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Congress and the Fusion Energy Sciences Program: A Historical Analysis

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ABSTRACT

The U.S. government has been funding research into controlled thermonuclear fusion since 1951. Since 1957, when the program was declassified, a public record is available in the form of appropriations and authorization reports presenting congressional decisions about fusion research. This report analyzes that record in order to assess how the program may fare in the future. The program recently underwent a major restructuring at the direction of Congress, and is currently establishing plans about how to proceed toward the goal of developing a practical fusion powerplant. These plans are likely to be the subject of close congressional scrutiny during review of the FY2001 budget request from the Department of Energy. The report should be helpful, to Members and staff who will be part of that review, in putting the program's budget request into perspective. It supplements a CRS Issue Brief, IB91039, on the DOE Fusion Energy Sciences Program. This report will be updated as appropriate.

Congress and the Fusion Energy Sciences Program: A Historical Analysis

Summary

In FY1996, the Department of Energy's Fusion Energy Science program carried out a significant restructuring at the request of Congress. The program's budget was reduced by 40% from the previous fiscal year, and the program was directed to increase emphasis on fusion and plasma science research. At the same time, the program's primary goal remains development of a long-term energy source. While Congress appears satisfied with the changes made by the fusion program since 1995, it remains to be seen how that support will fare if and when the program again requests funds to pursue development of a fusion power reactor.

How Congress might address such a request will be informed by analyzing how Congress has dealt with the program in appropriation and authorization actions since its inception. The program, which began in 1951 in the former Atomic Energy Commission, was declassified in 1957. In 1975, the program moved to the former Energy Research and Development Administration and, in 1978, to the Department of Energy.

Since the fusion program's declassification, congressional appropriations and authorization reports provide a written record of congressional views about the program. From a review of those reports, nine themes emerge. These themes are: continuing support for the goals of fusion research, recognition of the long time needed to reach the goal of fusion energy, uncertainty about the time needed to reach program goals, larger and more complex facilities, international fusion research competition and cooperation, federal budget constraints, relation to the nation's energy situation, debate over program focus — science vs. energy — and the role of alternative concept research. Throughout the 42 years of congressional consideration of fusion budget requests, these factors appear again and again, usually as prominent issues, in the appropriations and authorization reports.

As Congress considers the program in the coming years, several questions are likely to arise about how it should continue. These questions, for the most part, are extensions of the themes described above. They include: is U.S. fusion research a science or energy program? If fusion is a science program will it be sustained? As an energy program, how long can fusion research be sustained? What will happen when larger research facilities are requested? What would be the role of international collaboration? Under what conditions could U.S. fusion research be expanded? How these questions are addressed and answered will likely determine the future of fusion research in the United States.

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Introduction

This report reviews and analyzes the 42-year history of congressional deliberations over funding of the magnetic fusion research and development (R&D) program. That analysis provides the basis for an assessment about how the program might fare in the future as it proceeds in the direction of developing a long-term energy source from fusion. The assessment is presented as a series of questions that Congress may wish to address in determining the program's future.

In 1995, Congress appropriated 40% less money than DOE requested for FY1996 for the Fusion Energy Science (FES) Program of the Department of Energy. In addition, Congress directed DOE to restructure the program, emphasizing fusion and plasma science and to expand its efforts on alternate confinement concepts. Congress also told DOE that it could expect no more than level budgets for the foreseeable future and that it should integrate its plans for the restructured program with the international fusion effort.[1] Subsequent to this action, in 1998, Congress directed DOE to discontinue its participation in the International Thermonuclear Experimental Reactor (ITER) project upon completion of the U.S. commitment to the project's Engineering Design Activity in July 1998. Congress provided enough funds for FY1999 to close out DOE's obligation to the project.[2]

Today, the DOE FES program is as small as it has been since the early 1970s, as shown in Figure 1 (next page - see Appendix for data), which presents the budget history of the program in year 2000 dollars. Two medium-sized facilities are being supported, the DIII-D tokamak device at General Atomics and the Alcator Mod-C tokamak at MIT. In addition, the program is funding an expanded effort in alternate concepts and has placed significantly more emphasis on plasma and fusion science and engineering. The program changed its name from Magnetic Fusion Energy to Fusion

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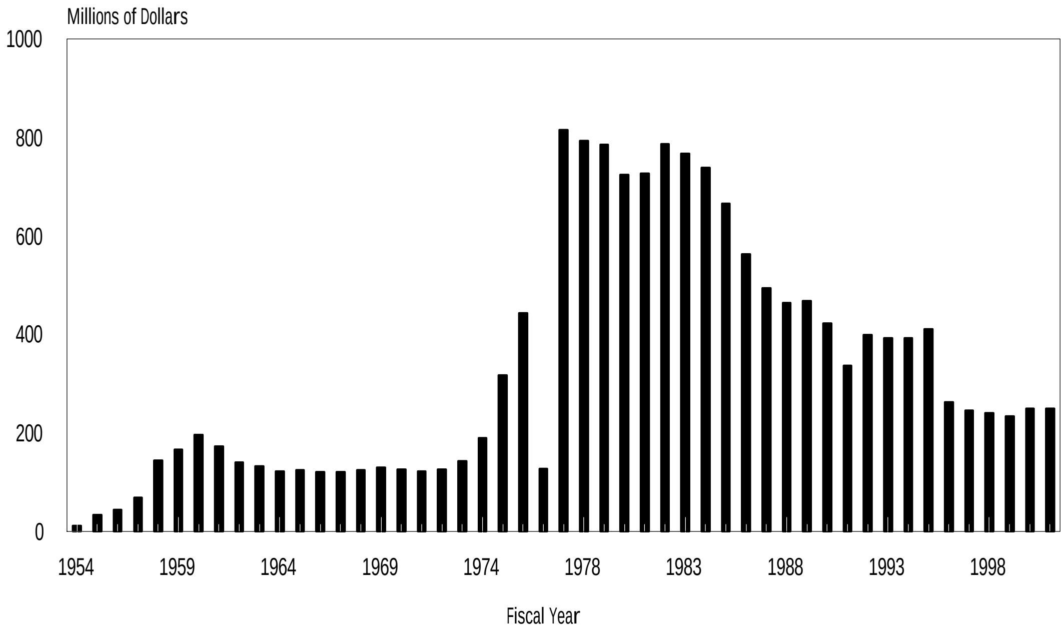
[1] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1996*, 104th Congress, 1st Session, H.Rept. 104-149, 76; Senate Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1996*, 104th Congress, 1st Session, S.Rept. 104-120, 95.

[2] Conference Report, *Making Appropriations for Energy and Water Development for the Fiscal Year Ending September 30, 1999, and for Other Purposes*, 105th Congress, 2nd Session, H.Rept. 105-749, 100.

Energy Sciences and moved to the Science account within DOE.[3] Currently, a series of reviews have been or are in the process of being completed about the program and, among other things, a convergence of magnetic and inertial fusion energy research appears to be in the offing.

Figure 1. Fusion R&D Funding History (Year 2000 Dollars)



Congress appears to be satisfied with the steps the program has taken and its primary status as a science program. For FY2000, Congress approved a budget $15 million above the request and in line with the recommendations of the Fusion Energy Sciences Advisory Committee[4] and the Fusion Task Force of the Secretary of Energy's Advisory Board.[5] In the Conference Report on the FY2000 Energy and Water Development Appropriations (H.Rept. 106-336), Congress approved the support for the program expressed by the SEAB Task Force and urged DOE to follow the recommendations of the FESAC report in allocating the additional funds provided for FY2000.

Currently, there appears to be clear congressional support for the fusion program as it now exists. As long as the fusion program remains primarily focused on fusion science and does not request significant increases in its budget, Congress probably will

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[3] For a discussion of current issues facing the program see; Congressional Research Service, *Magnetic Fusion: The DOE Fusion Energy Sciences Program,* by Richard E. Rowberg, CRS Issue Brief 91039.

[4] U.S. Department of Energy, Fusion Energy Sciences Advisory Committee, *Report of the FESAC Panel on Priorities and Balance*, September 13, 1999, http://vlt.ucsd.edu/revisedpanel.pdf.

[5] U.S. Department of Energy, Secretary of Energy Advisory Board, *Realizing the Promise of Fusion Energy; Final Report of the Task Force on Fusion Energy,* August 9, 1999, http://vm1.hqadmin.doe.gov:80/seab/

support the program. The program, however, very likely cannot continue at its current level indefinitely if progress towards a fusion power reactor is to be made. At some point, larger machines are likely to be needed if promising concepts are to be tested and additional funds are likely to be requested. How Congress will react to such a request depends on factors that are uncertain at this time.

