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issues & events

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The nearly 5000 carbon tiles that line the inside of the Joint European Torus, the world's largest tokamak, are being unbolted. They're to be replaced with beryllium and tungsten tiles, the same combination planned for ITER, the international prototype fusion reactor under construction in Cadarache, France. The €100 million (roughly $150 million) JET makeover began on 26 October and is scheduled to be done by the end of next year, with ITER-relevant experiments—including the fusion of tritium and deuterium—to start soon thereafter.

Located at the UK's Culham Centre for Fusion Energy, the 26-year-old JET holds the fusion power record, 16 MW for 1–2 seconds, produced in 1997. More than once it came close to being shuttered. "It is a project that had to fight for going ahead every time," says director Francesco Romanelli. The machine's interior has been modified several times, he notes. "It was built in a very flexible way, so it's been able to adapt every time to new requests from researchers." Over the past decade, adds UK fusion program director Steven Cowley, "JET has been busily doing science. There is nothing at the scale just below ITER except JET. It's the only machine on which you can practice for ITER, so the lead up to ITER is a critical time for JET. Everything now is preparation for ITER."

"A bit of cookery"

The mission of ITER, which will start up no sooner than 2018, is to create power by fusing tritium and deuterium. Carbon, a typical tokamak lining material, "sucks up tritium like crazy," which makes the walls radioactive, says Cowley. So, although ITER is due to start out with carbon walls, a switch to tungsten and beryllium is planned before the machine goes full throttle. Tungsten has been used successfully in the ASDEX Upgrade, a tokamak in Garching, Germany. "Nobody believed it would work," says the facility's director, Hartmut Zohm. "If tungsten gets into the plasma, it radiates a lot at these temperatures" of up to 200 million degrees. Anything that radiates UV and x-ray photons cools the plasma by taking heat from electrons. But tungsten has the highest melting point of any metal and minimal erosion under plasma particle bombardment, so, Zohm says, "if you can prevent it from getting into the plasma, it's a great wall material."

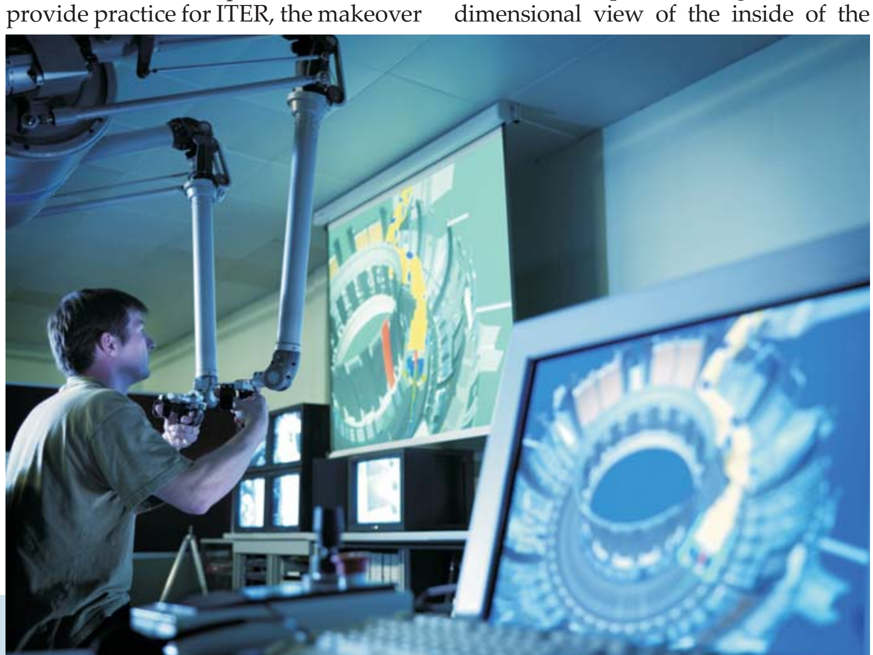
The plan at JET—and ITER—is to use tungsten in the diverter, where particles strike the wall and, along with impurities, are swept out of the tokamak. The remaining roughly 90% of the wall will be lined with solid beryllium and beryllium-coated tiles. Like carbon, beryllium has the advantage of low atomic number and doesn't cool the plasma. "What we've learned is that a bit of cookery goes into fusion plasmas. The impurities that get into the plasma are critically important," says Cowley. Because beryllium radiates much less than tungsten, it is less damaging. Beryllium, he adds, "is a nasty substance. It's bad for your lungs. But JET is equipped to work with it."

