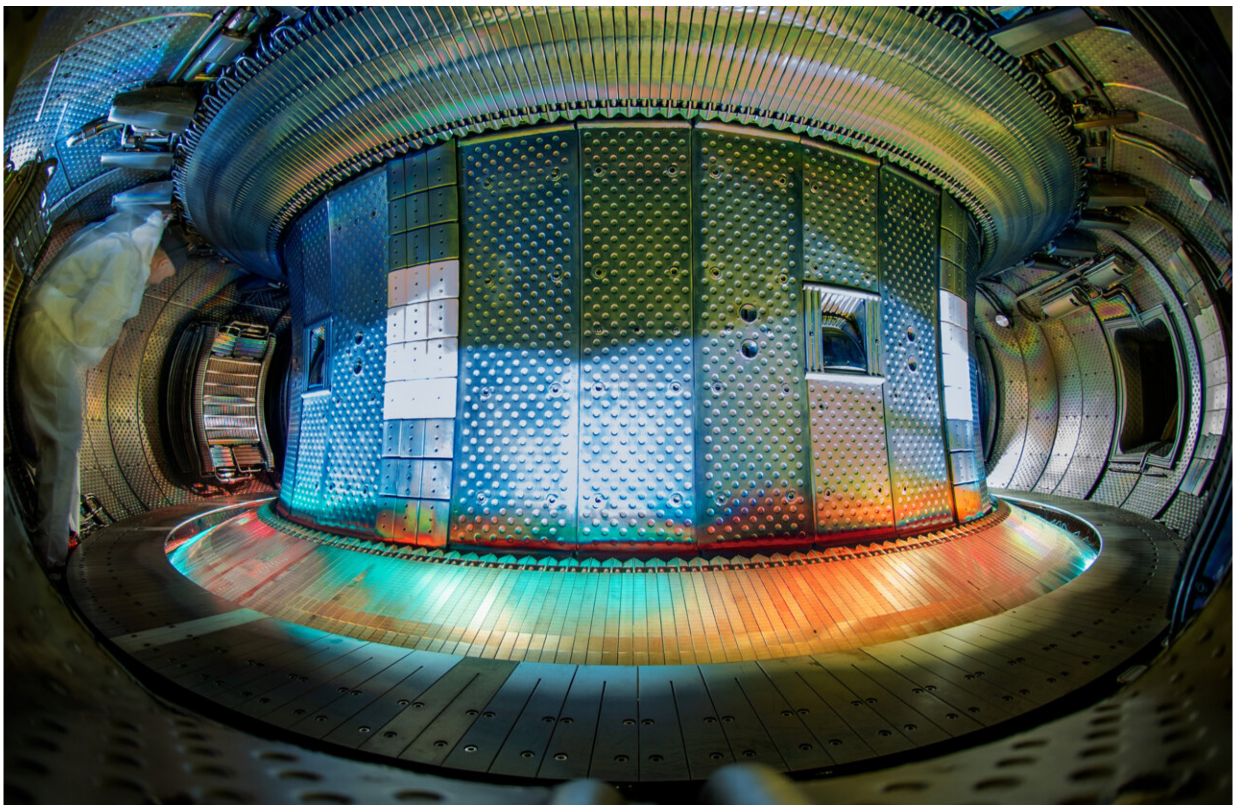
PHYS.ORG

Fusion record set for tungsten tokamak WEST

May 6 2024, by Rachel Kremen



The interior of WEST, the tungsten (W) Environment in Steady-state Tokamak, where the fusion record was achieved. Credit: CEA-IRFM

Researchers at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) measured a new record for a fusion device internally clad in tungsten, the element that could be the best fit for the commercial-scale machines required to make fusion a viable energy source for the world.

The device sustained a hot fusion plasma of approximately 50 million degrees Celsius for a record six minutes with 1.15 gigajoules of power injected, 15% more energy and twice the density than before. The plasma will need to be both hot and dense to generate reliable power for the grid.

The record was set in a fusion device known as WEST, the tungsten (W) Environment in Steady-state Tokamak, which is operated by the French Alternative Energies and Atomic Energy Commission (CEA). PPPL has long partnered with WEST, which is part of the International Atomic Energy Agency's group for the Coordination on International Challenges on Long duration OPeration (CICLOP).

This milestone represents an important step toward the CICLOP program's goals. The researchers will submit a paper for publication in the next few weeks.

"We need to deliver a new source of energy, and the source should be continuous and permanent," said Xavier Litaudon, CEA scientist and CICLOP chair. Litaudon said PPPL's work at WEST is an excellent example.