Nevertheless, a review of congressional actions on the program's budget requests since the program was declassified in 1957 and the issues Congress has addressed in the course of those deliberations is useful. While the membership of Congress has changed numerous times over that period, there are certain "constants" about congressional responsibilities and interests related to the program. These "constants" include congressional appropriations and oversight duties, its representational focus, and its fundamental interest is the nation's well-being. These "constants" will continue to hold in the future, and are expected to channel congressional response towards future fusion program budget requests in a manner similar to that in the past depending on the conditions that prevail at the time.

Historical Assessment

Background

Magnetic fusion research (hereafter called the fusion program) originated as a classified program in 1951 in the former Atomic Energy Commission. Since declassification in 1957, congressional consideration of the program's budget request and oversight of the program's progress have been a matter of public record. A large hearing record has been built up over the last 42 years, along with an extensive report record from the appropriation and authorization committees.

The fusion program remained in the Atomic Energy Commission (AEC) until 1975, when the Commission was abolished. At that time, fusion research was included in the Energy Research and Development Administration (ERDA). A second change occurred in 1978 when ERDA was abolished and the fusion program became part of the Department of Energy (DOE), where it has resided ever since. For FY1958 and FY1959, the fusion program's appropriation was included in the Atomic Energy Commission Appropriations bill. From FY1960 to FY1975, the entire AEC appropriation, and with it the fusion program's appropriation, was contained in the Public Works (to FY1967) and the Public Works and Water Development and Atomic Energy Commission (to FY1975) appropriations bills. With the formation of ERDA and subsequently DOE, the fusion program's appropriation was contained in the Public Works for Water Development and Energy Research Appropriations bill (to FY1979) and finally the Energy and Water Development Appropriations bill (to present). Authorization was the responsibility of the Joint Committee on Atomic Energy (JCAE) through FY1977, and has since been the responsibility of the House Science Committee and the Senate Energy and Natural Resources Committee.

Themes

By examining the reports prepared by the congressional appropriations and authorization committees in conjunction with the appropriations and authorization bills covering the fusion program, an historical overview of how Congress has regarded the federal effort to achieve controlled fusion can be readily obtained. Several themes emerge from that overview about how Congress has dealt with the program as it has undergone many changes over the past 42 years.

1. Continuing support for the goals of fusion research.

From the program's inception, Congress has acknowledged the significant potential of fusion energy as a long-term source of energy for the planet. The fusion research effort (first known as Project Sherwood in the AEC) was a high priority of the JCAE.[6] During the 1960s, the JCAE continued to note the potential benefits of fusion and urged the AEC to provide more resources for the program. In the 1970s, when the nation began experiencing the energy problems it would face throughout the decade, both the JCAE and the Appropriations committees asserted support for the program and recognition of its long-term potential. Concern was often expressed by Congress, in this context, about the slow pace of development. For example, in consideration of the FY1972 AEC budget, the House Committee on Appropriations stated,

> The Committee continues to be concerned at the slow pace of the development of this program which, if successful, could be the answer to the long range energy problems facing the Nations and the world. ... the Committee believes that we must proceed now without further delay. This is more reason, however, for the AEC to place greater current emphasis on this program ... for acceleration of this research and development effort in the public interest.[7]

During the mid-1970s, Congress begin authorizing and appropriating funding increases for the program above the requested amounts. In 1972, the JCAE noted with approval the establishment of a separate division within the AEC for controlled thermonuclear research as indicative of the program's importance.[8] Fusion was viewed as the likely key to the nation's long-range energy future. This support continued throughout the 1970s. In 1978, both the House and Senate Committee on Appropriations, in considering the FY1979 DOE budget request, stated,

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[6] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission,* 85th Congress, 1st Session, U.S. Senate, Report No. 791, 7.

[7] House Committee on Appropriations, *Public Works for Water and Power Development and Atomic Energy commission Appropriations Bill, 1972,* 92nd Congress, 1st Session, H.Rept. 92-381, 8.

[8] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year, 1973,* 92nd Congress, 2nd Session, S.Rept. 92-802, 25.

> However, the potential promise of a clean, inexhaustible source of energy from the fusion process is of sufficient importance to warrant an aggressive development program.[9]

Both committees recommended increases to the funds being requested.

In 1980, Congress passed the Magnetic Fusion Energy Engineering Act, which, among other things, provided a recognition of the importance of continued pursuit of the goal of commercial production of energy from fusion. In addition to the potential energy benefits, Congress stated that successful fusion energy development in the United States could mean substantial economic benefits for the country.[10]

In the early 1980s, Congress continued to express its support of the fusion R&D program, although the rapid funding growth of the 1970s ceased. While the Reagan Administration dramatically reduced requests for most of the energy R&D funded by DOE in FY1981, it did not do so for fusion research until FY1986[11]. Language in the appropriations committees' reports continued to express a belief in the potential long-term energy, environmental, and economic benefits of fusion energy. That language had not changed significantly since the early 1960s. Congress also supported the Administration's budget requests until FY1985. From FY1985 to FY1988, however, funding for fusion research declined substantially, triggered in part by the large drop in the request from FY1985 to FY1986.[12] Some of that decline was also due to congressional actions that reduced the appropriation below the request in three of those years. Nevertheless, Congress continued to express its support of the fusion effort. Both House and Senate Committees on Appropriations continued to note long support of the program and continued interest in its success. In 1988, for example, the Senate Committee on Appropriations in reporting its recommendations on the FY1989 DOE budget request stated,

> Because of uncertainties in the long-term energy supply, it is important to maintain steady progress toward the realization of fusion energy. The Committee has, therefore, long been supportive of the fusion program and believes it is important

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[9] House Committee on Appropriations, *Public Works for Water and Power Development and Energy Research Appropriation Bill, 1979,* 95th Congress, 2nd Session, H.Rept. 95-1247, 33. See also, S.Rept. 95-1069, 29.

[10] House Committee on Appropriations, *Fusion Energy Research and Development, and Demonstration Act of 1980,* 96th Congress, 2nd Session, H.Rept. 96-1096, 3.

[11] For FY1982, the first Reagan budget, the request for fusion energy R&D was $460 million compared to a request of $396 million for FY1981. By way of comparison, the request for renewable energy R&D was $241.7 million compared to $654.4 million in FY1981. These actions reflected the new Administration's desire to reduce federal funding of R&D it believed was best carried out by the private sector but to continue support of basic research. The fusion program budget request grew to $483.1 million for FY1985, but declined sharply over the next two years to $333 million for FY1987.

[12] The House Committee on Appropriations had in FY1985 recommended a reduction of $64 million from the request (see below).

> for the Government to support the program through the present research phase until a definitive engineering and economic assessment can be performed.[13]

In the 1990s, Congress maintained its support of the goals of the fusion program but effected significant changes in its financial support. Funding for FY1996 was reduced by 40% from the request. Even before that reduction, however, Congress was tightening the budget allocations for the program and restricting the start of new major projects. While explicit language emphasizing that Congress had long supported the goals of fusion and continued to do so was notably absent during the decade, the ultimate value of the program was not questioned in report or bill language either. Congress continued to note the long-term energy focus of the program. In its report for the FY1993 DOE appropriations, the Senate Committee on Appropriations noted,

> the Committee ... endorses a magnetic fusion energy program that can lead to an ultimate long-term advanced energy source for the country ... .[14]

Even after the FY1996 changes, expressions of support continued. In the FY2000 DOE appropriations report, the House Committee on Appropriations stated,

> The Committee remains committed to a fusion program that is based on ... the ultimate goal of practical fusion energy.[15]

During the 42-year span that witnessed substantial changes in budget levels, congressional support for a federally funded fusion energy R&D effort and for its goal appears to have remained high. Over that period, Congress has noted also other benefits of the program such as advances in plasma science and engineering and the production of many highly trained scientists and engineers.

2. Recognition of the long time needed to reach the goal of fusion energy.

Another theme of congressional consideration of fusion R&D budgets over the years has been the awareness that success in achieving the goal of energy production from controlled fusion would take a long time. There has been an acknowledgment that achieving successful energy production from fusion would be one of the most challenging scientific and technical endeavors ever attempted. Estimates have changed since 1957 of how long it would take to reach that goal from the year in question. The Magnetic Energy Fusion Engineering Act of 1980, adopted a 20-year time frame by setting a goal of 2000 for the demonstration of fusion power. As discussed below, DOE, at the time, believed that demonstration could be obtained in less time if annual funding levels were increased. The 20-year period, however, has been the most optimistic time frame considered by Congress with periods of 40 to 50 years cited in the early 1980s.

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[13] Senate Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1988,* 100th Congress, 1st Session, S.Rept. 100-159, 116.

[14] Senate Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1993,* 102nd Congress, 2nd Session, S.Rept. 102-344, 89.

[15] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 2000,* 106th Congress, 1st Session, H.Rept. 106-253, 115.