Remote manipulations

To avoid exposure to the radioactive walls, meet exact specifications, and provide practice for ITER, the makeover is being done remotely by human-controlled robots. "This is a huge project," says Gary Hermon, a shift leader for the robotic work. "We have been practicing with simulations and a physical mockup for two years." Hermon is one of about 50 people involved in the relining of JET, which is being carried out night and day over about 14 months. "I generate scripts. Tighten this bolt, go back and torque that bolt. Due to the complexity and diversity of the tasks, they are broken down into very simple steps," Hermon says.

Besides the tiles being replaced, the diagnostics systems are being upgraded. "Passive and active systems will be installed in, on, and behind the tiles," says Cowley. "These will measure almost every physical quantity of interest—plasma temperature, density, fields, heat loads, et cetera."

The JET robotics system is a master–slave pair. "The operator sits between two dangling articulated [master] arms. At the ends are grippers," says Hermon. The arms, each about a meter long, have eight degrees of freedom. "You can pitch the hand, lift the wrist up and down, roll in a way a human hand can't . . . ," says Hermon. The master arms are in front of a bank of computers that give a three-dimensional view of the inside of the



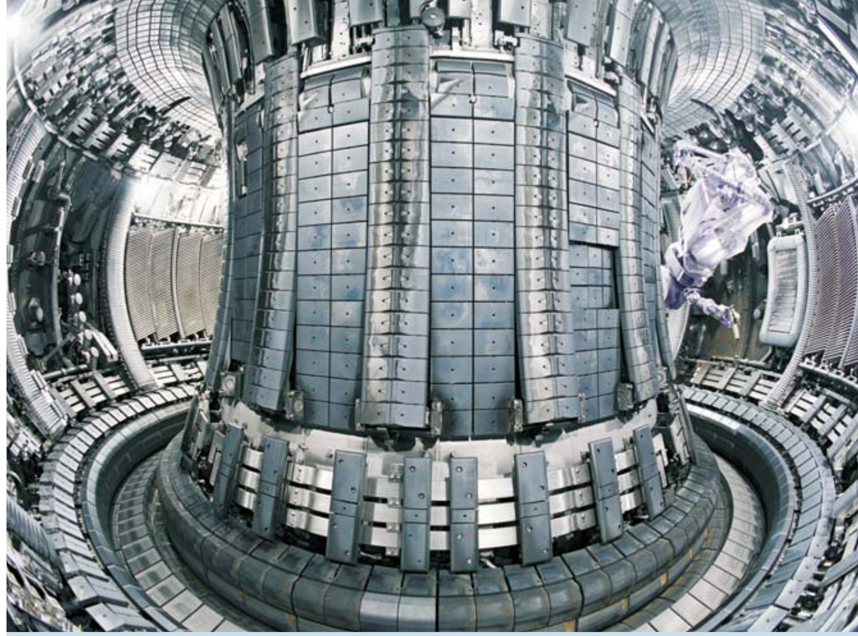
UK ATOMIC ENERGY AUTHORITY

Master arms manipulate their slave counterparts inside the Joint European Torus.

tokamak, some 200 meters away. Synchronized to the master arms are the slave arms, which do the actual work from the end of a several-meter-long boom. "We have feedback on the system," says Hermon. "You can feel weight, or rubbing. We don't use robots as manipulators. There is always a man in the loop. We have submillimeter tolerance. You need a human."

