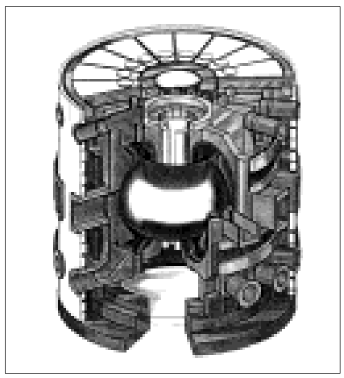
The Federal Fusion Energy Research Program 2

After more than 40 years of federally supported research into fusion energy, researchers have made substantial strides in the understanding of plasma physics and in the design and operation of controlled fusion reactions in the laboratory. Many more scientific and technical challenges remain to be overcome before fusion energy's scientific and engineering feasibility can be conclusively established. Most researchers believe that, even if current research and development (R&D) plans are fully funded and technically successful, commercial generation of electricity from fusion powerplants still remains decades away.[1] Even then, fusion's economic feasibility as a power source will be determined in large part by the availability, costs, and public acceptability of competing fossil, fission, and renewable energy technologies.

The U.S. Department of Energy (DOE) sponsors fusion research under two separate programs on magnetic fusion and inertial confinement fusion. DOE's fusion energy research programs have been heavily reviewed over the years. Most reviews have complimented the steady technical and scientific progress achieved. Over the past decade, however, several major reviews have expressed concern about the narrowing scope of the magnetic fusion energy program, the lack of support for research on alternate concepts, and the adequacy of funding to carry out even narrow program objectives on the scales and schedules proposed. Fusion's potential attractiveness as an energy source has contin-



[1] Commercial power generation has been a major goal of government fusion research almost from the beginning, however, other potential applications of fusion technology have been suggested, such as space propulsion, for example.

ued to garner political and financial support in the United States and in foreign nations, despite its uncertain future.

The Energy Policy Act of 1992 committed the nation to a five-year "broad-based" fusion energy program "that by the year 2010 will result in a technology demonstration which verifies the practicability of commercial electric power production."[2] The DOE magnetic fusion program has proposed moving forward with a major new domestic fusion experiment, the Tokamak Physics Experiment (TPX), the first new U.S. tokamak in two decades. The United States has also been engaged in an ongoing collaboration on the engineering design of the International Thermonuclear Experimental Reactor (ITER), a machine that is intended to reach the critical milestone of an ignited fusion plasma and provide an engineering test bed for reactor components needed to design a demonstration fusion powerplant. Design and construction costs for the ITER facility are currently estimated on the order of $10 billion; more precise preliminary cost projections for building and operating ITER are scheduled to be available in summer 1995. Final cost estimates will not be made until after a site has been selected. Under the current ITER agreement, there is no commitment by any of the parties to proceed beyond the engineering design activities phase. If constructed, ITER would be funded, built, and operated as an equal partnership with the Japanese, Russian, and European Community fusion programs and marks an unprecedented level of cooperation in a large science and technology project. Recently, the ITER parties have begun discussions on a possible collaboration on a fusion materials irradiation facility.

This chapter provides an overview of the federal fusion research program, its history, legislative authority, goals and organizational structure.

HISTORY OF U.S. FUSION ENERGY RESEARCH

Early Years: 1950 to 1970

U.S. research on controlled fusion for energy purposes began in 1951 as an offshoot of classified weapons-related research under the Atomic Energy Commission's Project Sherwood. Over the decade, federal dollars supporting research in fusion and the new "plasma physics" grew and research programs were established at national laboratories, universities, and several private companies.[3] Initially, fusion research was pursued with the objective of using fusion reactions to produce plutonium and tritium for nuclear weapons, but later discovery of ample domestic uranium resources eliminated this objective. However, early on, many scientists became intrigued with the prospects of fusion as a nearly inexhaustible energy source. Researchers of the time believed that harnessing fusion would not be an especially difficult challenge, requiring perhaps one or two decades to develop a fusion reactor. The key would be discovering a "magnetic bottle" that could contain the fusion reaction. During the 1950s, several magnetic confinement approaches were investigated, including mirrors, stellarators, and pinches, but, in all of them, researchers encountered instabilities in the plasmas that limited the confinement times, temperatures, and pressures. It also became more widely apparent that progress in the science of fusion plasmas and development of a commercial fusion

[2] Public Law 102-486, Oct. 24, 1992, 106 Stat. 2776, at section 2114, 106 Stat. 3073-3074 (codified as 42 U.S.C. 13474).

[3] For more on the history of the fusion program, see U.S. Congress, Office of Technology Assessment, *Starpower: The U.S. and the International Quest for Fusion Energy*, OTA-E-336 (Washington, DC: U.S. Government Printing Office, October 1987), ch. 3; and Committee on Magnetic Fusion in Energy Policy, Energy Engineering Board, Commission on Engineering and Technical Systems, National Research Council, *Pacing the U.S. Magnetic Fusion Program* (Washington, DC: National Academy Press, 1989).

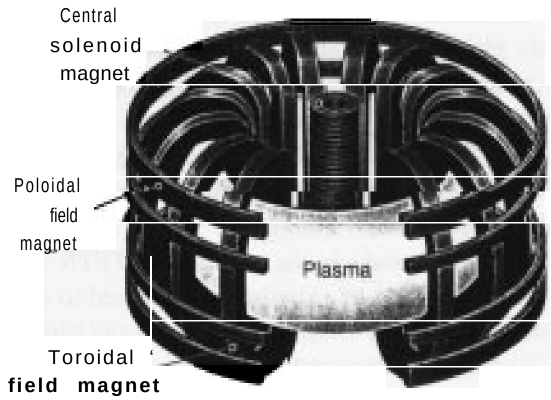
power reactor would be a long and expensive undertaking.

In 1958, the United States declassified fusion research as a result of the Second Geneva Convention on the Peaceful Uses of Atomic Energy and opened the door to international cooperation among U.S., Soviet, and European fusion researchers. Since then, international cooperation has grown from informal contacts among scientists and exchanges between research laboratories to formal collaborative agreements between government programs and to the ongoing collaboration on the design of ITER.

During the 1960s, research continued on plasma physics and ways of overcoming instabilities in the plasma to improve confinement times and densities, but progress was very slow. By the second half of the 1960s, government and private interest in fusion R&D was waning. Then, in the late 1960s, the Russians announced significant advances in confinement conditions using their tokamak concept. Conflation of the tokamak results gave renewed impetus to fusion energy research activities overall and resulted in a redirection of research efforts in the United States, Europe, and Japan. The United States converted a stellarator to tokamak configuration and built several new small tokamaks at Oak Ridge National Laboratory, Massachusetts Institute of Technology, and General Atomics in San Diego.

The 1970s: Program Expansion

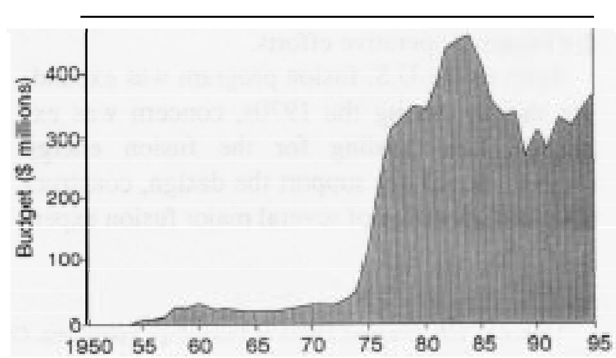
Fusion research funding expanded substantially from $34 million in 1970 to over $350 million in 1979 as shown in figure 2-1. These increases were part of the overall expansion of federal energy R&D in response to the 1973 OPEC oil embargo and reflected the optimism generated by the relative successes of the tokamaks and the belief that fusion technologies ultimately could prove more publicly acceptable on environmental and safety grounds than competing nuclear fission reactors. In the reordering of federal energy research activities in 1974, fusion energy research activities of the Atomic Energy Commission became part of the Energy Research and Development Administration, which was later absorbed into the new Department of Energy in 1977. Magnetic fusion and inertial confinement fusion energy activities remained in separate programs.



Tokamak magnets. A tokamak uses three types of magnets. Toroidal field magnets create a 'container" for the plasma, while poloidal field magnets keep the plasma centered and stable. The central solenoid magnets induce an electric current in the plasma.

The U.S. magnetic fusion program supported a broad range of research activities. The tokamak continued to be the most technically advanced of the magnetic confinement concepts and a number

FIGURE 2-1: Magnetic Fusion Program Funding, 1952-Present (in nominal dollars)



SOURCE: Office of Technology Assessment, 1995, based on historical information from the U.S. Department of Energy, and budget documents.

of small and mid-size tokamak fusion reactors were placed in operation in U.S. research laboratories and many continue operating today. Construction of a major new machine, the Tokamak Fusion Test Reactor (TFTR) was begun at the Princeton Plasma Physics Laboratory (PPPL). The TFTR remains among the largest and most advanced tokamaks in the world. The TFTR was to pursue a series of experiments planned to culminate in the early 1980s in deuterium and tritium (D-T) reactions that could approach or even reach the key fusion milestone of breakeven. At the same time, the program expanded the exploration of alternative confinement concepts as well as research into the various reactor-related component technologies and materials that would be needed for eventual commercial fusion power systems. Fusion energy research programs were supported at a number of national laboratories and universities, and the program provided support for training the majority of the plasma physicists in the United States. In 1976, design and construction began on a second major fusion experiment, the Mirror Fusion Test Facility B (MFTF-B) at Lawrence Livermore National Laboratory, that was intended to compete with the tokamak concept.

The 1970s also marked the beginning of ambitious fusion R&D programs in Japan and the European Community with commitments to construction of major new tokamak facilities and significant increases in research budgets. International collaboration among fusion researchers also expanded during this period, setting the stage for future cooperative efforts.

Even as the U.S. fusion program was expanding rapidly during the 1970s, concern was expressed that funding for the fusion energy program could not support the design, construction, and operation of several major fusion experimental machines as competitors to the tokamak, and that the focus on tokamaks was prematurely narrowing the search for an attractive commercial reactor confinement concept.[4] Although the tokamak was delivering promising results in the laboratory, questions raised about its ultimate acceptability as a design for a commercial power reactor continued to spur interest in development of alternative concepts. An outside review of the ambitious DOE fusion energy research plan in 1978 supported the redirection of the program toward development of fusion power reactor technology and endorsed the concept of a "two-horse race" between the tokamak and mirror concepts that could be expanded to include other serious contenders as they emerged.[5] A 1980 review by the DOE Energy Research Advisory Board (ERAB) recommended that the fusion program should proceed to development of a next-step engineering test reactor and called for a doubling of the magnetic fusion budget over the next seven years. These recommendations were subsequently embodied in the Magnetic Fusion Energy Engineering Act of 1980.[6]

The 1980s: Technical Progress and Declining Budgets

In the 1980s, the sense of urgency generated by the 1970s "energy crisis," which had pushed the program to develop a fusion demonstration powerplant, rapidly abated, and funding began to decline. Policy shifts and growing budgetary pressures contributed to a de-emphasis on research on alternative concepts and the cancellation, mothballing, or shut-down of a number of major experimental facilities. Throughout the 1980s, the magnetic fusion program underwent a series of management reviews and redirections as budgets

[4] See, e.g., U.S. Congress, Office of Technology Assessment, *Comparative Analysis of the 1976 ERDA Plan and Program,* OTA-E-28 (Washington, DC: U.S. Government Printing Office, May 1976), pp. 98-102; and reports cited in Committee on Magnetic Fusion in Energy Policy, op. cit., footnote 3, pp. 18-39.

[5] Committee on Magnetic Fusion in Energy Policy, op. cit., footnote 3, citing U.S. Department of Energy, Review Committee on the Magnetic Fusion Energy Program, "Final Report," DOE/ER-0008, June 1978.

[6] For a discussion of this act, see the next section of this chapter.

continued to decline in real terms. As a result, the program began to be increasingly focused on gaining approval and funding for an advanced tokamak successor to the TFTR and for its involvement in an international collaboration to build an ignition tokamak. That focus continues today.

The Reagan Administration held markedly different views of the appropriate role of federal energy R&D activities than did its predecessors, and sharply reduced the budgets of many energy research programs. However, because it was undeniably targeted at high-risk, long-term research, the magnetic fusion program fit more closely with the new administration's priorities than fossil, renewable, and energy-efficiency research projects that were focused on nearer term commercial efforts. Consequently, the fusion budgets fared better than some other programs during the Reagan years. The fusion program budget actually increased in nominal dollars to peak at $468 million in fiscal year (FY) 1984 before it began its decline. (According to an analysis by DOE using special "high energy physics" equipment and construction indices, the fusion program funding peaked in real terms in 1977 and thereafter failed to keep progress with inflation. By 1988 the magnetic fusion program funding had effectively been cut to half of what it was at its 1970s peak).