The recognition of the long period that would be required for success meant that fusion was never considered an immediate oil replacement energy source. Furthermore, fusion was not considered a direct competitor to near-term fission energy, i.e., the light water reactor. [16] Indeed, the JCAE stated in 1967

> .... fusion research and its later development can stimulate the nuclear fission effort, including the infant breeder program ... . [17]

The program has been considered along with solar and, during the 1970s, the breeder reactor, as the leading candidate for the nation's primary long-term energy source. In 1975, the House Committee on Appropriations stated,

> Two of the most important potential sources of infinite energy are solar power and controlled thermonuclear fusion. ... The Committee strongly supports these two programs although the payoff ... is in the distant future.[18]

In 1981, it stated,

> Both the nuclear fission and fusion programs [within DOE] offer the potential for virtually inexhaustible energy resources for the future.[19]

This absence of near-term competition probably contributed to congressional support of the program for such a long period. Congress appears to have accepted the notion that short-term goals are not meaningful for this program and has judged it more on how it has advanced fundamental scientific and technical knowledge of plasma physics and fusion science and engineering. In this sense, Congress may have been judging the program in a manner similar to how it considered other long-running basic research programs such as high-energy physics.

3. Uncertainty about the time needed to reach program goals.

While recognizing the long-term nature of the fusion R&D effort, Congress also continually probed fusion program officials about how long would it take to reach program goals of scientific and commercial demonstration. During the 1960s, when progress was slow, Congress on several occasions exhorted AEC officials to focus on the most promising concepts in order to permit savings and accelerate progress.[20]

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[16] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission,* 85th Congress. 1st Session, S.Rept. 791, 7.

[17] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1968,* 90th Congress, 1st Session, H.Rept. 369, 39.

[18] House Committee on Appropriations, *Public Works for Water and Power Development and Energy Research Appropriation Bill, 1976,* 94th Congress, 1st Session, H.Rept. 94-319, 8.

[19] House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1982,* 97th Congress, 1st Session, H.Rept. 97-177, 70.

[20] House Committee on Appropriations, *Public Works Appropriation Bill, 1963,* 87th

(continued...)

In 1967, the JCAE stated its belief that the feasibility of fusion could be demonstrated within 10 to 11 years, in line with a target date set by the AEC for itself.[21] In the early 1970s, the appropriations committees began to express concern about the slow pace of the program. For the FY1971 AEC appropriations, the House Committee on Appropriations stated,

> The committee has long been concerned at the slow pace of the development of this program which, if successful, could be the answer to the energy problems facing the Nation and the world.[22]

Such expressions coincided with the first concerns about the nation's energy future. When the program began to make significant advances in the early 1970s with the advent of the tokamak, Congress began to press for closer targets for achieving scientific feasibility. In 1972 the JCAE noted that during hearings it had held in 1971 on the fusion program, a date of 1980 was advanced as possible by the AEC for achieving scientific feasibility assuming adequate funding.[23] Based on those statements, program funding was increased over the requested amounts. In 1974, in response to AEC statements that a demonstration power reactor would not be possible before the late-1990s rather than the mid-1990s given in earlier estimates, the JCAE increased the authorization for the program and directed an acceleration of efforts.

When the fusion program was absorbed by ERDA in 1976, the program's pace slowed and it was reported to the JCAE in 1976 that a demonstration power reactor could not be ready before the 2005 to 2010 period. A 1976 report prepared by ERDA presented funding requirements for achieving a demonstration plant in the late 1990s, but the Administration chose to proceed at a slower pace with smaller budget requirements.[24] At that time, the Committee found "this slippage to be unacceptable" and directed that the program be accelerated to meet a late-1990s goal and added funds to the authorization.[25]

In the early 1980s, Congress noted the possibility that demonstration of scientific feasibility could be close because it was expected that the Tokamak Fusion Test

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[20] (...continued)
Congress, 2nd Session, H.Rept. 2223, 61.

[21] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1968,* 90th Congress, 1st Session, S.Rept. 349, 39.

[22] House Committee on Appropriations, *Public Works for Water, Pollution Control, and Power Development and Atomic Energy Commission Appropriation Bill, 1971,* 91st Congress, 2nd Session, H.Rept. 91-1219, 10.

[23] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1973,* 92nd Congress, 2nd Session, S.Rept. 92-802, 25.

[24] U.S. Energy Research and Development Administration, *Fusion Power by Magnetic Confinement Program Plan,* ERDA-76/110 (July 1976).

[25] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Energy Research and Development Administration for Fiscal Year 1977,* 94th Congress, 2nd Session, S.Rept. 94-762, 10.

Reactor (TFTR), then under construction, might be able to achieve energy breakeven when using deuterium and tritium. Successes on the tokamak during the 1970s had made fusion researchers optimistic about being able to achieve that goal. Based on those successes and the findings of the above-mentioned 1976 ERDA report, Congress enacted the Magnetic Fusion Energy Engineering Act of 1980 in an attempt to accelerate development of practical fusion power.[26] That Act set 1990 as the target for a fusion engineering device and 2000 for a demonstration reactor. Appropriations action, however, did not provide the funds that the Act authorized to meet the 2000 target. In 1983, Congress stated that even though demonstration of scientific feasibility appeared close, it would still be a very long time to practical power, requiring considerable basic science research.[27] Congress did not give any indication of how long it believed that period to be.

The following year, the House Committee on Appropriations expressed concern with statements from DOE that practical fusion power was 40 to 50 years off. In 1989, Congress noted that the date that commercial fusion power might be achieved continued to move further away.[28] The realization that it would take at least several decades to reach a commercial fusion power plant seems to have marked a turning point in congressional treatment of the program. Since the late 1980s, no mention has been made by Congress of explicit target dates.[29] Furthermore, while remaining supportive of the program's goals, Congress began to try to change the focus of the program more towards science, and its budgetary support started to decline. It is likely that the large budgetary requirement of continuing the program for 40 to 50 years at the level of effort existing in the late 1980s has been a major factor in the reorientation of the program that Congress directed over the last 15 years.

4. Larger and more complex research facilities.

Almost from the onset, progress in fusion research has required larger and larger facilities. Congress has acknowledged that need, and a major portion of its appropriation and authorization efforts about the fusion program has been directed

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[26] In 1979, the House Science and Technology Committee asked DOE to prepare budget and schedule plans that would result in a demonstration plant on line in 1995 and 2000. The first case was estimated to cost a total of $12.1 billion (in 1981 dollars) from 1981 to operation of the demonstration plant in 1995, while the second case was estimated to cost $11.9 billion from 1981 to 2000, also in 1981 dollars. The former would have reached annual spending levels of over $1 billion while the latter would have peaked at $700 million per year. It is likely that those high annual funding levels are the main reason ERDA and DOE did not proceed with the accelerated case. House Committee on Science and Technology, Subcommittee on Energy Research and Production, *The Magnetic Fusion Energy Program – Its Objective and Pace; Hearings,* 96th Congress, 1st Session, December 11, 1979, 9.

[27] House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1984,* 98th Congress, 1st Session, H.Rept. 98-217, 87.

[28] House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1990,* 101st Congress, 1st Session, H.Rept. 101-96, 77.

[29] In 1990, the DOE Fusion Power Advisory Committee recommended to the DOE Secretary a 2025 target date for commercial fusion, which was adopted by DOE until 1995. Dr. Steven Dean, President, Fusion Power Associates, private communication.

at reviewing requests for those facilities. While Congress was generally supportive of larger machines until the late 1980s, questions continually arose about the program's efforts to determine which of the facilities were the most promising. (It is worth noting that such support did not result in the construction of any new major facilities past 1983 for reasons that will be discussed below.) This was particularly true during the 1960s when the program was pursuing several different approaches. In the early 1960s, Congress directed the AEC on two occasions to choose among the five options the agency was pursuing in order to make more efficient use of limited budget resources.[30] The AEC did not comply, stating it was premature to select a most promising option.

During the 1970s, when fusion program budgets were rising rapidly and the tokamak concept emerged, Congress generally backed AEC, ERDA, and DOE requests for construction of ever-larger machines, primarily tokamaks. That support, however, was often accompanied by requests for more evidence of success. In 1974, the JCAE stated,

> The Joint Committee also notes the desire of the Commission to proceed with larger experiments. While the scientific progress during the year appears to justify this action, the Joint Committee encourages the Commission to demonstrate scientific feasibility before building the more expensive larger experiments.[31]

Nevertheless, two years later Congress approved start of construction of the Tokamak Fusion Test Reactor (TFTR), the largest project to date in the U.S. magnetic fusion program.[32] Congress also anticipated that this project would "allow the first major demonstration of scientific breakeven."[33]

When funding leveled off in the early 1980s, however, it was necessary for DOE to shut down a large facility testing the magnetic mirror concept. In the mid-1980s, Congress acknowledged the likelihood that an ignition experiment would eventually be needed following successful demonstration of scientific feasibility in the TFTR. At the time, however, it directed DOE to focus its efforts more on establishing the scientific base needed for fusion energy and to delay any commitment to such a project until FY1987.[34] Nevertheless. Congress provided funds to begin preliminary

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[30] House Committee on Appropriations, *Public Works Appropriation Bill, 1963,* 87th Congress, 2nd Session, H.Rept. 2223, 61; House Committee on Appropriations, *Public Works Appropriation Bill, 1964,* 88th Congress, 1st Session, H.Rept. 902, 57.

