

PHYSICS COMMUNITY

Remaining ITER Partners Settle on an Outline Design for a Downsized Fusion Reactor

Plans to build a large tokamak as a step toward one day producing fusion energy are back on track after having been derailed in 1998, when the US pulled out of the International Thermonuclear Experimental Reactor (ITER) project. This past January the remaining partners—the European Community, Japan, and Russia—agreed on a design for a smaller machine that is supposed to cut the original cost in half, to about \$4 billion.

The scaled-down design has more modest physics and engineering goals, but holds to the overall aim of trying to learn enough to build a prototype fusion power plant. ITER would study fusion of deuterium and tritium to yield neutrons and alpha particles—similar to the process that powers stars.

Project supporters claim fusion is the best long-term choice for a safe, clean energy source: It wouldn't pollute the atmosphere with carbon dioxide; there is no danger of a chain reaction should something go wrong inside the reactor; and much less long-lived radioactive waste would result than from fission. But critics have doubts about fusion energy's feasibility and implementation, among other things, and also worry about the high development costs. It wouldn't solve all the waste and proliferation problems associated with fission, says Edwin Lyman, of the Washington, DC-based Nuclear Control Institute. "It's a really regressive dream to try to make fusion energy work. If anything like the tens of billions of dollars that's been spent on fusion R&D had gone into soft, renewable energy—such as solar and wind—who knows where we'd be now. . . ."

The ITER partners need to win wide support for fusion energy. In addition, before the new ITER can happen, they still need to refine the design, get funding, and choose a site—Japan and Canada (which participates in ITER as a member of the European team) are both keen to host it. The biggest difficulties in going ahead with ITER, says project director Robert Aymar, "are not scientific or technical, but financial, political, and social. ITER could go on-line by

▶ If a smaller, cheaper version of ITER actually goes ahead, the US might just rejoin the project.

around 2013. And fusion energy could become commercially available in the second half of the 21st century."

A smaller, cheaper ITER

The new ITER abandons the goal of ignition, or infinite power gain, aiming instead for a gain of 10 or more ($Q \geq 10$) with an inductively driven plasma, and $Q \geq 5$ for steady state. Backing off from ignition is no great loss, ITER scientists insist, because a power station would need a steady-state gain of about 30, rather than the less controllable ignition.

When deuterium and tritium fuse, a fifth of the energy goes to alpha particles, which heat the plasma. So for $Q > 5$, the alpha heating tops the

tokamak size—the planned radius is now 6.2 m, down from 8.1 m—with the plasma volume being correspondingly more than halved. The expected burn time, plasma current, power, and other parameters have also been cut. (See the table on page 66 for a comparison of some key parameters.)

The main sacrifices in downsizing ITER follow from reducing the gain. With less alpha heating, exploration of plasma behavior won't as closely approach the relevant regime for a commercial reactor. "We can still achieve a Q of 10, the minimum acceptable value," Aymar says. "We would like to reach higher values, and are therefore fighting against performance-limiting boundaries." And the decreased neutron flux means that "we cannot see the longtime effects of radiation on materials." Parts of the tokamak would become radioactive by absorbing neutrons, and before going ahead with a prototype power plant, a separate neutron source might be needed to test for long-lasting materials that would keep radioactivity lifetimes and levels low.

Despite the lower neutron flux, Aymar says ITER would still be useful for materials testing. It would be used to study tritium breeding, for instance. Part of the original ITER design, the idea is to place a lithium-containing blanket such that fusion neutrons get absorbed to form tritium, which is then sent back to the plasma to feed fusion. "Such tritium fuel breeding will be an essential part of a commercial reactor," says Aymar.

"We have frozen the main physics parameters, the structural design, and the size. But we have left open technical options, such as how to make the coil windings on the magnets," continues Aymar. In the next year or so, details about such things as what materials to use closest to the plasma, the design of the exhaust divertor, and the superconducting magnets will have to be worked out. But agreeing to the outline design means that the partners have settled on a strategy, says Aymar: "To go with ITER—not with smaller experiments."



PARTIES OF ITER

THIS ARM, ATTACHED TO A RAIL INSIDE A PLASMA VESSEL, can exchange surface modules weighing up to four tons by remote control. In ITER, such a device would be used both for maintenance and for installing modules for materials testing.

input energy. That, says Aymar, "is a big step for physics, and it will require new engineering." The standing gain record is 0.6, held by the Joint European Torus, in the UK, which besides Princeton University's now-defunct Tokamak Fusion Test Reactor, is the only place where deuterium-tritium experiments have been done.

The biggest dent in the cost of ITER would come from reducing the

Crucial timing

The timing of the agreement was crucial for tying into the long-term budgets in both Europe and Japan. This summer, the European Commission will start laying out its Sixth Framework Programme, the five-year R&D funding plan that begins in January 2003, and ITER planners want to make sure the project gets included from the start. Similarly, in Japan the aim is to have ITER ready for the government to consider by next January, when a spending moratorium on large scientific projects is expected to be lifted.