DOE's 1983 Comprehensive Program Management Plan (CPMP) for the fusion program (required by the Magnetic Fusion Energy Engineering Act of 1980—MFEEA) reflected the Reagan policies and explicitly ruled out a government-built demonstration reactor. The CPMP defined the mission of the fusion program as supporting research that would allow selection of a confinement concept for further development by the private sector and to allow a decision to build an engineering test reactor by 2000.

The CPMP was strongly criticized by the fusion technical advisory committee of ERAB in its first triennial review of the fusion program required under MFEEA. The panel concluded that program budgets would not allow the CPMP goals to be met, and that the proposed schedule would force a premature choice between the competing mirror and tokamaks concepts, and could delay progress on tokamak advances. Moreover, it called for construction of an engineering test reactor (ETR) before necessary technology would be available. The panel recommended a redirection of the program to delay construction of an ETR, allow construction of a tokamak successor to TFTR to study ignition and burning plasma physics issues, and to maintain a strong innovative program in plasma physics, technology development, and alternate confinement concepts.[7]

In 1985, responding to these criticisms and others, DOE issued a revised Magnetic Fusion Program Plan (MFPP) that states that "the goal of the magnetic fusion program is to establish the scientific and technological base required for fusion energy."[8] This goal has remained the central mission of the fusion program ever since. The MFPP reduced the emphasis on reactor development that had characterized the 1983 plan and concentrated on the science and engineering requirements. It laid out several key technical issues to be resolved by the fusion energy program, recommended construction of a compact ignition tokamak (CIT) to explore the physics of ignited plasmas, and established a goal of international collaboration rather than international leadership. Like the CPMP, it too, precluded government construction of a demonstration reactor. ERAB's second triennial review of the fusion energy program endorsed the direction and strategy in the 1985 plan. The panel raised concerns over the potential impacts

[7] Technical Panel on Magnetic Fusion of the Energy Research Advisory Board, *Magnetic Fusion Energy Research and Development*, final report, DOE/S-0026 (Washington, DC: January 1984).

[8] U.S. Department of Energy, Office of Energy Research, *Magnetic Fusion Energy Program Plan*, DOE/ER-0214 (Washington, DC: February 1985), executive summary.

on the program of proceeding to construct the CIT under constrained budgets and recommended that the CIT be funded as an increment to the MFE budget.

By 1986, budget constraints were already taking their toll on the breadth of the fusion program leading to project cancellations and cutbacks (see figure 2-2). The huge $330-million tandem mirror experiment at Lawrence Livermore National Laboratory, the MFTF-B, was mothballed almost immediately after its completion in 1986 without ever operating as a fusion facility. DOE determined that it could not operate both the MFTF-B and its competitor, the TFTR at Princeton, with available funds.[9] Earlier, DOE canceled the Fusion Materials Irradiation Test Facility at Hanford, Washington, which was to support advanced materials development. Funding constraints also led DOE to defer the start of the critical D-T experiments in the TFTR. In 1987, construction was completed on the Advanced Toroidal Facility (ATF) at Oak Ridge National Laboratory, then the world's largest stellarator, but funding problems limited the extent of its experimental operations from the start. Work was allowed to continue on construction of a smaller, and less-expensive, reversed field pinch device at Los Alamos National Laboratory.

During the 1980s, international collaboration efforts grew as DOE pursued the negotiation of an international initiative for the joint design, construction, and operation of an engineering test reactor as equal partners with the Japanese, Soviet, and European Community fusion programs. The ITER effort began as a result of discussions between President Reagan and Soviet Leader Gorbachev at the 1985 Geneva summit. An agreement to work jointly on a conceptual design for ITER was concluded in 1988 among the four governments.[10]

OTA's 1987 report, *Starpower: The U.S. and the International Quest for Fusion Energy,*[11] examined the magnetic fusion program and noted the substantial progress that had been made in the scientific and technical challenges of proving the feasibility of fusion power. *Starpower* found that most researchers expected that at least three decades of additional R&D would be required before a prototype commercial fusion reactor could be demonstrated. Meeting even this schedule, however, would require a substantial increase in U.S. fusion research budgets or a dramatic expansion of international collaboration in fusion research. The OTA report emphasized that important scientific uncertainties and technological challenges remained to be resolved before fusion's commercial potential could be assessed. The report further cautioned that it was still too early in the research program to determine which confinement concept would be most likely to form the basis of an attractive commercial fusion reactor, and whether once developed, fusion reactors would be economically competitive with other energy sources. These conclusions still hold today, especially as the increased funding required to pursue scientific and technical issues have not received a high priority in an era of tight federal budgets.

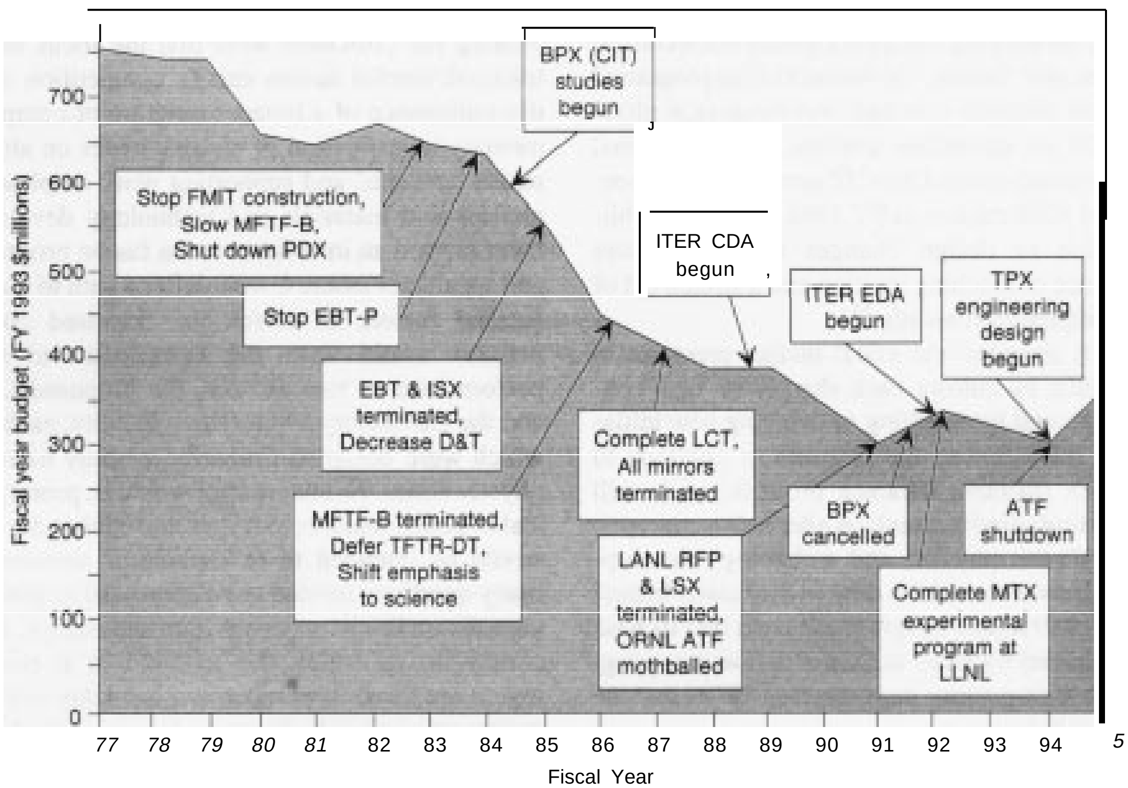
The impacts of funding constraints on the fusion program did not escape the attention of congressional committees. During the FY 1988 appropriations process, Congress directed DOE to submit a five-year flat budget plan that detailed how the program would support D-T experiments on the TFTR, construction of the proposed CIT, and participation in ITER conceptual design acti-

[9] At the time, there were concerns about the potential technical performance of MFTF-B because of the difficulties encountered by smaller mirror experiments in meeting their performance targets. However, budget constraints seemed to have been the decisive factor in sealing the fate of the MFTF-B.

[10] For more on ITER, see box 1-1 in ch. 1 of this report.

[11] Office of Technology Assessment, op. cit., footnote 3.

FIGURE 2-2: U.S. Magnetic Fusion Budget and Project History, Fiscal Years 1977-94
(FY 1993 dollars in millions)



KEY:

BPX/CIT=Buming Plasma Experiment/Compact Ignition Tokamak
DT=Deuterium-Tritium
EBT=Elmo Bumpy Torus
EBT-P=Elmo Bumpy Torus-P
FMIT=Fusion Materials Irradiation Test Facility
ISX=Impurity Studies Experiment (a tokamak)
ITER CDA=International Thermonuclear Experimental Reactor Conceptual Design Activities
ITER EDA=International Thermonuclear Experimental Reactor Engineering Design Activities
LANL RFP=Los Alamos National Laboratory Reverse Field Pinch
LCT=Large Coil Test Facility (superconducting magnets)
LLNL=Lawrence Livermore National Laboratory
LSX=Large S Experiment (afield-reversed compact toroid device)
MFTF-B=Mirror Fusion Test Facility-B
MIX= Microwave Tokamak Experiment
ORNLATF=Oak Ridge National Laboratory Advanced Toroidal Facility (a stellarator)
PDX=Princeton Divertor Experiment
TFTR=Tokamak Fusion Test Reactor
TPX=Tokamak Physics Experiment

SOURCE: U.S. Department of Energy, 1994.

vities under constant dollar funding of about $360 million annually.

In testimony, DOE explained that CIT design and ITER activities were being funded by stretching out the CIT construction schedule, eliminating the mirror program for budgetary not technical reasons, and "taxing" the balance of the programs' work on alternate concepts and theoretical physics.[12] In the meantime, internal reviews showed the projected costs of the CIT growing from an estimated $360 million in FY 1986 to almost $1 billion due to design changes to give greater assurance of reaching ignition and a stretch out of the completion schedule.[13]

DOE absorbed the initial budget pressures in the 1980s by cutting back sharply on new construction and mothballing or delaying new initiatives. This allowed the program to continue to fund the mainline tokamak projects, while still supporting some research on alternative concepts, basic plasma physics, and technology development. However, a sharp drop in the fusion budget in FY 1989 forced the program to cut into its base program and tokamak activities to continue progress on high-priority items such as TFTR and the ITER collaboration.

Budget pressures, a change in administrations, and internal reviews led to more program reviews and budget reductions. In 1989, DOE decided to defer the CIT as then planned while conducting a transport initiative, sponsored by taxing other projects, in an attempt to resolve the physics issue of heat loss from tokamaks.[14] Secretary Watkins also proposed a head-to-head competition between magnetic fusion (i.e., tokamaks) and inertial fusion (see figure 2-3).

These shifts were met with criticism from many in the fusion community and Congress.[15] Among the criticisms were that the focus on a tokamak/inertial fusion energy competition and discontinuance of a broader program of complementary investigation of physics issues on alternative concepts, and supporting work on plasma physics and materials and technology development created an imbalance in the fusion program and would not assure a well-defined path to commercial fusion. In effect, the proposed competition would limit the comparison to the performance of two devices, the proposed CIT and the Laboratory Microfusion Facility, each of which were designed primarily to study narrow physics issues. Neither reactor would be prototypical of power reactors to follow and neither device would be intended to or capable of answering many questions needed to be addressed in selecting a future line of approach to fusion energy. According to its critics, the competition as posed would not serve its purpose and the delay in CIT construction would idle many fusion researchers and engineers.[16]

Secretary Watkins responded by calling for another high-level review panel to recommend a new policy direction for the fusion energy program. The panel was also tasked with conducting the third triennial review of the magnetic fusion

[12] See testimony of James F. Decker, Acting Director, Office of Energy Research, U.S. Department of Energy, and supplemental materials, in U.S. Congress, House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Energy Research and Development, "Hearing on Fiscal Year 1989, Department of Energy Authorization (Magnetic Fusion Energy), " 100th Congress, 2d sess., Mar. 30, 1988, vol. vi , pp. 11-22, 97-98.

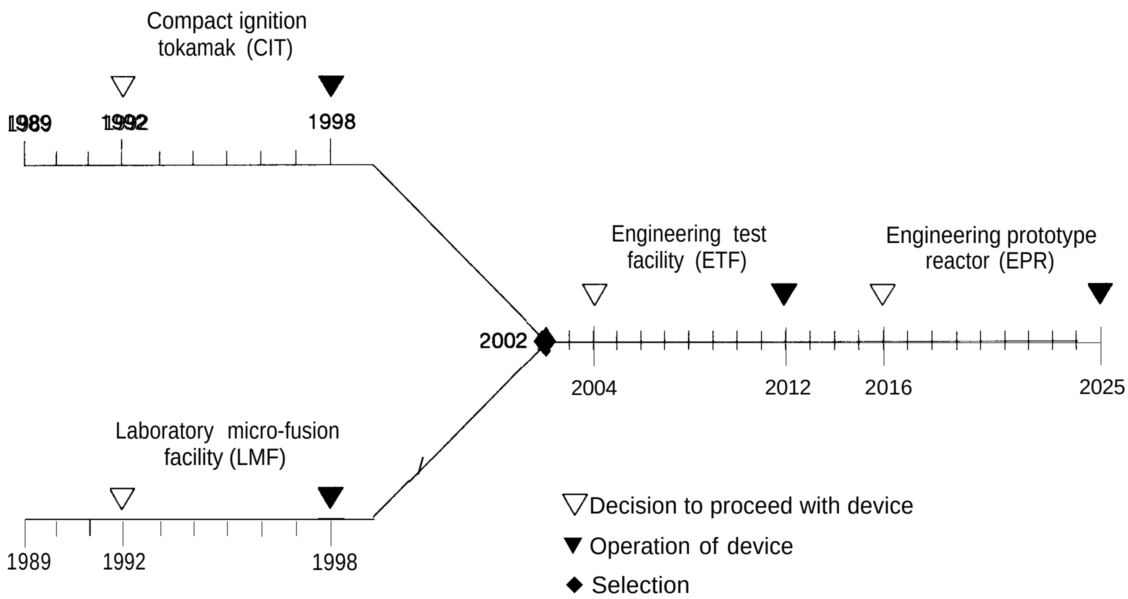
[13] David Crandall, U.S. Department of Energy, Office of Fusion Energy, personal communication, November 1994.