As part of their interviews for the robotic handling team, operators had to use robotic arms to stack toy building blocks. "You have to be dexterous," says Hermon. "A good operator can build a tower. He can go in and feel if a block is moving." The JET work can be delicate, he adds, "almost like threading a needle. And plug-in sockets, for example, are easily damaged because they have ceramic insulation. We are not allowed to damage the surface at all." The individual beryllium tiles weigh up to about 12 kg and cost tens of thousands of dollars, he adds.

"There is an enormous amount of work, and so many strands that have to come together," says Hermon. "Some components are still being manufactured, and there is the occasional last-minute design change. The major challenge is sheer time."


EFDA-JET

The thousands of carbon tiles lining the plasma-facing wall inside the vacuum vessel of the Joint European Torus are being replaced using a remote-controlled slave arm.

Scaling up to ITER

JET "will be a completely new machine when it comes back," says Cowley. Although tungsten and beryllium have each been tested alone, says Romanelli, "the combination has never been tested. Our plan is to demonstrate that we can run up to the highest performance reliably with the combination." Experiments exploring how the new wall behaves and any required modifications will take about three years, he says. Then, for the first time since 1997, JET will embark on a tritium campaign in late 2013.

ITER will be about twice JET's size, its pulses will be about 20 times as long (400 seconds compared with about 20 seconds at JET), and it is intended to produce around 30 times the power (500 MW compared with 16 MW). Still, says Mario Merola, who oversees planning for ITER's plasma-facing components, "we need the information coming from [JET] for finalizing the scenarios for the ITER machine, which will have exactly the same situation as far as the plasma-facing wall.

"JET will address major scientific topics," Merola says. "For example, how the melted layer of beryllium—which results from large, fast energy deposition in off-normal plasma events, like vertical displacement or plasma disruptions—behaves under electromagnetic loads, and how eroded beryllium penetrates into the gaps between tungsten tiles. We will also get information on the behavior of tungsten under high and cyclic thermal loads and on how the plasma behaves with a tungsten diverter." Cooling the much larger number of tiles in ITER using pressurized water will be a technological challenge, he adds. JET is also key for training physicists and engineers in remote handling, beryllium and tritium handling, and burning plasmas, among other things.

Merola says he doesn't expect the JET results to lead to changes in the ITER design, "but they will provide us with information on the lifetime of components, and from a physics standpoint, how the plasma behaves with a combination of beryllium and tungsten. We are very keen on getting these results."

Toni Feder

Augustine panel urges more autonomy for NASA

Congressionally imposed restrictions limit NASA managers' capacity to streamline operations.

On 29 October, one week after a blue-ribbon advisory committee declared that NASA's timetable for returning astronauts to the Moon is unrealistic, a prototype of the Ares-1 rocket that will lift humans into space launched successfully from Kennedy Space Center. Several options for a future US human space exploration were presented to President Obama by a committee led by retired Lockheed Martin chairman Norman Augustine. In the coming weeks, the president will choose from among those options.

In addition to its recommendation that NASA's exploration budget be boosted by $3 billion, the panel's report urges that NASA administrators be given greater latitude to manage the agency, realign its bloated 1960s-era infrastructure, and adjust the workforce.

"You [can] either spend your money on fixed costs and overhead, or you can spend it doing exciting exploration," Augustine said at the press conference marking the release of the committee's final report. "I think NASA is going to have to face that question, but if they are not given any latitude by the Congress, basically, or the White House—I should say both—they won't be able to do that."

Although the committee was asked only to chart a course for future manned space missions, the report argues that the agency's severely constrained resources make it vital that the administrator be allowed to move resources around. "Good management is especially difficult when funds cannot be moved from one human spaceflight budget line to another, and where new funds can ordinarily be obtained only after a two-year budgetary delay (if at all)," the report says.