[31] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1975,* 93rd Congress, 2nd Session, S.Rept. 93-773, 23.

[32] The TFTR was authorized at $215 million in 1975. Joint Committee on Atomic Energy, *Authorizing Appropriations for the Energy Research and Development Administration for Fiscal Year 1976 and for the Transition Quarter Ending September 30, 1976,* 94th Congress, 1st Session, S.Rept. 94-104, 42.

[33] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1982,* 97th Congress, 1st Session, H.Rept. 97-177, 87.

[34] House Committee on Appropriations, *Energy and Water Development Appropriation Bill,*
(continued...)

planning work on a larger ignition tokamak that would be called the Compact Ignition Torus (CIT).[35] In the early 1990s that project was canceled by DOE with congressional consent.

In the early 1990s, Congress approved DOE participation in the engineering design of the International Thermonuclear Experimental Reactor (ITER) project. This program allowed Congress to approve the design of a large experiment to demonstrate scientific and engineering feasibility of fusion. The experiment's cost would be shared by the international fusion research community. In 1992, Congress gave DOE approval to begin preliminary work on the tokamak physics experiment (TPX), a follow-on device to the TFTR.[36] The TPX was to be a steady-state tokamak that would supplement the ITER facility. In 1993, however, the Senate Committee on Appropriations, expressing concerns about the TPX, stated,

> While the Committee supports design activities related to TPX, the Committee is concerned that moving forward with construction of TPX, in absence of a commitment from other countries to build ITER, runs a serious risk that any U.S. investment in TPX will be lost.[37]

Finally, in 1995, Congress reduced the fusion budget significantly, as discussed above, resulting in the end of the TPX project. Concerns about ITER resulted in termination of U.S. involvement in that project three years later.

The history of congressional decisions about fusion program requests for larger facilities has been somewhat mixed. Recognition by Congress that such facilities would be needed to advance fusion research toward the goal of practical power production has been tempered by concerns about the pace of the program and budget constraints. It seems clear that the latter has dominated since about 1985. Nevertheless, as attested by approval of construction of the National Spherical Tokamak Experiment (NSTX) as well as upgrades of the two existing large tokamaks — the DIII-D and Alcator C-Mod — Congress remained, to a degree, supportive of large device fusion research.

5. International fusion research competition and cooperation.

From the outset, fusion research has been an international effort. Throughout the last 42 years, Congress has been supportive of U.S. participation in that effort, although at times, that support has been tempered by concerns about international competition. Furthermore, until the late 1980s, when ITER first appeared,

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[34] (...continued)
1985, 98th Congress, 1st Session, H.Rept. 98-755.

[35] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1988*, 100th Congress, 1st Session, H.Rept. 100-162, 80.

[36] Conference Committee, *Energy and Water Development Appropriations Bill, 1993*, 102nd Congress, 2nd Session, H.Rept. 102-866, 77.

[37] Senate Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1994*, 103rd Congress, 1st Session, S.Rept. 103-147, 95.

international considerations were mentioned only briefly in reports accompanying appropriations and authorization legislation.

During the 1960s, Congress made note of the research efforts being carried out by other nations including the Soviet Union, and on occasion suggested that international research efforts were growing faster than those in the U.S.[38] The introduction of the tokamak into the U.S. research program was accompanied by congressional statements referring to the Soviet success in the development of that concept.[39] In 1971, the JCAE expressed approval of the free flow of information among the several countries engaging in fusion research. It stated,

> The Joint Committee recognizes the fact that considerable progress has been made in the past few years by teams of scientists in this and other countries, and commends the outstanding international cooperation as reflected by symposia where information is exchanged and reciprocal visits to facilities in various nations.[40]

During the energy price shocks of the 1970s, the international focus of Congress appeared to be primarily on how successful development in the U.S. could aid the nation's long-term energy independence. This factor might have contributed to the rapid increase in fusion budgets during the decade.

In the 1980s, the international focus shifted toward cooperation. House authorization bills over that period directed DOE to continue international cooperative efforts. The report accompanying the FY1981 bill stated,

> In addition, a continued international cooperative effort should be maintained to ensure the most rapid progress possible with respect to physics and technology developments pertinent to advancing fusion power production.[41]

The importance of international cooperation was also part of the Magnetic Fusion Energy Engineering Act of 1980, although Congress directed that such cooperation not dissipate U.S. leadership in fusion research.[42] The Act also noted that successful U.S. development of fusion power would be of substantial economic benefit.

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[38] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1967,* 89th Congress, 2nd Session, S.Rept. 1142, 30.

[39] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1971,* 91st Congress, 2nd Session, S.Rept. 852, 32.

[40] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1972,* 92nd Congress, 1st Session, S.Rept. 92-249.

[41] House Science and Technology Committee, *Authorizing Appropriations for the Department of Energy (DOE) for Civilian Research and Development Programs for Fiscal Year 1981,* 96th Congress, 2nd Session, H.Rept. 96-1179, 27.

[42] Senate Energy Committee, *Magnetic Fusion Energy Engineering Act of 1980,* 96th Congress, 2nd Session, S.Rept. 96-942, 5.

In the mid-1980s, the shift toward encouraging international cooperation intensified, and comments about international cooperation began to appear regularly in the reports. Congress began to assert that the development of fusion power would require an international effort, and that DOE should seek cooperative funding to make full use of domestic funds. It recommended international participation in an ignition experiment.[43] At the same time, Congress requested a plan from DOE on international cooperation. The plan was designed to ensure that there was no duplication of major facilities and that U.S. interests were protected by ensuring an equitable distribution of responsibilities.[44] In 1986, Congress noted the initial discussions among the major fusion research nations on the ITER experiment.[45] Funding for the initial design of ITER was first provided by Congress in FY1988. In the early 1990s, Congress made special note of how important it considered the ITER project and broader international cooperation to achieving practical fusion power. The House Committee on Appropriations stated,

> The Committee expects the Department of Energy (DOE) to remain a full and vigorous partner in the Engineering Design Activity (EDA) of the International Thermonuclear Experimental Reactor (ITER) and the Committee considers this collaboration a model of successful partnerships on large, scientific projects.[46]

In addition, legislation was reported in the Senate in 1994 that would have made ITER the primary focus of the domestic program.[47] Although Congress ended U.S. participation in the ITER project in the FY1999 appropriations bill, it stated in the conference report that the action was not a judgement about the value of international fusion research ventures. Rather, questions were raised about whether the "tokamak is the most promising technology" and "whether the current partners in ITER are willing and able to meet their commitments."[48] In the FY1999 conference report, Congress reiterated its support of international collaboration and encouraged continued DOE efforts.[49]

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[43] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1985*, 98th Congress, 2nd Session, S.Rept. 98-502, 105.

[44] House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1986*, 99th Congress, 1st Session, H.Rept. 99-195, 94.

[45] House Committee on Appropriations, *Energy and Water Appropriation Bill, 1987*, 99th Congress, 2nd Session, H.Rept. 99-670, 89; Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1987*, 99th Congress, 2nd Session, S.Rept. 99-441, 105.

[46] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1993*, 102nd Congress, 2nd Session, H.Rept. 102-555, 72.

[47] Senate Energy Committee, *International Fusion Energy Act of 1993*, 103rd Congress, 1st Session, S.Rept. 103-62.

[48] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1999*, 105th Congress, 2nd Session, H.Rept. 105-581, 87.

[49] Conference Committee, *Making Appropriations for Energy and Water Development for the Fiscal Year ending September 30, 1999, and for Other Purposes*, 105th Congress, 2nd Session, 100.

While Congress has expressed interest in the international aspects of the fusion program from its beginnings, emphasis on international cooperation has risen significantly during the past 15 years, reaching a peak with the ITER EDA. Even with the demise of that program, however, Congress appears to believe that eventual success in obtaining fusion energy production will require an international effort.

6. Federal budget constraints.

Throughout the past 42 years, Congress has on a number of occasions stated that budget constraints limited its support of the fusion program. That was especially true in the 1960s and from the late 1980s to the present time. Late in the 1960s, budget constraints were cited by the JCAE as the reason for withdrawing its prior approval of a plan to double the program's budget from FY1968 to FY1973.[50] During the 1970s, however, the focus on energy issues appears to have overcome concerns about budget limitations.