[14] Testimony of Robert O. Hunter, Jr., Director, Office of Energy Research, U.S. Department of Energy in U.S. Congress, House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Investigations and Oversight, "Hearings on Fusion Energy Program: Status and Direction," 101st Congress, 2d sess., Oct. 5, 1989, pp. 297-317.

[15] U.S. Congress, House of Representatives, Committee on Science, Space, and Technology, "Hearings on Fusion Energy Program: Status and Direction," 101st Congress, 2d sess., Oct. 5, 1989.

[16] Statement of Senator Frank Lautenberg, in debate on the FY 1990 Energy and Water Appropriations Bill, *Congressional Record* (daily ed.), S8947, July 27, 1989.

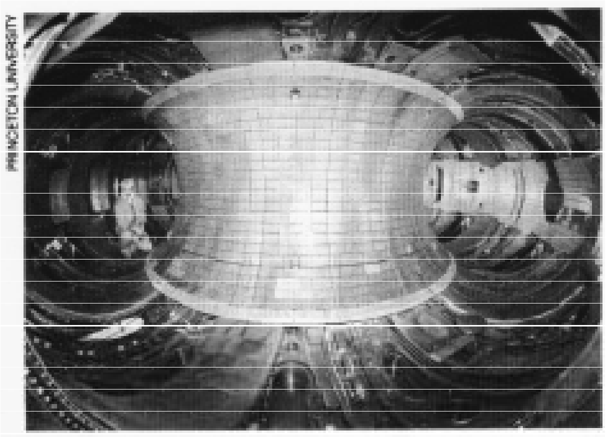
FIGURE 2-3: Proposed Fusion Development Plan Showing Head-to-Head Competition Between Magnetic Confinement (Tokamak) and Inertial Confinement Concepts, Circa 1989



SOURCE: Testimony of Robert O. Hunter, Jr., Director, Office of Energy Research, US. Department of Energy, Attachment, in US Congress, House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Investigations and Oversight, "Hearings on Fusion Energy Program. Status and Direction, " 101st Congress, 2d sess., Oct. 5, 1989, p. 335.

program required under the 1980 Act. The Fusion Policy Advisory Committee (FPAC) reported back in September 1990 supporting a "responsible, goal-oriented fusion energy development program" directed at achieving the goals of "at least one operating Demonstration Power Plant by 2025 and at least one operating Commercial Power Plant by 2040."[17] The committee expressed its belief that the U.S. fusion energy program was "technically ready" to construct devices to demonstrate significant fusion power production in a burning tokamak plasma and ignition in an inertially confined pellet. The committee noted that attaining its conceptual goals would require an immediate ramp up in funding and, recognizing the tight budget climate, provided a number of next-step options with lower immediate effects on the fusion budget. The committee cautioned, however, that "the first funding increments for new facilities in the constrained program are essential for fusion to be an energy program. If these increments are not forthcoming, the program would remain only a research effort without rea-

[17] Letter from H. Guyford Stever, Chairman, Fusion Policy Advisory Committee to Admiral James D Watkins, Secretary Of Energy, Sept. 25, 1990, transmitting the committee report, reprinted in U.S. Department of Energy, Fusion Policy Advisory Committee (FPAC), *Report of the Technical Panel on Magnetic Fusion of the Energy Research Advisory Board, Final Report,* DOE/S-0081 (Washington, DC: September 1990), hereinafter referred to as *FPAC 1990.*



Inside the vacuum vessel of the TFTR at the Princeton Plasma Physics Laboratory Graphite and graphite composite tiles protect the inner wall of the vessel.

sonably timed energy objectives."[18] FPAC made a number of specific recommendations, including:

1. The United States should commit to fusion as a potential energy source.
2. The program should support both magnetic fusion and inertial confinement fusion as distinct and separate approaches and should plan for major new facilities in each. In recommending this strategy, the FPAC report observed: "The committee affirms its belief that the two concepts are not ready for a choice of one over the other. Pursuing both options at this time reduces technological risk."[19]
3. The United States should participate actively as an equal partner in the ITER engineering design activities (EDA) collaboration while maintaining a strong and balanced domestic program.
4. The U.S. fusion program should support "an independent program of concept improvement, including study, and where promising, development of alternative configurations that may be more suitable for commercialization," plus vigorous technology and materials development.
5. The program should increase opportunities for U.S. industry participation to allow them to take advantage of fusion technology advances, while continuing involvement of universities and national laboratories.

The committee estimated that its conceptual program would require U.S. fusion program budgets (including the defense inertial confinement fusion program) to reach about $1 billion per year in constant dollars over the period 1990 to 1997 to allow construction of essential new facilities. (Note that this estimate did not include the costs of ITER construction scheduled to begin after 1998.) Constrained budget approaches and priorities were also suggested.[20]

At its full budget level, FPAC called for the magnetic fusion energy (MFE) program to support participation in ITER EDA activities, completion of D-T experiments in the TFTR, construction of the Burning Plasma Experiment (BPX—an outgrowth of the previous CIT design), a modest increase in the base program, design of a new steady-state tokamak, and increased emphasis on low activation materials and nuclear technology. This recommendation would require an increase in the magnetic fusion budget from $316 million in FY 1990 to over $600 million in FY 1996 in 1990 dollars.

At reduced budgets, FPAC gave priority to holding the base program roughly constant, funding D-T experiments in TFTR, stretching out construction of BPX by two years, and participation in ITER. Construction of BPX/CIT was seen as making the United States a "strong and attractive partner in magnetic fusion research," achieving an important milestone intermediate between existing facilities and ITER, and re-establishing U.S. leadership in magnetic fusion. FPAC estimated that to achieve these priorities the budget would have to increase to about $470 million (1990 dollars) by FY 1996.

[18] Ibid.

[19] *FPAC 1990,* p. 4.

[20] Ibid., p. 5.

FPAC recognized that inertial confinement fusion (ICF) would need to remain primarily a defense program and supported as its highest priority mission, the study of target physics leading to the demonstration of pellet ignition. FPAC noted that ongoing ICF work on target physics and drivers will be beneficial for advances in inertial fusion energy (IFE). To provide more effective support for the goal of developing IFE technology, FPAC recommended that an IFE program be integrated into the Office of Fusion Energy as a separate division. The new IFE program would concentrate on efforts that would be complementary to the ICF activities—e.g., developing an efficient and low-cost driver with repetition rates of several pulses per second,[21] concurrent work on materials and reactor designs, and investigation of environment, health, safety, waste disposal, and decommissioning matters related to an IFE powerplant.

FPAC endorsed a suggestion by a separate National Academy of Sciences (NAS) Panel that DOE develop the heavy-ion Induction Linac System Experiments (ILSE) within the IFE program and a glass laser facility in the defense program as intermediate steps before proceeding with a proposed Laboratory Microfusion Facility.[22] FPAC noted that unlike the situation in magnetic fusion, the U.S. program remained the world leader in ICF offering potential opportunities to capitalize on that position if IFE proves commercial.

FPAC offered several budget priorities for ICF programs including upgrades to the Nova laser at Lawrence Livermore National Laboratory and to other existing laser facilities and continued work on target physics at an increment of about $44 million over FY 1990 ICF budgets by FY 1991. Additional priorities, if funding were available, would be to support IFE development work on heavy-ion drivers, light-ion drivers, and krypton-fluoride lasers. This would increase the FY 1996 budget by an additional $34 million to $64 million over FY 1990 levels. FPAC estimated that support of IFE base program activities and construction of ILSE would require about $90 million over five years.[23]

As for the general management of the DOE fusion program, FPAC recommended that fusion R&D activities be conducted in a disciplined goal-oriented manner with detailed development strategies, appropriate milestones, key decision points, and “down-selection” among competing options following adequate technical evaluations on a path to achieve a demonstration of one or more fusion powerplants by 2025. The magnetic fusion path would include ITER, a burning plasma facility and support of alternate concepts, concept improvement, and materials and technology development. FPAC also recommended that the IFE program build on advances in target physics under the defense programs while investigating several competing driver technologies, including heavy-ion drivers. An early decision would be made to pursue either a light-ion or krypton-fluoride laser alternative driver based on technical performance. At each major step, the program should be subject to rigorous feasibility and cost analysis by a qualified external group prior to approval. While recognizing that the national laboratories would continue to have responsibility for new facilities, FPAC recommended that the labs develop more effective mechanisms to work cooperatively and share responsibility while providing opportunities for more university, industry, and interna-

[21] There are several technologies under consideration as possible drivers for IFE power production including heavy-ion drivers, light-ion drivers, and krypton-fluoride lasers. Research on light ions and krypton-fluoride lasers is supported by the ICF program because of defense-related applications and experience there could be transferred to energy applications in the future. The National Academy of Sciences has remarked favorably on the potential use of heavy-ion accelerators as IFE drivers and encouraged construction of a device that could be used to demonstrate and experiment with the characteristics of a full-sized heavy-ion driver. ICF researchers in Europe and Japan are also exploring use of heavy-ion drivers, but are focusing instead on using radio frequency acceleration rather than the induction Linac approach. Ibid., pp. 43-47.

[22] Ibid., pp. 41-43.

[23] Ibid., p. 44.

tional collaboration in the design, construction, and operation of new facilities.

An NAS committee also released a review of the priority and pace of the magnetic fusion R&D program in 1990.[24] The NAS panel found a loss in U.S. leadership in MFE research due primarily to the halving of program funding in constant dollars since 1977, which also led to narrowing of U.S. programs. This committee concluded that current DOE program funding levels would be inadequate to meet even the near-term objectives of the 1985 MFPP. The committee estimated that funding levels would have to be increased by at least 20 percent annually over 1990 levels in the early 1990s and by an additional 25 percent in the late 1990s to allow the U.S. program to proceed with the proposed CIT experiment and to participate in ITER construction. The committee offered several interim recommendations for the magnetic fusion program:

1. U.S. participation in an international collaboration on next-step major facilities as the most cost-beneficial U.S. approach to fusion over the next decade;
2. an increase in program funding to permit construction of CIT to allow resolution of central scientific feasibility questions and participation in construction of ITER in the late 1990s; and
3. development of a revised program plan providing greater participation by U.S. companies in activities such as design and construction of major systems and subsystems.

The committee noted that these recommendations were made without consideration of competing demands for resources from other energy technologies or national programs. The NAS panel commented on the absence of any comprehensive comparative assessment of the energy, environmental, health, safety, economic, and institutional aspects of various competing alternative future energy technologies on which to base informed choices for overall U.S. energy research priorities.

The 1990s: Growing Internationalization and Tough Budget Choices

Secretary Watkins adopted the FPAC findings "subject to existing budget constraints." But the funding increases recommended by FPAC and the NAS panel did not win support within DOE or in Congress. Indeed, fusion budgets continued to diminish. Budget cuts driven by deficit reduction and reprogramming took the MFE program from $316.7 million in FY 1990 to $273.6 million in FY 1991. According to the then-director of the Office of Energy Research:

> This translated into terminating work on alternative confinement concepts and pursuing only the tokamak concept within the magnetic fusion energy program as a precursor to a Burning Plasma Experiment (BPX) that would be integrated into a larger international fusion energy program.[25]

Even in the face of these budget cuts, the Bush Administration released its National Energy Strategy (NES), which adopted fusion energy as an important long-range element incorporating the recommendations of FPAC. The NES fusion goals were to prove fusion energy to be a technically and economically credible energy source, with an operating demonstration plant by about 2025 and an operating commercial plant by about 2040. This would be accomplished by developing both magnetic and inertial confinement approaches to fusion separately until sufficient R&D exists to make a choice, and also by achieving early industrial involvement. The NES called for continued international collaboration and cost-

[24] Committee on Magnetic Fusion in Energy Policy, op. cit., footnote 3.

