusion machine to produce more energy than is used to heat the plasma. Several groups have set their sights on achieving net positive fusion energy by 2050. And a new collaboration between MIT and a company called Commonwealth Fusion Systems announced that the partners hope to put nuclear fusion on the grid in 15 years.

Editor's Note: *This story was updated to note that light signals, rather than light frequencies, are converted to audio signals.*

Originally published on Live Science.

15. PPPL PRINCETON PLASMA PHYSICS LABORATORY

Steven Cowley named director of DOE’s Princeton Plasma Physics Laboratory

May 16, 2018

https://www.pppl.gov/news/2018/05/steven-cowley-named-director-doe’s-princeton-plasma-physics-laboratory

By Office of Communications, Princeton University

PRINCETON, New Jersey — Steven Cowley, a theoretical physicist and international authority on fusion energy, has been named director of the U.S. Department of Energy’s (DOE) Princeton Plasma Physics Laboratory (PPPL), effective July 1.

Cowley has served as president of Corpus Christi College and professor of physics at the University of Oxford since 2016. From 2008 through 2016, he was chief executive officer of the United Kingdom Atomic Energy Authority (UKAEA) and head of the Culham Centre for Fusion Energy.

Cowley will become the seventh director of PPPL, which is one of 10 national science laboratories funded by the DOE’s Office of Science. Princeton has managed PPPL since its origin in 1951, when Professor Lyman Spitzer, a founder of the field of plasma physics, initiated the study of fusion at the University.

Cowley already has experience with PPPL and Princeton. He earned his Ph.D. in astrophysical sciences from Princeton in 1985. He was a staff scientist at PPPL from 1987 to 1993 and also taught at the University. In his new role, Cowley will be appointed professor of astrophysical sciences at Princeton.

“Steve’s background and experience are ideal for leadership of PPPL,” said David McComas, vice president for PPPL and professor of astrophysical sciences. “I am delighted that we were able to recruit him to PPPL and am looking forward to working with him very closely going forward.”

Culham includes the Joint European Torus (JET) and Mega Amp Spherical Tokamak (MAST) fusion facilities. During Cowley’s tenure, he provided the vision and strategy for and led the fusion research program for the U.K. This included overseeing more than 1,000 employees and contractors and having management authority for implementation and operations for the Culham Laboratory and UKAEA.

In parallel, he expanded and strengthened relations with other fusion programs in Europe and around the world, and served in key advisory roles for the U.K., U.S. and European governments.

"Steve Cowley is a spectacularly good physicist and a proven leader of large-scale scientific projects. He understands and respects the missions of the Plasma Physics Laboratory, the Department of Energy's Office of Science and Princeton University," said Christopher L. Eisgruber, president of Princeton University. "I am confident that Steve is the right person to take the reins of the laboratory today and guide it into the future."

As director of PPPL, Cowley will be responsible for managing all aspects of the laboratory, including its performance in science, engineering, operations, project management and strategic planning. He will lead PPPL's scientific and technical programs in fusion energy science and technology, as well as broader investigations in plasma science, and provide leadership to the U.S. and world fusion energy efforts.

"I am delighted, privileged and enthused by the opportunity to lead PPPL," said Cowley. "We have an exciting program to advance — including an essential upgrade of the innovative fusion experiment, NSTX. Working together with the talented staff of PPPL to hasten the delivery of fusion energy promises to be both scientifically and personally rewarding."

From 2004 to 2008, Cowley was director of the Center for Multi-Scale Plasma Dynamics at the University of California-Los Angeles. He served on the faculty of UCLA from 1993 to 2008, becoming a full professor in 2000. From 2001 to 2003, he was professor and head of the plasma physics group at Imperial College London, where he continued with part-time research and teaching until 2016.

From 1985 to 1987, Cowley was a senior scientific officer at Culham Laboratory.

Cowley has held numerous advisory roles including membership of the U.K. Prime Minister's Council for Science and Technology. He is a fellow of the Royal Society of London and the Royal Academy of Engineering. He holds a bachelor's degree in physics from Oxford.

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).

