dence of efficacy against the guinea pig hepatomas, but have been less successful against mouse mammary tumors. Goldberg argues, though, that the mouse is not a good model for assessing immune responses and he is looking for other animal models. Meanwhile, he and Cantrell are refining their results with polymer-bound drugs, and Ohanian is working with Jurgen Bier of Frei Universitat in Berlin, West Germany, to obtain a better understanding of how intratumor therapy works in both guinea pigs and mice.

Despite these preliminary successes, it may be quite some time before the technique is used to any significant extent in humans. Both surgery and radiation are effective therapies for solid tumors, and the use of a new therapy would provide an ethical dilemma for physicians. Goldberg suggests that one way to avoid this problem would be to inject the tumor with drug prior to surgery to provoke an immune reaction, and then to remove the tumor perhaps a week or two later. Goldberg and Cantrell have recently shown that this is one of the most effective treatments in guinea pigs. Even this approach, however, might present difficulties when applied to humans since most surgeons prefer to remove a tumor as soon as it is diagnosed and are reluctant to manipulate it in any way for fear of dislodging cells that might produce metastasis. To meet this situation, Goldberg suggests, the surgeon might coat the interior of the cavity with a chemotherapeutic agent after the tumor is removed to attempt to kill any residual cells. Such "intracavity" therapy may only be feasible with the polymer-bound drugs, since Ohanian has already shown in animals that it is not successful when the free drug is used.—THOMAS H. MAUGH II

Magnetic Fusion in Flux

Technical maturity and a federal law mandate a new emphasis on fusion engineering; industry ponders its role

There is a growing consensus within the magnetic fusion research community that advances in plasma physics are no longer enough, that it is time to get to work on the practical engineering problems of designing a working fusion power plant. This perception has been solidified into law as the Magnetic Fusion Engineering Act of 1980, and it was the inspiration for a recent conference on industry's involvement in fusion, sponsored by the Atomic Industrial Forum (AIF).*

"Scientific feasibility is at hand," declared one session chairman, Sidney H. Law, director of research at the Northeast Utilities Service Co. and chairman of the AIF committee on fusion. Major research programs are under way in the United States, the Soviet Union, Europe, and—a recent strong contender—Japan. Each nation is constructing an advanced, toroidal tokamak device; within the next few years one of these machines should achieve scientific breakeven, generating as much fusion energy as was required to start the reaction. Meanwhile other devices, such as the linear magnetic mirror machines, are emerging as attractive alternatives to the tokamak.

Industry's involvement in all this stems from the ever-increasing size and complexity of the experimental reactors, said Frank Graham, special projects manager for the AIF and an organizer of the conference. Contractors and consultants from the private sector will become more and more important because of their experience in managing large-scale engineering projects.

Not surprisingly, a glance at the nametags of the 130 conference participants showed affiliations such as Exxon, General Atomic, Battelle, and Electric Power Research Institute, organizations that are already leaders in the fission power industry. If fusion research continues to go well, many of these companies will be selling fusion power equipment in a few decades. And the lessons to be learned from the fission experience were much on everyone's mind.

Make sure that the research results in a power plant that utilities will want to buy, said Howard R. Drew of Texas Utilities Services, Inc. That means a plant that is affordable, maintainable, and reliable.

Be sure to give plenty of thought to such issues as plant safety, radioactive waste disposal, materials availability and public acceptance, warned serveral more speakers. Do it now, while fusion power plants are still in the conceptual stage.

And don't overpromise, said AIF public information head Carl Goldstein. "Erase from your lexicons the words 'breakthrough,' 'threshold,' 'unlimited,' and 'nonpolluting.' "

The immediate incentive for greater industry interest in fusion is the federal largess promised by the Magnetic Fusion Engineering Act of 1980, the legacy of former Representative Mike McCormack of Washington State (*Science*, 24 October 1980, p. 415). The bill calls for construction of a fusion engineering device (FED) by 1990. Although all fusion reactors have their engineering aspects, FED would be the first in which the study of engineering problems would predominate over plasma physics. It would serve as a test-bed for reactor systems in a more or less realistic reactor environment, providing engineering data for constructing a demonstration power reactor by the turn of the century. A Center for Fusion Engineering would be created to manage the program, possibly from outside the Department of Energy (DOE).

According to Allan Mense, the congressional staffer who worked for McCormack on the bill, the billion-dollar fusion engineering program enjoys wide support in the DOE, in Congress, and even in David Stockman's Office of Management and Budget (OMB). The Reagan Administration's recently revised budget gives it essentially no money, however. For once this had little to do with Reaganomic frugality: OMB actually offered more money for fusion energy than the DOE was willing to accept—at least not while its other energy programs were being cut back drastically.

Thus, the fusion engineering schedule has been delayed at least a year. The DOE's director of fusion energy research, Edwin E. Kintner, without ever quite saying so, appealed to industry for lobbying support as planning starts on

*Industry's Role in the Development of Fusion Power, 3 to 6 May, New York.