[25] William Happer, "Charge to the Fusion Energy Advisory Committee," Sept. 24, 1991, reprinted as app. E in Fusion Energy Advisory Committee, *Report on Program Strategy for U.S. Magnetic Fusion Energy Program*, DOE\ER-0572T (Washington, DC: U.S. Department of Energy, Office of Energy Research, September 1992.) Hereinafter referred to as *FEAC, September 1992*.

sharing in the magnetic fusion program. The NES, however, explicitly recognized that:

> The technical complexity associated with fusion development is such that substantial investments are required for new experiments, design facilities, and test facilities. This implies the need for long-term growth in research and development funding. [26]

In September 1991, Secretary Watkins followed a Secretary of Energy Advisory Board (SEAB) Task Force recommendation that the proposed BPX project not be funded because of growing cost estimates and anticipated budget constraints. This cancellation left the U.S. fusion program potentially bereft of any large-scale fusion experimental facility after the scheduled closure of the TFTR in FY 1994. Actual funding for the magnetic fusion program in FY 1992 was $337.1 million and restored much of the funding loss in FY 1991, but funding demands to support TPX design and ITER activities resulted in a continued narrowing of the program

Once again, DOE turned to an advisory committee for assistance in setting priorities. In response to the request, the Fusion Energy Advisory Committee (FEAC) issued a series of reports[27] reviewing the physics and engineering/technology requirements for meeting the 2025 goal for a Demonstration (DEMO) reactor under four alternative future budget scenarios and indicated their recommended priorities under each.[28]

FEAC strongly concluded that:

- Reaching the goal of an operating DEMO by 2025 is the approximate target date required if fusion is to be a significant contributor to U.S. energy supply by the middle of the 21st century.
- Fusion program budgets will have to increase at least 5 percent per year in real terms over the FY 1993 total of $337.9 million with an *additional* increment for ITER construction to be plausibly consistent with the DEMO target date.
- Highest priority should be given to completion of D-T experiments in the TFTR and participation in ITER EDA under all budget scenarios.

Under its first or “reference” scenario, the panel called for an annual increase in the magnetic fusion program budget of 5 percent over inflation over the FY 1993 level of $330.7 million, or an increase to about $420 million in FY 1998 (in 1993 dollars). In addition to support for D-T experiments and participation in ITER, the panel recom-

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[26] National Energy Strategy, *Powerful Ideas for America, First Edition 1991/1992* (Washington, DC: U.S. Government Printing Office, February 1991), pp. 130-131.

[27] *FEAC, September 1992*; Fusion Energy Advisory Committee, *Advice and Recommendations to the U.S. Department of Energy in Response to the Charge Letter of September 18, 1992*, DOE/ER-0594T (Washington, DC: U.S. Department of Energy, Office of Energy Research, June 1993), hereinafter referred to as *FEAC 1993*. Fusion Energy Advisory Committee, *Advice and Recommendations to the Department of Energy in Partial Response to the Charge Letter of September 24, 1991: Part D,* DOE\ER-0555T (Washington, DC: U.S. Department of Energy, Office of Energy Research, June 1992). FEAC was established to advise the Director of the Office of Energy Research/Assistant Secretary for Energy Research.

[28] Two scenarios requested in the charge to the committee were a constant dollar budget for magnetic fusion through FY 1996 and increasing the budget at 5 percent real growth per year through FY 1996. FEAC’s report included four scenarios:

- The “SEAB Task Force Scenario”—increasing the MFE budget in FY 1994 by 5 percent in real terms over the FY 1993 request ($360 million) and annual growth at 5 percent per year in real terms thereafter;
- The FEAC “Reference Scenario”—increasing MFE funding at 5 percent in real terms above inflation starting from the appropriated FY 1993 level ($339.7 million);
- The Constant or “Flat Budget Scenario”—allowing adjustments only for inflation for fiscal years 1993-96; and
- The “Declining Budget Scenario”—in which the MFE budget is frozen at the FY 1993 level in as spent dollars and declines at the rate of inflation (assumed at 3.1 percent per year).

See *FEAC, September 1992*, pp. 1-16.

mended construction of the TPX (steady-state advanced tokamak),[29] upgrades to the General Atomics DIII-D tokamak to support TPX and ITER, and restart of the ATF stellarator. The panel also recommended modest enhancements of the fusion materials program and of the fusion development and technology base programs to support ITER activities and student training in various areas of fusion engineering, and maintaining research in applied plasma physics at least at present levels. The panel did not include any allowance for expected increases in funds needed to complete ITER EDA activities over the levels originally agreed to among the four parties in 1992. TPX construction costs were then estimated at about $500 million in FY 1989 dollars. Noting the persisting scientific uncertainties in extrapolation of the tokamak to a competitive commercial reactor despite its scientific successes to date, the committee suggested establishment and maintenance of a concept improvement program to investigate both tokamak and nontokamak confinement concepts as part of the U.S. fusion program as a matter of policy.[30]

The committee report contrasted the reference scenario with the budget levels recommended by a 1991 SEAB task force of a 5 percent annual increase above inflation over the FY 1993 budget request or an increase to $360 million in FY 1993 rising to about $460 million in FY 1998 (in 1993 dollars). SEAB had concluded that such an increase would be required to restore the program balance to a healthy base of activity. At a base of $20 million over the reference scenario priorities, FEAC recommended studying a U.S. site for ITER, enhancing the U.S. ITER EDA support activities, and enhancing activities on improved tokamaks and other concepts, fusion theory, computation, materials research, and technology development. The FEAC panel concluded that even this higher budget, while meeting recommended priorities, "would jeopardize U.S. ability to compete in hosting a site for ITER and require that base programs be held at levels lower than FEAC believes is appropriate given their importance."[31]

Under a flat budget scenario approximately $337.9 million per year in constant 1993 dollars) in FY 1993-FY 1998, adjusted for inflation, FEAC recommended proceeding with TPX on an extended construction schedule by prematurely terminating the Princeton Beta Experiment Modified (PBX-M) tokamak at the Princeton Plasma Physics Laboratory (PPPL) and delaying design of the 14 MeV neutron source.

Under the declining budget scenario, the annual program budget would remain at $337 million in 1993 dollars unadjusted for inflation over five years. FEAC concluded that TPX could not be built, nor could design of the 14 MeV neutron source materials test facility begin until after FY 1997. Planned upgrades of existing facilities to support ITER would have to be stretched out. With shutdown of TFTR, the U.S. program would be faced with the loss of critical personnel and PPPL's position as a world leader in experimental confinement physics research would be threatened. According to FEAC, the primary consequences of such a strategy would be to severely undermine the U.S. fusion program and its ability to participate effectively in ITER. It is unlikely under this scenario that the United States could participate in ITER construction and operation.[32]

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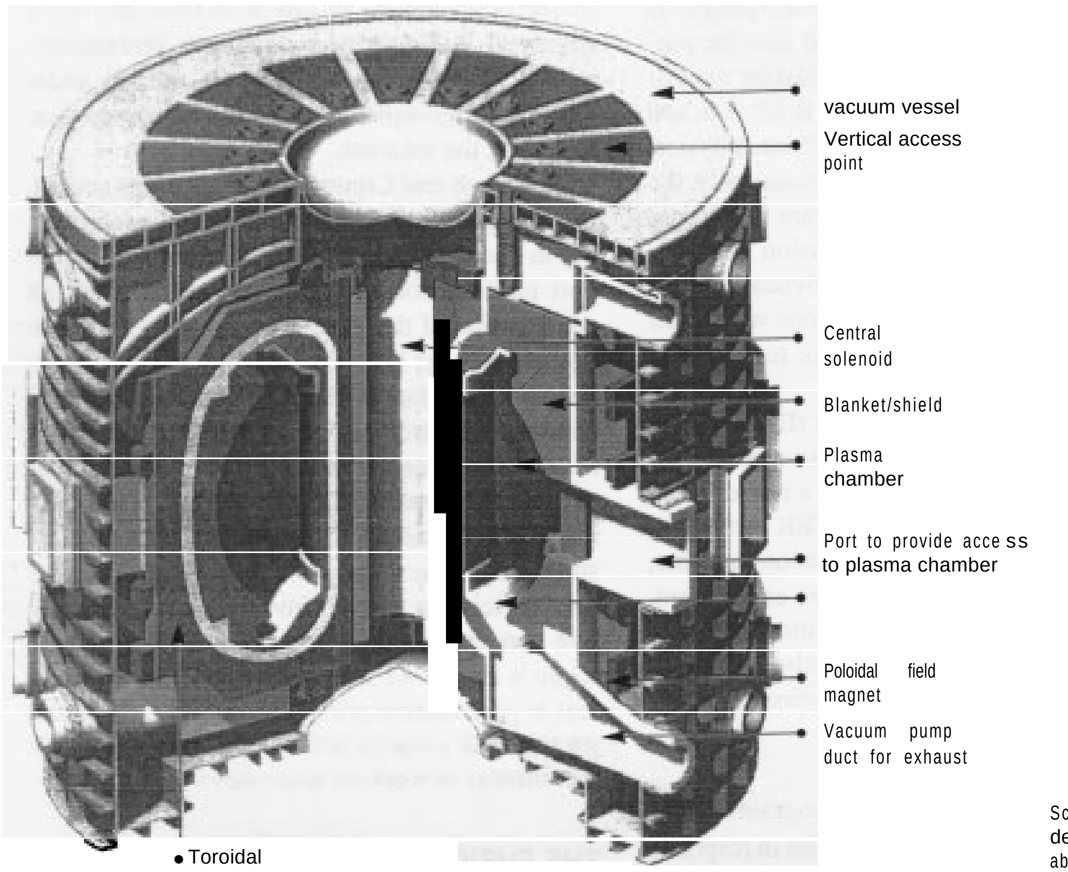
[29] After cancellation of the BPX, a planning effort directed by the Princeton Plasma Physics Laboratory resulted in the proposal to build a smaller successor to the TFTR as a steady-state advanced tokamak machine with superconducting magnets and divertor designs that would be complementary to ITER. For more on the history and design of TPX, see ch. 3 of this report.

[30] *FEAC, September 1992*, p. 10.

[31] Ibid., pp. 11-13.

[32] Ibid., pp. 15-16.



Major components of the proposed ITER.

Another FEAC panel report made recommendations for IFE activities and indicated budget priorities, emphasizing research needs supporting heavy-ion drivers, and reiterated many of the conclusions of FPAC on the attractiveness of IFE.[33] In all cases the panel called for a balance among experimental and analytical program support for IFE, accelerator development, and beam physics. Three budget cases set by DOE were reviewed. According to the panel, the most significant development since the 1990 FPAC review was a reduction in the estimated cost for building ILSE to $45 million because of technical advances, design changes, and availability of an existing site and facilities.[34] At an annual budget level of $17 million (1992 dollars), the panel gave highest priority to ILSE construction and experiments along with supporting work on accelerator theory, reactor system studies, and technology development. At a middle funding level of $10 million/year, the panel concluded that it would not be possible to com-

[33] *FEAC 1993.*

[34] Ibid., pp. 9-10. Estimate of $45 million for ILSE costs is from U.S. Department of Energy comments on OTA draft report, November 1994.

plete the integrated ILSE demonstration project as proposed. The panel recommended that the program proceed with scaled up accelerator experiments in the low energy part of the ILSE plan and continue support in accelerator and beam physics. At a low funding level of $5 million annually, the panel concluded that a U.S. program would not support a "credible" heavy-ion fusion development program and suggested that advocates of the heavy-ion program enter negotiations with other offices in DOE that might be more receptive to their work.

The Energy Policy Act of 1992 (EPACT), included a mandate for a five-year fusion energy research program. EPACT called for a broad-based program with participation in ITER activities, construction of a new major U.S. fusion machine, development of a heavy-ion driver experiment, and increased industrial participation. EPACT also imposed additional administrative and management requirements on DOE's fusion program.

▮ The Fusion Program Today

In the 1990s, the magnetic fusion program continues to evolve and redirect its activities in response to the suggestions of FPAC, FEAC, and congressional appropriations committees and the requirements of the fusion energy provisions of EPACT. The Office of Fusion Energy's magnetic fusion activities have been narrowed to an even greater focus on tokamak concepts, national facilities, and greater reliance on international collaboration to move toward achievement of the next milestones in fusion energy development. The result is that work has been drastically curtailed on exploration of alternative confinement concepts that might have more attractive characteristics as a commercial energy source than tokamaks. Even more significantly to some in the fusion community, little progress can be expected at current funding levels on the development of low activation and other advanced materials and on fusion powerplant-related technologies that will be needed under virtually all magnetic confinement approaches, including the tokamak.

The Bush and Clinton administrations sought, and Congress provided, increases in fusion funding in fiscal years 1993 to 1995 primarily to support participation in ITER, and design, but not construction of the TPX. The modest increase in funding has not been sufficient to offset the continued narrowing of the program as alternative concepts research and base program activities have been squeezed to keep major tokamak experiments operating. Despite EPACT's endorsement of a broad-based fusion program and the strong recommendations of several outside advisory reviews to support investigation of alternative concepts, budget pressures, combined with explicit directions from appropriations committees to give highest priority to full funding of major tokamak projects and ITER, have resulted in curtailment of work on alternates to the tokamak.

