Australian ITER Forum Website News Update 9/18

B.J.Green (16/9/18)

1. Solving the Electricity Trilemma with Nuclear Power, low cost, very low emissions and maximum reliability

http://nuclearforclimate.com.au/wp-content/uploads/2018/09/Solving-Australias-Energy-Trilemma.pdf

Over the period 2022 to 2050 approximately 20,000 MWe of base-load generating plant will need replacement. There is no national plan for this critical issue and ongoing debate has been hampered by ideology on all sides of the political divide.

A range of options have been widely promoted across the Australian community and media. Very little understanding has been shown for whole of system design requirements, cost, reliability, and emission outcomes for these options.

Many are not actually feasible and this leads to wide spread misinformation. Important factors for each option system have also not been ready available for decision makers. This paper (see website address above) has been prepared by Mr. Robert Parker, Dr Robert Barr and Mr. Barrie Hill and follows from our search for a solid grounding on how our energy system really works, what options we have for the future and how Australia can truly prosper in the future.
The paper documents the relative costs, benefits, and overseas experience for coal, gas, nuclear and renewable generation options for progressive replacement of Australia's electricity generation fleet.

The recommended outcome is for the introduction of nuclear power in public ownership based on reliability and emission criteria at a cost only marginally above that of coal or gas. While a well-engineered renewable generation option offers acceptable low emissions the total cost to achieve a reliable outcome at double that of the nuclear power option is unacceptable.

2. Discovered: Optimal magnetic fields for suppressing instabilities in tokamaks
September 10, 2018, Princeton Plasma Physics Laboratory

https://phys.org/news/2018-09-optimal-magnetic-fields-suppressing-instabilities.html
Fusion, the power that drives the sun and stars, produces massive amounts of energy. Scientists here on Earth seek to replicate this process, which merges light elements in the form of hot, charged plasma composed of free electrons and atomic nuclei, to create a virtually inexhaustible supply of power to generate electricity in what may be called a "star in a jar."

A long-time puzzle in the effort to capture the power of fusion on Earth is how to lessen or eliminate a common instability that occurs in the plasma called edge localized modes (ELMs). Just as the sun releases enormous bursts of energy in the form of solar flares, so flare-like bursts of ELMs can slam into the walls of doughnut-shaped tokamaks that house fusion reactions, potentially damaging the walls of the reactor.

Ripples control new bursts

To control these bursts, scientists disturb the plasma with small magnetic ripples called resonant magnetic perturbations (RMPs) that distort the smooth, doughnut shape of the plasma—releasing excess pressure that lessens or prevents ELMs from occurring. The hard part is producing just the right amount of this 3-D distortion to eliminate the ELMs without triggering other instabilities and releasing too much energy that, in the worst case, can lead to a major disruption that terminates the plasma.

Making the task exceptionally difficult is the fact that a virtually limitless number of magnetic distortions can be applied to the plasma, causing finding precisely the right kind of distortion to be an extraordinary challenge. But no longer.

Physicist Jong-Kyu Park of the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL), working with a team of collaborators from the United States and the National Fusion Research Institute (NFRI) in Korea, have successfully predicted the entire set of beneficial 3-D distortions for controlling ELMs without creating more problems. Researchers validated these predictions on the Korean Superconducting Tokamak Advanced Research (KSTAR) facility, one of the world's most advanced superconducting tokamaks, located in Daejeon, South Korea.

KSTAR ideal for tests

KSTAR was ideal for testing the predictions because of its advanced magnet controls for generating precise distortions in the near-perfect, doughnut-shaped symmetry of the plasma. Identifying the most beneficial distortions, which amount to less than one percent of all the possible distortions that could be produced inside KSTAR, would have been virtually impossible without the predictive model developed by the research team.

The result was a precedent-setting achievement. "We show for the first time the full 3-D field operating window in a tokamak to suppress ELMs without stirring up core instabilities or excessively degrading confinement," said Park, whose paper—written with 14 coauthors from the United States and South Korea—is published in *Nature Physics*. "For a long time we thought it would be too computationally difficult to identify all beneficial symmetry-breaking fields, but our work now demonstrates a simple procedure to identify the set of all such configurations."

Researchers reduced the complexity of the calculations when they realized that the number of ways the plasma can distort is actually far fewer than the range of possible 3-D fields that can be applied to the plasma. By working backwards, from distortions to 3-D fields, the authors calculated the most effective fields for eliminating ELMs. The KSTAR experiments confirmed the predictions with remarkable accuracy.

Findings provide new confidence

The findings on KSTAR provide new confidence in the ability to predict optimal 3-D fields for ITER, the international tokamak under construction in France, which plans to employ special magnets to produce 3-D distortions to control ELMs. Such control will be vital for ITER, whose goal is to produce 10 times more energy than it will take to heat the plasma. Said authors of the paper, "the method and principle adopted in this study can substantially improve the efficiency and fidelity of the complicated 3-D optimizing process in tokamaks."

More information: Jong-Kyu Park et al, 3D field phase-space control in tokamak plasmas, *Nature Physics* (2018). DOI: 10.1038/s41567-018-0268-8

Journal reference: Nature Physics
Provided by: Princeton Plasma Physics Laboratory

3. Steady as she goes: Scientists tame damaging plasma instabilities in fusion facilities

August 22, 2018 by John Greewald, Princeton Plasma Physics Laboratory

https://phys.org/news/2018-08-steady-scientists-plasma-instabilities-fusion.html#nRlv

Before scientists can capture and recreate the fusion process that powers the sun and stars to produce virtually limitless energy on Earth, they must first learn to control the hot plasma gas that fuels fusion reactions. In a set of recent experiments, scientists have tamed a plasma instability in a way that could lead to the efficient and steady state operation of ITER, the international experiment under construction in France to demonstrate the feasibility of fusion power. Such continuous operation will be essential for future fusion devices.

Fusion powers the sun and stars by fusing light elements in the form of plasma—the hot, charged state of matter composed of free electrons and atomic nuclei—to produce massive amounts of energy. Scientists are seeking to replicate fusion on Earth for a virtually inexhaustible supply of electricity-generating power.

The most recent findings, developed by a team of researchers led by physicist Raffi Nazikian of the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) and Craig Petty of General Atomics, stem from experiments conducted on the DIII-D National Fusion Facility operated by General Atomics for the DOE in San Diego. The results build on earlier work led by DIII-D scientists that demonstrated the conditions needed for steady-state operation of the core of ITER plasmas and established techniques to control these plasma instabilities.

