Nuclear Fusion Reactor in France Could Bring Breakthroughs That Will Provide Limitless, Clean Energy and Secure the Planet's Future

Alok Jha | The Guardian

The construction site at Saint-Paul-lez-Durance: when the reactor building is complete, it will rise some 60 metres into the air and reach 10 metres below the ground.

The countryside of Saint-Paul-lez-Durance in Provence is a serene terrain of thickly wooded hills. On chilly January mornings, the air becomes thick with mist and the sky glows red as the sun pokes up above the horizon at dawn. By mid-morning, that haze is usually gone, leaving behind a bright blue sky with only the faintest wisp of high-altitude cloud.

As picture-postcard scenes go, it is as rural and peaceful as it gets. But incongruously nestled among these hills and vineyards, the most sophisticated, expensive machine ever built is slowly taking shape at the local Cadarache nuclear facility. It is a scientific collaboration on a worldwide scale, meant to tackle one of the biggest challenges of the 21st century – with the human population growing every year, how do we continue to make ever more electricity past 2050 (the date that the EU has set for full decarbonisation of power generation) without destroying the environment? The scientists and engineers in Saint-Paul-lez-Durance think the solution is nuclear fusion – they want to recreate a star in a box on Earth.

Everything about the project, known as Iter (formerly known as the International Thermonuclear Experimental Reactor), is huge. The main fusion reactor will be built on a flattened area of concrete that has been blasted into the hills at Cadarache and stretches to 60 football pitches. Around 2.5m cubic metres of earth and rubble were excavated from what was originally a small valley that undulated by several hundred metres in parts. That concrete baseplate sits on dozens of pillars containing layers of rubber sandwiched between the mortar and cement – not only do these pillars raise the building above the height of the surrounding countryside (the height was calculated to be above the maximum height that water would flow past if the nearby dam broke), they also create a "seismic isolation pit" that will protect the building from earthquakes.

At the centre of the concrete box where the main building will go, you can already see a circle of steel bars that trace the shape of what will become the ring-shaped vacuum vessel, where the fusion reactions will take place. Ready to haul in the huge components over the coming years, four giant cranes are rooted into the site, one of them within the circle itself. When the main building containing the reactor is complete, it will rise 60 metres into the air and reach 10 metres below the ground.

When the million or so pieces that make up the Iter machine have been delivered to site and are finally bolted and welded together, the whole thing will weigh around 23,000 tonnes, three times the weight of the Eiffel tower. The entire reactor complex – including the foundations and buildings that will sit in the seismic isolation pit – will weigh 400,000 tonnes, more than the weight of the Empire State Building.

Visiting the Iter site, I meet Steven Cowley, who has been working on the theoretical physics of nuclear fusion for three decades and is now chief executive of the UK Atomic Energy Authority(UKAEA). The last time he saw the site, there was still mud at the bottom of the main pit. Standing over the recently finished concrete platform, he gestures to where the super-hot plasma will one day start burning and fusing atoms. “It’s not ordinary by any stretch of the imagination and when it’s working, you know, it will be one of the great wonders of the world.”

Cowley has been waiting for Iter his whole career. His commitment to it is not just driven by a desire to answer scientific questions that have occupied his mind for so many decades, though. “We don’t know where we are going to get our energy from in the second half of this century, and if we don’t get fusion working we are going to be really stuck,” he says. “We have to make [Iter] work. It’s not just because I work in it that I think that: it has to work and all this effort of thousands of people all the way round the world is to make sure that in 2100 you can flick a switch on the wall and have electricity.”

Nuclear fusion is different from the more familiar nuclear fission, which involves splitting heavy atoms of uranium to release energy and which is at the heart of all nuclear power stations. The promise of fusion, if scientists can get it to work, is huge – unlimited power without any carbon emissions and very little radioactive waste.

The process goes on at the core of every star and the idea that mimicking it could become a source of power on Earth has been around since the years after the second world war. But for many decades fusion has seemed out of reach, requiring materials and an understanding of the chaotic behaviour of hot plasmas that was beyond the technology of the time. However, decades of smaller experiments have led to Iter, the giant project in which fusion scientists have their best possible chance to finally show that this technology could work.

Iter has its roots in a summit between Ronald Reagan and Mikhail Gorbachev towards the end of the cold war, in 1985. They agreed on very little but, almost as an afterthought, they mentioned developing fusion as a new source of energy that could benefit all mankind. Europe and Japan joined the Americans and Russians on the tentative project soon after it was conceived and, today, it also includes China, India and South Korea – in total there are 35 countries involved.

Its design is centred on heating a cloud of hydrogen gas to 10 times hotter than the core of the sun, some 150m degrees celsius, inside a ring-shaped container called a tokamak, which has superconducting magnets fixed around it like hoops fitted on a circular curtain rail. These magnets create an overlapping set of fields that keep the electrically charged gas inside from touching the sides of the tokamak and therefore losing energy.

Building a working tokamak is not straightforward. “The plasma is a bit like a lump of jelly and you are holding it with a magnetic field which is a bit like knitting wool – and imagine holding a lump of jelly with a few pieces of knitting,” says Cowley. The magnets have to be strong and Iter’s design uses superconducting magnets that only work at -269C.

Since the earliest designs, several generations of tokamak-based nuclear fusion reactors have proved that it is possible to build and run the technology at increasingly large sizes. The biggest of these is the Joint European Torus (Jet), based at Culham in Oxfordshire and run by the UKAEA. In the early 1990s, experiments there showed it was possible to fuse hydrogen and then release the resulting energy in a controlled way.

But it took more energy to fuse atoms at Jet than the scientists got back out at the end – which is useless if you want to use the technology to build a power plant. Iter's primary goal is to fix that problem by creating what they call a "burning" plasma, something that keeps going without the need for external heating, in the same way that a log fire keeps burning after it has initially been set alight by a match. Its design is a scaled-up version of Jet and the scientists here want to produce 500 megawatts of power, 10 times its predicted input.

But scientific challenges are not the only complexities with a mega-project such as Iter. With so many countries involved, so much money and so many engineering contracts, the path to laying even the first building block of this experimental reactor has been far from smooth.

The seven partners agreed on Cadarache in 2004 and they signed an agreement two years later, which costed the project at an estimated €5bn to build and a similar amount to run for its 20-year lifetime. The agreement stated that, as hosts for the project, Europe pays 45% of the total cost while the remaining partners split the bill for the rest between them. Countries do not pay funds directly to Iter but rather provide the equivalent value in parts and services to the reactor project. The ratios are important – they were to remain in place even if the cost rose. Which it did: after a design review in 2008 that incorporated several advances in fusion science into the basic design and also took into account the increased cost of steel and concrete, the construction budget rose to €15bn.

When the Iter agreement was signed in 2006, the reactor was supposed to begin operations in 2016. With the subsequent redesign and construction delays, the current timetable does not involve a switch-on until 2020 and there will not be a working plasma in the tokamak before around 2022. The all-important fusion reactions are not likely to occur before 2027, more than 20 years after building started.

Iter will need 100,000km of superconducting wire for its magnets – enough to wrap around the equator twice.

Iter's director general, the Japanese plasma physicist Osamu Motojima, has been in charge since 2010 and is now in the final months of his tenure. His team came under criticism in 2013 in an assessment carried out by independent consultants, who said the project's management was inflexible and top-heavy.

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