THE FUSION PROGRAM GOALS IN LAW AND POLICY

Fusion energy research is carried out under various grants of authority and congressional mandates. The most important sources of general authority for the fusion program are EPACT,[35] The Magnetic Fusion Energy Engineering Act of 1980,[36] and the Atomic Energy Commission Act of 1954.[37] These laws are summarized in box 2-A.

EPACT directs the Secretary of Energy to conduct a five-year fusion energy program to result in a technology demonstration by 2010 verifying fusion's "practicability'' for commercial power production. EPACT's general goals for fusion energy research include:

[35] Public Law 102-486, section 2114, Oct. 24, 1992, 106 Stat. 3073-3074, 42 U.S.C. 13474.

[36] Public Law 96-386, Oct. 7, 1980, 94 Stat. 1539, 42 U.S.C. 9301.

[37] Act of Aug. 30, 1954, ch 1073, 60 Stat. 921, as amended, 42 U.S.C. 2011 et seq.

BOX 2-A: Summary of Major Legislation on Fusion Energy Research

The **Energy Policy Act of 1992**[1] **(EPACT)** directs the Secretary of Energy to conduct a fusion energy program resulting in a technology demonstration by 2010 to verify fusion's "practicability" for commercial power production. EPACT set forth general goals for a broad-based fusion energy research effort and established several new management and reporting provisions including a requirement for a comprehensive fusion management plan and biannual reports. The Act also (under sections 3001 and 3002) applies general provisions relating to cooperative energy research and cost sharing to fusion research activities. To support this program, EPACT authorizes appropriations of $339.7 million for fiscal year 1993 and $380 million in fiscal year 1994.

Under EPACT, DOE's fusion energy research programs also are intended to support more general goals for federal energy supply R&D including: reducing oil import dependence, increasing the energy efficiency of the U.S. economy, stimulating economic growth, stabilizing and reducing greenhouse gas emissions, promoting environmental protection, developing more environmentally sustainable energy systems, enhancing technological competitiveness, fostering international cooperation and technology transfer, creating new market opportunities for American industry, and contributing to advancing fundamental scientific knowledge.

The **Magnetic Fusion Energy Engineering Act of 1980 (MFEEA)**[2] also sets forth policy goals and management requirements for the fusion energy program. The act called for an aggressive magnetic fusion R&D program with the goals of establishing engineering feasibility by 1990, and developing an operating magnetic fusion device by 1990 and an operating magnetic fusion demonstration plant for electric power production "by the turn of the 21st century. " Section 4 directs the Secretary to maintain a "broadly based research program on alternative confinement concepts and on advanced fuels" in addition to "an aggressive plasma confinement research and construction program on the current lead concept, "[3] The program was to promote broad participation of industry and greater public understanding of fusion energy. The act also provided for continued cooperation in international fusion research and maintaining U.S. leadership in magnetic fusion.

The MFEEA requires the Secretary of Energy to prepare a comprehensive fusion program management plan, create a national fusion engineering center, establish a technical advisory panel on magnetic fusion to review the program and advisory committees for each fusion laboratory or facility, and report on program activities annually. The required management plans were issued in 1983 and revised in 1985 to reflect comments of a technical review panel and the changing energy research policy of the Reagan Administration. Triennial reviews were conducted in 1983, 1986, and 1990.

The MFEEA goals and program structure reflected the "energy crisis" mentality of the times and adopted the recommendations of the fusion technical review panel for a shift in the program from a focus on fundamental fusion science and plasma physics to technology development. The act called for substantial increases in annual appropriations for fusion research in later years to achieve these ambitious goals. These increases were not provided.

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[1] Public Law 102-486, section 2114, Oct. 24, 1992, 106 Stat 3073-3074, 42 U S C 13474.

[2] Public Law 96-386, Oct. 7, 1980, 94 Stat. 1539, 42 U.S.C. 9301.

[3] 42 U.S.C. 9303.

(continued)

BOX 2-A (cont'd.): Summary of Major Legislation on Fusion Energy Research

DOE's fusion energy research activities are also conducted under the **Atomic Energy Commission Act of 1954,**[4] which provides basic authority for federal nuclear R&D activities and regulation. The act carried on many provisions of the prior act of August 1, 1946 under which fusion research was supported by the Atomic Energy Commission (AEC) and its successors. Most of the AEC's nuclear research responsibilities were transferred to the new Energy Research and Development Administration in 1974.5 In 1977 these duties were vested in the newly formed Department of Energy.[6]

Among the purposes of that act are: to assist R&D to "encourage maximum scientific and industrial progress, " to aid education and training, promote widespread participation in development of peaceful uses for atomic energy;[7] and to encourage international cooperation.[8] The federal government is authorized to support a broad range of research activities relating to nuclear processes, atomic energy theory and production, use of nuclear energy or materials for generation of usable energy, and for commercial and industrial applications.

The AEC was authorized to make grants and other contributions to the construction and operation of reactors and other facilities at educational and charitable institutions for education and training purposes,[9] and to conduct research activities and studies in its own facilities.[10] The AEC Act thus provides additional legislative authority for DOE support of fusion-related nuclear physics (including plasma physics) and the engineering education and training missions of the Office of Fusion Energy and Defense Programs.

[4] Act of Aug. 30, 1954, ch 1073, 60 Stat 921, as amended, 42 USC 2011 et seq.

[5] Public Law 93-438, Oct 11, 1974

[6] Department of Energy Organization Act, Public Law 95-91, Aug. 4, 1977.

[7] Atomic energy is defined as all forms of energy released in the course of nuclear fission or nuclear transformation. 42 U.S.C. 2014 Transformation is interpreted to include fusion.

[8] 42 U.S.C 2013

[9] 42 U.S.C. 2051(c).

[10] 42 U.S.C. 2052

- support of a broad-based fusion energy program;
- participation in the ITER engineering design activities and related efforts;
- development of a technology for fusion power, and industrial participation in technology development;
- design and construction of a major new machine for fusion research and technology development;[38] and
- R&D on inertial confinement fusion energy, and development of a heavy-ion inertial confinement fusion experiment.

EPACT's reference to a broad-based fusion program echoes the language of MFEEA, which requires a "broadly based research program" on attractive alternate concepts and alternate fuels while also aggressively pursuing scientific progress via the tokamak path. The EPACT language is

[38] The major new machine has been interpreted by some as authorization for the proposed TPX, but others maintain that construction of the facility has yet to be authorized specifically.

cited by proponents of alternate fusion concepts as requiring DOE to support a more active and varied alternate concepts research program. Fusion program officials at DOE, however, interpret this directive as requiring them to support a broad range of research activities conducted by a variety of research institutions.

The comprehensive management plan for the fusion energy program required under EPACT is to include specific objectives, milestones, schedules, cost estimates, program management resource requirements, and an evaluation of the appropriate extent of participation by universities and the private sector in fusion activities. The plan must evaluate the requirements needed to build and test an inertial fusion energy reactor for purposes of power production. The plan also is to describe proposed U.S. participation in the design, construction, and operation of ITER and include an evaluation of international cooperative agreements on fusion research and of the need for strengthening existing agreements or negotiating new ones. The management plan was to have been completed within 180 days of passage of EPACT, i.e., by April 1993, however, DOE had not completed it as of December 30, 1994.[39]

EPACT also requires DOE to issue a report detailing fusion program organization staffing, funding, and expenditures, and describing the program's progress in achieving the specific objectives, milestones, and schedules in the fusion management plan as part of the energy technology inventory and status report for the management plan on energy research, development, demonstration, and commercialization under section 2304.[40] The first report was to have been submitted by October 1993. Updates on the progress of the fusion plan are to be included in subsequent reports every two years; by December 30, 1994, the first periodic progress report had yet to be delivered.

DOE has been slow to implement the new management and reporting requirements for the fusion program established by EPACT. Various reasons have been suggested for the lack of progress in issuing a comprehensive management plan for the future development of fusion power and for participation in ITER. The most important factors contributing to the delay appear to be the uncertainty over future budget levels for the fusion research program (under the current policy of level spending in discretionary programs) and a lack of key decisions about the priority to be accorded to fusion power among competing federal energy and science research programs, including decisions about ITER. These policy decisions are not made at the Office of Fusion Energy level and explain in part the absence of an updated management plan for fusion development. At the same time, there does not yet appear to be any public analysis of alternative long-term paths for federally sponsored fusion energy research efforts under constrained funding. Several developments may advance the opportunities for a reconsideration of fusion research policy. The Office of Fusion Energy recently reconstituted FEAC. Over the next year, the fusion research efforts are also likely to come under review by one or more panels convened by the Secretary of Energy. These include SEAB, the Task Force on Strategic Energy Research and Development, and the task force reviewing the work of the national laboratories.

[39] DOE has released two reports relevant to some of the planning material requested. On November 21, 1994, Secretary Hazel O' Leary transmitted to several congressional committees the "Interim Report to the Congress on Planning for International Thermonuclear Experimental Reactor Siting and Construction Decisions," in partial response to requests for a detailed ITER siting and development plan in the FY 1993 and FY 1994 Energy and Water Development Appropriations conference reports. The Secretary advised the committees that a more complete response could not be provided until the ITER Interim Design Report is completed and accepted by the parties. In August 1994, the Department of Energy released for comment a draft of "A Management Plan for the Conduct of Research, Development, Demonstration, and Commercial Application of Energy Technologies" required under section 2304 of EPACT. The appendix to the draft contains a very brief one-page figure on fusion technology issues, performance goals, benefits/leverage, and technology readiness dates.

[40] 42 U.S.C. 13523(c).

LEGISLATIVE DIRECTIVES

Priorities for the fusion energy programs are shaped by directives contained in appropriations acts and reports and pending legislation. In some instances, DOE has given greater weight to the directions of appropriations committees than to the recommendations of its technical reviewers and to more general provisions of law. For example, the FY 1994 Energy and Water Appropriations Conference Report directed DOE to:[41]

- focus the DOE magnetic fusion program on elements that further the design, construction, and operation of ITER and a future demonstration fusion reactor;
- set priorities for the domestic fusion energy program identifying elements that contribute directly to development of ITER or DEMO;
- provide a plan describing: 1) a selection process for a U.S. host site for ITER; and 2) the necessary steps by the international partners for selecting a final ITER host site and for the design, construction, and operation of ITER by 2005, including relevant milestones and budget estimates;
- begin evaluation and selection of a U.S. ITER host site;
- give highest priority in the national program in FY 1994 to D-T experiments in the TFTR at PPPL; and
- proceed with design and R&D tasks on TPX, upgrades of the DIII-D tokamak, and an aggressive program on low activation materials to be tested in ITER and used in DEMO, and provide a $500,000 increase in funding for the IFE program.

Effectively, the appropriations conference report applied many of the provisions of S. 646, a bill passed by the Senate in June 1993, that would have focused the magnetic fusion program almost exclusively on activities in support of ITER and TPX tokamak approaches and eliminated investigation of nontoroidal concepts. This approach was highly criticized by many in the fusion research community.

In contrast to the appropriations directives and S. 646, the House passed H.R. 4908, the Hydrogen, Fusion, and High Energy and Nuclear Physics Research Act of 1994 in August 1994. H.R. 4908 would have supported ongoing TPX and ITER activities. It also would have restored research activities on alternative fusion confinement concepts through establishment of a separate program that would have responsibility for advancing heavy-ion inertial fusion energy and other alternate concepts. It is expected that similar legislation will be introduced in the 104th Congress.

Attempts to cut the fusion energy program budget to produce savings for deficit reduction and support of competing renewable and energy efficiency technologies also were before the House of Representatives in the 103d Congress. In November 1993, the proposed Penny-Kasich amendment to H.R. 3400, the Government Reform and Savings Act of 1993, included a provision rescinding $70 million from the fusion energy program.[42] During consideration of the FY 1995 Energy and Water Appropriations Act in the House, an amendment to strike the $67-million funding for TPX construction was defeated.[43]

FEDERAL FUSION ENERGY RESEARCH PROGRAMS

DOE supports a variety of R&D activities related to fusion energy in its science and defense programs. Primary responsibility for fusion energy science and technology development rests with the Office of Fusion Energy (OFE) in the Office of Energy Research. OFE oversees most of the civilian research efforts involving plasma physics, confinement concepts, reactor studies, and related

[41] Conference Report on H.R. 2445, H. Rept 103-292, 103d Cong., 1st sess., at 139 *Congressional Record* H7948, Oct. 14, 1993 (daily ed.)

[42] See 139 *Congressional Record* H10479, Nov. 20, 1993 (daily ed.).

[43] See 140 *Congressional Record* H4431-4439, June 14, 1994 (daily ed.).

technology development. The Office of Defense Programs sponsors research on ICF science and technology for potential applications in meeting its nuclear weapons and stockpile stewardship responsibilities as well as for long-term energy potential. OFE also supports R&D on the energy applications of fusion technologies developed under the separate weapons-related inertial confinement fusion program.

