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Nuclear Fusion Is Already Facing a Fuel Crisis

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In the south of France, ITER is inching towards completion. When it's finally fully switched on in 2035, the International Thermonuclear Experimental Reactor will be the largest device of its kind ever built, and the flag-bearer for nuclear fusion.

Inside a donut-shaped reaction chamber called a tokamak, two types of hydrogen, called deuterium and tritium, will be smashed together until they fuse in a roiling plasma hotter than the surface of the sun, releasing enough clean energy to power tens of thousands of homes—a limitless source of electricity lifted straight from science fiction.

sounds good

Or at least, that's the plan. The problem—the white elephant in the room—is that by the time ITER is ready, there might not be enough fuel left to run it.

Like many of the most prominent experimental nuclear fusion reactors, ITER relies on a steady supply of both deuterium and tritium for its experiments. Deuterium can be extracted from seawater, but tritium—a radioactive isotope of hydrogen—is incredibly rare.

not so good

Atmospheric levels peaked in the 1960s, before the ban on testing nuclear weapons, and according to the latest estimates there is less than 20 kg (44 pounds) of tritium on Earth right now. And as ITER drags on, years behind schedule and billions over budget, our best sources of tritium to fuel it and other experimental fusion reactors are slowly disappearing.

Right now, the tritium used in fusion experiments like ITER, and the smaller JET tokamak in the UK, comes from a very specific type of nuclear fission reactor called a heavy-water moderated reactor. But many of these reactors are reaching the end of their working life, and there are fewer than 30 left in operation worldwide—20 in Canada, four in South Korea, and two in Romania, each producing about 100 grams of tritium a year. (India has plans to build more, but it is unlikely to make its tritium available to fusion researchers.)

But this is not a viable long-term solution—the whole point of nuclear fusion is to provide a cleaner and safer alternative to traditional nuclear fission power. "It would be an absurdity to use dirty fission reactors to fuel 'clean' fusion reactors," says Ernesto Mazzucato, a retired physicist who has been an outspoken critic of ITER, and nuclear fusion more generally, despite spending much of his working life studying tokamaks.

The second problem with tritium is that it decays quickly. It has a half-life of 12.3 years, which means that when ITER is ready to start deuterium-tritium operations (in, as it happens, about 12.3 years), half of the tritium available today will have decayed into helium-3. The problem will only get worse after ITER is switched on, when several more deuterium-tritium (D-T) successors are planned.

These twin forces have helped turn tritium from an unwanted byproduct of nuclear fission that had to be carefully disposed of into, by some estimates, the most expensive substance on Earth. It costs $30,000 per gram, and it's estimated that working fusion reactors will need up to 200 kg of it a year. To make matters worse, tritium is also coveted by nuclear weapons programs, because it helps makes bombs more powerful—although militaries tend to make it themselves, because Canada, which has the bulk of the world's tritium production capacity, refuses to sell it for nonpeaceful purposes.

In 1999, Paul Rutherford, a researcher at Princeton's Plasma Physics Laboratory, published a paper predicting this problem and describing the "tritium window"—a sweet spot where tritium supplies would peak before declining as heavy-water-moderated reactors were switched off. We're in that sweet spot right now, but ITER—running almost a decade behind schedule—isn't ready to take advantage of it. "If ITER had been doing deuterium-tritium plasma like we planned about three years ago, everything kind of would have worked out fine," says Scott Willms, fuel cycle division leader at ITER. "We're hitting the peak of this tritium window roughly now."

Scientists have known about this potential stumbling block for decades, and they developed a neat way around it: a plan to use nuclear fusion reactors to "breed" tritium, so that they end up replenishing their own fuel at the same time as they burn it. Breeder technology aims to work by surrounding the fusion reactor with a "blanket" of lithium-6.

some hope for the future

When a neutron escapes the reactor and hits a lithium-6 molecule, it should produce tritium, which can then be extracted and fed back into the reaction. “Calculations suggest that a suitably designed breeding blanket would be capable of providing enough tritium for the power plant to be self-sufficient in fuel, with a little extra to start up new power plants,” says Stuart White, a spokesperson for the UK Atomic Energy Authority, which hosts the JET fusion project.

Tritium breeding was originally going to be tested as part of ITER, but as costs ballooned from an initial $6 billion to more than $25 billion it was quietly dropped. Willms’ job at ITER is to manage smaller-scale tests. Instead of a full blanket of lithium surrounding the fusion reaction, ITER will use suitcase-sized samples of differently presented lithium inserted into “ports” around the tokamak: ceramic pebble beds, liquid lithium, lead lithium.

Even Willms admits that this technology is a long way from being ready to use, however, and a full-scale test of tritium breeding will have to wait until the next generation of reactors, which some argue might be too late. “After 2035 we have to construct a new machine that will take another 20 or 30 years for testing a crucial task like how to produce the tritium, so how are we going to block and stop global warming with fusion reactors if we will not be ready until the end of this century?” says Mazzucato. urk

There are other ways of creating tritium—actively inserting breeding material into nuclear fission reactors, or firing neutrons at helium-3 using a linear accelerator—but these techniques are too expensive to be used for the quantities required, and they will likely remain the reserve of nuclear weapons programs. In a perfect world, there would be a more ambitious program developing the breeding technology in parallel to ITER, Willms says, so that by the time ITER has perfected the fusion reactor there's still a fuel source to run it. "We don't want to get the car built and then run out of gas," he says.

The tritium problem is fueling skepticism of ITER, and D-T fusion projects more generally. These two elements were initially chosen because they fuse at a relatively low temperature—they're the easiest things to work with, and it made sense in the early days of fusion. Back then, everything else seemed impossible.

But now, with the help of AI-controlled magnets to help confine the fusion reaction, and advances in materials science, some companies are exploring alternatives. California-based TAE Technologies is attempting to build a fusion reactor that uses hydrogen and boron, which it says will be a cleaner and more practical alternative to D-T fusion.

It's aiming to reach a net energy gain—where a fusion reaction creates more power than it consumes—by 2025. Boron can be extracted from seawater by the metric ton, and it has the added benefit of not irradiating the machine as D-T fusion does. TAE Technologies CEO Michl Binderbauer says it's a more commercially viable route to scalable fusion power.

hmmm, a ray of hope . . .

But the mainstream fusion community is still pinning its hopes on ITER, despite the potential supply problems for its key fuel. "Fusion is really, really difficult, and anything other than deuterium-tritium is going to be 100 times more difficult," says Willms. "A century from now maybe we can talk about something else."

this is a hard problem, alright

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