16. Positrons are shining brighter

Discovery: Phosphors are less excited by electrons than by their antiparticles

May 17, 2018

https://www.ipp.mpg.de/4398976/03_18

Phosphors have long been in daily use, e.g. in TV screens or PC monitors and in science for investigating plasmas and particle or antiparticle beams. Whether particles or antiparticles are involved, if these impinge on phosphors they excite it to luminescence.

It was hitherto not known, however, that the light emission due to electrons is much lower than due to positrons, their antiparticles. This was discovered by Dr. Eve Stenson at Max Planck Institute for Plasma Physics (IPP) in Garching and Greifswald while preparing for experiments with matter-antimatter plasmas.
“If antimatter were not so hard to come by, one could envision an era of low-voltage, high-brightness displays in which screens were excited not by electrons but by positrons”, is how Dr Eve Stenson comments her discovery, albeit with a twinkle in her eye. “But this is, unfortunately, not feasible”. Nevertheless, there may be a future for positron-induced luminescence.

First it must be clarified, states Eve Stenson, why positrons excite phosphors much more strongly than equally fast electrons. Both electrons and positrons transfer their kinetic energy to the luminescent material on impact. Such collisions raise the electrons of the luminous matter from a lower to a higher energy level. When they drop back again, the energy rereleased is emitted as light – the material luminesces at the impacted site.

In the case of an impacting positron, however, there is a second effect: After it has deposited its energy in the phosphors the positron annihilates with an electron, its antiparticle. This leaves a hole in the sea of electrons of the phosphor into which other electrons from higher energy levels can fall, thus giving rise to additional emission of light. This accounts for the higher light emission of positrons. “This bonus light could yield information about the material properties of the phosphor and the mechanism of luminescence”, states Eve Stenson. As she points out, although luminescent materials and phosphor screens have been in use for decades – in TV sets, displays, signposts, physical sensors or as nanoparticles in medicine – important physical details of their behaviour have not yet been clarified.

The different effects of electrons and positrons were discovered by Eve Stenson when calibrating the phosphor screen on a particle trap that can store either electrons or positrons. She was astonished to find that the two types of particles resulted in two completely different shapes of curves: Positrons with an energy of a few tens of electron volts generate in the zinc sulphide or zinc oxide phosphor screens she investigated as much light as electrons with several thousand electron volts. “In order to understand this, I suddenly found myself on an unscheduled detour from plasma physics deep into solid-state physics”. For she was confronted by the fact that the luminescence yielded by electrons and positrons had hitherto apparently never been compared for low energies, although both kinds of particles were being routinely detected with luminescent screens.

The particle trap forms part of an experimental setup now being put together by a team headed by Professor Dr. Thomas Sunn Pedersen at IPP. Its goal is to produce the first ever matter-antimatter plasma composed of electrons and positrons (see IPP press release **3/2017**).

Isabella Milch

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E. V. Stenson, U. Hergenhahn, M. R. Stoneking, T. Sunn Pedersen

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17. Japanese utility seeks to start up new reactor

22 May 2018

Chugoku Electric Power Company has today requested permission from local governments to apply for pre-startup inspections of unit 3 at the Shimane nuclear power plant in Japan's Shimane prefecture. Construction of the 1373 MWe advanced boiling water reactor (ABWR) is nearing completion.

http://www.world-nuclear-news.org/RS-Japanese-utility-seeks-to-start-up-new-reactor-2205184.html

Construction of Shimane 3 started in December 2005 and the unit had been scheduled to begin commercial operation in December 2011. However, in February 2011 - a month before the accident at the Fukushima Daiichi plant - Chugoku announced that fuelling and start-up of the reactor had been delayed by three months due to a fault with the control rod drive mechanism. Like Japan's other operable reactors, Shimane 3 remained idle following the accident.

Under Japan's revised nuclear regulations, plant operators are required to apply to the Nuclear Regulation Authority (NRA) for: permission to make changes to the reactor installation; approval of its construction plan to strengthen the plant; and, final safety inspections to ensure the unit meets new safety requirements. Operators are required to add certain safety-enhancing equipment within five years of receiving the NRA's approval of a reactor engineering work program.

Chugoku announced today that it has asked the Shimane prefectural government and the Matsue city government for permission to apply for NRA safety inspections at Shimane 3.