Fusion research activities are carried out at national laboratories, universities, and private companies. Figure 2-4 shows the distribution of major fusion research facilities funded by OFE. In FY 1994, DOE's magnetic fusion program was budgeted at about $347.6 million with much of that funding going to support fusion activities at PPPL, Oak Ridge, Lawrence Berkeley, and Lawrence Livermore National Laboratories, and at General Atomics in San Diego and various universities. The Defense Program's ICF program was funded at $169.2 million in FY 1994 with activities concentrated at Livermore, Sandia, and Los Alamos National Laboratories, the Naval Research Laboratory, and the Laboratory for Laser Energetics at the University of Rochester.

Program Goals

Goals for the DOE fusion energy program are set by legislation and/or presidential or secretarial decisions, and the program offices have little leeway to change them. Thus, fusion program goals have remained relatively constant in objectives and schedules and untempered by budget constraints that could hamper their timely achievement. The FY 1995 DOE budget request for the magnetic fusion energy program states that "the overarching goal of the program is to demonstrate that fusion energy is a technically and economically viable energy source." More specifically, according to DOE, the major long-term goals of the magnetic fusion energy program are to establish the "practicability of electric power production by 2010" (as called for in EPACT); to show the engineering and economic feasibility of fusion power production by having an operating demonstration reactor by (around) 2025, to be followed by an operating commercial prototype reactor by (around) 2040 (as set out in the 1990 NES and FPAC recommendations). Other goals for the program include the education and training of fusion scientists and engineers, and encouragement of international collaboration. DOE's FY 1995 budget request admits that "budgetary constraints over the past few years may mean that the schedule for meeting such objectives is delayed."[44]

DOE has developed more detailed goals and strategies that it has relied on in setting priorities for its magnetic and inertial fusion energy research and technology development programs

Magnetic Fusion

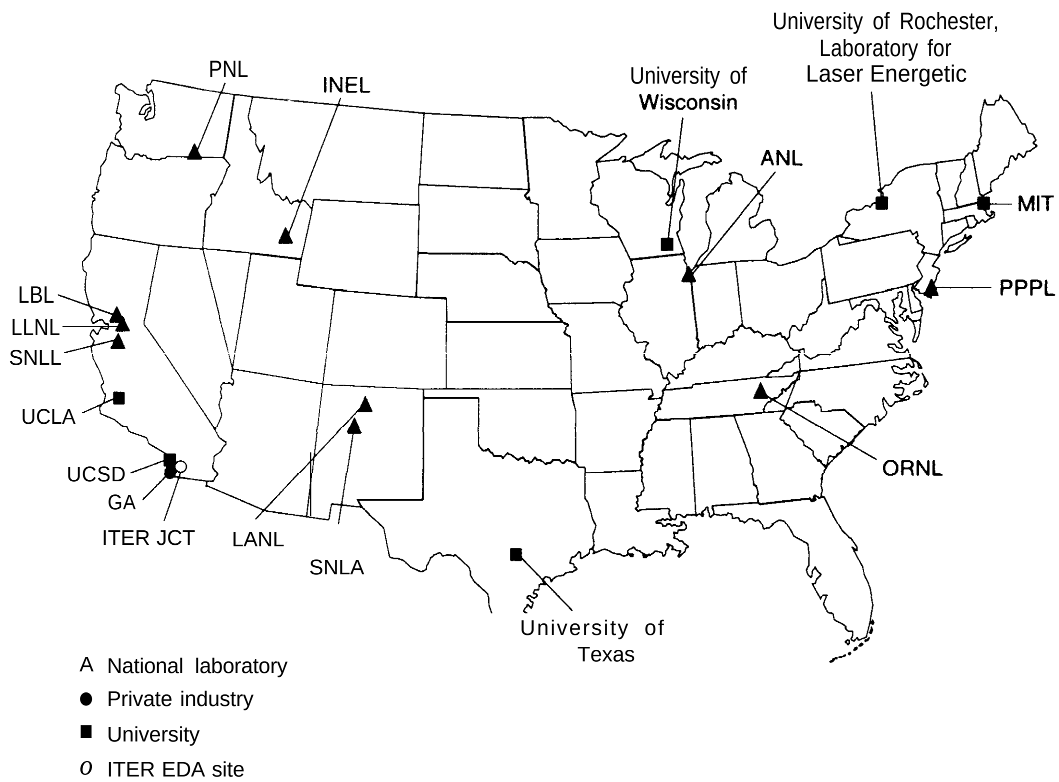
For the magnetic fusion program, among the most important scientific and technical issues that must be addressed to achieve the program's goals are ignition physics, fusion nuclear technology, magnetic confinement optimization, and development of low activation materials.[45] The budget request outlines the four major elements of DOE's magnetic fusion activities directed at resolving these issues.

1. *Study of* D-T-*fueled reactions in the TFTR*. Beginning in FY 1994, D-T fuel was introduced into the TFTR to allow experiments to increase the amount of energy obtained from fusion reactions and to verify of extrapolations made from nontritium reactions such as D-D or a mix of deuterium and helium^3 (D-He^3). The goal of the TFTR experiments is the production of 10-million watts of power for one second. (This will move laboratory production of fusion power approximately 30 percent of the way toward achievement of the goal of breakeven). TFTR's D-T experi-

[44] U.S. Department of Energy, Office of the Chief Financial Officer, "FY 1995 Congressional Budget Request: vol. 2, Energy Supply Research and Development," DOE/CR-0021, 1994, p. 425.

[45] Ibid., p. 426.

FIGURE 2-4: Major Fusion Research Centers Funded by the Office of Fusion Energy, FY 1994



KEY
ANL= Argonne National Laboratory
GA= General Atomics
INEL= Idaho National Engineering Laboratory
ITER JCT= ITER Joint Central Team
LANL= Los Alamos National Laboratory
LBL= Lawrence Berkeley Laboratory
LLNL=Lawrence Livermore National Laboratory
MIT=Massachusetts Institute of Technology
ORNL=Oak Ridge National Laboratory
PNL=Pacific Northwest Laboratory
PPPL= Princeton Plasma Physics Laboratory
SNLA=Sandia National Laboratory-Albuquerque
SNLL=Sandia National Laboratory-Livermore
UCLA= University of California, Los Angeles
UCSD=University of California, San Diego

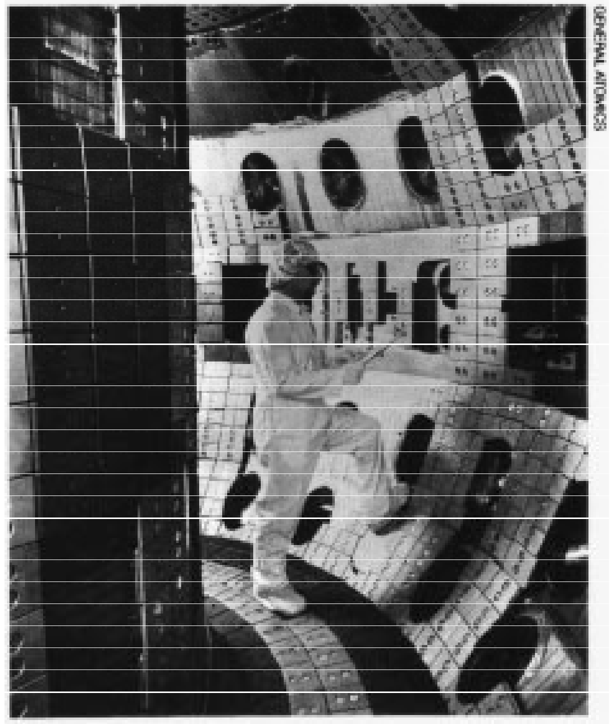
SOURCE: U.S. Department of Energy, 1994

ments will be the first to generate important data and experience on plasmas with internally generated heat from alpha particles. Attainment of alpha particle heating will be critical for self-sustained fusion reactions in future development steps such as ITER and for eventual fusion powerplants.

2. ***Participation in the ITER international collaboration.*** ITER is intended to demonstrate the scientific and technical feasibility of fusion by producing over 1,000 MW of fusion power under ignition conditions and serving as a test bed for fusion technology in support of a demonstration powerplant--e.g., remote handling, divertor, fuel injection, heat transfer, maintenance, materials, and blankets.

3. ***Development, construction, and operation of a new domestic advanced tokamak device.*** The Tokamak Physics Experiment to be sited in the TFTR test cell at PPPL will be the first major new U.S. fusion facility in over a decade, if it is constructed. The proposed TPX will provide the opportunity to study long-pulsed advanced tokamak operations and is designed to take advantage of the TFTR site and much of its existing equipment. TPX is intended to significantly improve the physics results of tokamak reactors by exploring advanced operating modes with the potential for better confinement conditions, higher pressure limits, and efficient steady-state current drive. TPX would be built using superconducting magnets and thus would contribute to U.S. industry experience with key components also needed for the ITER project. TPX also would provide critical operating experience in the steady-state/long-pulse mode that will be the focus of a later ITER nuclear testing phase.

4. ***Maintenance of a base program of fundamental physics and technology research.*** OFE will continue to maintain a range of base program activities required to support development of ITER, TPX, and DEMO, and operation of existing major U.S. tokamaks, DIII-D and Alcator-C-Mod. The base program funds research on fusion theory and modeling, fusion computing systems, and development of low activation materials.

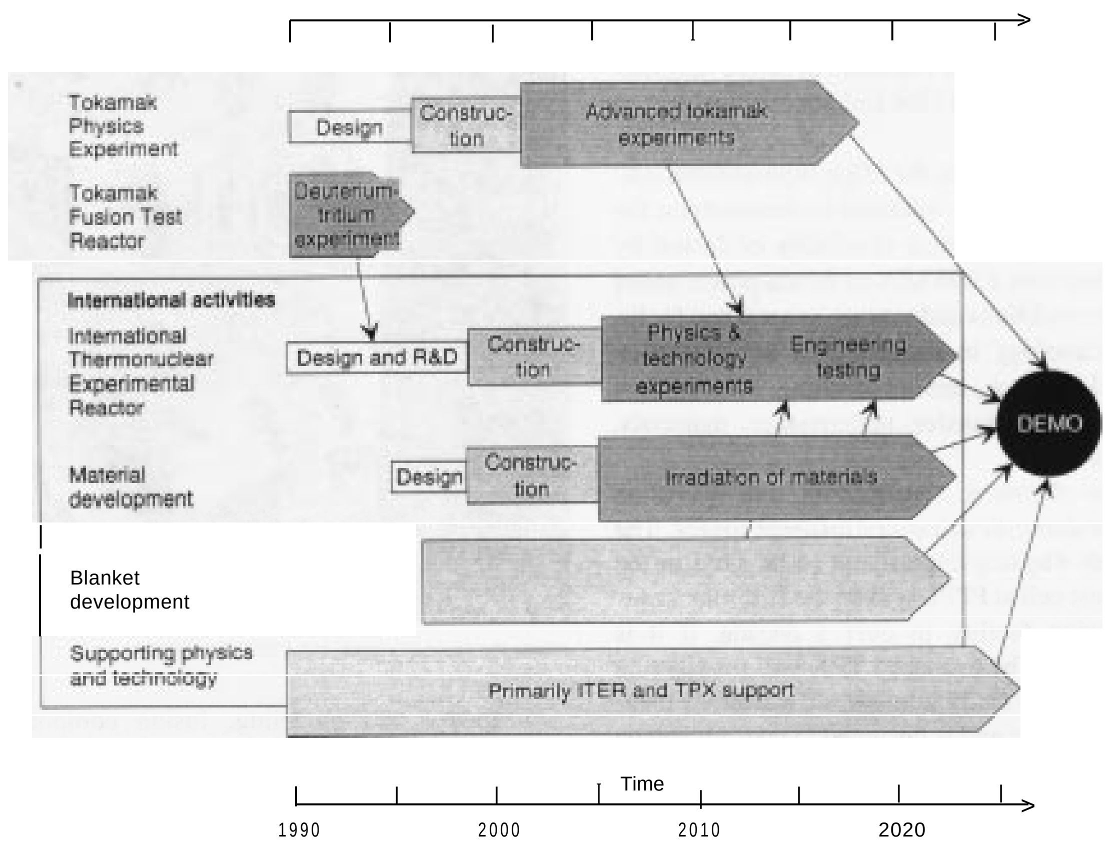


Inside the vacuum vessel of the DIII-D tokamak.

These elements are spread over several subprograms and support what is now characterized as the mainline magnetic fusion energy development program shown in figure 2-5. This long-term strategy was developed in consultation with the fusion community, generally reflecting priorities established in the fusion program in the mid-1980s as modified to take into account changing budget conditions and the recommendations of FPAC and FEAC.

Under this magnetic fusion development strategy, research will progress through a number of critical steps and new facilities to result in eventual demonstration of commercial power production by the middle of the 21st century. The pathway reflects a heavy reliance on the success of the tokamak confinement approach as the most likely (and only available) technology to meet key development milestones for fusion power.