The situation begin to change in the early 1980s, as energy receded as a policy issue. In 1981, the Senate Committee on Appropriations cited fiscal austerity in directing DOE to take special efforts to control costs on its proposed fusion engineering device.[51] In 1988, budget constraints were cited by Congress as the reason for denying any of the requested construction funds for the compact ignition torus proposal.[52] While not explicitly stated, the large funding reduction that took place in 1995 was driven, to a large degree, by congressional desires to rein in federal spending. Finally, in referring to its actions for FY1997, Congress noted budget pressures in being unable to provide the full request even though it expressed approval of the steps DOE had taken in reorienting the program.[53]

While concerns about federal spending have existed throughout most of this period, Congress has not often invoked those concerns in dealing with the program's budget request. It seems clear that while fiscal constraints are an important consideration for Congress, other issues, such as the nation's energy problems, may override those constraints to some degree.

7. Relation to the nation's energy situation.

Congressional treatment of the fusion program and Congress's view of the nation's energy situation have been intertwined since the program's beginning. During the early 1960s, when energy prices were stable and supplies apparently secure, Congress supported the program with essentially no budget growth. Although

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[50] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1969,* 90th Congress, 2nd Session, S.Rept. 1074, 44.

[51] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1982,* 97th Congress, 1st Session, S.Rept. 97-256, 95.

[52] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1989,* 100th Congress, 2nd Session, H.Rept. 100-618, 69.

[53] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1998,* 105th Congress, 1st Session, S.Rept. 105-44, 94.

it acknowledged fusion had great potential as a long-term energy supply option, as described above, Congress did not express any urgency about the program. As the 1970s began, however, and pressure mounted on energy prices and supply, fusion research took on a new importance. Even though fusion was considered a long-term option with no prospect to relieve the immediate problems, Congress took steps to accelerate development of options it believed would provide long-term energy security for the nation. As early as 1971, the House Committee on Appropriations noted the importance of energy as stated above. As a result, the budget for the fusion program grew dramatically, and Congress on occasion increased funding above the requested amount.

In the 1980s, the energy pressures abated as the price of oil began to fall from the peaks of the late 1970s. Congress continued to acknowledge the importance of the potential of fusion (see above), but the urgency of the 1970s appeared to abate. When combined with the realization that a practical fusion power plant was much further away than had been believed during the late 1970s, budget support began to decline. In 1982, the House Committee on Appropriations noted,

> Fusion has the potential of becoming a principal energy option for the Nation in the next century. This potential is based on a number of important features — the fuel reserves for fusion are vast, are readily available to all, and are free from the threat of embargo; .... Even so, obtaining economic fusion energy is a very long-term prospect .... The Committee endorses this measured approach [balancing science with a desire to proceed with engineering demonstration] of the Department [DOE].[54]

In the 1990s, energy concerns receded further from congressional consideration with respect to the fusion program. To be sure, Congress continued to recognize the ultimate objective of fusion as discussed above. In 1990, the Senate Committee on Appropriations noted,

> The target for completion of magnetic fusion development is determined by the present technical, economic, and political uncertainty of energy supply.[55]

While a desire to control federal spending was at the heart of the 1995 funding reduction, those actions were probably made easier by the absence in Congress of any overriding urgency about the need for new long-term energy sources. In addition, that belief also appears to have been part of the congressional direction that the program focus more on science and less on energy technology development.

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[54] House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1983,* 97th Congress, 2nd Session, H.Rept. 97-850, 35-36.

[55] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1991,* 101st Congress, 2nd Session, S.Rept. 101-378, 88.

8. Debate over program focus – science vs. energy.

An issue that has emerged in the past few years is about the broad focus of the fusion program. In 1998, the program was moved by direction of Congress from the DOE energy supply account to the DOE Science account.[56] The move appeared to be justified because of the intensified focus of the program on plasma and fusion science and engineering. The question that has emerged is whether the fusion program is now a science or an energy program.

For nearly all of the 42 years the fusion program has been declassified, appropriations and authorization report language emphasized the energy goals of fusion. While recognizing the long-term nature of fusion energy development, as described above, it is clear that Congress considered the fusion program primarily an energy program. Indeed, it is unlikely that Congress would have supported the program at the levels it has if advancement of plasma physics, not energy, was the primary goal of the program. On the other hand, Congress on many occasions over the years has referred to the scientific development of fusion. From 1960 to 1972, fusion research was included in the physical research division of the AEC, which contained all of the Commission's civilian basic research. For the most part, the programs of the DOE's Office of Science evolved from those physical research programs. In 1964, the JCAE noted,

> The controlled thermonuclear research program has, by it very existence, stimulated a completely new area of research — plasma physics. Because of this stimulus, basic knowledge about this newly recognized form of matter, different from solid, liquid, or gas —a fourth state of matter — is now available. .... The committee believes that the intrinsic results of the controlled thermonuclear program and the stimulated new outputs from plasma physics research justify the investment in controlled thermonuclear research.[57]

The Committee also noted the broad range of applications of that new knowledge.

During the 1970s, the attention of Congress focused almost exclusively on the energy goals of the fusion program. In 1972, the AEC created a separate division for controlled thermonuclear (fusion) research, a move that was approved by the JCAE.[58] While no specific mention was made of the science aspects of the fusion program during the 1970s, Congress continued to support the basic and applied plasma physics elements of the program in order to provide a base for achieving scientific feasibility. For example, for the FY1974 appropriations, the House Committee on

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[56] Conference Committee, *Making Appropriations for energy and Water Development for the Fiscal Year Ending September 30, 1999, and for Other Purposes,* 105th Congress, 2nd Session, H.Rept. 105-749, 100.

[57] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1965,* 88th Congress, 2nd Session, S.Rept. 987, 30.

[58] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1973,* 92nd Congress, 2nd Session, S.Rept. 92-802, 25.

Appropriations increased the fusion program's budget by $4.7 million "to accelerate the program to achieve scientific feasibility of controlled thermonuclear fusion."[59]

In the 1980s, a shift in emphasis began toward the science aspects of the program. To be sure, the science discussed was that underlying the fusion energy effort, and not plasma physics in general. The decade began with the Magnetic Fusion Engineering Energy Act of 1980, which directed DOE to put most of its emphasis on engineering and technology development leading to power production.[60] In 1982, however, Congress appeared to endorse an approach that would balance scientific goals with engineering goals. (See above, reference 54). In 1984, the House, in expressing concern about the pace of the program, directed DOE to shift program focus to the establishment of the science base needed for fusion energy before proceeding with engineering development.[61] The Senate, that year, also directed DOE to focus its efforts on establishing scientific feasibility in the TFTR before making a commitment to an ignition experiment.[62] From that point until 1995, Congress appeared to direct DOE to concentrate on both sound scientific research and the long-term goal of electric power generation from fusion. This direction was based on a DOE strategic plan development that emphasized, in the near term, establishment of the scientific and technological data base needed for fusion energy development.[63] In 1986, Congress also noted other benefits of fusion research:

> fusion research has resulted in significant advances in other areas of technology and scientific research .... It has also made outstanding contributions to the education of a generation of scientists and engineers with ... skills that are invaluable to the Nation for fusion and other high technology research. [64]

In the 1990s, concerns about the program's direction and pace grew. One result was that Congress began to increase its call for DOE to emphasize science relative to energy technology development. In 1990, the House Committee on Appropriations recommended that "the Department focus its research activities in a scientifically

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[59] House Committee on Appropriations, *Public Works for Water and Power Development and Atomic Energy Commission Appropriation Bill, 1974,* 93rd Congress, 1st Session, H.Rept. 93-327, 8.

[60] 94 STAT. 1539.

[61] House Committee on Appropriations, *Energy and Water Development Appropriation Bill,1985,* 98th Congress, 2nd Session, H.Rept. 98-755.

[62] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill. 1985,* 98th Congress, 2nd Session, S.Rept. 98-502, 105.

[63] House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1986,* 99th Congress, 1st Session, H.Rept. 99-195, 93; Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1986,* 99th Congress, 1st Session, S.Rept. 99-110, 105.

[64] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1987,* 99th Congress, 2nd Session, S.Rept. 99-441, 104.

oriented program."[65] Yet the energy goal was not abandoned but rather was included with science goals. In 1992, the Senate Committee on Appropriations stated,

> the Committee ... endorses a magnetic fusion energy program that can lead to an ultimate long-term advanced energy source for the country while broadening our understanding of plasma science and developing advanced technologies.[66]

In 1995, Congress accelerated the change of program emphasis to plasma science and engineering. DOE was directed to restructure the program to emphasize fusion science and alternative concepts. In subsequent years, Congress has approved the restructured program that now has plasma and fusion science as a primary focus. Symbolic of this restructuring was the program's name change from magnetic fusion energy to fusion energy sciences. Congress continues to recognize the ultimate energy goal of fusion through congressional support of DOE's "balanced program" that considers both scientific advancement and energy development as its goals. In 1999, the House Committee on Appropriations stated,

> The Committee remains committed to a fusion program that is based on both quality science and the ultimate goal of practical fusion energy.[67]

The view that success in fusion was a lot further off than believed or hoped during the 1970s and early 1980s, combined with budget constraints, has caused Congress to direct changes in the fusion program's focus over the last 15 years. To a significant degree, those two factors may be related. If funding had been available, scientific feasibility might have been proven and, possibly, a demonstration plant could have been operating within the time frames projected in the 1976 ERDA study and the followup 1979 analysis for the House Science and Technology Committee. DOE and Congress, of course, decided not to take that course, and Congress redirected the program more towards science. Today, from a congressional perspective energy appears to be a primary goal for the program. The emphasis on science likely reflects Congress's desire that the basis for an eventual fusion power reactor be as solidly grounded in fundamental science and engineering as possible.

