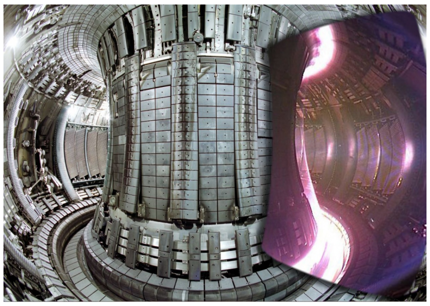

A small Sun on Earth

The quest to produce power from fusion is back on track after the test-bed reactor JET restarted successfully. But some serious challenges, which require heavy computing, still lie on the scientists' path between here and realising their dream. Scientists are installing extremely sensitive infra-red cameras to find tiny hot-spots in the walls of the container, which might show why and where energy is lost. And they must also tackle one of the most important unsolved problems of classical physics: turbulance.

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In a small

Image of upgraded JET vacuum vessel with new 'ITER-like' wall of beryllium and tungsten

The upgraded JET vacuum vessel with new 'ITER-like' wall of beryllium and tungsten. Image courtesy EFDA-JET.

village in Oxford, England, the next stage has begun in a revolutionary project to master the energy of the Sun. The Joint European Torus (JET) project, in the Culham Centre for Fusion Energy, is the world's largest experimental nuclear fusion facility. For the last 18 months, researchers have been replacing the materials inside JET and in early September they switched it on and ramped up the heat even more.

Nuclear fusion not only powers our Sun, but all the stars in our universe. If we could master fusion power, it would be a clean, almost limitless supply of energy for future generations. In addition, fusion power will leave no long-term radioactive waste - any waste will decay in less than a century, compared with today's fission power plant waste that'll take thousands of years to disintegrate.

However, JET only represents the first, small stage of the experiments. "If all goes to plan, a demonstration powerplant will be up and running in the late 2030s and fusion will be on the electricity grid," said Francesco Romanelli, the European Fusion Development Agreement Associate Leader for JET.

Reigniting the flame

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JET was built primarily to prove that fusion power is possible, by fusing two stable hydrogen isotopes, deuterium and tritium, in a plasma - which is a very hot gas, consisting of ions, electrically charged particles, instead of everyday gas molecules such as carbon dioxide. But, it takes more energy than it produces - JET produced 16 megawatts (MW) of power output, but required 24 MW of power input.

Energy gain will be the goal of the International Thermonuclear Experimental Reactor (ITER) that will be built in Cadarache, France in the next few years. "It will have a net energy gain of 10, requiring a 50 MW input for a 500 MW output, which is approaching the levels we will need for commercial power stations," said Romanelli.

Then, if ITER is a success, DEMO (DEMOnstration Power Plant) is the planned commercial successor of ITER. "This prototype power plant will have the extra components, i.e. blankets and electrical conversion systems required to put energy onto the grid," said Romanelli.

For now, JET is the test-bed for many of ITERs systems. "For example, the wall inside the JET machine has just been stripped out and replaced with the beryllium and tungsten materials that ITER will use, to verify that they will perform as expected. JET is also being used to rehearse plasma experiments for ITER. The longer JET continues operating, the better it will be for ITER - ensuring a smooth start-up and providing skilled scientists and engineers with experience of running a large fusion device," said Romanelli.

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In order to get large amounts of fusion energy, JET uses a magnetic bottle called a tokamak to hold and heat plasma to extreme temperatures, in which fusion reactions take place. In the Sun, fusion occurs at between 10 to 15 million Kelvin (about 10 to 15 million °C), but on Earth temperatures of 100 million Kelvin (about 100 million °C) are required. This is because the Sun's sheer size ensures that fusing hydrogen protons alone will produce significant amounts of power for billions of years, whereas on Earth's smaller scale, fusing deuterium and tritium actually produces more power than fusing hydrogen, but requires higher temperatures.

As the plasma heat up in the tokamak, it becomes turbulent, which means the motion of the ions are chaotic and unpredictable

Predicting turbulence

Scientists, for now, cannot describe exactly how a gas or liquid transitions into a turbulent state, much the same as when we bring water to boil; heat is convected from the bottom of the pot to the top and bubbles start forming.