FIGURE 2-5: Magnetic Fusion Program Development Plan, 1994



SOURCE: U.S. Department of Energy, 1994.

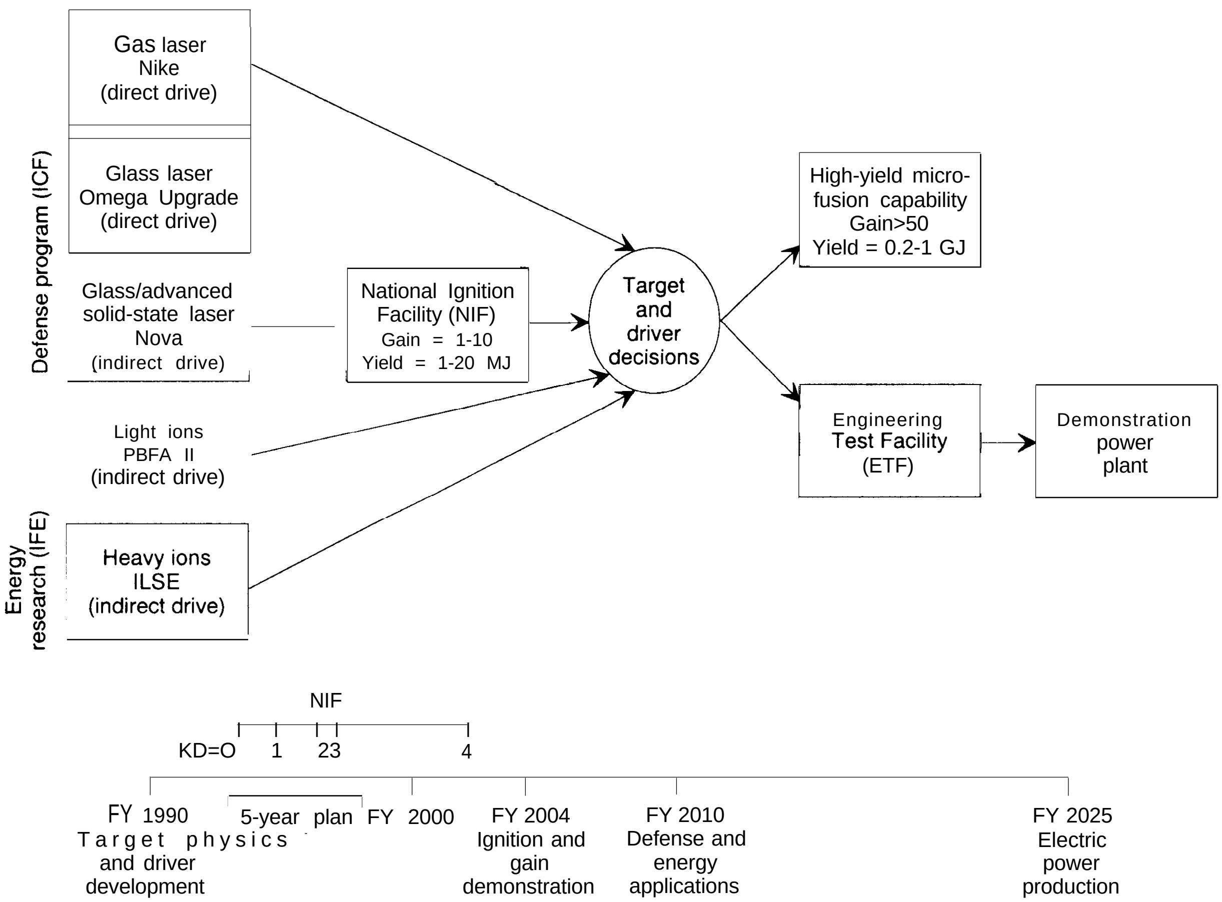
Key elements shown are:

- D-T experiments and alpha heating in the m ,
- demonstration of ignition, long-pulse, and technology testing in ITER,
- achievement of steady-state/advanced tokamak reactor conditions in TPX,
- development of low activation materials for fusion reactors in a 14 MeV materials test facility,
- possible development of a blanket test facility, and
- maintaining balance in the rest of program.

Inertial Fusion Energy

Major goals for the civilian energy aspects of the inertial confinement fusion energy program are development of components for fusion energy systems and reactor systems that can take advantage of the target physics developed by the Defense Programs' ICF research. Activities include continuing support for the investigation and development of a high-efficiency, high-repetition driver, targets, and reactor concepts that are particularly important to energy applications of ICF, but not of concern in weapons stewardship/research. The current IFE program emphasizes support for

FIGURE 2-6: Inertial Confinement Fusion Program Development Plan, 1994



KEY
KD=Key Decision

SOURCE U S Department of Energy.

development of the heavy-ion accelerator driver approach, and development of IFE target designs with features of high gain and ease of production The IFE program plan relies heavily on progress in the ICF program, such as the proposed National Ignition Facility (NIF), to achieve key IFE milestones and experience to allow a decision to proceed with an IFE engineering test facility.

Cutbacks in alternate concepts research in the MFE program have left inertial confinement as the only alternative fusion technology sufficiently advanced to compete with the tokamak concept when the key decision for choice of a demonstration fusion reactor concept is made. The long-term development path for demonstration of commercial power production using inertial confinement fusion technologies is shown in figure 2-6. Critical technology development for IFE along this path includes: achievement of ignition in the proposed NIF, development of an efficient repetitive driver, improvements in target design and manufacture, and development of a fusion energy target chamber and energy extraction technology for use in a IFE engineering test facility.

This strategy parallels the path and key decision points for magnetic confinement fusion in the competition between MFE and IFE that was adopted as the future fusion strategy in 1990. A proposed change in the ICF plan could permit an alternative development path with fewer major facilities by integrating the IFE engineering test facility and the laboratory microfusion facilities using separate target chambers but a common driver.[46] It should be noted, however, that many questions concerning the detailed cost estimates and choice of technologies for an IFE development path remain to be resolved.[47]

OFE Program Structure

The Office of Fusion Energy under the Assistant Secretary for Energy Research has three operating divisions—Confinement Systems, Applied Plasma Physics and Technology, and ITER and Technology—roughly corresponding to its budgetary subprograms: Confinement Systems, Applied Plasma Physics, and Technology and Development.[48] The discussion here is organized according to the budgetary subprograms used in appropriations requests.

The **Confinement Systems Subprogram** supports the planning, design, and operation of existing and new reactors and facilities to improve the tokamak concept through research to achieve a more detailed understanding of fusion plasmas in reactor-like conditions. The goal of this research is to develop technically and economically credible fusion power reactors for commercial energy production in the 21st century. Major areas of research include: energy confinement, plasma heating, fuel injection, power handling and particle control, current drive, and alpha particle heating and its impacts on confinement and stability. The division also conducts physics R&D on existing machines for ITER EDA activities. The FY 1995 budget request reports that budget- and policy-driven program redirection in the past decade have reduced the number of operating fusion facilities supported by the programs as activities are increasingly concentrated on ITER, TPX, and high-priority issues. The division has tried to offset some of the impacts of this redirection by encouraging the scientific staff of the affected laboratory and university programs to collaborate at facilities with operating fusion devices, including international collaborations in Germany, France, England, and Japan. Total funding for the confinement systems subprogram in FY 1994 was $168 million with 45 percent going to operation of the TFTR, 40 percent to operation of base toroidal facilities (e.g., DIII-D and Alcator C-Mod), 11 percent to TPX design activities, and 4 percent for advanced toroidal facilities (i.e., the ATF stellarator). More than half of the subprogram's budget is dedicated to programs at the Princeton Plasma Physics Laboratory. The subprogram's FY 1995 budget request was $150.5 million.

The **Applied Plasma Physics and Technology Subprogram** supports research to improve understanding of fusion principles and to investigate innovative techniques leading to improved plasma confinement conditions. Responsibility for this budget subprogram rests with the Applied Plasma Physics and Technology Division. This division oversees work on experimental plasma research, fusion theory and computing, theoretical and experimental physics, and analysis and de-

[46] Alex Friedman, Lawrence Livermore National Laboratory, personal communication, Aug. 11, 1994; and C. Olson et al. "ICF Diverse Strategies for IFE," paper presented at the International Atomic Energy Agency Technical Committee Meeting, Paris, Nov. 14-18, 1994.

[47] Some researchers have proposed an alternative path to the mainline ITER-DEMO tokamak-based development path for magnetic fusion. See, e.g., Stephen O. Dean, "Fusion Power Development Pathways," *Journal of Fusion Energy,* vol. 12, 1994, pp. 415-420; and Stephen O. Dean et al., "An Accelerated Fusion Power Development Plan," *Journal of Fusion Energy,* vol. 10, 1991, pp. 197-206.

[48] The operating divisions were reorganized in 1992 to reflect the growing concentration on ITER and to aggregate longer term issues in an Advanced Physics and Technology Division covering materials, systems studies, alternative fusion concepts (including IFE), exploratory toroidal improvements, and theory. The budgetary subprograms remained unchanged, however.

sign supporting major devices. The program also is responsible for developing diagnostics, plasma heating and control concepts, and data necessary to design and run major experiments. A major initiative of this subprogram in recent years has been support of development of computer codes and capabilities for simulating plasma confinement conditions on high-performance computers and establishment of improved computer networks linking major energy research centers and fusion facilities in the United States and overseas. With 1990s program redirection, primary emphasis is given to research activities in support of ITER and TPX design.

This division also administers OFE's modest program to support innovative nontoroidal confinement methods research as recommended by FPAC and FEAC. Through a process of solicitation of proposals, several researchers are given grants on a three-year basis for small-scale, proof of concept experiments for innovative tokamak improvement concepts and unconventional toroidal concepts. A total of $1.2 million per year was allocated to this initiative. Not included in this program are the funds used for work in alternative toroidal concepts, such as the reversed field pinch, and on physics issues that are complementary to and supportive of work on the tokamak confinement concept.

Funding for plasma physics activities in FY 1994 was $59 million with about 31 percent going to plasma theory, 44 percent to support experimental research, and 25 percent to MFE computing. Lawrence Livermore National Laboratory, which operates a major fusion computer center, received about 17 percent of total funding under this program in FY 1994. The FY 1995 request was $54.3 million.

The **Technology and Development Subprogram** supports work on the design and technology development for ITER; the development of technologies needed for TPX, DIII-D, and other fusion experiments; and studies of future fusion systems. (Subprogram responsibilities are mainly carried out under the ITER and Technology Division.) Projects are organized in three technical areas: ITER, plasma technologies, and fusion technologies.

The ITER technical area includes funds for the U.S. share of ITER design and development work, except for the advanced materials, theory, and diagnostics research activities funded under the applied plasma physics and confinement systems subprograms. Funds are used to pay for ITER technology development tasks negotiated with the ITER Director and approved by the ITER Council. Total operating funds for ITER activities under this program were $62.4 million in FY 1994 with an increase to $68.6 million requested for FY 1995.

The plasma technologies activities include developing technologies for forming, confining, heating, and sustaining a reacting fusion plasma such as magnet systems, heating systems, fueling systems, and materials in the plasma environment. A major focus of these efforts has been directed at development of reliable high-field pulsed and steady-state superconducting magnet systems for ITER and TPX. These efforts were funded at $5.8 million in FY 1994, with a request for $5.3 million for FY 1995

The fusion technologies activity supports research that is important for TPX, ITER, and future power reactors, including materials development and long-term waste issues, safety and environmental considerations, component reliability, tritium fuel breeding and processing, and power extraction. This area also has supported scoping studies for a high-energy neutron irradiation test facility, which is critical to the development of low activation materials for future devices, and cooperative work under ITER, the International Atomic Energy Agency (IAEA), and U.S.-Japan bilateral agreements on blanket engineering, and Tritium Systems Test Assembly. Fusion system studies activities support analytical, engineering, and computational studies of fusion systems to identify potential problem areas and to provide future program direction. The FY 1994 funding for various fusion technologies activities was about $12 million. The FY 1995 request of about $15 million accommodates an increase in funding for advanced materials activities.

Total funding for the Development and Technology Subprogram in FY 1994 was about $80 million. Major funding recipients included Argonne, Lawrence Livermore, Los Alamos, Sandia, Pacific Northwest, and Oak Ridge National Laboratories. DOE has requested $89 million for this subprogram in FY 1995.

The Defense ICF and IFE Programs

The ICF program is part of DOE's nuclear weapons research and technology development activities under the Office of Defense Programs. ICF is supported because of the ability to produce pure thermonuclear burn in a laboratory environment to study weapons physics and effects as an alternative to underground testing and to provide the research base for longer term fusion energy applications. The primary emphasis of the program is on demonstrating ignition in a laboratory microfusion device and developing both direct and indirect driver technologies. Related work focused solely on energy aspects of ICF is supported under the Office of Fusion Energy Applied Plasma Physics and Technology Division. Following significant accomplishments in target physics in the late 1980s that supported the scientific feasibility of ICF, the ICF program began to focus on appropriate drivers primarily intended for defense and ICF physics purposes and to proceed with the design of the proposed NIF. In December 1993, Energy Secretary Hazel O'Leary declassified portions of the Defense Programs relevant to IFE. Thus, results from the experiments with ignition of ICF plasmas may be used for energy applications.

