ers must be totally committed to statistically sound experiments. It also probably marks the end of experiments lacking a reasonably sound investigation of physical processes. Some other weather modification experiments appear to have achieved limited success by paying close attention to these lessons. A future story will investigate the results of these experiments and the prospects for practical weather modification.

—RICHARD A. KERR

Additional Reading

1. *The Management of Weather Resources*, vol. 2, *The Role of Statistics in Weather Resources Management* (Department of Commerce, Washington, D.C., 1978).
2. W. L. Woodley *et al.*, *J. Appl. Meteorol.* **21**, 139 (1982).
3. ——, *Bull. Am. Meteorol. Soc.* **63**, 273 (1982).

Slower Magnetic Fusion Pace Set

DOE drops its next big machine and establishes a Magnetic Fusion Advisory Committee to tell it how to progress to fusion power on a constant budget

It seemed to be too good to be true, and it was. In September 1980, Congress passed by unanimous voice vote the Magnetic Fusion Energy Engineering Act that called for the demonstration of an electricity-producing fusion reactor by the turn of the century. To spend the $20 billion that the act foresaw as necessary to achieve this goal, the Department of Energy (DOE) would have to more than double its annual expenditures on magnetic fusion, then at $394 million.

But the bill neither authorized nor appropriated a penny for this purpose, and the magnetic fusion budget likely to be adopted for fiscal 1983 is $444 million, which is $10 million below this year's figure. Administration spokesmen have repeatedly said that level spending should be the optimistic expectation for a number of years. DOE's former fusion chief, Edwin Kintner, resigned in protest last November. The latest casualty is the Fusion Engineering Device (FED). DOE has begun circulating within the fusion community a draft of a fusion plan that foresees no start before 1990, at the earliest, on any big new facilities—such as the FED—of the type that must precede a demonstration reactor.

All magnetic fusion experiments up to now have been—and those in the soon-to-be-completed Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory will be—investigations of the physics of plasmas and of how to bring plasma temperatures and densities up to those required in a working fusion reactor. The FED was to be the first machine aimed at collecting data on the numerous systems other than the plasma itself needed in a power-producing device. The data would contribute to the design of the demonstration reactor. The fusion energy act mandates that an FED be running by 1990 at the latest. A panel of DOE's Energy Research Advisory Board agreed that the time was right to move fusion into an engineering development phase and set $1 billion as a reasonable cost for such a machine, a finding that the board as a whole endorsed in August 1980.

But this year in late May, Alvin Trivelpiece, DOE's director of energy research, established a Magnetic Fusion Advisory Committee and hastily summoned the group to a 1 June meeting. Given the current budget situation, Trivelpiece explained to attendees of a recent "Industry-Government Seminar on Fusion Energy Development"* "the idea that we will be able to proceed immediately with the FED is a little bit hard to imagine." So, one charge to the new committee is to see "to what extent we can fulfill or satisfy some aspects of the intent of the magnetic fusion act using the equipment we now have."

Also in late May at a controversy-filled meeting with fusion scientists, officials from DOE's Office of Magnetic Fusion expressed a desire to abandon the FED. DOE's new strategy is contained in a document, now in draft form and circulating for comment, that will be part of a congressionally mandated plan for the development of fusion energy. Somewhere around 1992 will commence "the design, construction, and operation of the first fusion power-generating device, the engineering test reactor (ETR). The ETR will include elements of both the FED and [the demonstration reactor] from the previous strategy."

The turnaround is a bit surprising because as late as this April, DOE's current fusion chief, John Clarke, explained at a meeting of the American Physical Society that the department had great hopes of trimming the cost of the FED, thereby making it affordable. Nonetheless, a slower fusion program was all but inevitable.

*Industry-Government Seminar on Fusion Energy Development, sponsored by Atomic Industrial Forum, Electric Power Research Institute, and Fusion Power Associates, Washington, D.C., 22 June 1982.

