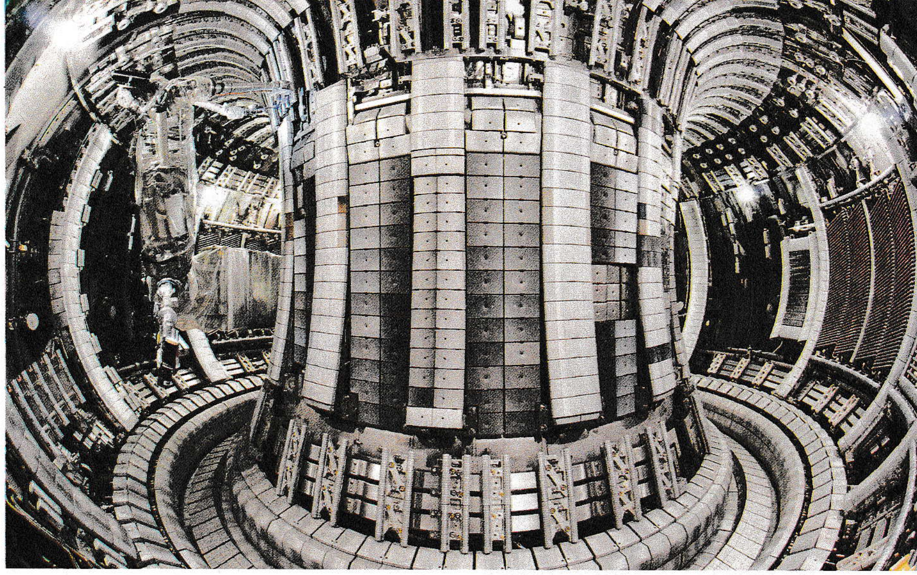

The Joint European Torus produced a record 59 megajoules of energy over 5 seconds.

FUSION

European fusion reactor sets record for sustained energy

World's largest tokamak paves the way for ITER with a capstone run of pulses using power-producing tritium

By **Daniel Clery**

In experiments culminating the 40-year run of the Joint European Torus (JET), the world's largest fusion reactor, researchers announced this week they have smashed the record for producing controlled fusion energy. On 21 December 2021, the U.K.-based JET heated a gas of hydrogen isotopes to 150 million degrees Celsius and held it steady for 5 seconds while nuclei fused together, releasing 59 megajoules (MJ) of energy—roughly twice the kinetic energy of a fully laden semitrailer truck traveling at 160 kilometers per hour. The energy in the pulse is more than 2.5 times the previous record of 22 MJ, set by JET 25 years earlier. "To see shots in which it sustains high power for a full 5 seconds is amazing," says Steven Cowley, director of the Princeton Plasma Physics Laboratory (PPPL).

JET's achievement doesn't mean fusion-generated electricity will flow into the grid anytime soon, however. Researchers had to put roughly three times as much energy into the gas as the reaction produced. But the result gives them confidence in the design of ITER, a giant fusion reactor under construction in France, which is supposed to pump out at least 10 times as much energy as is fed in. "This is very good news for ITER," says Alberto Loarte, head of ITER's science division. "It strongly confirms our strategy."

Fusion has long been promoted as a future green energy source. If the same nuclear reaction that powers the Sun could be duplicated on Earth, it could provide plentiful energy with small amounts of nuclear waste and no greenhouse gases. But producing net energy has proved elusive. In August 2021, researchers at the National Ignition Facility, which triggers fusion by heating and crushing tiny pellets of fuel with 192 converging laser beams, reported they had gotten to 71% of this break-even mark, closer than anyone else, but only for an instant (*Science*, 20 August 2021, p. 841).

JET and ITER represent a different approach, one that is more suitable for sustained energy production. Both are tokamaks: doughnut-shaped vessels wrapped in a grid of powerful magnets that hold the superhot ionized gas, or plasma, in place and prevent it from touching and melting the vessel walls. Researchers in the 1980s believed JET and a rival machine at PPPL (now dismantled) would quickly reach breakeven. JET got close in 1997, generating a short, 1.5-second burst that reached two-thirds of the input power.

But slow progress spurred researchers in the 1990s to design ITER, a giant tokamak 20 meters wide that holds 10 times as much plasma as JET. A larger plasma volume, models predicted, would maintain fusion conditions longer by making it harder for heat to escape. The $25 billion ITER, funded by China, the European Union, India, Japan, South Korea, Russia, and the United States, is due to start operation in 2025 but won't produce large amounts of power until 2035, when it is due to start burning the energy-producing isotopes deuterium and tritium (D-T).

JET's early operation taught ITER's designers a key lesson. JET was lined with carbon because it resists melting. But it turned out to "soak up fuel like a sponge," says Fernanda Rimini, JET's plasma operations expert. So ITER's designers opted to use the metals beryllium and tungsten.

No one knew how they would perform, however, and JET provided a testbed. Starting in 2006, engineers upgraded its magnets, plasma heating system, and inner wall to make it as ITER-like as possible. When it restarted in 2011, the signs were not good, says Cowley, who was then director of the Culham Centre for Fusion Energy, which runs JET on behalf of the European Union's EuroFusion agency. "We couldn't get into the same [high power] regimes."

Painstakingly, the JET team worked out what was going on. They found that high energy plasma ions were knocking out tungsten ions from the wall, causing them to radiate energy and bleed heat out of the plasma. Over many years, the team worked out a coping strategy. By injecting a thin layer of gas, such as nitrogen, neon, or argon, close to the vessel wall, they could cool the outermost edge of the plasma and stop ions from hitting the tungsten. "Bit by bit we clawed back performance," Cowley says.

In September 2021, JET researchers set out to see what their redesigned machine could do. That meant switching fuel, to D-T (*Science*, 5 April 2019, p. 14). Most fusion reactors run on ordinary hydrogen or deuterium, which allows them to explore the behavior of plasmas while avoiding the complications of tritium, which is both radioactive and scarce. But JET staff were itching to test their machine in real power-producing conditions. First, they had to revive the reactor's tritium-handling facilities, not used for 2 decades, which extract unburned tritium and deuterium ions from waste gas after each shot and recycle them.

The recent successes set the stage for ITER and show its designers' gamble on a full metal wall ought to pay off. "This confirms we took the right level of risk," Loarte says. But for JET, the D-T run is something of a swan song. Joe Milnes, head of JET operations, says the reactor will have one more experimental run, from mid-2022 to the end of 2023, before closing. "It's been the most successful fusion experiment ever," he says, but it's time "to hand the baton to ITER." ■