"These are beautiful results. We have reached a stationary regime despite being in a challenging environment due to this tungsten wall."

Remi Dumont, head of the Experimentation & Plasma Development Group of the CEA's Institute for Magnetic Fusion Research, was the scientific coordinator for the experiment, calling it "a spectacular result."

PPPL researchers used a novel approach to measure several properties of the plasma radiation. Their approach involved a specially adapted X-ray detector originally made by DECTRIS, an electronics manufacturer, and later embedded into the WEST tokamak, a machine that confines plasma—the ultra-hot fourth state of matter—in a donut-shaped vessel using magnetic fields.

"The X-ray group in PPPL's Advanced Projects Department is developing all of these innovative tools for tokamaks and stellarators around the world," said Luis Delgado-Aparicio, PPPL's head of advanced projects and lead scientist for the physics research and the X-ray detector project.

This is just one example of PPPL's strengths in diagnostics: specialized measurement tools used, in this case, to characterize hot fusion plasmas.

"The plasma fusion community was among the first to test the hybrid photon counting technology to monitor plasma dynamics," said DECTRIS Head of Sales Nicolas Pilet.

"Today, WEST achieved unprecedented results, and we would like to congratulate the team on their success. Plasma fusion is a fascinating scientific field that holds great promise for humanity. We are incredibly proud to contribute to this development with our products, and are thrilled by our excellent collaboration."

Scientists worldwide are trying different methods to reliably extract heat from plasma while it undergoes a fusion reaction. But this has proven to be particularly challenging, partly because the plasma must be confined long enough to make the process economical at temperatures much hotter than the center of the sun.

A previous version of the device—Tore Supra—achieved a slightly longer reaction, or shot, but back then, the machine's interior was made of graphite tiles.

While carbon makes the environment easier for long shots, it may not be suitable for a large-scale reactor because the carbon tends to retain the fuel in the wall, which will be unacceptable in a reactor where efficient recovery of tritium from the reactor chamber and reintroduction into the plasma will be paramount.

Tungsten is advantageous for retaining far less fuel, but if even minute amounts of tungsten get into the plasma, radiation from the tungsten can rapidly cool the plasma.

"The tungsten-wall environment is far more challenging than using carbon," said Delgado-Aparicio. "This is, simply, the difference between trying to grab your kitten at home versus trying to pet the wildest lion."

Novel diagnostic measures record shot

The shot was measured using a novel approach developed by PPPL researchers. The hardware for the measurement tool, or diagnostic, was made by DECTRIS and modified by Delgado-Aparicio and others on his research team, including PPPL researchers Tullio Barbui, Oulfa Chellai and Novimir Pablant.

"The diagnostic basically measures the X-ray radiation produced by the plasma," Barbui said of the device, known as a multi-energy soft X-ray camera (ME-SXR).

"Through the measure of this radiation, we can infer very important properties of the plasma, such as the electron temperature in the real core of the plasma, where it is the hottest."

Off the shelf, the DECTRIS diagnostic can normally be configured with all pixels set to the same energy level. PPPL developed a novel calibration technique that allows them to set the energy independently for each pixel.

Barbui said the approach has advantages over the existing technique used in WEST, which can be hard to calibrate and generates readings that are sometimes affected by the radio frequency waves used to heat the plasma. "Radio frequency waves don't bother our diagnostic," Barbui said.

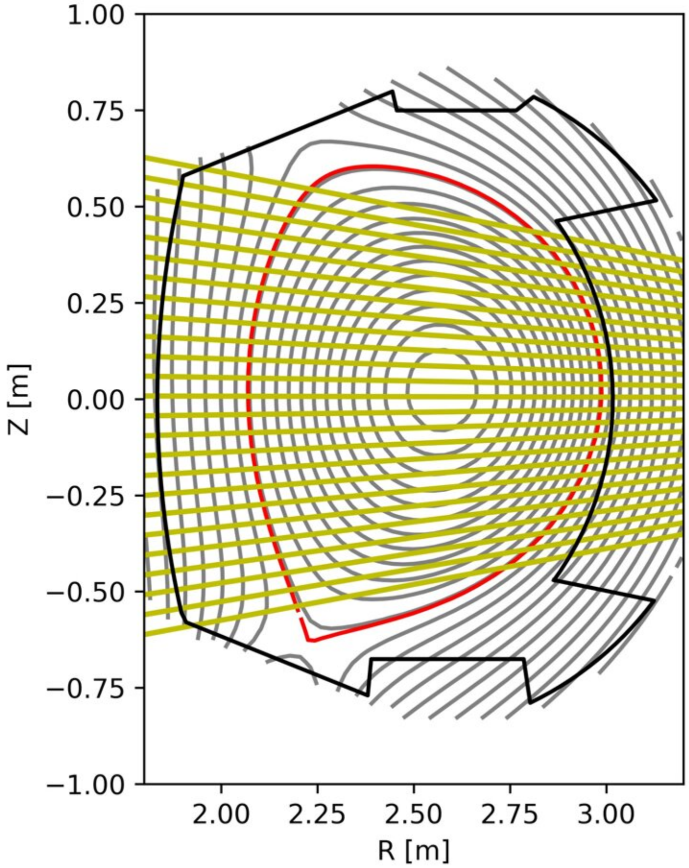
"During the six-minute shot, we were able to measure quite nicely the central electron temperature. It was in a very steady state of around 4 kilovolts. It was a pretty remarkable result," he said.

