How to build an artificial star on Earth

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Editorial: "There's more to nuclear fusion than ITER"

An artificial sun will burn here *(Image: ITER Organization)*

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THE sun beats down through a cloudless sky as we weave between concrete blocks, each about as tall a person. Hundreds of the blocks are arranged in lines that fan out from a central point, like a child's drawing of the sun, cast at the bottom of a huge limestone pit in southern France. It is as if I'm standing in a shrine to our closest star, and in a way I am. If all goes well, the space above my head will one day rage with humanity's first self-sustaining fusion reaction, an artificial sun ten times hotter than the one that gives our planet life.

The blocks - each fitted with an elastomeric top to absorb vibrations - are seismic plinths, designed to shield the building that will rise above from damage in the event of an earthquake. Together they form the bowels of ITER, the International Thermonuclear Experimental Reactor, an ambitious and unusual collaboration between seven of the world's biggest powers: China, the European Union, India, Japan, South Korea, Russia and the US. Their goal is to build the first energy-producing fusion reactor - harnessing the process that powers the sun and most other stars. At extremely high temperatures, hydrogen nuclei will fuse to form helium, spitting out more energy than the process consumes, something that has never yet been achieved by a human-made device.

Read more: "ITER: The way to a benign and limitless new energy source"

With many advantages over its more toxic cousin, fission, it has long been clear that nuclear fusion could be a wonder energy source. Only now - following major budget cuts in the 1990s and years of bitter political wrangling to determine its location - are the formidable structures and devices that will make ITER a reality starting to take shape. "This is one of the most complicated things you could possibly imagine building," says Richard Pitts, leader of ITER's plasma-wall interactions group. "It is a truly massive scientific endeavour."

The 60-metre-high building that will one day stand above me will be the centrepiece of a 39-building compound, and will house the burning, doughnut-shaped hydrogen-helium mixture at ITER's heart. At a fiercely hot 150 million °C, deuterium, an isotope of hydrogen with one extra neutron, and tritium, with two, will form a state of matter known as a plasma, in which their nuclei fuse to form helium. When they achieve "plasma burn", they will spit out power in the form of a highly energetic neutron that will be used to heat the walls of the reactor, and in future reactors, would be used to drive a turbine.

If plasma is ITER's heart, magnets are its skeleton. Containing the superhot, charged plasma means building several of the largest magnets in the world. The biggest of these are the poloidal field coils, which will run horizontally around the reactor's torus at its widest point (see diagram). At 25 metres across and weighing 400 tonnes, the coils are too large to be transported, so instead are being built on site, in a specially constructed, 250-metre-long metal hangar.

When we enter, it seems empty, its floor so shiny it looks wet. But spanning the ceiling is a huge circular crane perched on rails that run the length of the building. The magnetic coils, made of a niobium-titanium alloy, will begin their life here, slowly making their way through an assembly line of super-precise machining. The finished magnets must be almost perfectly level - the maximum slope they can tolerate amounts to a 2 millimetre difference in height.

Once installed, the enormous magnets will be cooled to around 4 degrees above absolute zero, that's about -269 °C, until they become superconductors. This is necessary to limit energy consumption, but it means that some of the coldest objects on the planet will be just a few metres from one of the hottest things in the universe - ITER's plasma.

Our final stop is the cabins that ITER's creators currently inhabit, where we get a glimpse of another technology vital to ITER: robotics. Though fusion is much cleaner than fission, it will still produce radioactive and toxic materials. Most of this comes from the high-energy neutrons that gradually embed themselves in the walls of the torus, creating atoms such as cobalt-60. Tritium is also radioactive, while the beryllium used to line the torus is toxic.

Virtual reality robots

To deal with this, ITER's designers are developing a remote-control system consisting of a fleet of "nuclear lifts", each about the size of a large bus. These will use robotic arms to remove and transport eroded, radioactive parts from the torus to a storage room called the hot cell, and replenish the torus with fresh parts. Crucially, says Jim Palmer, a remote handling engineer at ITER, the robots will have the functionality to carry out unforeseen tasks. "ITER is an experiment," he says. "We have a bunch of physicists that will want to play with their gadget."

Although fission reactors already rely on robotic equipment to help deal with radioactive material, their shape is less complex and so is less of a challenge, robotically speaking. "A fission reactor is a series of fission rods going up and down," says Carlo Damiani, team leader for ITER's remote handling project. "But ITER is a torus, so in order to enter you have to make a complex combination of movements."

That's why ITER's operators will use a virtual reality system to control the robots. The virtual model of the reactor provides a clearer picture than that produced by the radiation-resistant cameras inside, enabling the robotic arms to be moved accurately. The system is also programmed to predict collisions - allowing an operator to avert them.

A further task, once fusion begins, is to explore a method for "breeding" tritium inside the reactor itself, by diverting neutrons produced by fusion onto a lithium target. Tritium will be brought to the reactor to start with, but a way to produce it on site is necessary if fusion is to become commercially viable.

"There is near universal excitement about seeing what plasma burn looks like," says Dennis Whyte, a nuclear scientist at the Massachusetts Institute of Technology. "We are basically making a star on the planet."

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