The new research targets instabilities called Edge Localized Modes (ELMs) that develop at the periphery of fusion plasmas. Such instabilities can cause periodic heat bursts that can damage plasma-facing components in a tokamak. "In these results we observe the suppression of large ELMs, leaving small benign ELMs in plasmas that overlap with the conditions required for steady-state ITER operation," said Nazikian, lead author of a scientific paper in IAEA's *Nuclear Fusion* journal that lays out the findings. "These new experiments are a great example of successfully combining two separate advances, in this case 100 percent current drive in the plasma core and large ELM suppression in the edge, in an efficient and effective manner" said Petty, lead author of a prior Nuclear Fusion paper on the DIII-D findings relevant to the steady state core of the ITER plasma.

To keep large ELMs from occurring, researchers produce small magnetic ripples known as resonant magnetic perturbations (RMPs) that distort the smooth doughnut shape of tokamak plasmas. In the recent experiments, the scientists found that increasing the overall pressure of the plasma makes the plasma far more responsive to the ripples to better control ELMs and produce the conditions needed for steady-state ITER operation.

The higher pressure also increases a self-generated current that forms inside tokamak plasmas. This can be combined with particle beams and microwaves to drive and sustain the plasma current indefinitely in a so-called steady state. These higher self-generated currents make this process more efficient, and thus a fusion power plant more attractive.

When researchers projected the recent DIII-D results to ITER, they found that the higher plasma pressure and bootstrap current, together with additional sources of current from particle beams and microwaves, could create a fully sustainable steady-state regime that generates four-to-five times more power than it will take to heat the plasma and drive the current. Support for this work comes from the DOE Office of Science (FES) and the General Atomics Postdoctoral Research Participation Program administered by Oak Ridge Associated Universities (ORAU).

Going forward, physicists seek to create a greater percentage of bootstrap current to increase the fusion power gain and reduce the additional power needed to drive current. These DIII-D experiments produced about 30 percent self-driven current, although the bootstrap current fraction are projected to increase in ITER as its higher field means its ions collide less often, enabling current to be driven more easily.

"What we are currently working on in DIII-D is to develop the basis for fully steady-state high pressure plasma for ITER and beyond," Nazikian said. "A central goal of the DIII-D program now is to identify ways in which high-pressure plasmas can drive most of the current required for steady-state reactors. We are undertaking major upgrades to the facility to meet this goal while exploring regimes that are free of dangerous ELMs."

More information: R. Nazikian et al, Grassy-ELM regime with edge resonant magnetic perturbations in fully noninductive plasmas in the DIII-D tokamak, *Nuclear Fusion* (2018). DOI: 10.1088/1741-4326/aad20d

Provided by: Princeton Plasma Physics Laboratory

4. State-Of-The-Art Supercomputer Will Help Us Tackle Nuclear Fusion

Alfredo Carpineti 28/8/18

https://www.iflscience.com/technology/supercomputer-will-help-us-tackle-nuclear-fusion/

Nuclear fusion promises unlimited clean energy by harnessing the physics at the core of stars. Progress towards such a power plant has been steady, but the difficulties in actually getting fusion to be tamed are several. To tackle some of them, we will soon get the help of a state-of-the-art supercomputer.

"Accelerated Deep Learning Discovery in Fusion Energy Science" is one of 10 Early Science Projects on data science and machine learning for the Aurora supercomputer, which is being developed by the US Department of Energy's (DOE) Princeton Plasma Physics Laboratory. It will be operational by 2021, and it will perform 1 billion billion calculations per second – 50 to 100 times faster than the most powerful supercomputer today.

"Our research will utilize capabilities to accelerate progress that can only come from the deep learning form of artificial intelligence," project lead Professor William Tang, from Princeton University, said in a statement.
Deep learning is a computational technique that allows computers to be trained to solve complex problems quickly and accurately. The goal of the project is to work out how to minimize and even control disruption in the flow of plasma, a serious problem in the tokamak fusion reactors.

Donut-shaped tokamaks are one of two types of reactors. The plasma – the hot and charged state of matter – is kept in the reactor with magnetic fields. The plasma is heated to a point where it begins fusing, forming heavier elements. The goal is to achieve a self-sustaining reaction. This is expected to be realized in the ITER project, the international reactor currently under construction in France, to demonstrate that fusion energy is a practical way to produce electricity.
ITER will require the software to predict disruption with 95 percent accuracy and at least 30 milliseconds (or longer) before a disruption occurs – a challenging requirement, but one that this computing process will try to achieve. The software will study data from disruptions in smaller reactors and learn from models and theoretical simulations. It is currently being tested on "smaller" supercomputers, but only the upcoming one will give the project the detailed resolution needed for ITER's requirements

5. Congress sends Trump energy spending bill that includes healthy boost for science

By Adrian ChoSep. 13, 2018 , 5:35 PM
http://www.sciencemag.org/news/2018/09/congress-sends-trump-energy-spending-bill-includes-healthy-boost-science

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The U.S. Congress today sent President Donald Trump a 2019 spending bill that boosts funding for the Department of Energy's (DOE's) basic research efforts—and rejects **deep cuts to the department's applied research programs that the White House had proposed**.

If Trump signs the bill into law—as many observers expect—DOE's Office of Science would get a 5.2% spending boost, to $6.585 billion, in fiscal year 2019, which begins 1 October. In contrast, the Trump administration had proposed slashing the Office of Science budget by 13.9% to $5.39 billion.

The White House had called for an even bigger cut to applied energy research supported through DOE's Office of Energy Efficiency & Renewable Energy (EERE), a 70% whack to $696 million. Instead, the bill—which the House of Representatives approved today and the Senate passed yesterday—gives EERE a 2.5% increase to $2.379 billion. Similarly, the White House had sought to eliminate the Advanced Research Projects Agency-Energy (ARPA-E), which seeks to quickly translate the best ideas from DOE-funded basic research into budding technologies that can be developed further by private industry. The bill gives ARPA-E a healthy 3.7% boost to $366 million.

In a report accompanying the bill, congressional appropriators warn the administration against trying to cut or kill the EERE and ARPA-E programs. "The Department shall not use any appropriated funds to plan or execute the termination of ARPA-E," it states. "In addition, the Department is directed to disburse funds appropriated for ARPA-E on eligible projects with a reasonable time period, consistent with past practices." In April 2017, DOE came under fire from Congress for **refusing to dispense the grant money Congress had appropriated for ARPA-E**.

The report contains similar language ordering DOE “to maintain a diverse portfolio of early-, mid-, and late-stage research, development, and market transformation activities” within EERE. In its call to slash the EERE budget, the White House had said it would do so in large measure by shifting the program’s focus to early stage research alone.