Chugoku President Mareshige Shimizu visited the Matsue city government and submitted documents to Mayor Masataka Matsuura. He also delivered a consent request to Shimane Governor Zembee Mizoguchi. Shimizu told Mizoguchi the reactor is essential for establishing a stable power supply, reducing carbon dioxide emissions and stabilising electricity prices, the *NKK*news agency reported.

Both the prefectural and city governments plan to ask their respective assemblies to discuss the request, according to the *Asahi Shimbun*.

Chugoku would become the second Japanese utility to apply to the NRA for pre-operation safety inspections for a new nuclear power reactor since the Fukushima Daiichi accident. The first was Japan Electric Power Development Corp (J-Power), which applied in December 2014 for inspections of unit one at its Ohma nuclear power plant, also an ABWR, being built in Aomori prefecture. However, with construction of Shimane 3 more advanced than Ohma 1, Shimane 3 is likely to be the first new reactor to begin operating in Japan.

Researched and written
by World Nuclear News

18. Floating plant arrives at Murmansk for fueling

21 May 2018

A ceremony has been held to welcome the *Akademik Lomonosov*, **Russia's first floating nuclear power plant, following its arrival at Atomflot's berth in the port city of Murmansk in the far northwest part of the country. Fuel will be loaded in to the vessel's two reactors prior to its delivery to Russia's northernmost city of Pevek next year.**

http://www.world-nuclear-news.org/NN-Floating-plant-arrives-at-Murmansk-for-fueling-2105184.html

The *Akademik Lomonosov* - 144 metres in length, 30 metres wide and having a displacement of 21,000 tonnes - left the Baltiysky Zavod shipyard in Saint Petersburg on 28 April. It arrived in Murmansk on 17 May after having been towed over 4000 kilometres and travelling through four seas: the Baltic, Northern, Norwegian and Barents.

On its arrival at Murmansk, a welcome ceremony took place during which the plant was handed over to the customer, Rosenergoatom, the nuclear power plant operator subsidiary of state nuclear corporation Rosatom. The ceremony was attended by Rosatom Director General Alexey Likhachov, Rosatom Deputy Director General Alexander Lokshin, Rosenergoatom Director General Andrey Petrov, Atomflot Director General Vyacheslav Ruksha, Chukotka regional governor Roman Kopin and Murmansk regional deputy director Eugene Nikora.

Likhachov said: "We have successfully towed the power unit, not yet loaded with fuel, to Murmansk and are here going to fully launch this unique project, which was only made possible thanks to cooperation of many companies." He added, "*Akademik Lomonosov* is an unparalleled piece of engineering by Russian scientists. It is a first-of-a-kind, reference project for mobile medium capacity range nuclear power units, a product we expect to be growing in demand in the coming years. For instance, we see great interest from all island nations where it is difficult, for various reasons, to set up a developed centralised power transmission infrastructure."

Rosatom said fuel will be loaded into the two reactors on *Akademik Lomonosov* in the coming months. The vessel is expected to be towed to its permanent base at Pevek in Russia's Chukotka region in the summer of 2019. It noted construction work is under way in Pevek to create all the necessary on-shore infrastructure. Rosatom said that once in operation the facility will both the world's only operational floating nuclear power plant and the northernmost nuclear installation. *Akademik Lomonosov* will replace the Bilibino nuclear power plant and the Chaunskaya thermal power plant. The first Bilibino unit is scheduled to be shut down next year and the whole plant will be shut down in 2021.

The keel of *Akademik Lomonosov* was laid in April 2007 at Sevmash in Severodvinsk, but in August 2008 Rosatom cancelled the contract - apparently due to the military workload at Sevmash - and transferred it to the Baltic Shipyard in Saint Petersburg, which has experience in building nuclear icebreakers. New keel-laying took place in May 2009 and the hull was launched at the end of June 2010. The two 35 MWe KLT-40S reactors were installed in October 2013.

Rosatom said it is already working on a second generation of floating nuclear power unit which will be equipped with two RITM-200M reactors, each having a capacity of 50 MWe. It noted that although having a greater generating capacity, the new "optimised" units will be smaller in size.

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