9. The role of alternative concept research.

Another topic that recurs during congressional consideration of the fusion program is the emphasis on alternative concepts and the role of one such concept in particular, inertial confinement fusion (ICF). Sporadically, throughout the past 42 years, Congress has included these topics in report language. It has on occasion called on the fusion program to put more resources into the development of alternative concepts that might provide a less complex path to a practical fusion powerplant. These calls were relatively rare, however, until the last few years when

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[65] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1991,* 101st Congress, 2nd Session, S.Rept. 101-536, 85.

[66] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1993,* 102nd Congress, 2nd Session, S.Rept. 102-344.

[67] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 2000,* 106th Congress, 1st Session, H.Rept. 106-253, 116.

Congress directed the major restructuring of the program. In the FY1996 Conference Report, the conferees stated,

> The restructured program should emphasize continued development of fusion science, increased attention to concept development, and alternative approaches to fusion ....[68]

That was not the first call, however, for more research on alternative concepts. Congress called for more effort on alternative concepts in 1974 when the JCAE asked the AEC "to keep an active interest in and support of exploratory concepts ...."[69] In 1978, the House Committee on Appropriations recommended that DOE "pursue an aggressive evaluation of the small fusion system concepts to determine the potential of such alternative concepts ... ."[70] Similarly, the House Committee on Science and Technology in 1979 urged DOE to take such actions.[71] In 1984, the House Committee on Appropriations noted that it "attaches a high value to maintaining a broad and vigorous base program with emphasis on .... tokamaks, mirrors, and alternative concepts."[72] In 1995, as noted above, Congress directed major changes in the fusion research program and has continued to emphasize support of alternative concepts.

The alternative fusion concept that Congress has given the most attention to is inertial confinement fusion (ICF). Since the 1960s, Congress has been funding research in ICF first at the AEC, then ERDA, and now DOE. While the primary focus of the ICF program has been to support the nation's nuclear weapons program, Congress has also noted over the years the potential contribution of ICF research to the overall effort to achieve energy production from fusion.[73] In 1976, when ERDA took over the AEC research activities, Congress consolidated ICF and magnetic fusion under the general title of fusion power R&D within its appropriations accounts even though the ICF program was under ERDA's atomic weapons activities.[74]

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[68] Conference Committee, *Making Appropriations for Energy and Water Development for the Fiscal Year Ending September 30, 1996, and for Other Purposes,* 104th Congress, 1st Session, H.Rept. 104-293, 62.

[69] Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1975,* 93rd Congress, 2nd Session, S.Rept. 93-773, 23.

[70] Senate Committee on Appropriations, *Public Works for Water and Power Development and Energy Research Appropriations Bill, 1979,* 95th Congress, 2nd Session, S.Rept. 95-1069, 30.

[71] House Committee on Science and Technology, *Authorizing Appropriations for the Department of Energy for Fiscal Year 1979,* 95th Congress, 2nd Session, H.Rept. 95-1078, 271.

[72] House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1985,* 98th Congress, 2nd Session, H.Rept. 98-755, .

[73] Congress first noted the existence of the ICF program in the context of fusion energy in 1973. Joint Committee on Atomic Energy, *Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1974,* 93rd Congress, 1st Session, S.Rept. 93-224, 26.

[74] House Committee on Appropriations, *Public Works for Water and Development and*

(continued...)

Apparently, Congress considered both programs to have the same objective, although it did note the weapons applications of ICF (laser fusion at the time) as well.[75] When DOE was established, however, the ICF program was moved by Congress to the nuclear weapons R&D appropriation account and no longer was considered jointly with magnetic fusion. Nevertheless, Congress did acknowledge that there were civilian applications of ICF.[76] And, in the early 1980s, the House, on occasion, directed DOE to fund a small amount of ICF research on civilian applications within the magnetic fusion program.[77] Because the Senate did not agree to this action,[78] however, throughout the 1980s research on the civilian applications of ICF remained within the main ICF program under DOE's weapons activities.

In 1989, the Senate noted that DOE was adopting a new policy that would consider both inertial and magnetic fusion. While expressing concern about the long time it took "to put a stable and logical fusion program in place", the Committee's statement implied support for consideration of both options.[79] In 1991, Congress once again provided funding within the magnetic fusion program for research on civilian applications of inertial fusion energy.[80] Such funds continue to be provided to this day. Indeed, for FY1994 and FY1995, Congress added funds to that activity above those requested by DOE. Finally, in 1998, Congress directed DOE to undertake a thorough review of all of the fusion R&D it funded to develop an integrated fusion energy research effort. Most of the ICF effort, however, would remain within the DOE defense programs.

Congressional attention on alternative concepts has risen as estimates of the time to reach commercial fusion have grown. Part of that heightened attention was likely a result of increased concern by Congress that the mainline approach — the tokamak — might not be the best path to a practical fusion reactor, and that DOE should not bet everything on one approach. Congress, in recent years, has directed DOE, as part

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[74] (...continued)
Research Appropriation Bill, 1977, 94th Congress, 2nd Session, H.Rept. 94-1223, 18.

[75] This separation had been a cause for concern for the fusion research community over the years, primarily because a significant portion of the ICF work has been classified for national security reasons.

[76] House Committee on Appropriations, *Public Works for Water and Power Development and Energy Research Appropriations Bill, 1979,* 95th Congress, 2nd Session, H.Rept. 95-1247, 34.

[77] The first record of this direction took place in 1979. House Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1980,* 96th Congress, 1st Session, H.Rept. 96-243, 23.

[78] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1981,* 96th Congress, 2nd Session, S.Rept. 96-297, 18.

[79] Senate Committee on Appropriations, *Energy and Water Development Appropriation Bill, 1990,* 101st Congress, 1st Session, S.Rept. 101-83, 79.

[80] House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 1992,* 102nd Congress, 1st Session, H.Rept. 102-75, 83.

of the fusion program's restructuring, to ensure that alternative concept exploration be a key element of the fusion research effort.

Consequences for the Future

Current Status

At present, the Fusion Energy Sciences program has completed most of the restructuring mandated by Congress over the past five years. Several reviews of the program have been completed and DOE is preparing a research management plan based on the recommendations of the Fusion Energy Science Advisory Committee in concert with the findings of the Fusion Task Force of the Secretary of Energy's Advisory Board.[81] The recommendations have two major aspects. The first is the development of an R&D roadmap that incorporates a convergence of the inertial and magnetic fusion energy paths. The roadmap is being designed to guide the program towards development of a demonstration fusion power reactor sometime in the next 50 years. The second aspect is the development of a vertical strategy to guide decision making for moving a concept for achieving fusion power production from the concept exploration stage to the demonstration stage, as laid out in the roadmap.

Questions

As stated at the beginning of this report, Congress appears to be well satisfied with the program's current status and the direction in which it is heading. The profound changes that have taken place since 1995, and which were set in motion 17 years ago, have left the program much different than it was for most of its existence. In one sense it is similar to its earliest years — prior to the mid-1960s — in that U.S. fusion research is again focused primarily on developing the scientific basis for fusion energy production. Of course, there have been vast advances in fusion science and technology over the past 42 years (see below), and the present scientific effort is building on a much greater knowledge base.

In the next several years, as the science base is expanded further, the program and Congress will be faced with critical choices about how the program should continue. The most important of these questions are likely to be about extensions of the themes described above. By examining those questions in light of the lessons provided by the themes it is possible to gain some insight into how those questions might be addressed and into possible answers.

Is U.S. fusion research a science or an energy program?

This question has emerged as one of the most controversial now facing the fusion program. It seems evident that Congress intends a much larger role for basic science and engineering research within the fusion program. Since 1983 Congress has

[81] U.S. DOE FESAC, *Report of the FESAC Panel* and U.S. DOE SEAB Fusion Task Force, *Realizing the Promise of Fusion Energy.*

been directing DOE to increase it emphasis on science at the expense of energy technology development. The 1995 changes accelerated that action, and the fusion energy science program, as the civilian fusion research effort is now called, is included with all of the other basic research programs in DOE. This shift includes more emphasis on basic plasma physics in general as well as the basic plasma physics and engineering research underlying fusion energy development.