In the bill, all of the Office of Science’s six research programs get a lift. The advanced scientific computing research program, which funds DOE’s supercomputing efforts, would score the biggest win, with its budget climbing 15.4% to $935 million. High energy physics would see its budget bulge by 7.9% to $980 million. Fusion energy sciences would receive a 6% increase to $564 million, including $132 million—$10 million more than last year—for the United States contribution to ITER, the enormous fusion experiment under construction near Cadarache in France.

Biological and environmental research, which funds research ranging from genomics and the development of biofuels to climate modeling, would receive a 4.8% boost to $705 million. The Office of Science’s biggest program, basic energy sciences (BES), would see its budget grow 3.6% to $2.166 billion. BES funds research in chemistry, materials sciences, condense matter physics, and related field, as well as running most of DOE’s user facilities, such as x-ray synchrotrons and neutron sources. Nuclear physics would see its budget inch up 0.9% to $690 million.

House and Senate appropriators generally split the differences in their versions of the bill. The Senate had requested $139 million less for fusion, but $45 million more for computing, $27 million more for BES, and $20 million more for nuclear physics. House appropriators had proposed spending $32 million less on biological and environmental research and $26 million more on fusion.

The budget also includes $65 million for research and development of **a controversial reactor**, sometimes called the Versatile Fast Neutron Source or the Versatile Fast Test Reactor, to be built at Idaho National Laboratory in Idaho Falls. DOE had requested $15 million for that work, which is still in its early stages. If completed by 2025, the new reactor would be the first that DOE has built since the 1990s.

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6. BREAKING SYMMETRY FOR STABILITY —

A third dimension helps Tokamak fusion reactor avoid wall-destroying instability

Korean Tokamak shows instabilities can be cured via additional magnetic fields.
CHRIS LEE - 9/13/2018, 9:24 PM
https://arstechnica.com/science/2018/09/a-third-dimension-helps-tokamak-fusion-reactor-avoid-wall-destroying-instability/

The success of Tokamaks for fusion is a story unto itself, with the toroidal magnetic containers setting records for keeping high-energy plasmas under control, a necessary step for sustaining fusion. The overriding narrative, at least on the scientific side, is that when you have an unstable plasma, it is really hard to build a control system that keeps the plasma hot and confined, even in a Tokamak.

Now, researchers have used the Korean KSTAR Tokamak to show that they can gain control of a particularly nasty plasma instability called an edge localized mode. The instability essentially exhausts the plasma onto the wall, ablating it away. If a plasma reactor the size of ITER were to have an edge localized mode instability, it would likely destroy the inner lining of the vacuum vessel.

Symmetries giveth, symmetries taketh

I don't pretend to understand plasma instabilities in a Tokamak very well. But I do know that some of the problems are the result of the shape of the magnetic field. The shape of the Tokamak is a boon: it's symmetric, which makes the device simple, it makes calculations possible, and it offers high confinement.

Unfortunately, that same symmetry is one of the reasons that there are many possible instabilities in the plasma, including edge localized modes.

One way to suppress these instabilities is to break the magnetic field's symmetry by applying additional magnetic fields around the outside. In fact, because actual instruments can never be perfect, these magnets already exist to correct for any asymmetries in the field.

Early experimental results have suggested that carefully applied asymmetry has some benefits. The problem, it turns out, is not allowing some asymmetry—it's figuring out which asymmetry to allow. Essentially, most asymmetries will make things worse: they reduce the confinement of the plasma, for instance. You want to pick out the ones that don't.

Creating a map of treacherous and friendly locations

Instead of guessing which ones are helpful, the researchers built a simplified model of the magnetic fields associated with the plasma. The point (I think) is that the instabilities are magnetic field instabilities, so a model that can take a short cut to calculate the magnetic fields generated by the plasma would be very useful. The second idea is that the inner part of the plasma should (in the beginning) be unaffected by what is happening at the edge, so you can calculate the core and the edge separately, and then force the two calculated magnetic fields to agree at their boundary.

The final point is that the researchers don't appear to be interested in the final geometry of the field or any spatial information at all. All they need to know is when the size of the magnetic field goes insane enough to set off an instability. Previous research has pointed to what these critical field values are, so it is basically a question of creating a geometry, calculating the field, and making sure that it falls beneath this cutoff for stability.

Then comes the grunt work. KSTAR is designed to have flexibility in the way the magnetic field is generated. That means you need to map out which magnetic fields will suppress instabilities, which fields will prevent plasma from being confined, and which fields will *generate* instabilities. Thanks to KSTAR's flexibility, this is a 6D picture, where each pixel is color coded as good, bad, and really bad.

Stable operation

The researchers tested their findings against KSTAR's operation and could successfully prevent the formation of edge localized modes. They also found that the unstable regions were indeed unstable. In fact, the model is remarkably accurate and shows quite a bit of promise for the future.

The researchers also investigated how KSTAR would fare if there were more magnets available. The additional magnets would allow KSTAR to operate in a wider variety of stable configurations. However, the new configurations require electrical currents that exceed KSTAR's design limits.

I know that every time we write about fusion, someone somewhere says that fusion will always be 10 years away. But if we separate out the political and managerial problems associated with fusion, there has been remarkable progress in achieving high-confinement plasmas, control systems, and all the other engineering details.

In fact, since the last management shake up (in response to a scathing report), ITER seems to be hitting its construction targets regularly. This gives me some confidence that ITER will succeed in demonstrating fusion with a net energy win. Whether the fusion power is an economic win as well is a whole different story, of course.

Nature Physics, 2018: DOI: 10.1038/s41567-018-0268-8. (About DOIs)

7. Separating the sound from the noise in hot plasma fusion

Date:

September 11, 2018

Source:

American Institute of Physics

Summary:

For fusion power plants to be effective, scientists must find a way to trigger the low-to-high confinement transition, associated with zonal flows of plasma. Theoretically, these consist of both a stationary flow and one that oscillates at the geodesic acoustic mode. For the first time, researchers have detected GAM at two different points simultaneously within the reactor. This experimental setup will aid investigating the physics of zonal flows, and their role in the L-H transition.

https://www.sciencedaily.com/releases/2018/09/180911152508.htm

In the search for abundant clean energy, scientists around the globe look to fusion power, where isotopes of hydrogen combine to form a larger particle, helium, and release large amounts of energy in the process. For fusion power plants to be effective, however, scientists must find a way to trigger the low-to-high confinement transition, or "L-H transition" for short. After a L-H transition, the plasma temperature and density increase, producing more power.