Umberto Finzi, who oversees fusion research in the European Union, expects intergovernmental negotiations on ITER's legal framework to start by the end of the year. "We feel strongly that the legal aspects should be kept separate from the site decision. Then, wherever it's built, we would all have guarantees of access to decisions and to results." In Japan, he adds, there are "big difficulties in accepting something that is completely independent from the national authorities."

The partners would all contribute more to ITER in components than in cash. The host country would be expected to pony up at least 25% of the total outlay for construction, on top of sharing the rest, which would probably be covered mostly by Europe and Japan, with Russia putting in 10–15%, and additional contributions coming from any future new members—China and South Korea are interested in joining ITER, for example. (US costing methods differ from those of the ITER partners, which is why the US estimate for building the original ITER was \$10 billion, compared to \$5.8 billion—see table. These figures are in January 1989 dollars, as that is how the ITER partners do their accounting.) ITER's running costs are estimated to be about \$3.5 billion over the project's expected 20-year lifetime.

Japan or Canada

As Japan sees it, hosting ITER could be a ticket to a leading role in international science R&D. And the local governments where ITER might go are also keen to promote domestic industry and regional development, notes Saichi Nakazawa, the deputy director of Japan's Science and Technology Agency's atomic energy bureau. The three sites being considered are Naka, on Japan's main island, Honshu, and home to the Japan Atomic Energy Research Institute, one of the country's main fusion labs; Rokkasho, on the northern tip of

	new ITER	original ITER
Construction cost*	\$3.2 billion	\$5.8 billion
Q (inductively driven plasma)	10	∞
Q (steady state)	5	10–15
Tokamak major radius	6.2 m	8.1 m
Tokamak minor radius	2.0 m	2.8 m
Burn time		
(inductively driven plasma)	400 s	1000 s
Burn time (steady state)	~2000 s	~10 000 s
Power output	400 MW	1500 MW
Plasma current		
(inductively driven plasma)	15 MA	21 MA
Plasma current (steady state)	9–12 MA	12 MA
Plasma volume	840 m ³	2000 m ³
Average neutron wall load	0.6 MW/m ²	1 MW/m ²
Integrated average neutron wall load	0.3 MW-year/m ²	1–3 MW-year/m ²
*In January 1989 dollars. In today's dollars, the current estimate for the new ITER is about \$4.3 billion.		

Honshu; and Tomakomai, on the island of Hokkaido. Before officially bidding to host ITER, however, Japan is carrying out studies on such things as the technical feasibility of both fusion energy and alternative energy sources; the country's long-term energy needs; the distribution of money across all fields of research; and the nitty-gritty of participation in an international project.

The other possible host is Canada, where two sites are being considered. Bruce and Darlington, both near Toronto, Ontario, are on land owned by a nuclear power utility, which could speed up the licensing process. The sites are also already equipped to handle nuclear waste, and they are near the reactor that would supply ITER with tritium, so it wouldn't have to be shipped far. What's more, Canada's cheaper labor and electricity would save an estimated 15–20% on operating ITER compared to Japan. Finally, locating ITER in Canada could give added incentive to the US to rejoin the project, says Don Dautovich of the nonprofit organization ITER Canada. If Canada is chosen, he adds, "it would be natural [for it] to be an ITER party. . . . We might want to negotiate on our own basis," instead of as a junior partner.

Japan and Canada are expected to put in formal bids next year to host ITER, with a decision likely to follow sometime in 2002. And, although Canada is widely seen as more technically and geographically attractive, Japan is expected to put more money on the table.

The US and ITER

The European Commission, Japan, and Russia all hope the US will rejoin

ITER—both for its expertise and its money. And many in the US fusion community would like to be a part of the project too. Congress ended US ITER activity in 1998 because it didn't want money spent on a project it believed would never be built, and because, in the words of one Department of Energy (DOE) official, "energy crisis" had been dropped from our lexicon." (See PHYSICS TODAY, November 1998, page 48.)

At the time, continued involvement in ITER was controversial in the US fusion community, recalls Charles Baker, who headed up US ITER activities and now coordinates fusion technology work for DOE. "People tended to worry that putting money into ITER would hurt the rest of the program." Since the US withdrew from ITER, however, US funding for fusion research has increased, and the controversy has died down considerably. Ironically, adds Baker, "the new design includes a lot of things that we had been advocating to improve the tokamak and cut the cost."

Perhaps in hopes of rejoining ITER, US scientists seem to see the project more as a plasma physics experiment than as a step toward a power station—a view more in line with the US government's emphasis on basic fusion research than with the ITER partners' perspective.

In any case, says Baker, "I'd like to be optimistic, but in my realistic reading of the present situation, I cannot see the US rejoining ITER. It would take some major external change—like the others going ahead, not contingent on us joining, and then asking us if we'd like to join."

That's the tack the ITER partners plan to take.

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