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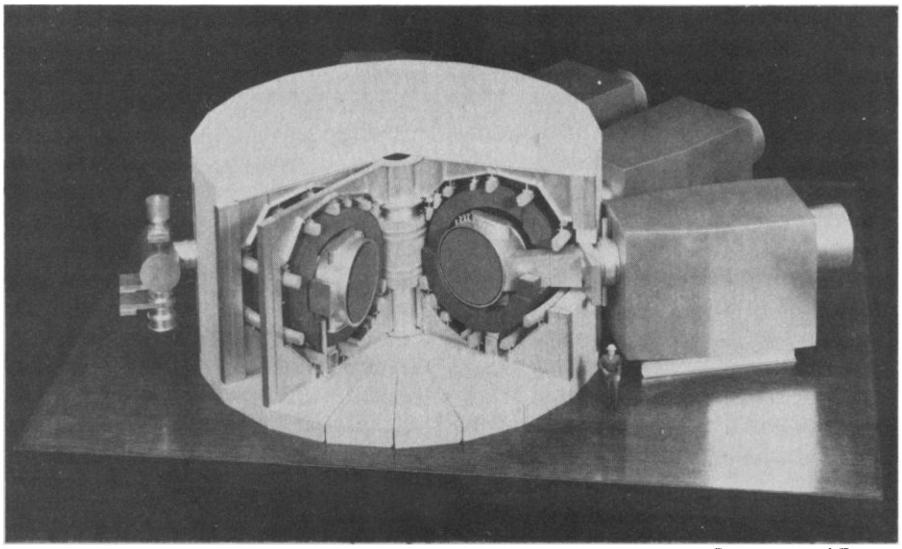

Cutaway model of the Tokamak Fusion Test Reactor (TFTR) Department of Energy

The reactor is scheduled to begin operating in late 1981 at Princeton Plasma Physics Laboratory. The human figure gives scale. The large boxes to the right inject neutral atomic beams into the torus to heat the plasma.

the fiscal 1983 budget request. "The decision, yes or no, on whether or not to proceed with engineering development will have to be made over the next 6 months," he warned.

Meanwhile, under the assumption that the support is there, and that money will also be there in future years, conceptual studies for the fusion engineering device continue apace. The current thinking was reviewed for the conference by John R. Gilleland of General Atomic Co., who heads the FED design team.

In simplest terms, a fusion reaction unites two heavy isotopes of hydrogen, deuterium and tritium, to form helium-4 plus two neutrons. Tritium, with its 12-year half-life, does not exist in nature. So a way has to be found of regenerating what is burned. The universal assumption is that the plasma of a working reactor would somehow be surrounded by a blanket of lithium. The lithium nuclei would absorb the fusion neutrons, convert to tritium, and thereby close the cycle.

A major goal of the FED, says Gilleland, will be to demonstrate this tritium fuel cycle in a practical setting. How is the tritium to be extracted from molten lithium? Can the gaseous, radioactive tritium be handled without leaks and mishaps? The neutron flux from the fusion reaction will make the walls of the reactor radioactive; will it be possible to do adequate repair and maintenance by remote control?

"There are too many paper studies in this field," he told *Science*. "We need to get burned now, early, and find out what the real problems are instead of fretting about ghosts."

There is a certain danger that the FED will prematurely lock in one type of technology. But few at the conference seemed to feel this was very likely. The FED will use the doughnut-shaped tokamak design because this approach is more fully developed than any other, said Gilleland. But the technologies that will be tested in the system—tritium handling, lithium blanket operation, remote maintenance, superconducting magnets, and the like—are generic to all approaches. They would be equally applicable to magnetic mirror machines or even to inertial confinement fusion, should either prove better for a working reactor.

Because FED will not attempt to break new ground in physics, there is nothing fundamentally innovative in its design, says Gilleland. It is basically a scale-up of the Tokamak Fusion Test Reactor (TFTR) now nearing completion in Princeton. As currently conceived, FED will produce about 180 megawatts, compared to a maximum of 40 megawatts at the TFTR. Expressed another way, the power output of the FED plasma will be five to ten times the power input; the same ratio for the TFTR, the so-called Q value, will be about 2. FED will also be able to contain its plasma for about 100 seconds, compared to only about 1 second for TFTR.

There was also some concern expressed at the conference that the FED project might stall U.S. participation in a major cooperative project: the International Tokamak Reactor (INTOR). INTOR has been planned as the single major fusion device between the coming generation of tokamaks—TFTR in the United States, the Joint European Torus in Great Britain, the JT-60 in Japan, and the T-15 in the Soviet Union—and the first demonstration power plant. The plans have been evolving since 1979, with representatives of each of the four major national programs (counting Europe as a single nation) meeting regularly at the headquarters of the International Atomic Energy Agency in Vienna. (Because that agency is part of the United Nations, the INTOR project is one of the few channels in this post-Afghanistan world through which American and Soviet fusion scientists still communicate with their once-customary freedom.)

As described by the U.S. representative, Weston M. Stacey of the Georgia Institute of Technology, INTOR would be a far more ambitious device than the American FED. "The basic goal of FED is to put everything together and see if it works," he said. "INTOR will do that, *plus* it will achieve ignition, *plus* it will generate the kind of neutron flux that will really test reactor materials and components." FED would cost about $1 billion, he adds. INTOR would cost about $3 billion—split four ways.

In the aftermath of the McCormack bill, however, the question is whether INTOR will ever be built. Although the FED would not necessarily preclude U.S. participation in INTOR, it would not make it any easier to get the required funds out of Congress. It might also dilute the enthusiasm of the other three partners.

The four participants in INTOR have probably always had in the back of their minds that they might want to go it alone, Melvin B. Gottlieb, emeritus director of Princeton University's Plasma Physics Laboratory, believes. Quite aside from the prospect of coping with the politics of four separate institutions, there has been a fear that the disparate languages would make the INTOR project something of a Tower of Babel.

The United States, with FED, was simply the first to go public with the go-it-alone approach, he said. Now the Europeans are talking about something called the Next European Torus, and the Japanese are having similar thoughts. "The cooperative picture is very much in flux," he said.

On the other hand, INTOR has brought together the best people from each of the four programs on a regular basis. It has given them a chance to bounce ideas off each other, and poke holes in the other side's designs. "Even if INTOR is never built, it's been a very, very valuable exercise," says Gottlieb.

—M. MITCHELL WALDROP