Scientists observe the L-H transition is always associated with zonal flows of plasma. Theoretically, zonal flows in a plasma consist of both a stationary flow with a near-zero frequency and one that oscillates at a higher frequency called the geodesic acoustic mode (GAM), which is a global sound wave of the plasma. For the first time, researchers at Hefei University of Technology have detected GAM at two different points simultaneously within the reactor. This new experimental setup will be a useful diagnostic tool for investigating the physics of zonal flows, and their role in the L-H transition. The researchers report these findings in a new paper published in *Physics of Plasmas*, from AIP Publishing.

Zonal flows occur anywhere there is turbulence, such as inside a fusion device or in a planet's atmosphere. "The most famous zonal flows in nature may be the well-known Jovian belts and zones, which make Jupiter look like a colorful, multilayered cake," said Ahdi Liu, an author on the paper. In fusion plasmas, zonal flows are crucial for regulating turbulence and particle transport within the reactor. "With the gradual improvement of diagnostic technology, zonal flows in fusion plasma has become a research hot spot in the past two decades," Liu said.

In these experiments, researchers used the Experimental Advanced Superconducting Tokamak (EAST), a magnetic fusion energy reactor in Hefei, China. They installed two Doppler reflectometers on different sides of EAST, which can detect fluctuations in turbulence and plasma density with high precision. The detected GAM had a pitch of F, five octaves above middle C.

Previously, researchers at ASDEX-U, the fusion research device at the Max Plank Institute of Plasma Physics, used a similar system to detect GAM, but they measured the plasma at a single location, which makes the setup prone to interference. "This disadvantage is the main motivation for using two sets of Doppler reflectometers," Liu said. "We could 'purify' the GAM information by comparing the two location's measurements."

The measurements taken at the two points did not entirely agree, showing that each reflectometer also picked up information from nonzonal flows. "It is completely necessary to extract accurate zonal flows information from multipoint measurement," Liu said. Using both measurements, they could clearly show that GAM interacted with the ambient turbulence. Going forward, the researchers will further investigate the role of zonal flows in turbulence and turbulent transport within EAST.

Story Source:

Materials provided by **American Institute of Physics**. *Note: Content may be edited for style and length.*

Journal Reference:

1. Xiaohui Zhang, Ahdi Liu, Chu Zhou, Jianqiang Hu, Mingyuan Wang, Xi Feng, Chunhua Li, Xingming Yang, Lei Sang and Jiaqiu Ai. **Observation of geodesic acoustic mode in EAST using Doppler backscattering system**. *Physics of Plasmas*, 2018 DOI: 10.1063/1.5033432

8. Celebrating the Heroes of Fusion Research: Q&A with an Award-Winning Filmmaker

Matteo Barbarino, IAEA Department of Nuclear Sciences and Applications
Aleksandra Peeva, IAEA Department of Nuclear Sciences and Applications
https://www.iaea.org/newscenter/news/celebrating-the-heroes-of-fusion-research-qa-with-an-award-winning-filmmaker
The documentary Let There Be Light narrates the story of dedicated scientists working to make nuclear fusion a reality: unleashing perpetual, inexpensive and clean energy for humanity. The possibility that fusion, which powers the Sun, could be achievable on Earth as an energy source has driven scientists for almost a century. After decades of enormous international efforts, a massive push is now underway to demonstrate that fusion can work in an experimental setting. In the south of France, scientists from 35 countries are building the most complex machine ever attempted. This endeavour, named ITER, if successful, will illuminate the way to produce clean, cheap, and abundant energy for millions of years.

The film has been awarded the *University of Bergen's Gulluglen Award* at the Bergen International Film Festival in 2017 and the *Artistic Vision Award* at the Big Sky Documentary Film Festival the same year.

Follow the upcoming 27th IAEA Fusion Energy Conference (FEC 2018), which will provide a forum for discussion of key physics and technology issues as well as innovative concepts of direct relevance to the use of nuclear fusion as a source of energy.

Co-founder of *EyeSteelFilm* and co-director of the movie, Mila Aung-Thwin has produced more than 25 feature documentaries, including *Up the Yangtze*, *Forest of the Dancing Spirits*, and the Emmy Award-winning *Last Train Home*. He served for five years as president of the Rencontres International du Documentaire (RIDM), Montreal’s international documentary festival, as well as a juror for the International Emmy Awards, AFI DOCS, the New Zealand Film Awards, and the Sundance Film Festival. He has also taught documentary film programs to students in places such as Inukjuak, Canada, and Yangon, Myanmar.

You had not worked in fusion or anything related to ‘nuclear’ before this film. Why did you choose to focus on this topic?

To be honest, I hadn't done that much in science documentaries in general. But I've always been interested in the human side of science, why people are driven to discover new things and solve big problems. I knew energy and energy resources were big problems, and I wanted to make a film about potential pie-in-the-sky future sources of energy. And I was months into the research before I heard that ITER was being built. And the more I found out about it, the more interested I became. But I was also increasingly confused why more people weren't talking about it. So, to me that's an excellent starting point for a documentary.

The movie zips through a few fusion projects although several other ambitious initiatives are underway around the world. Why did you decide to feature ITER, Wendelstein 7-X, General Fusion and LPPFusion?

I suppose there were simply too many examples to choose from if I were to do a proper survey of everything. The film is meant to illuminate some of the approaches to fusion, some of the challenges, as told by unique individuals. When you make a film, one of the big things that can kill the flow of the story is simply making a list: "here's one example, here's another, here's another…". What you want to do instead is find contrasts and counter-examples to keep the audience engaged. If they get excited by this, then they can go and read more about all the other examples. So, I had to choose unique pieces of the puzzle, and unique characters. I wanted ideas and approaches that contrasted each other as much as they complimented.

What do you think about the many start-ups that have recently sprung up doing their own fusion projects?

In general, I think it's great that there's more private entities supporting innovation. Perhaps we are at the level of technology now where start-ups can compete with national labs and agencies, as they seem to be in space travel. It was explained to me that that is indeed the aim of national labs: to push research into areas where it is not profitable in the short-term, so that it gets to the point where the free market can come in and innovate once the proof-of-concept exists. So, in that case it's great. However, I think – like most who have studied the history of fusion – I am wary of those who promise more than they can deliver.

The documentary juxtaposes the complexity and scale of the ITER machine and the human stories of the people involved in the quest for fusion. What inspired you to focus on these individual stories?

In brief, it’s very hard to care about a machine in a film. We tend to care about people and their challenges. We only can comprehend that a machine is hard to build if we see a person struggling because we need to understand the human scale, human know-how and human motivation. Also, I wanted to celebrate the heroes of fusion. I’ve met a lot of people who work in fusion who have shown this to their friends and family and the reactions have been that they finally understand that whet they are dedicating their lives to is indeed very cool and not incomprehensible.

