Fusion Research at the Crossroads

After more than a decade of cuts, the U.S. fusion program will soon be operating only two major machines. As the focus shifts to engineering and energy production, can basic fusion research survive?

PRINCETON, NEW JERSEY—On 10 December 1993 the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory generated 6 million watts, a world record for the amount of power produced by a fusion reactor. The achievement was heralded as proof of fusion's potential as a virtually inexhaustible supply of electrical energy. Sometime in late 1994 or early 1995 the 43-year-old lab will set another, less auspicious record: TFTR will be shut down, and the flagship lab in the U.S. fusion program will be left without an operating fusion experiment.

But it's not just Princeton that has fallen on hard times. The entire U.S. fusion program is undergoing a sweeping transformation. After pumping $7.4 billion into the program over the past 40 years, Congress wants fusion researchers to focus on generating useful power, not on doing more basic plasma physics. As one congressional aide puts it, "It's time to put up or shut up."

Last week Martha Krebs, director of the Department of Energy (DOE)'s energy research program, told a congressional hearing on fusion that DOE was planning to do just that. "The fusion development program is in a period of major transition," she said, "from a program focused on research to one focused on engineering development, from a laboratory and university base to an industry base, from a domestic program to an international program." Researchers who have spent their careers trying to understand the basic physics of fusion reactions fear these shifts could stymie advances in fusion technology—and even put their jobs in jeopardy.

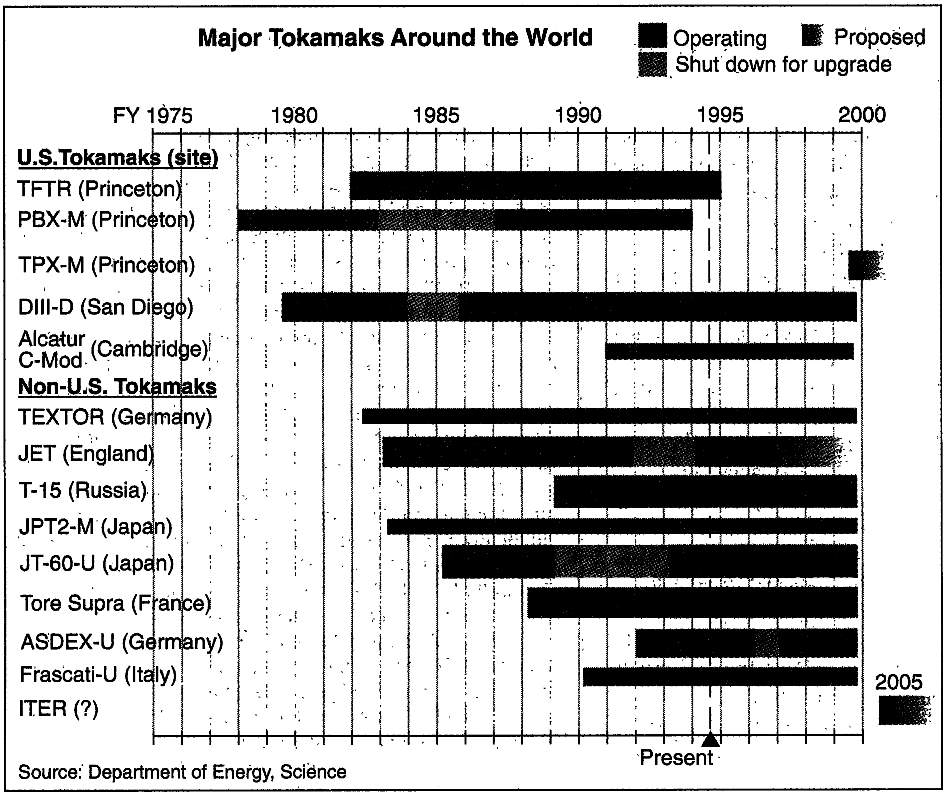
The changes are occurring not just because of congressional impatience. In real terms, the program's funding has shrunk by half in the past 15 years, dropping the United States from first to third, behind Europe and Japan. What's more, by next year the country will have only two major machines operating, a far cry from the 19 on line in 1984. And even those machines are limping along: DIII-D, at General Atomics in San Diego, is running at one-third capacity and will conduct just 11 weeks of experiments this year, and Alcator C-Mod, at the Massachusetts Institute of Technology, has only enough money to run at half capacity next year.

The immediate future looks like more of the same. The United States is pinning its hopes on two machines: the proposed $700-million Tokamak Physics Experiment (TPX) at Princeton, which would use superconducting magnets to demonstrate for the first time continuous plasma confinement at high pressure; and the International Thermonuclear Experimental Reactor (ITER), a multi-nation engineering project designed to follow on the TPX results by demonstrating continuous power production in the billion-watt range, at an estimated cost of $8–10 billion (see box on page 650). The two projects will require some $80 million more in fiscal year 1996, but DOE does not plan to request any significant increase in its overall fusion budget. This promises to create a situation that, in the words of Anne Davies, who runs DOE's fusion program, "will cause us some major, major problems." If DOE can't find more money, program managers may be forced to mothball either DIII-D or Alcator C-Mod, too.