The latter aspect, however, sets fusion energy science research apart from DOE basic research programs such as high energy and nuclear physics. The basic research supported by the fusion program has a definite purpose in mind – that is solving the problem of harnessing the nuclear fusion reaction for peaceful energy production.[82] In that sense it shares a commonality with other basic research funded by DOE, such as most of the activities within the Basic Energy Sciences and Biological and Environmental Science programs. Within the fusion energy science program this basic research "with a purpose" is highlighted by research on alternative concepts, which attempts to determine whether alternative methods for heating and confining plasmas might lead to a practical way to generate fusion power. To be sure, most of the research funded on the tokamak by DOE since the early 1970s also fell, and continues to fall, within this category of basic research.

As discussed above, it seems clear that Congress considers the goal of practical energy production to be the objective of fusion research. Nevertheless, increased emphasis on the science aspects of that quest raises a question about the program's future were it to be judged primarily as a science program.

If fusion research is a science program, will it be sustained?

If Congress were to decide that fusion research was to be primarily a science program albeit with a definite goal, the question arises as to how long and at what level it would continue to support the program. As a science program, it may have certain limitations that would not be there if it were considered primarily an energy development program. An important example concerns growth in the scale of research facilities. A program that was concerned only with basic plasma physics research would likely be able to continue for several years without needing to scale up facilities to the multi-million dollar level. It also is possible that such a program would be funded at levels considerably below current amounts.

If fusion science were also part of the research agenda, as it currently is, much larger facilities would eventually be necessary to advance the science. To be sure, they would probably not be ITER scale, but they could reach the multi hundred million dollar to one billion dollar level. If Congress considered the program primarily science-based at the time a request for such a project was made, it is doubtful that it would approve the project without, at a minimum, substantial contributions from international partners. Without such facilities, the advancement potential of fusion

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[82] For an extensive discussion of this concept, see: Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation,* (Washington, DC: Brooking's University Press, 1997).

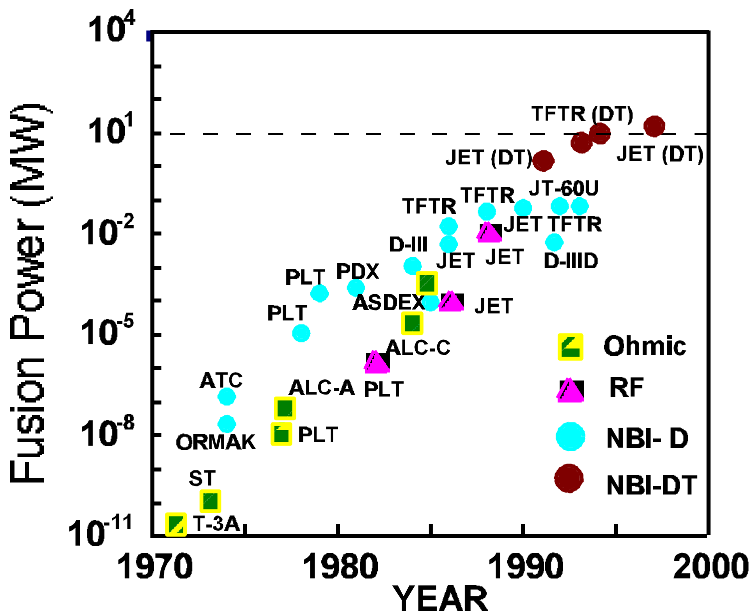
science would seem more limited, and questions about whether a fusion science program should continue would likely arise.

At this time, however, there appears to be no indication that Congress wishes to abandon the energy goal of fusion research or reduce its priority relative to other possible goals. The FESAC and SEAB studies, noted with approval by Congress (see above) in the FY2000 DOE appropriation, assume that fusion energy development is the prime goal of the fusion research effort.[83] Given this condition, then, some may ask whether Congress would support that effort until either demonstration of practical fusion power is clear or it is shown that fusion power would not be competitive with other long-term energy sources.

As an energy program, how long can fusion research be sustained?

Even if the program is successful in dramatically reducing the scientific uncertainties about fusion energy development, the time to a practical power reactor is still likely to be substantial. To be sure, continued scientific advances should significantly reduce uncertainties, compared to the current state of knowledge, when a demonstration reactor is built. Over the past 30 years, advances towards proving scientific feasibility of fusion have been substantial, as shown in data, provided by the Princeton Plasma Physics Laboratory, in Figure 2. The production of fusion power in tokamak facilities has risen by a factor of nearly one trillion over that period. In

Figure 2. Magnetic Fusion Power Production Trend



PPPL PRINCETON PLASMA PHYSICS LABORATORY

[83] U.S. DOE FESAC, *Report of the FESAC Panel* and U.S. DOE SEAB Fusion Task Force, *Realizing the Promise of Fusion Energy.*

terms of the measure of power gain, or Q — that is, fusion power produced divided by power used to heat the plasma — the largest tokamaks have achieved a value of Q of about 0.6 when operating with a deuterium and tritium plasma.[84] An operating reactor will require a Q greater than 10. The SEAB report concluded that "the threshold scientific question — namely, whether a fusion system producing sufficient net energy gain to be attractive as a commercial power source can be sustained and controlled — can and will be solved."[85]

Demonstration of scientific feasibility, however, is only the first step towards a practical fusion reactor. Beyond that point lie a range of engineering challenges including conversion of fusion energy to electricity, fueling the fusion reaction, removing plasma ash from the reactor, and a host of other problems that must be solved to make an economic power reactor. Solving those problems is likely to be just as difficult as demonstrating the underlying science. Furthermore, the first concept on which scientific feasibility is proven may not provide the best path to a fusion reactor.[86] Rather another concept, one that is currently less well along in its development than the tokamak, might be a better reactor candidate. Therefore, a long period — possibly several decades — is likely to be required before a definitive answer about a fusion power plant is available. Such a long period means that a substantial total funding commitment would be needed even if yearly funding levels were about the same as those currently provided.

The long history of congressional support of fusion research suggests to many that Congress will continue support for an extended period if progress is apparent and specific and realistic goals and target dates are provided and adhered to. Because budget stringency is likely to continue for an indefinite period, however, it appears unlikely that significant, annual budget increases will be available any time soon, if ever. Therefore, the program will likely have to evolve toward fusion energy development within relatively constrained budgets.

It is important to note, in this context, that DOE does not have a target date for achieving commercial fusion power. Currently, its policy is to advance plasma and fusion science and engineering on a broad front and allow those developments to set the pace of the program.[87] There have been some estimates that it could take as long as 50 years to reach the point that a commercial plant was possible within existing budget levels, but it is also possible that breakthroughs in one or more of the concepts now under investigation by DOE could shorten the time to success, but it is still likely to be long without significantly higher funding.

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[84] U.S. Department of Energy, Fusion Energy Sciences Advisory Committee, *Opportunities in the Fusion Energy Sciences Program,* Washington, DC, June 1999, 2-21. [http://wwofe.er.doe.gov/More_HTML/FESAC_Charges_Reports.html]

[85] U.S. DOE SEAB Task Force on Fusion Energy, *Realizing the Promise,* 1.

[86] Due to its relatively advanced scientific and technical status, scientific feasibility is likely to be demonstrated first on a tokamak device.

[87] Dr. N. Anne Davies, Associate Director, DOE Office of Fusion Energy Sciences, Briefing to Congressional Staff, January 19, 2000.

It is not clear that the progress towards demonstration of fusion energy can be sustained for the period necessary, given this policy. In particular, at the point larger facilities are required, a critical decision will need to be made. While Congress supported the construction of large facilities in the late 1970s – primarily the TFTR – it is uncertain whether a similar level of support would be forthcoming in the future, given competing priorities.[88]

What will happen when larger facilities are requested?

Current estimates[89] show that as a concept moves from the concept exploration to the proof-of-principal stage, the total project cost would move from about less than $10 million to the $10–100 million range. A move to the performance extension phase would raise project costs to anywhere from $100–500 million, and the fusion energy development stages would require projects costing in the range of $0.5–3 billion. In addition, the operating costs of each successive stage would increase. For the fusion energy development stage, operating cost estimates are anywhere from $50 to $300 million per year. Therefore, it appears that if a promising concept is to move to the demonstration stage — the stage following fusion energy development — a significant increase in program budget would be necessary, the program would have to devote most of its resources to that project alone, or both. In addition to the budget requirements, technical uncertainties are likely to increase as the project size grows. To be sure, the new program strategy of reducing scientific and engineering uncertainties should lower the technical risk for these larger projects. Those risks, however, will not disappear.