What was the most surprising thing about fusion energy that you learned while working on the documentary?

The most surprising thing was the level of international cooperation required to make ITER, and the fact that it dated back to the cold war. This ongoing pursuit of the dream of fusion energy is so different from how most people experience progress in daily life. We don’t see decades-long struggles to get things done very often – to the point where we don’t even know if they are possible. We’ve resigned ourselves to short-term goals and don’t think we can change the future for the better. We don’t think we can collaborate for the common good. The story of ITER refutes that way of thinking.

Mila Aung-Thwin, ITER Director-General Bernard Bigot and Scientific Director of IPP Sibylle Gunter will speak at the session on "Fusion Energy for Peace and Sustainable Development" — during the 62nd IAEA General Conference on Wednesday, 19 September 2018, starting at 9:30 AM in Vienna. The event will review the progress in the quest for controlling thermonuclear fusion for energy production, the potential for fusion to revolutionize both technology and society, the challenges ahead and the role of the IAEA.

Right after the event, Let There Be Light will be shown at 10:40 AM.

9. Pushing the limit

PSFC researchers discover a way to overcome the plasma density limit in quest for steady-state fusion

Paul Rivenberg | PSFC

August 22, 2018

https://www.psfc.mit.edu/news/2018/pushing-the-limit

For decades researchers have been exploring ways to replicate on earth the physical process of fusion that occurs naturally in the sun and other stars. Confined by its own strong gravitational field, the sun's burning plasma is a sphere of fusing particles, producing the heat and light that makes life possible on earth. But the path to a creating a commercially viable fusion reactor, which would provide the world with a virtually endless source of clean energy, is filled with challenges.

Researchers have focused on the tokamak, a device that heats and confines turbulent plasma fuel in a donut-shaped chamber long enough to create fusion. Because plasma responds to magnetic fields, the torus is wrapped in magnets, which guide the fusing plasma particles around the toroidal chamber and away from the walls. Tokamaks have been able to sustain these reactions only in short pulses. To be a practical source of energy, they will need to operate in a steady state, around the clock.

Researchers at MIT's Plasma Science and Fusion Center (PSFC) have now demonstrated how microwaves can be used to overcome the barriers to steady-state tokamak operation. In experiments performed on MIT's Alcator C-Mod tokamak, before it ended operation in September 2016, research scientist Seung Gyou Baek and his colleagues have studied a method of driving current to heat the plasma called Lower Hybrid Current Drive (LHCD). The technique generates plasma current by launching microwaves into the tokamak, pushing the electrons in one direction -- a prerequisite for steady-state operation. Furthermore, the strength of the Alcator magnets has allowed researchers to investigate LHCD at a plasma density high enough to be relevant for a fusion reactor. The encouraging results of their experiments have been published in Physical Review Letters.

Pioneering Lower Hybrid Current Drive

“The conventional way of running a tokamak uses a central solenoid to drive the current inductively,” Baek notes, referring to the magnetic coil that fills the center of the torus. “But that inherently restricts the duration of the tokamak pulse, which in turn limits the ability to scale the tokamak into a steady-state power reactor.” Baek and his colleagues believe LHCD is the solution to this problem.

MIT has pioneered LHCD since the 1970s using a series of “Alcator” tokamaks known for compact size and high magnetic fields. On Alcator C-Mod, LHCD was found to be efficient for driving currents at low density, demonstrating plasma current could be sustained non-inductively. However, researchers discovered that as they raised the density in these experiments to the higher levels necessary for steady-state operation the effectiveness of LHCD to generate plasma current disappeared.

This fall-off in effectiveness as density increased was first studied on Alcator C-Mod by research scientist Gregory Wallace.

“He measured the fall-off to be much faster than expected, which was not predicted by theory,” Baek explains. “The last decade people have been trying to understand this, because unless this problem is solved you can’t really use this in a reactor.”

Researchers would need to find a way to boost effectiveness and overcome this LHCD density limit. Finding the answer would require a close examination of how lower hybrid (LH) waves respond to the tokamak environment.

Driving the Current

Lower hybrid waves drive plasma current by transferring their momentum and energy to electrons in the plasma.

Head of the PSFC’s Physics Theory and Computation Division, senior research scientist Paul Bonoli compares the process to surfing.

“You are on a surf board and you have a wave come by. If you just sit there the wave will kind of go by you. But if you start paddling, and you get near the same speed as the wave, the wave picks you up and starts transferring energy to the surf board. Well, if you inject radio waves, like LH waves, that are moving at velocities near the speed of the particles in the plasma, the waves start to give up their energy to these particles.”

Temperatures in today’s tokamaks – including C-Mod – are not high enough to provide good matching conditions for the wave to transfer all its momentum to the plasma particles on the first pass from the antenna, which launches the waves to the core plasma. Consequently, researchers noticed, the injected microwave travels through the core of the plasma and beyond, eventually interacting multiple times with the edge, where its power dissipates, particularly when the density is high.

Exploring the Scrape-Off Layer

Baek describes this edge as a boundary area outside the main core of the plasma where, in order to control the plasma, researchers can drain – or “scrape-off” – heat, particles and impurities through a divertor. This edge has turbulence, which, at higher densities, interacts with the injected microwaves, scattering them, and dissipating their energy.

“The scrape-off layer is a very thin region. In the past RF scientists didn’t really pay attention to it. Our experiments have shown in the last several years that interaction there can be really important in understanding the problem, and by controlling it properly you can overcome the density limit problem.”

Baek credits extensive simulations by Wallace and PSFC research scientist Syun’ichi Shiraiwa, for indicating that the scrape-off layer was most likely the location where LH wave power was being lost.

Detailed research on the edge and scrape-off-layer conducted on Alcator C-Mod in the last two decades, has documented that raising the total electrical current in the plasma narrows the width of the scrape-off-layer and reduces the level of turbulence there, suggesting that it may reduce or eliminate its deleterious effects on the microwaves.

Motivated by this, PSFC researchers devised an LHCD experiment to push the total current by a nearly factor of three from 500,000 Amps to 1,400,000 Amps, enabled by C-Mod’s high-field tokamak operation. They found that the effectiveness of LCHD to generate plasma current, which had been lost at high density, reappeared. Making the width of the turbulent scrape-off layer very narrow prevents it from dissipating the microwaves, allowing higher densities to be reached, beyond the LHCD density limit.

