Major Breakthrough in Nuclear Fusion Reactor Technology*

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ITER, the world's biggest nuclear-fusion experiment, is the main part of humanity's effort towards a zero-carbon, zero-radiation energy source [1]. In the run-up to ITER, design choices, carefully made by teams of expert scientists and engineers from thirty-five countries, are checked and validated in smaller scale facilities. The aim is to generate significantly more heat (at least ten times) than is needed to heat and confine a plasma of deuterium and tritium, which will fuse to produce helium and energy in a sustained manner. JET (Joint European Torus), checked out the deuterium-tritium fuel mix that will eventually power ITER, in an experiment that lasted all of five record-breaking seconds when the radioactive mixture burned inside the doughnut-shaped plasma chamber. JET, with its inner wall made of beryllium and tungsten, is a testbed for ITER and is the only tokamak in the world to share the same material environment as ITER. The fuel mix ignites at temperatures around 100 million kelvin, creating a self-sustaining fusion reaction. Along with helium-4, the reaction produces neutrons which can make the chamber radioactive; the aneutronic reaction of a proton fusing with boron-11 (producing helium-4) requires higher temperatures for ignition.

The JET withstood the onslaught from the hotter than the Sun's core, burning, radioactive plasma confined within its walls by a magnetic field. On 9 February, scientists at the JET near Oxford, UK, announced that they had generated the highest sustained energy pulse ever created on Earth by atomic fusion. A video of the five second pulse lighting up the interior of the JET is available at [2].

In nuclear fission, high atomic number nuclei with comparatively high neutron to proton ratio split into more tightly bound daughter nuclei which also have high neutron to proton ratio and are hence radioactive, while releasing energy and also free neutrons. In nuclear fusion, nuclei of elements with low atomic numbers and comparatively low neutron to proton ratio fuse together to produce more tightly bound higher atomic number nuclei which also have a low neutron to proton ratio. This carries the possibility of producing energy without producing radioactive waste. The Sun is powered by fusion reactions taking place in its hotter than 25 million Kelvin core, where hydrogen nuclei fuse together by thermonuclear fusion producing helium and energy. The energy for compressing and heating the (mainly) hydrogen gas to produce the burning plasma is drawn from the Sun's gravitational potential energy. Huge amounts of energy are needed to generate a burning plasma under confined conditions on earth. Currently, fusion research has not yet reached a point where more energy is produced than is input to attain fusion temperatures and to manage

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the containment of the burning plasma. $Q = \text{energy output/energy input} = 0.33$ for the present experiment. The milestone of reaching break-even condition (energy output = input) is planned for 2025. Research on heat resistant materials that are needed to build systems to extract the heat energy produced by the burning plasma are under way. A power grid will take at least another quarter century more of concerted effort. Climate scientists carefully point out that this is not soon enough for combating global warming.

"Nuclear fusion reactor smashes energy record"—so goes the title of a report in Nature [3]. A few quotes from the report:

"Producing the energy over a number of seconds is essential for understanding the heating, cooling and movement happening inside the plasma that will be crucial to run ITER."
—Fernanda Rimini (Plasma scientist at the Culham Centre for Fusion Energy, UK)

"JET really achieved what was predicted. The same modelling now says ITER will work. It's a really, really good sign and I'm excited. Research is under way to work out which design should best withstand the heat, but researchers are not there yet."
—Josefine Proll (Fusion physicist at Eindhoven University of Technology in the Netherlands)

"I am sure I am not alone in the fusion community in wanting to extend very hearty congratulations to the JET Team."
—Anne White (Plasma physicist at the Massachusetts Institute of Technology in USA)

PS: As this article was being written, a physics breakthrough was announced—artificial intelligence (AI) was successfully used to control the plasma in a fusion experiment [4]. But that is a different story. Catch it by googling up AI breakthrough in fusion research!

Suggested Reading


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