Research on systems to explore the development of IFE as a potential civilian energy source is carried out as a separate subprogram of OFE. The primary technology activity has been support for the development of a heavy-ion driver and study of inertial fusion energy targets. IFE subprogram activities are closely coordinated with the Defense ICF Programs. In fact, work on inertial fusion energy in OFE is often closely tied to projects supported by the Defense ICF Program. Work on ICF physics, and target design benefits energy applications. Researchers from both programs maintain close professional contact.

The Defense ICF Program was funded at $169 million in FY 1994 and at $176 million in FY 1995. Inertial fusion energy programs received $4 million in FY 1994—half the level of the program's fiscal year 1993 budget—reflecting a decision by DOE to defer consideration of construction of the accelerator for the Induction Linac Systems Experiment.

Fusion Program Budgets

The FY 1995 DOE budget request sought $372.6 for the Magnetic Fusion Energy Program. The request supported U.S. direct and indirect activities for ITER, TPX design and construction startup activities, and continuing analysis of data from the TFTR D-T experiments following shutdown in FY 1994 to allow the test cell to be prepared for TPX construction. The request also called for hardware upgrades to DIII-D to support its capabilities to address key issues in design and operation of ITER and next generation machines. In addition, funding was sought for the base physics program, including support of ITER, and tokamak improvements, along with modest increases in funds to support materials development for future fusion devices (including preliminary work on design of a neutron source facility as an international collaboration through IAEA coordination, much like early phases of ITER project development).

Congress appropriated the full requested $372.6 million for the Office of Fusion Energy activities.[49] However, the conferees declined to ap-

[49] Conference Report on H.R. 4506, The FY 1994 Energy and Water Appropriations Act, H. Rpt. 103-533, S. Rpt. 103-291, 103d Cong., 2d sess., Aug. 3, 1994, published in 140 *Congressional Record* H6888, Aug. 4, 1994 (daily ed.) Subsequent general reductions in the DOE budget have left $364.563 million for fusion program expenditures in FY 1994.

prove construction spending for TPX, but did allow DOE to continue with TPX engineering design and R&D ($42 million) and to purchase long-lead-time superconducting materials (up to $2 million). The conferees directed DOE to use standard phased industrial contracts for TPX design activities to provide for future construction approval, when and if authorized by Congress.

The conferees also provided $65 million for continuation of additional D-T experiments in the TFTR until such time as TPX construction is approved and TFTR activities are wound down. Without these additional funds, TFTR was scheduled to be shutdown at the end of FY 1994 to make funds available for TPX activities. Senate and House members called for legislation explicitly authorizing TPX construction. An additional $8 million was provided for operation of the PBX-M tokamak facility at PPPL and $8.7 million was provided for IFE energy development activities to allow progress on the ILSE heavy-ion driver. Additionally, the conference report calls on the President's Council of Advisors on Science and Technology (PCAST) to review the magnetic fusion energy and inertial confinement fusion energy development programs and to report to Congress on their future direction given the large sums required for program expansion.[50] PCAST is expected to begin their review of the fusion program early in 1995 and to complete their recommendations by June 1995, according to DOE. [51]

The FY 1995 budget provides adequately for ITER activities and in that respect is in agreement with FEAC, FPAC, congressional recommendations, and the DOE request. Delays in construction of TPX are not consistent with the schedules recommended by the advisory panels and will eventually add to its cost. (Preliminary estimates of the cost of the one-year delay have not yet been made public.) The budget increases restore some funding for development of ILSE in the IFE program but are still less than reviewers recommendations.[52] TPX and ITER supporting research and development activities continue to absorb most of the rest of the fusion program budget given the directives of the FY 1993 conference report (see figure 2-7).

Overall the FY 1995 budget is approximately at the levels and priorities analyzed by FEAC for magnetic fusion, but is less than the funding level suggested for IFE. Appropriations levels and intra-program allocations have continued to fall far short of the recommendations of FPAC for both programs. It is probably too early to determine what effect, if any, the project delays and decreased funding of basic program components may have on attainment of the ultimate goal of developing a technically viable demonstration fusion reactor by 2025.

To the extent that ITER and TPX become the exclusive driving focus of the magnetic fusion program, FEAC and FPAC hopes that recommended budget increases would restore balance to the program in support of basic physics, alternative concepts, and materials and technology development have not been met.

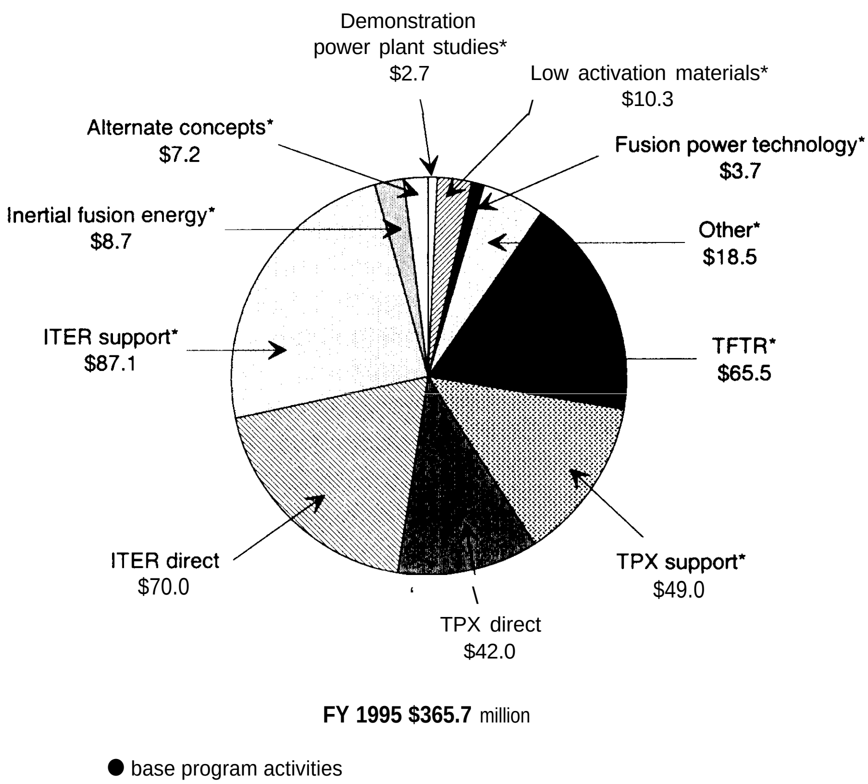
ITER and TPX-related budget demands will continue to create budget pressures on other program elements. TFTR decommissioning expenses will absorb much of the roll off from shutting down TFTR operation for several years. Over the next few years, DOE and the program will need to obtain additional increments required for TPX construction and operation, ITER final design and siting activities, ITER construction, and development of heavy-ion drivers. FPAC estimated that these increments could increase the to-

[50] Conference Report on H.R. 4506, at 140 *Congressional Record* H6942, Aug. 4, 1994 (daily ed.)

[51] "Curtis Warns New Congress, Tight Budget Will Harm Fusion Program," *Inside Energy with Federal Lands*, Dec. 5, 1994, p. 11.

[52] The status of ILSE is still uncertain. The Office of Energy Research has suggested that Lawrence Berkeley Laboratory scale back the ILSE project and proceed with construction of the first third of the proposed project on a stretched out schedule and call it "ELISE." Roger Bangerter, Lawrence Berkeley Laboratory, personal communication, Nov. 17, 1994.

FIGURE 2-7: U.S. Department of Energy Magnetic Fusion Program Budget, FY 1995, by Activity



NOTE: Total funding for fusion activities reflects the Office of Fusion Energy share of the general reduction in DOE spending of $8 million from the FY 1995 appropriation of $3726 million. Activity categories reflect DOE program managers' assessments of how fusion funds are allocated among R&D activities and are not identical with budget categories used in appropriations requests

SOURCE: Office of Technology Assessment, 1995, based on information from the U.S. Department of Energy

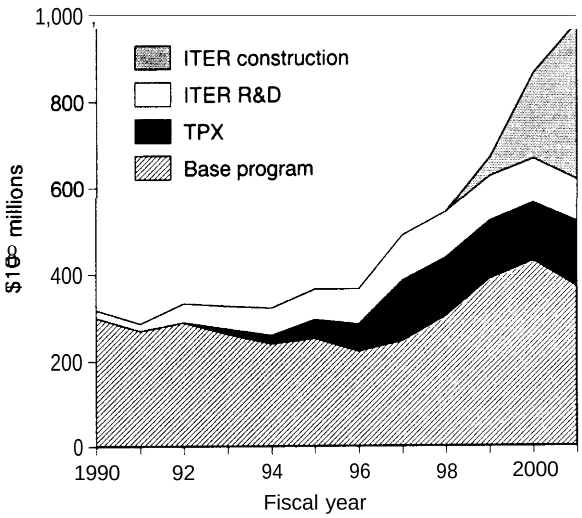
tal fusion program budget to $1 billion per year by the late 1990s and that annual budgets of at least this amount will be needed to support activities needed to enable informed decisions on selection and design of a demonstration reactor to be operational by about 2025.

FUTURE BUDGET CHOICES

To meet the magnetic fusion program's fusion energy development path laid out in prior program plans calling for maintenance of a base program, construction of TPX and participation in ITER EDA activities, funding would have to rise from the current level of $372 million in FY 1995 to almost $550 million in FY 1998. A decision to proceed with ITER construction could require annual increments above 1998 levels rising from about *$50* million in FY 1999 to about $400 million in FY 2001[53] and higher as construction activity increases (see figure 2-8). This estimate assumes

[53] Estimates are from figures prepared by DOE for remarks of N. Anne Davies, Director, Office of Fusion Energy, presented to the Fusion Energy Advisory Committee, Dec. 1, 1994. The estimates are based on internal planning documents of OFE and are not reflected in DOE out-year budget estimates included in the President's FY 1995 budget request to Congress.

FIGURE 2-8: Estimated Funding Levels for Magnetic Fusion Energy Program for TPX, ITER and 2025 DEMO, FY 1990-2001 (S in millions as spent)



NOTE: This figure is based on internal Off Ice of Fusion Energy planning estimates and the funding levels shown are not reflected in FY 1995 budget request documentation The increase in base program funding in FY 1997-2001 reflects increased activity in support of TPX and ITER and for a proposed fusion materials test facility

SOURCE: Office of Technology Assessment, 1995, based on information from the U.S. Department of Energy

that ITER is not located in the United States, thus avoiding a possible host country premium.[54] However, present budget plans calling for flat budgets for discretionary programs would seem to rule out any real increase in the fusion program budget without a substantial justification for it and a corresponding reduction in another program.

The fusion program would seem to have several options under a five-year flat-budget horizon. It could try to meet direct funding needs for EDA activities and a stretched out construction schedule for TPX by cutting more deeply into base programs. How viable such an approach would prove is questionable, since a significant portion of the base program activities underwrite research programs that lend indirect support to ITER and TPX projects or are complementary to them. Cutting into the base program would make it even harder to fund initiatives to expand consideration of alternative nontokamak confinement concepts, including inertial fusion energy and the development of advanced materials and reactor technologies necessary for progress toward DEMO. Such a funding scenario might also call into question the rationale for proceeding with a major new domestic tokamak and ITER while substantially weakening the domestic base program and the research and industrial infrastructure that is intended to benefit from these activities.

As difficult as the problems for the fusion program seem under a future flat-budget scenario, proposals to cut energy research spending dramatically, including fusion, may trigger further debate about the appropriate role and direction for the fusion program under lower budgets. Some members of the fusion research community question whether a low budget path would be warranted at all, except perhaps to document the state of fusion research for future generations or perhaps to allow U.S. researchers to participate at some level in the fusion research programs in Japan, Europe, and Russia—assuming of course that those nations elect to continue their efforts in the absence of an active United States program. Others are not nearly so pessimistic, although they too would express disappointment if the U.S. were not to participate directly in the next “big step” fusion project. Among this latter group, some see the possibility

[54] In discussions investigating issues related to ITER siting, representatives of the parties and observers have suggested that the host country for ITER could be requested to pay an additional '“premium” or contribution to ITER costs in recognition of the economic benefits that might flow to the local economy from hosting such a large construction project and research facility. A precedent for such a premium is the arrangement that led to the Joint European Torus (JET) facility being located at Culham, United Kingdom, where the British Government agreed to pay more than its proportional share of the costs for this European fusion program facility.

of sustaining progress in fusion research by focusing on physics issues using existing smaller machines, increasing international collaboration, a modest effort in investigating alternative concepts, and concentrating on materials and technology advances that would be necessary for fusion power reactors. Eventually, however, progress toward development of a fusion powerplant will require a commitment to construction of very expensive new facilities.