The results from these experiments suggest a path to a steady-state fusion reactor. Baek feels they also provide additional experimental support to proposals by the PSFC to place the LHCD antenna at the high-field (inboard) side of a tokamak, near the central solenoid. Research suggests that placing it in this quiet area, as opposed to the turbulent outer midplane, would minimize destructive wave interactions in the plasma edge, while protecting the antenna and increasing its effectiveness. Principal Research scientist Steven Wukitch is currently pursuing new LHCD research in this area through PSFCs' collaboration with the DIII-D tokamak in San Diego.

Although existing tokamaks with LHCD are not operating at the high densities of C-Mod, Baek feels that the relationship between the current drive and the scrape-off layer could be investigated on any tokamak.

“I hope our recipe for improving LHCD performance will be explored on other machines, and that these results invigorate further research toward steady-state tokamak operation.”

10. Transatlantic partnership will strengthen MAST Upgrade project | 14/08/2018

A team of leading US plasma physicists will join the **MAST Upgrade project** at Culham ahead of experiments next year.
http://www.ccfe.ac.uk/news_detail.aspx?id=462

It follows a $12.5m investment over a three-year period by the US Department of Energy (DOE). This followed a call issued for the involvement of American fusion scientists.
The ten collaborators will offer varied research topics including understanding transport in the hot core of fusion plasmas, studying the edge “pedestal” to energetic particles, and developing an understanding of plasma exhaust. The team is from US-based universities and national laboratories, and supported by post-doctoral scientists largely based at Culham Centre for Fusion Energy.
Head of MAST Upgrade Operations, Andrew Kirk, said: “This funding will accelerate and broaden the MAST Upgrade research programme through the provision of new diagnostics and involvement in the experimental programme and modelling studies. It will be of benefit to both MAST Upgrade and to the US fusion research programmes.”
Final details for each project are subject to negotiations between the DOE and awardees.
Below are the various collaborators:

- Lawrence Livermore National Laboratory
- Columbia University in the City of New York
- University of California, Irvine
- DIII-D National Fusion Facility, General Atomics
- University of California, Los Angeles
- Lodestar Research Corporation
- Institute for Fusion Studies, University of Texas

More details of the research topics covered by the investment **are given here**.

11. 27 August 2018

Discover the test facility of the ITER Pre-Compression Rings

http://fusionforenergy.europa.eu/mediacorner/newsview.aspx?content=1264

A set of 18 Toroidal Field (TF) coils will create a massive magnetic cage to confine ITER's superhot plasma. While keeping the hot gas away from the walls of the vacuum vessel, they may experience some fatigue or deformation resulting from the powerful magnetic fields. Nine pre-compression rings hold the key to the survival of the TF coils. They will need to be positioned at different levels—three on top and three below the inner "vault" formed by the wedged noses of the TF coils. An extra set of three will be manufactured as spare in case there is any future need to replace the lower set.

The pre-compression rings have an inner diameter of approximately 5 m, a cross-section of nearly 300 x 300 mm and will weigh roughly 3 t each. They are made of fiberglass composite, consisting of more than a billion minuscule glass fibers, which will be glued together using epoxy resin. Europe is responsible for their production. While their fabrication is still ongoing, ITER International Organization (IO) has taken the initiative to develop a facility where they will undergo a series of tests. The contract has been awarded to the consortium CNIM/Douce Hydro. F4E has developed the conceptual design of the test facility and is responsible for technical progress.

A brand new 140 m^2 test facility, located in La Seyne-sur-Mer, is getting ready to receive the first pre-compression rings. The construction works are completed and the central beam has been recently installed. This central column will host a tooling of 36 actuators exercising a force of 1000 t each. The goal will be to test the fabrication quality of each of the pre-compression rings by checking their resilience to the high loads they will experience in operation. When one of them is positioned on the tool, the 36 actuators will start to operate simultaneously, maintaining a position accuracy of 0.1 mm while releasing a total force of 36 000 t. This stress test will last a few hours and will be supplemented by other tests to confirm that the creep and fatigue performance is also adequate.

All teams, counting in total approximately 40 people, are working round the clock to meet the tight schedule making sure that the facility is fully operational by September. The first tests will be performed during the last quarter of the year when the first pre-compression rings prototypes will be delivered. Luigi Semeraro, F4E Metrology Group Leader, and Thierry Boutboul, F4E Magnets

Technical Officer, explained that “F4E and ITER IO, in collaboration with the CNIM/Douce Hydro consortium, have made remarkable efforts to set up this test facility and deliver it on record time.”

Philippe Lazare, Managing Director of CNIM Industrial Systems Division, elaborated on the background and on-going progress. “CNIM, expert in manufacturing large parts of technical composite, and Douce Hydro, specialist in high-pressure hydraulics, have partnered to provide ITER with the Pre-Compression Rings Test Facility. The tight schedule has been respected, the study and the production has been delivered on time. In a few weeks, the machine that will be installed at CNIM will measure the millimetric deformations of the first rings subjected to exceptional mechanical constraints.” he stated.

12. 20 August 2018

Crown of concrete and doors of steel at the ITER Tokamak complex

http://fusionforenergy.europa.eu/mediacorner/newsview.aspx?content=1261

As the temperatures rise in the south of France and we enter the summer hiatus, the activity in the region gradually slows down. On the ITER site, however, the pace remains intense. The noise from drilling, building, and lifting, as the cranes gracefully lift massive loads, does not abate. The F4E team, responsible for the construction of the 39 buildings, ITER International Organization (IO), and the 2 000 contractors' staff on the ground, remain focused on their tasks. People work round the clock, new equipment is arriving, shifts change, but there is one thing that doesn't change - the race against time.

The civil engineering works at the Tokamak complex, which consists of the Tritium, Tokamak, and Diagnostics buildings, are advancing. The construction works of the walls of the last floor (Level 5) of the Tokamak building have started, raising the total of people involved in the construction of the complex to 750. And just as the building is rising by one level, more concrete is poured to form the so-called crown, where the ITER machine will rest upon. Out of the four plots in total, two have been poured signaling a 50% completion of the works, which are expected to be fully completed by the end of August. Next, it will be the turn of the cryostat support bearings to be installed.

On the first floor of the Tokamak building (Level B1) the first six out of the 46 port cell doors have arrived. Romaric Darbour, F4E Deputy Programme Manager for Buildings, Infrastructure and Power Supplies, explains that “after three years of design, development and qualification, and almost one year of manufacturing, the first ITER Port Cell doors have been delivered at the Tokamak building. Each door of around 5.5 x 4 m is made of 30 t of steel. The doors have been transported from the area of Munchen (Germany) in a special lorry. The company manufacturing the Port Cell doors is Sommer, a sub-contractor of the Vinci Ferrovial Razel (VFR) consortium, which has the overall responsibility of the construction of the ITER Tokamak Complex. Once the doors are delivered to the Tokamak building, they are filled with heavy concrete increasing the weight up to 58 t and lifted to their final position with the help of a mounting tool, especially manufactured for this purpose.”