No alternatives

Faced with a serious money crunch, DOE began drastically reshaping the program 4 years ago. Then-DOE secretary James Watkins decided to focus on the donut-shaped tokamak technology, freezing out more than a dozen alternative fusion machines, from stellarators, in which the confining fields come entirely from external magnets without contributions from currents within the plasma, to ball-shaped spheromaks. Watkins shut down all of the major non-tokamak machines, including all the fusion facilities at DOE's Los Alamos, Lawrence Livermore, and Oak Ridge national laboratories. Today, research on tokamak alternatives represents just 3% of the overall fusion budget.

Watkins' decision still rankles many researchers. They agree that the tokamak is currently the most advanced fusion technology, but say it is far from perfect. In particular, they believe a working power reactor based on tokamak technology would be too complicated and expensive for utility companies. "A tokamak reactor looks like it will be comparable in cost and scale to a large fission plant," says University of Texas fusion researcher Richard Hazeltine. "It is easy to believe that there might be



Headed offshore. The focus of fusion research is shifting away from the United States.

The High Cost of Cooperation on ITER

Like partners in a modern marriage, the four sponsors of the International Thermonuclear Experimental Reactor (ITER) agreed from the start that their union would survive only if they treated each other as equals. This arrangement, they decided, would be far preferable to the old-fashioned partnership that was to have built the Superconducting Super Collider but that achieved little in the way of real global commitments. But the participants in ITER—the United States, Japan, Russia, and the European Union—are learning that true equality takes a lot of work.

Begun in 1988 and still in the design stage, ITER has developed an organizational structure only a diplomat could love. The project, expected to cost an estimated $8–10 billion, has a steering council made up of representatives from the four parties, which picks the ITER director, currently Europe's Paul-Henri Rebut. The director heads the Joint Central Team, which conducts its work at sites in San Diego, California; Garching, Germany; and Naka, Japan; Russia did not propose a site of its own. The four partners have promised to provide a combined total of 150 scientists and engineers, with each nation's workers distributed equally among all three work sites. Their work supplements the efforts of national research teams—scientists from domestic laboratories, universities, and industry—that are assigned research tasks in equal shares.

This enforced equality is supposed to prevent any partner from dominating the project or monopolizing a lucrative bit of technology. That rule will be put to the test in 1996, when the partners hope to choose a single site for the reactor itself, a prize that promises the winner jobs and a boost to its high-tech economy. U.S. officials expect those negotiations will make the current arrangements look simple in comparison.

In the meantime, the effort to maintain balance is already taking its toll on the participants. "The management attention for something like ITER is just beyond what you could imagine," says Anne Davies, director of the Department of Energy (DOE) fusion program, which funds the U.S. ITER work. "When you do these big things the way we're doing ITER—equal contributions, equal benefit, equal management—it is extraordinarily complicated, and it costs more than if one country did it."

One case in point is the cost of relocating scientists and engineers. U.S. officials must budget about $340,000 a year for each member of the US technical delegation, nearly $100,000 more than the cost of keeping the same individual at a U.S. lab. That means DOE will spend $12 million this year supporting just three dozen US representatives at the joint work sites, while the entire domestic research and development effort for ITER amounts to only $38 million.

At present, DOE sees few easy ways to reduce those costs. The partners are considering giving some tax relief to relocated personnel, but none of the countries is willing to give up its on-site representation, certainly not with the big prize only a few years away. Still, the ITER experience has taught DOE something. Future joint projects, Davies says, are likely to emphasize remote collaborations, using computer networks rather than personal contact to reach out at an affordable price.

–C.A.

something else much more economically attractive."

One alternative is the stellarator, which has a magnet configuration that naturally keeps the plasma in the center of the device, removing the risk from tokamaks that the plasma will collapse to the wall of the machine and damage it. But the stellarator magnets have traditionally been very complicated to design and manufacture. Today, however, high-powered computers can greatly simplify the magnet design task, and both Germany and Japan have invested in large new stellarators.

DOE says its 1990 decision to focus on tokamaks was endorsed by outside experts, including the standing Fusion Energy Advisory Committee (FEAC). But FEAC has since been disbanded, and researchers now criticize DOE for taking further radical steps without consultation. DOE officials say they hope by the end of the year to create a new advisory panel to review the fusion program that will include scientists from industry, the national labs, and universities.

While researchers may disagree on the most promising fusion technology, there is consensus that fusion research should continue. So they're particularly concerned about DOE's intention to de-emphasize fusion science in favor of engineering. In February, Hazeltine and 36 other fusion researchers wrote to Krebs and Davies to warn that the shift jeopardizes the chances of success. "It is extremely premature to limit the vision of a fusion reactor, still several decades before construction, to what is allowed by the present state of scientific knowledge," they wrote. "To enforce such narrowing is analogous to terminating aviation research at the Wright airplane."