Turbulence has been called the most important unsolved problem of classical physics, by famous physicist Richard Feynman.

Heat is lost during turbulent flows of plasma, which means loss of energy. "The difficulty is to predict quantitatively the consequence of turbulence. How much energy is carried per unit of time for a given temperature difference? But, the main question is we want to know how much energy is carried away when the plasma is brought to thermonuclear conditions. For this work powerful computers and complex simulations are needed." said Maurizio Ottaviani, a plasma physicist on PRACE, the Partnership for Advanced Computing in Europe.

At JET, turbulence analysis is made through several diagnostics and modeling. This work will directly impact the design of the next fusion reactors.

For JET's successor, ITER, simulating 500 MW of power produced by burning plasma and adding all the other intricacies associated with plasma discharges requires simulations with petabytes and even exabytes of data. This means millions of CPU hours (one CPU running a task for a million hours or a million CPUs running for one hour).

"For ITER, turbulence is one aspect of the work that requires heavy computation. Europe develops extended work on modelling ITER using the high-performance computers such as the HPC-FF (High Performance Computing for Fusion) in PRACE."

Currently, the main software tool used by scientists to understand the complex equations in turbulence is the GENE code, which stands for Gyrokinetic Electromagnetic Numerical Experiment. It is an open source simulation code that is specially designed to run on high performance computers such as PRACE and is helping improve plasma turbulence research.

Recent simulation work done on PRACE's systems has helped fusion researchers understand how turbulence transport depends on the size of the device. "This is a crucial question because transport sets the energy confinement time, which is a key factor when determining the expected performance of the fusion device," said Frank Jenko, Max Planck Institute for Plasma Physics in Germany. Now, Jenko is working on more advanced problems in relation to transport barriers and plasma confinement which are necessary in reliable predictions for ITER.

"I'm pleased that one of the first projects completed using PRACE facilities has produced exciting results relevant to fusion power, a problem of obvious socio-economic importance," said Richard Kenway, Chairman of the PRACE Scientific Steering Committee.

Image of the JET vacuum vessel with a fusion plasma superimposed on top.

The JET vacuum vessel with a fusion plasma superimposed. Image courtesy EFDA-JET.

Computing to the core

The JET tokamak may be smaller than ITER's, but the computing required is not. Computing touches every aspect of JET's fusion research, from data acquisition, analysis and storage, to engineering design, materials research, modeling and simulation, plasma scenarios and reactor real-time control. JET used the European Grid Infrastructure (EGI) for high-resolution simulations.

JET has a number of high-performance computers as well, such as Beowulf computing clusters for nuclear fusion data analysis and modeling work. (The computing cluster is named after the seventh century Anglo-Saxon poem because, like the Scandinavian hero, it has the strength of many.)

The main top-level control and data archival systems of these machines are run on Oracle's unix-based Solaris 10 operating system.

Finding the hot-spots

At JET, the wall material, carbon, has been recently replaced with beryllium. Carbon was not ideal because it takes out fuel from the plasma, reducing performance, and second it absorbs tritium - one of the hydrogen isotopes that are used to fuel the fusion plasma - which is radioactive.

"During the restart we learned how to operate with the new metal wall of beryllium and tungsten. The melting point of beryllium compared to carbon means that we have to be more careful than previously [because it has a lower melting point]," said Jonathan Farthing, Head of IT at the Culham Centre for Fusion Energy.

This requires the installation of sensitive measuring equipment and scalable computing resources to support the refit of the walls. "We are commissioning a real-time protection system which uses FPGA technology [field-programmable gate arrays, a customizable integrated circuit] to detect temperature 'hot-spots' from infra-red camera views, allowing us to ramp down heating systems as required," said Farthing.

With all the infrared cameras being installed and other diagnostics tools, the total data per pulse from JET's plasma is expected to be a total of 60GB. Each pulse lasts 40 seconds and 25 are performed per day. Per year this equates to over 300 TBs of data.

The data acquisition and storage requirements have to be constantly updated, which means Farthing always has to think ahead. Farthing said, "since day one, in June 1983, JET's data volumes have consistently followed Moore's law - doubling every two years."

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