Nearby the Tokamak Complex is the Assembly Hall, where piping, cabling, and electricity distribution are on-going. The works are expected to be completed by the end of the year so that the building is handed over to ITER IO. Similarly, the Magnets Power Conversion buildings are expected to be handed over to IO by November 2018. The galleries, consisting of an underground network cross-cutting the entire ITER platform where pipping will be installed, has advanced reaching a 74% completion rate.

As tooling keeps arriving from different parts of the world, the workforces in the Assembly Hall are busy putting together the sub-sector assembly tooling manufactured by ITER Korea. The growing number of components is gradually transforming the site from a construction platform to a technical hub. There is progress at the Cryostat workshop, managed by ITER India, where the massive shell is progressing bit by bit. A few metres away, the European tanks of the Cryoplant and cold boxes are fully installed, while other pieces of equipment are mounted inside the cryogenic facility. Europe's Poloidal Field coils are also manufactured on-site at a facility exclusively set up for their production. There is a wind of change as the pieces of the biggest fusion puzzle start falling into place. The end of this year promises to be a turning point with the completion of some key civil engineering works and the arrival of more components. Stay tuned!

13. UK and USA enhance nuclear research cooperation

14 September 2018

The UK's National Nuclear Laboratory (NNL) and the US Department of Energy's Oak Ridge National Laboratory (ORNL) have

agreed to cooperate on nuclear energy research. The announcement came as the UK and USA signed a nuclear R&D action plan.

http://www.world-nuclear-news.org/Articles/UK-and-USA-enhance-nuclear-research-cooperation?feed=feed

Under the memorandum of understanding (MoU) - which aims to leverage both organisation's expertise and capabilities - NNL and ORNL will collaborate on nuclear-related projects through idea sharing, staff exchanges and joint workshops. The collaboration will include developing modelling and simulation tools for advanced nuclear reactors, exploring accident-tolerant fuel concepts, developing management and assessment techniques for used fuel, and pursuing the production of isotopes for space, medical and industrial applications. The agreement will run for three years.

"The goal in each area is to provide different perspectives on how the two organisations tackle difficult research questions that meet the needs of the nuclear community," ORNL said.

NNL is known for its Nuclear Fuels Centre of Excellence and in-house high-performance computing capabilities. In addition, the laboratory has established analysis tools including the Orion fuel cycle modelling code and the Enigma fuel performance code. ORNL's nuclear capabilities span similar offerings that include the internationally recognised Scale code system, the Virtual Environment for Reactor Applications analysis tools from the Consortium for Advanced Simulation of Light Water Reactors and various R&D facilities for nuclear applications.

"It is an exciting opportunity to expand what we do as a national laboratory, and potentially do it better, through such a unique partnership with a leading nuclear institution like NNL," said Alan Icenhour, associate laboratory director for the Nuclear Science and Engineering Directorate at ORNL. "This agreement brings together two globally recognised leaders to continue answering our respective nations' calls for excellence in nuclear science and technology."

Paul Howarth, CEO of NNL, said: "I am delighted to reach agreement on this pioneering new MoU with ORNL, which will allow us to build on our already well-established relationship. Together we will draw on the world-leading expertise from our respective organisations and use our complementary skills and knowledge to further nuclear energy-related research and development. This will include the development of exciting and innovative technologies of the future."

Nuclear round table

The agreement between NNL and ORNL was announced during a meeting of UK and US decision and policy makers held earlier this week. The UK-US Nuclear Round Table was held at the British Embassy in Washington, DC, and was jointly hosted by NNL and the UK's Department for International Trade, and the Department for Business, Energy and Industrial Strategy (BEIS).

The event provided attendees with a senior briefing on UK and US policy developments affecting the sector as well as opportunities to discuss challenges and barriers between the two countries.

Rob Whittleston, VP Insight at NNL, said: "At a time of significant sector developments for our respective nations, this event brings together senior industry representatives and policy makers from both sides of the Atlantic."

He added, "In addition to UK and US policy updates, attendees heard tangible examples of industry experience of delivering value via successful UK-US collaboration in nuclear, and about the need to drive disruptive innovation into the sector. This was followed by a facilitated round table session which was a chance for industry representatives and policy makers to discuss opportunities and challenges, and consider how we can work more effectively together aligned to the policy/strategy ambitions of both nations, including through a commercial lens."

UK-USA action plan

The US Department of Energy's (DOE's) Office of Nuclear Energy announced on 13 September that an action plan between the

USA and UK had been finalised. The purpose of the plan - signed in Washington, DC, by the DOE and BEIS - is "to ensure nuclear energy's contribution to both countries' strategic energy resources, low carbon emissions targets, non-proliferation goals and nuclear energy safety objectives," it said.

"The action plan seeks to facilitate cooperation in R&D for advanced civilian nuclear energy technologies between the two countries," DOE said. "Both recognise a variety of approaches and technical pathways are needed to achieve optimal development of civil nuclear technologies over the long-term."

The plan calls for working groups to look at the following areas: radioisotopes for use in space technologies; nuclear reactor technologies; advanced fuels; fuel cycle technologies; advanced modelling and simulation; and, enabling technologies.

"Agreement of the US and UK action plan allows us to move forward and focus on a number of key advances in nuclear energy, including reactors and fuels," said Ed McGinnis, principal deputy assistant secretary of the DOE's Office of Nuclear Energy. "Both countries recognise the value of bilateral cooperation in nuclear energy innovation."

DOE noted the new action plan will complement, not replace, existing mechanisms of cooperation and build on the current collaboration between the USA and UK in the university, laboratory and industry sectors.

In June, BEIS said the UK had signed a new Nuclear Cooperation Agreement with the USA, the first in a series of new international agreements "ensuring uninterrupted cooperation and trade" following the UK's exit from the European Union in March next year.

Researched and written by World Nuclear News

14. Investment needed to maintain nuclear's growth, says IAEA

12 September 2018

New power reactors must be brought online over the coming decades to maintain nuclear's "key role" in combating climate change, according to newly published International Atomic Energy Agency (IAEA) projections.

http://www.world-nuclear-news.org/Articles/Nuclear-capacity-to-more-than-double-by-2050,-says?feed=feed

Energy, Electricity and Nuclear Power Estimates for the period up to 2050 is the 38th edition of the IAEA's annual publication, based on actual statistical data from the agency's Power Reactor Information System and the United Nations Department of Economic and Social Affairs.

