Rethinking the Future of Magnetic Fusion

Pushing too hard for energy breakeven now could cripple the program 10 years from now

As the Department of Energy (DOE) negotiates its fiscal 1984 budget request to the Reagan White House, members of the magnetic fusion research community are expressing serious concern about their program's direction.

Last spring the DOE sharply cut back on the fast-paced strategy mandated by Congress in the Magnetic Fusion Engineering Act of 1980, and for the foreseeable future committed the program to roughly constant funding at $400 million to $500 million per year (*Science*, 16 July, p. 236). At the same time, however, the department is continuing to push hard on the so-called "mainline" concepts, the donut-shaped tokamak and the linear tandem mirror. By mid-decade they should both approach scientific breakeven, wherein the fusion reaction generates as much energy as it takes to heat the plasma. The risk is that, in the process, tight budgets and rising costs might strangle the development of alternative reactor designs, which in turn could cripple the program in the 1990's.

The fate of the alternatives quickly became the major issue at the second meeting of MFAC, the DOE's new Magnetic Fusion Advisory Committee, on 30 and 31 August. The department is spending some $300 million to complete Princeton's Tokamak Fusion Test Reactor (TFTR) by 1984, and more than $200 million to finish Lawrence Livermore Laboratory's Mirror Fusion Test Facility (MFTF-B) by early 1986. DOE then plans to use the data from these machines to design a $3 billion Engineering Test Reactor to be built in the 1990's. But as more than one MFAC member pointed out, there is no guarantee that either the tokamak or the tandem mirror will work as well as expected.

"If you want insurance and a backup, you have to consider the balance of the program," said Henry Dreicer of Los Alamos, head of MFAC's subpanel on an alternate known as the Reversed Field Pinch. "I think it is ridiculous to talk about alternative concepts coming forward to save the day if you don't give them the money to prove themselves."

Moreover, even if the mainline approaches do work, they may not lead to reactors that the utilities will want to buy. In particular, some of the alternates could give rise to fusion power reactors that are smaller, cheaper, and more efficient than anything based on the mainline concepts. As one committee member said, "(They) may make the difference between commercially attractive reactors and a commercial disaster."

At the very least, others argued, the alternates are a prime source of new ideas in plasma physics, ideas that have often been fed back to improve the mainline concepts.

MFAC was formed last May to help DOE adapt its fusion strategy to the new budget constraints. Its official recommendations are due at the end of the year. However, DOE and the White House Office of Management and Budget start their negotiations on the department's fiscal 1984 budget request in September. Thus, MFAC was called together in August to formulate an interim report.

Most of the committee's 15 members are themselves the directors of major fusion projects, which accounted for the meeting's rather circumspect air: many had never before had to debate the fate of those projects in front of subordinates and reporters. (The audience numbered several dozen.) "What you're seeing now is the pain," said Robert W. Conn of the University of California, Los Angeles.

But the committee's discussion also illustrated fusion's larger political dilemma. Fusion researchers have become much more confident in recent years that their efforts will ultimately pay off. However, they are asking the federal government to put up anywhere from half a billion to a billion dollars per year for at least another generation, and they feel under pressure to demonstrate substantial progress—beginning with scientific breakeven—soon. Thus, there is a strong temptation to throw everything into the mainlines: "If ignition is the goal," said one panel member, "then go for it!"

On the other hand there is the experience of their brethren in the fission power industry, wherein the United States pursued a single reactor concept, the light water reactor, at the expense of others that might have proved cheaper, more efficient, or inherently more safe. If the program had kept more flexibility in the beginning, utilities might not be canceling nuclear plants now. "It's in the back of everyone's mind," Conn told *Science*. And that, he said, is why the committee was virtually unanimous about the need to support alternative devices such as the ELMO Bumpy Torus, the Stellarator, or the Reversed Field Pinch.

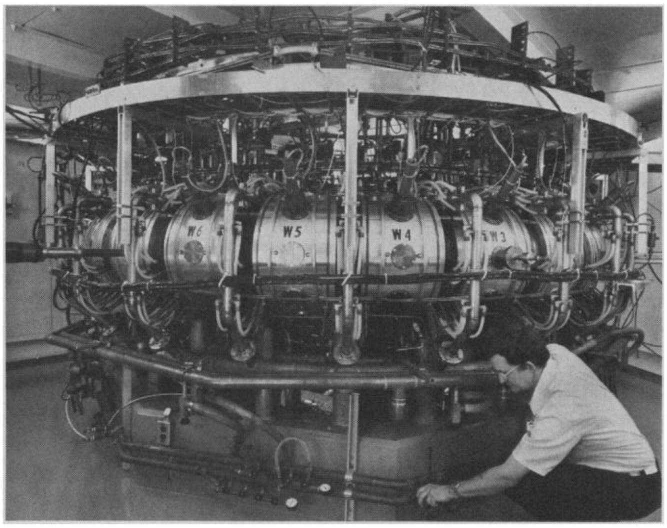
> "It is ridiculous to talk about alternative concepts coming forward to save the day if you don't give them the money to prove themselves."

MFAC was far from unanimous, however, when it tried to address the program's overall balance. There was no debate over the need to push the mainlines. But in a time of tight budgets, which alternates get priority?

The issue is made more difficult by the fluid nature of the technology. Consider the saga of DOE's best funded alternate, the ELMO Bumpy Torus (EBT).