When the Reagan Administration took office in January 1981, it made no bones about saying that its first objective was to reduce federal spending and slashed $46 million from former President Carter's fiscal 1982 fusion budget, which itself was well below the goal set by the fusion energy act. In July 1981, Secretary of Energy James Edwards wrote, "We have established that it is premature to establish fully the national magnetic fusion engineering center at this time." The center was the organization that was to build and operate the FED, among other things. Finally, in a November 1981 report, the Energy Research Advisory Board that had earlier endorsed a faster paced, engineering-oriented fusion program concluded that "a stretch-out of the program is possible if budgetary pressures demanded it."

The Administration's current view of magnetic fusion was presented at the industry-government seminar by John Marcum, an assistant director in the Office of Science and Technology Policy. Marcum discussed three points: the need for fusion, its technical progress, and budget prospects.

With regard to the need for fusion, Marcum observed that last year the United States produced almost 90 percent of the energy that it consumed. Moreover, he said, there are 50 years of exploitable oil and natural gas, 400 years of untapped coal reserves, and up to several thousand years of uranium if the breeder reactor works out. "The need or demand for fusion is clearly not a pressing need, not an urgent matter."

On the technical side, Marcum surprised much of the audience with the assertion that progress had slowed in the past 2 years. He referred specifically to scaling that was not as good as expected, presumably alluding to experiments on the Alcator C tokamak at the Massachusetts Institute of Technology and on the ISX-B, also a tokamak, at the Oak Ridge

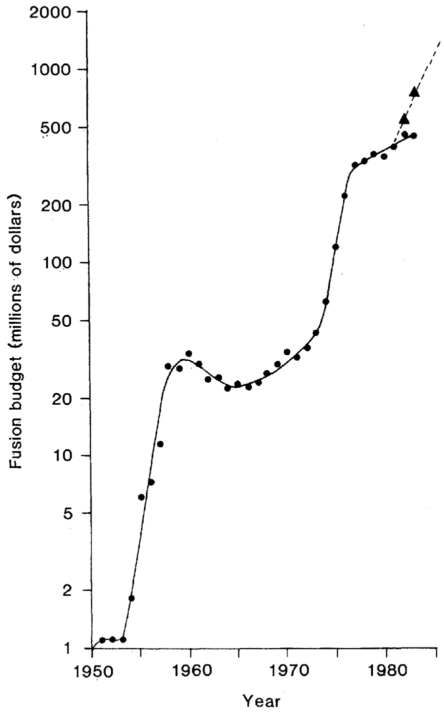
National Laboratory. Scaling laws are used to design future, larger machines and to predict their properties. If scaling breaks down before reactor-sized plasmas are achieved, then the laws become unreliable guides.

The problem at MIT was a lower than expected value for the product of the density and the confinement time, but the most recent experiments there suggest there is a way around the difficulty by increasing the electric current in the plasma. There is a lower limit to this product, called the Lawson number (after the British physicist J. D. Lawson), below which fusion does not occur significantly. Tokamaks are the doughnut-shaped machines that are currently the most advanced toward the goal of "scientific breakeven"—expected to be reached in the TFTR—in which the energy coming out of the plasma in the form of high-speed neutrons is as great as the energy injected into it.

Whether tokamaks are candidates for commercial machines is fiercely disputed. At Oak Ridge, for example, the pressure of the plasma (expressed as a percentage β of the magnetic field pressure) seemed to hit an upper limit of 2.5 percent, whereas a value in excess of 5 percent is usually cited as necessary for an economic tokamak fusion reactor. The parameter β is a measure of how efficiently the magnetic field confines the plasma. A machine with a small β, if it is to achieve the same power output as a reactor with a high β, must be physically larger, hence more expensive and less attractive.

All in all, concluded Marcum, "a great deal of basic research remains to be done," and he doubted that anyone in the audience would live to see a significant impact on electrical power generation by magnetic fusion because the technology of fusion was considerably more difficult than that of either the Manhattan or Apollo projects.