Searching for light at the right energy levels

The diagnostic looks for light from a specific kind of radiation known as Bremsstrahlung, which is produced when an electron changes direction and slows down. The initial challenge was figuring out what frequencies of light from Bremsstrahlung to look for because both the plasma and the tungsten walls can emit this sort of radiation, but the measurements need to focus on the plasma.

"The photon energy band between 11 and 18 kiloelectronvolts (keV) offered us a nice window of opportunity from the core emission never explored before and thus influenced our decision to carefully sample this range," said Delgado-Aparicio.

"Normally, when this technique is applied, you make only two measurements. This is the first time we have taken a series of measurements," Barbui said.



The red line represents the plasma's edge. The yellow lines represent the many lines of sight of the ME-SXR diagnostic so that it can thoroughly evaluate the plasma. The diagnostic readings can be used to calculate the temperature of the electrons in the plasma, the plasma charge and the density of impurities in the plasma. Credit: Luis Delgado-Aparicio and Tullio Barbui / PPPL

Delgado-Aparicio also pointed out that "the special calibration of our detector allowed us to obtain readings for each energy level between 11 and 18 keV, for each line of sight from the camera, while sampling the entire cross section."

Approximately 10 measurements are taken per second. The trick is to use the intensity from the lowest 11 keV energy as a reference level, and measurements from the other seven intensities are compared to the initial one. Ultimately, this process produces seven simultaneous temperature readings per line of sight, hence the high accuracy of the measurement.

"This innovative capability is now ready to be exported to many machines in the U.S. and around the world," said Delgado-Aparicio.

"From the eight different intensity measurements, we got the best fit, which was between 4 and 4.5 kilovolts for the core plasma. This represents nearly 50 million degrees and for up to six minutes," said Delgado-Aparicio.

The diagnostic readings can be used not only to calculate the temperature of the electrons in the plasma but also the plasma charge and the density of impurities in the plasma, which is largely tungsten that has migrated from the tokamak's walls.

"This particular system is the first of this kind with energy discrimination. As such, it can provide information on temperature and many details on the precise impurity content—mainly tungsten—in the discharge, which is a crucial quantity to operate in any metallic environment.

"It is spectacular," said Dumont. While this data can be inferred from several other diagnostics and supported with modeling, Dumont described this new method as "more direct."

Barbui said the diagnostic can gather even more information in future experiments. "This detector has the unique capability in that it can be configured to measure the same plasma with as many energies as you want," Barbui said. "Now, we have selected eight energies, but we could have selected 10 or 15."

Litaudon said he is pleased to have such a diagnostic on hand for the CICLOP program. "In fact, this energy-resolving camera will open a new route in terms of analysis," he said.

"It's extremely challenging to operate a facility with a tungsten wall. But thanks to these new measurements, we will have the ability to measure the tungsten inside the plasma and to understand the transport of tungsten from the wall to the core of the plasma."

Litaudon says this could help them minimize the amount of tungsten in the plasma's core to ensure optimal operating conditions for fusion. "Thanks to these diagnostics, we can understand this problem and go to the root of the physics for both measurement and simulation."

Time-intensive computer calculations carried out by CEA's Dumont, Pierre Manas and Theo Fonghetti also confirmed good agreement between relevant simulations and the measurements reported by the PPPL team.

Dumont also noted that the ME-SXR camera builds on the Lab's important diagnostic work at WEST. "The ME-SXR is only part of a more global contribution of diagnostics from PPPL to CEA/WEST," Dumont said, noting the hard X-ray camera and the X-ray imaging crystal spectrometer.

"This collaboration helps us a lot. With this combination of diagnostics, we will be able to perform very accurate measurements in the plasma and control it in real-time."

Provided by Princeton Plasma Physics Laboratory