Since the late 1960's the worldwide fusion community has been in the grips of Tokamania, obsessed with pushing the Soviet-invented tokamak design ever closer to the magic goal of energy breakeven. It was (and is) by far the most successful plasma confinement device ever found. By the late 1970's, however, many fusion researchers had become concerned that the obsession had gone too far, that the tokamak might shut out

 0036-8075/82/0924-1235$01.00/0



The ELMO Bumpy Torus.

Department of Energy

potentially better alternatives. The tokamak could probably be made into a reactor, but would it be an economic reactor?

Thus, in 1978 the DOE decreed that the tokamak program would have one backup—the obvious choice being the magnetic mirror, which was the furthest along at the time—and one alternative backup. To choose the latter DOE invited some 100 fusion experts to its center in Germantown, Maryland, for what participants now remember as "the Gong Show." Members of the audience were asked to rank the candidate reactor concepts on the basis of their readiness and attractiveness as reactors. When the votes were tabulated, the bumpy torus had won. Planning started soon afterward for a new EBT reactor, to be called EBT-P for "proof of principle." Oak Ridge National Laboratory was designated the lead center for the project. McDonnell Douglas was awarded the contract to build it.

"Tokamak grew like a weed," observes Harold P. Furth, director of the Princeton Plasma Physics Laboratory. "You couldn't stop it. EBT-P is promising too, but it is a hothouse plant force-grown by the DOE."

In essence, EBT is a series of short coils linked end-to-end to form a closed torus. Each segment acts as a magnetic trap, so that the plasma streaming around the inside of the torus forms a series of bulges, rather like a string of sausages (thus the name "bumpy torus"). As a power reactor, EBT would have two major advantages over the tokamak. First, assuming it could achieve fusion output at all, it would operate continuously, whereas present-day tokamaks have to be pulsed. The level temperatures of the steady state would be much kinder to reactor components. Second, EBT's segmented design is inherently modular, which would make it relatively easy to replace reactor components as they degrade from neutron damage. Current-generation tokamaks, on the other hand, are bound up in a massive tangle of coils and current loops, making maintenance a potential nightmare.

Things have changed since 1978, however. For one thing, the tokamak researchers have responded to the EBT challenge by incorporating many of its unique features. For example, two of the most advanced tokamak designs, a proposed international project called INTOR, and the recently canceled Fusion Engineering Device in the United States, call for modular construction. Moreover, new high-powered microwave tubes—among them those developed for the EBT, ironically enough—may prove useful in making tokamak plasmas much closer to steady-state operation.

Meanwhile, the magnetic mirror has evolved into the "tandem mirror," which uses two mirror fields to seal the ends of a long cylindrical plasma chamber. This approach is so promising that it now counts as a mainline concept in its own right—another irony because, if the tandem mirror fulfills that promise, it will owe a lot to those same EBT microwave tubes: researchers hope to use them to generate a "thermal barrier" in the plasma to control the remaining leaks in the end plugs. And, like EBT, a tandem reactor would also operate in a steady state and its central cylinder could easily be made in removable segments.

EBT's position has been further undermined since 1978 by the emergence of several other attractive alternative concepts. One is the Stellarator, actually a very old steady-state toroidal confinement scheme abandoned in the late 1960's with the advent of the tokamak. But by heating the plasma with neutral beam injection—a method unavailable in the 1960's—researchers at the Max Planck Institute for Plasma Physics in Garching, West Germany, have pushed their Stellarator temperatures and confinement parameters to within striking distance of the tokamak, and other teams in Europe, Japan, the Soviet Union, and the United States are gearing up to follow suit. Says Furth, "my hope is that from somewhere in the tokamak-Stellarator continuum there will emerge a steady-state toroidal reactor."

Another new concept is the Reversed Field Pinch, now being tested at the ZT-40 reactor at Los Alamos. The concept resembles a tokamak in that it is toroidal and operates in pulses. The power density is very high, however, which means that a Reversed Field Pinch power reactor could be made cheaper and more compact than either a tokamak or a tandem mirror reactor.

Finally, there is a group of concepts known as the compact toroids, now undergoing preliminary testing at a number of laboratories. If they work out, these devices would offer both high-power density and simplicity of design: they could eliminate the coil running through the hole of the tokamak donut.

Given the changes in the situation since 1978, then, the fate of EBT-P was perhaps the most sensitive issue that MFAC faced. No one suggested eliminating the EBT program itself. But many thought it would be better to refocus all the alternative efforts on questions of plasma physics, rather than trying to push one alternate to the point of being a viable reactor. In other words, does the DOE still need to be forcing a hothouse plant?

"It was my sense of the committee that the answer was 'No'," says John F. Clarke, head of the DOE's Office of Fusion Energy. (After heated debate, MFAC chairman Ronald C. Davidson of the Massachusetts Institute of Technology deferred final recommendations until the committee's official report at the end of the year.) "The committee's most fundamental point was that we've already adopted most of the benefits offered by the alternatives: we forced the mainlines into adaptive modes. So don't kill the alternatives. But don't ravage the mainlines to force something beyond its natural pace."

Within the DOE itself, he adds, magnetic fusion has been given a "generous and fair" budget for fiscal 1984. But, of course, the final budget levels and the fate of the various fusion alternates will only be determined by negotiations this fall with the White House.

—M. MITCHELL WALDROP