The country-by-country projections it contains are based on national projections supplied by countries to the OECD Nuclear Energy Agency and projections made by other international organisations, taking into account possible licence renewals, planned shutdowns and foreseeable construction projects. These are used to produce two scenarios: a low case, described as "conservative but plausible", which assumes that current market, technology and resource trends continue with few policy changes to affect nuclear power; and a high case, which assumes that current rates of economic and electricity demand growth continue.

The IAEA noted that at the end of 2017 there were 448 operational nuclear power reactors around the world, with a combined generating capacity of 392 GWe. These reactors produced a total of 2503 TWh of electricity last year, accounting for about 10% of total electricity production.

"Over the short term, the low price of natural gas and the impact of subsidised intermittent renewable energy sources on electricity prices are expected to continue to affect nuclear growth prospects in some regions of the world," the report says. "In the near term, ongoing financial uncertainty and declining electricity consumption in some regions will continue to present challenges for capital-intensive projects such as nuclear power."

Nuclear generating capacity is projected to reach 511 GWe by 2030 and 748 GWe by 2050 in the IAEA's high growth projection. This represents a 30% increase over current levels by 2030 and a 90% increase of capacity by 2050. The low case projects a 2030 nuclear capacity of 352 GWe, rising slightly to 356 GWe in 2050.

"There are increasing uncertainties in these projections owing to the considerable number of reactors scheduled to be retired in some regions around 2030 and beyond," the IAEA said. "Significant new capacity would be necessary to offset any retirements resulting from factors such as ageing fleets and economic difficulties."

In its low case, the IAEA projects that some 139 GWe of nuclear generating capacity will be retired by 2030, while 99 GWe of new capacity will be added. Between 2030 and 2050, a further 186 GWe will be retired and 190 GWe added. In the high case, which assumes several older reactors will be given licence extensions, only 55 GWe of capacity will be retired by 2030, with a further 207 GWe retired by 2050. In this case, 175 GWe of new nuclear capacity is added by 2030 and about 443 GWe added by 2050.

Total nuclear electricity production will continue to increase between now and 2050, according to the IAEA. In the high case, nuclear electricity production will increase to 3969 TWh in 2030 and 6028 TWh in 2050. In the low case, nuclear electricity production will increase to 2732 TWH in 2030 and 2869 TWh in 2050. The share of nuclear electricity in total electricity production will decrease in the low case from about 10.3% in 2017 to 7.9% in 2030 and 5.6% in 2050. In the high case, its share will increase to 11.5% in 2030 and to 11.7% in 2050.

The IAEA said interest in nuclear power "remains strong in the developing world", particularly in Asia. It suggests that commitments agreed to at the 21st session of the UN Climate Change Conference (COP21) "could also produce a positive impact on nuclear energy development in the future".

In a statement to the IAEA board of governors on 10 September, IAEA Director General Yukiya Amano said: "The Agency's latest annual projections show that nuclear power will continue to play a key role in the world's low-carbon energy mix. However, the declining trend in our low projection for installed capacity up to 2050 suggests that, without significant progress on using the full potential of nuclear power, it will be difficult for the world to secure sufficient energy to achieve sustainable development and to mitigate climate change."

The nuclear industry has set the Harmony goal for nuclear energy to provide 25% of global electricity by 2050. This will require trebling nuclear generation from its present level. Some 1000 GWe of new nuclear generating capacity will need to be constructed by then to achieve that goal. World Nuclear Association has identified three areas for action to achieve this: establishing a level playing field in electricity markets, building harmonised regulatory processes, and an effective safety paradigm.

Researched and written by World Nuclear News

15. Steady growth in nuclear generation continues

16 August 2018

Share

Global nuclear power generation in 2017 increased for the fifth consecutive year, reaching 2506 TWh, according to a new World Nuclear Association report. The Association says the industry is on target to meet the near-term goals of its Harmony programme.

http://www.world-nuclear-news.org/Articles/Steady-growth-in-nuclear-generation-continues

In the *World Nuclear Performance Report 2018*, the Association details power generation and construction achievements for the previous year. In addition, the report features five case studies covering topics including how one of the oldest operating reactors achieved a 100% availability factor, the restart of two reactors in Japan and the construction and operation of three new reactor models in China, Russia and South Korea.

At the end of 2017 the global nuclear capacity of the 448 operable reactors stood at 392 GWe, up 2 GWe compared with the end of 2016. Four new reactors were connected to the grid, with a combined capacity of 3373 MWe. The total number of reactors under construction fell by two to 59 over the course of 2017. Five reactors - two of which had not generated electricity for some years - were shut down, with a combined capacity of 3025 MWe.

The median construction time in 2017 was 58 months, down from 74 months in 2016, and equalling the lowest five-year median construction time achieved in 2001-2005.

The capacity factor for the global fleet stood at 81% in 2017, maintaining the high availability of around 80% that has been maintained since 2000, up from the 60% average capacity factor at the start of the 1980s. "In general, a high capacity factor is a reflection of good operation performance," World Nuclear Association said. "However, there is an increasing trend in some countries for nuclear reactors to operate in a load-following mode, resulting in lower annual capacity factors."

The Association noted there is no significant age-related trend in nuclear reactor performance. The mean capacity factor for reactors over the last five years shows no significant variation regardless of their age, it said.

Agneta Rising, Director General of World Nuclear Association said, "There is no sustainable energy future without nuclear energy. We will need all low-carbon energy sources to work together. Nuclear capacity must expand to achieve the industry's Harmony goal to enable nuclear energy to supply 25% of the world's electricity demand by 2050."

The Harmony goal will require a tripling of nuclear generation from its present level. Some 1000 GWe of new nuclear generating capacity will need to be constructed by then to achieve that goal.

"Much needs to be done to deliver the Harmony goal, but good progress has been made, both in terms of global reactor performance and new nuclear capacity additions," Rising said. "After 2015 and 2016 each saw nearly 10 GWe of new nuclear capacity start up, a more modest 3.3 GWe was connected to the grid in 2017. However, in 2018 and 2019 more than 26 GWe of new nuclear capacity is scheduled to come online, meeting the overall target for this first five-year period."

She added, "The pace of capacity additions required to meet the Harmony goal needs to accelerate in the next decade, eventually reaching an average of 33 GWe of new nuclear capacity added each year. Action is needed to enable this acceleration to happen."

World Nuclear Association has identified three areas for action to achieve this: establishing a level playing field in electricity markets, building harmonised regulatory processes, and an effective safety paradigm.

Researched and written by World Nuclear News