Bad timing

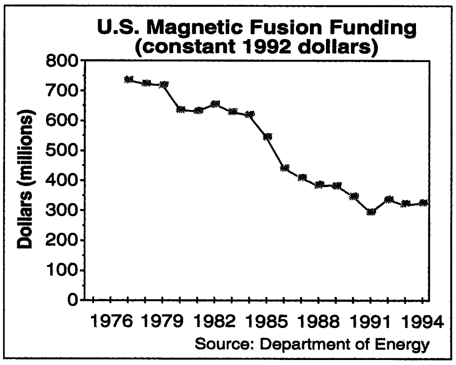
Ironically, the turmoil comes at a time when the U.S. program is riding a technological high. Last December's record-setting TFTR experiments produced a fifth of the input power required to heat the plasma by using a fuel that, for the first time in that machine, combines deuterium and tritium. TFTR's current run, which ends this fall, has exceeded virtually every technical target, from plasma temperature to confinement time.

Indeed, the TFTR result was the latest in a string of records for the fusion program. Despite the budget cuts, the fusion power record has quietly risen a million-fold over the last decade. Progress in fusion power, which has increased by a factor of 10 every 2 years for the past decade, exceeds even the much-touted improvements in computer memory chips, which have grown tenfold in capacity every 5 years. "This program has been a smashing success," says University of Wisconsin fusion scientist Stewart Prager. "It's taken a lot longer than even the pioneers thought, but recent progress has been absolutely tremendous."

In spite of its record-breaking achievements, however, the Princeton lab has not had much cause for celebration. Since the mid-1980s, the size of its staff has shrunk from 1300 to 800 employees. Even if the superconducting TPX is approved, few Princeton scientists will be involved in the project until it nears completion in 2000. (The lab has asked in the interim to restart a mothballed machine known as PBX-M, but DOE says it cannot afford the cost.)

For many Princeton scientists, the choice is to work elsewhere, or not at all. Princeton officials have not decided how many researchers they will be able to send to other labs, such as DIII-D and the Joint European Torus (see box on p. 649), but lab director Ronald Davidson says that it will be no more than a few dozen. Some scientists may be able to collaborate with researchers elsewhere while staying at Princeton, but for many the future is grim. Although Davidson says the lab has not determined how many will be laid off, lab scientists suspect the number may be as high as 20% of staff.

One of the greatest fears among Princeton researchers is that Congress will not provide enough money to build and operate TPX. And they cite the fusion program at Oak Ridge National Laboratory as an example. For most of the 1980s, Oak Ridge fusion researchers collaborated with other fusion labs while the $100-million Advanced Toroidal Facility (ATF) was under construction. Less than 2 years after ATF was turned on, however, budget cuts forced DOE



Cash flow. Fusion has fallen on hard times.

to mothball it (*Science*, 14 December 1990, p. 1501). Although ATF has run sporadically since then, it will be shut down next month. The funding roller coaster also took its toll on the scientific work force: Of the 300 fusion scientists and engineers at Oak Ridge when ATF began operations in 1989, only half remain.

What happens next

DOE officials say they have no plans to discard the Princeton lab, regardless of what happens to TPX. "They made a monumental effort over the past few years to get TFTR up and running," says Davies. "It's not a reflection on Princeton—their capability, or their importance to the program—that they're going to be without a major operating facility for some years."

In the meantime, DOE wants to focus its fusion research on the sort of problems that commercial power reactors face. "One of the things I'm not very happy about is that ITER is going to have to be built out of today's materials, which will become very, very radioactive" when exposed to the neutron radiation from the fusion reaction, she says. "That's because we haven't developed the low-activation materials that all of us expect will make fusion an environmentally attractive energy source." DOE hopes to be able to fund a proposed international particle accelerator that could bombard materials with neutrons to simulate fusion radiation.

But even with this restricted portfolio, the fusion program faces serious political hurdles. Last year, Senator J. Bennett Johnston (D–LA), chairman of both the appropriations subcommittee that funds DOE and the committee that authorizes its programs, warned DOE that he would not provide funding to start building TPX this year until the Administration assured him that it was committed to ITER. His stance was an effort to avoid the political wavering that led to the cancellation of the Superconducting Super Collider. Davies says the Clinton Administration intends to give Johnston some sort of assurance, but it is "premature for the United States to make an unqualified commitment to the construction of ITER. We don't have a good cost estimate and we don't have a good set design."

Among the options DOE is considering, says Krebs, is a proposal by Princeton's Davidson for a presidentially appointed special negotiator for discussions on ITER, for ITER to be part of July's meeting of the G-7 countries, and for a high-level interagency task force to coordinate ITER planning. White House science adviser John Gibbons says the Administration is weighing its response but that the President supports ITER and fusion in general. Clinton "was very impressed with the TFTR results," Gibbons says.

However, it will not be easy to reconcile the short attention span of politicians with the generation-long program of fusion researchers. "The difficulty with fusion is that it is a 100-year project, and politicians don't think in that way," says Krebs. International collaboration eases the cost for the United States, but it adds the nightmarish complexity of international negotiations.

Whatever happens, fusion researchers expect continued uncertainty and turmoil. But they are kept going by a belief that politicians will find it impossible to resist the lure of limitless energy.

–Christopher Anderson