As for fusion budgets, Marcum agreed with an earlier speaker that "budgets are unlikely to be increasing in the next few years." Moreover, "it is quite remarkable in this time of economic austerity . . . that we have been able to continue funding fusion at its current level, nearly half a billion dollars." The big question is, is it realistic to expect to continue receiving this amount for the 70 years until fusion becomes commercial? Marcum suggested the need for the fastest possible return on the taxpayers' investment in fusion "in order to maintain the momentum of the program." One way to a shorter term payoff would be the fusion-fission hybrid in which high-energy neutrons from the fusion reaction would be used to breed fissile fuel for fission reactors. The fusion community has some fears about catching the negative public image of fission, if it were to emphasize this approach.



Magnetic fusion budget

Federal expenditures on magnetic fusion have gone through two periods of rapid growth, one in the mid-1950's before fusion's difficulty was appreciated, and one in the period following the 1973 Arab oil embargo. The dotted line reflects budgets required by the 1980 magnetic fusion energy act.

Later in the day, Ronald Davidson, who heads MIT's fusion energy program and DOE's new fusion advisory committee, took the floor to contest Marcum's assertions in the area of technical progress. He cited numerous examples of encouraging experiments. One of the most promising was at Princeton, where physicists have been able to drive electric currents in low-density plasmas in the Princeton Large Torus, a predecessor of the TFTR, by means of radio-frequency electric fields. An important goal for the future is to demonstrate similar results in high-density plasmas. The plasma current produces part of the confining magnetic field for the plasma in a tokamak. Presently, driving is by pulsed transformer induction and, hence, creates undesirable repeated thermal stresses in reactor components. But radio-frequency electric fields, which also help heat the plasma, can be applied continuously, thereby eliminating the pulsed thermal stresses.

But the issue of technical progress may be at least partially unimportant. An observer at the seminar told *Science* that in the political struggle for energy dollars, technical arguments are often selected to support decisions made from other considerations.

So, what can fusion advocates look forward to during the next several years of constant research funding? One view was presented at the seminar by Paul Reardon, who heads the TFTR project at Princeton. Reardon recounted fusion's "three feasibilities": scientific feasibility, to be achieved by his machine in the mid-1980's; engineering feasibility; and economic feasibility. In the earlier DOE plan, the principal machine for engineering feasibility studies was the FED and for economic feasibility was the demonstration reactor.

With level budgets for the next decade, Reardon said that there would not be enough money available to address the kinds of issues FED was intended to look at—reactor systems other than the plasma itself—and still solve the remaining plasma physics problems. Reardon argued that in the latter area these problems can be solved "once and for all" by studies in the TFTR, both in its initial form and in a future upgraded version, in the Lawrence Livermore National Laboratory's mirror machine, the MFTF-B (which will be running around 1985, subject to continued funding), and a future upgrade, and in an upgraded version of the Doublet-III tokamak at the General Atomic Company in San Diego.

Nonetheless, Reardon admitted, there are more engineering issues to be resolved than plasma physics issues. Some of these, particularly plasma-related ones could be attacked in the above machines, but "we cannot do much more than this and still keep a level budget."

Former Representative Mike McCormack, who was mainly responsible for the magnetic fusion act, told the industry-government seminar that "I am totally confident that Congress would . . . overwhelmingly reaffirm its support for the magnetic fusion energy act of 1980, including its philosophy, goals, and funding levels." Indeed, 42 senators and representatives have sponsored a joint resolution that calls on the government to live up to the intent of the act. But seminar attendees seemed more inclined to accept the viewpoint of DOE's Trivelpiece, who said that "the economic conditions are such that, regardless of the merits of the activity, substantial new growth in fusion is unlikely" and that "we need to have an excellent case to justify the present program."

—ARTHUR L. ROBINSON