The likelihood that budget constraints will remain for the indefinite future suggests that large funding increases needed to build these projects are questionable. If those facilities are to be built, funding would probably have to come at the expense of other parts of the program, which could mean dramatic decline in funding for the rest of the fusion research program. It is also likely that only one concept could be funded in this manner, leading to a situation similar to that of the 1980s, when the program concentrated on the tokamak. This situation may not be acceptable to Congress unless it could be clearly shown that the chosen concept had the best chance of developing into a commercial power reactor. Even then, the historical record suggests that many in Congress would be concerned about a possible premature narrowing of concepts.

Given the technical uncertainties and budget constraints, it appears that international collaboration would be necessary to build the larger facilities needed for the performance extension and fusion energy development stage. While recent statements by Congress suggest support for such collaboration, U.S. participation in such an effort would still be governed by fiscal limitations. Furthermore, even with an international project with many funding sources, long periods would be necessary

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[88] The $215 million authorization cost of the TFTR in 1975 would be about $670 million in FY2000 dollars. The actual cost of reproducing the TFTR today would probably be higher.

[89] All of the following estimates are from, "Draft Report of the Panel on Criteria, Goals and Metrics for the Fusion Energy Sciences Advisory Committee," U.S. Department of Energy, June 18, 1999, 11. [http://wwwofe.er.doe.gov/More_HTML/FESAC_Charges_Reports.html

for completion and operation of the larger projects. During the TFTR program, Congress noted that demonstration of scientific feasibility was scheduled at several points, only to have the actual experiments pushed further into the future. Some uncertainty, of course, is inherent in any project that attempts to advance the scientific and technological knowledge base. Continued support during long projects is likely to require, at a minimum, clear and conservative goals and timetables.

Baring unforeseen circumstances such as a major global environmental or energy crisis, international collaboration appears to be necessary if the U.S. is to participate significantly in the further development of fusion energy. Yet questions remain about whether such collaboration would ultimately be successful.

What would be the role of international collaboration?

International collaboration in fusion research has been a hallmark of the program since its inception in the 1950s. Ideas have flowed into the U.S. program from the many countries carrying out fusion research and the United States has contributed substantially to foreign programs. The most notable foreign "import" was the tokamak, which was first developed in Russia in the early 1960s. Currently, international fusion research efforts — primarily located in Japan and the European Union — are considerably larger than the U.S. effort.[90] Large, billion-dollar-plus projects are now operating in both Japan and Europe. And the largest operating tokamak, the Joint European Torus, is located in England. About $25 million of the FY2000 U.S. fusion budget is spent on experimental activities that involve international collaboration.

It is also apparent to most of the worldwide fusion research community that extensive international collaboration will be necessary if fusion R&D is to result in a practical fusion power plant. The primary reason is that the cost of reaching that goal is likely to be greater than any one country is willing to pay. Yet there remain uncertainties about whether such collaboration can be carried off successfully, particularly if it were to involve construction of a new large, billion dollar plus research facility. The ITER Engineering Design Activity (EDA) was a success in many ways but also showed some of the pitfalls that are likely to confront future, large-scale international fusion research projects. First is the difficulty in making a decision about construction of the project. Currently, the remaining partners — Japan, the European Union, and Russia — are operating in a three-year transition period before that decision, originally scheduled at the conclusion of the EDA in 1998, is again considered. Uncertainty about that decision was a leading contributor to Congress's decision to direct DOE to terminate U.S. participation. Part of the reason for the construction decision delay was the technical uncertainties that arose toward the end of the project due in part to advances in tokamak theory made in the United States.

A second concern about ITER was how the project — if built — would be integrated into the various national programs. While no substantial problems were proclaimed, it was apparent in the United States, at least, that some tension existed

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[90] U.S. DOE, FESAC, *Opportunities,* 1-5.

between researchers pursuing other concepts and those dedicated to the ITER project. If a construction decision had gone forward, that tension might have increased because of the large domestic resources that would have been necessary for the project. A third concern was the role of other national issues in making decisions about significant commitments to large, international projects. It is apparent that changing perceptions about the urgency of long-term energy prospects and existing domestic economic conditions have an effect on the willingness of the partners to make such major construction commitments.

Nevertheless, continued and growing international collaboration appears to be a high priority for DOE and for Congress. A committee established by DOE to look at how the fusion program could "maximize the effectiveness of our international collaborations" recently recommended among other things that "future international collaborations should be developed as an integral part of the overall U.S. fusion program planning process — not independently."[91] While there are currently no international construction projects in fusion, a model for such an activity in the future may be U.S. participation in the Large Hadron Collider (LHC) project, which amounts to $650 million over several years. The annual average U.S. contribution to the LHC is less than 10% of the total annual HEP program budget. Prior to approval, Congress directed DOE to make sure that the United States would have a commensurate role in LHC management and that the contribution would not negatively affect the domestic High-Energy Physics (HEP) research program.

Under what conditions might U.S. fusion research be expanded?

So far the questions have dealt with congressional support for the program at or about its current level. There may be circumstances that would increase such support.

From the experience of the 1970s, it appears that an upsurge of concern about the nation's long-term energy future might result in significant increases in the fusion program budget as well as an acceleration of program activities. The level of support would depend on how promising the primary competitors of fusion as a long-term source — solar and fission — were and what the scientific and technical status of fusion was. It is possible, for example, that developments in solar or fission research could render fusion unnecessary. At this point, however, that situation does not seem to be the case and the potential benefits of fusion would likely keep it a high priority research program if development of a long-term energy source became more urgent.[92]

In addition to sudden, real or perceived shortfalls in energy supplies, another factor that could significantly increase attention to long-term energy sources would be a sharp upturn in concern about global climate change. This latter factor, of course, was not significant during the 1970s. Indeed, the possibility of global climate

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[91] Letter to Dr. N. Anne Davies, Associate Director, Office of Fusion Energy Sciences, U.S. Department of Energy, from Robert J. Goldston, Director, Princeton Plasma Physics Laboratory, March 1, 1999, 2. [http://wwwofe.er.doe.gov/More_HTML/Inter.Collab.html]

[92] Congressional Research Service, *Magnetic Fusion: The DOE Fusion Energy Sciences Program*, by Richard Rowberg, CRS Issue Brief IB91039.

change induced primarily by the combustion of fossil fuels is already used by proponents of each of the three long-term energy source candidates to help justify budget requests.

Another situation that could heighten interest in the United States in fusion research is the possibility of a substantial advance in achieving fusion power by Europe or Japan. If it seemed possible that such a development might leave the United States at a significant economic disadvantage, Congress might act to accelerate the U.S. program to try and catch up. As noted above, since the late 1960s international competition has not been a factor in congressional response to the fusion program budget request. Yet when it was a factor, Congress did note that international activity appeared to be greater than in the United States — a situation that again exists. If the U.S. program contained a significant international collaboration element, however, it is probable that concerns about international competition would be muted, although they would not be entirely eliminated, as the experience with the ITER EDA demonstrates.

Conclusion

The current status of the fusion program, with its dual goals of science and energy, its increased attention to alternate concepts, and the impending convergence of inertial and magnetic fusion approaches, reflects congressional decisions. Yet in many ways, the program is in an unstable state. It cannot remain as is and hope to achieve its goals. Yet once the program initiates those steps needed to reach those goals, it runs the risk of losing support by moving in a direction similar to those trod in the past, namely, focusing on one or two concepts and requesting increasingly larger facilities to test, prove, and develop those concepts. The themes that emerge from an assessment of the long historical record of congressional response to program budget requests may have lessons for the future. Congressional consideration of future expansion of the fusion program will likely include: the strength of the scientific base for moving forward, clear and realistic scientific and technical targets, budget realities, strength of management, and participation in a well-designed international program. Even then, external variables, in particular the state of the nation's long-term energy future, global environmental conditions, and the state of the economy, will likely affect congressional response to the program as much as any other factor.

Appendix

Table 1. Congressional Funding of Magnetic Fusion R&D
FY1951-FY2000

Magnetic Fusion R&D Funding - Budget Authority								
	Millions of Dollars				Millions of 2000 Dollars			
FY	Request	House	Senate	Appro	Request	House	Senate	Appro
1951-53	1.00			1.00	7.77			7.77
1954	1.74			1.74	12.57			12.57
1955	4.72			4.72	33.60			33.60
1956	6.64			6.64	44.97			44.97
1957	10.73			10.73	69.34			69.34
1958	26.70			23.42	164.31			144.12
1959	41.14			27.97	245.27			166.75
1960	37.00			33.10	219.81			196.64
1961	29.30			30.00	169.64			173.70
1962	26.50			24.74	151.14			141.10
1963	27.80			24.17	152.89			132.92
1964	24.70	20.90	22.90	22.60	133.48	112.95	123.76	122.13
1965	23.20	23.20	23.20	23.54	123.57	123.57	123.57	125.38
1966	25.28	22.28	23.28	23.54	130.60	115.10	120.27	121.61
1967	24.38	24.38	24.38	24.16	122.12	122.12	122.12	121.01
1968	27.98	27.98	27.98	26.04	134.41	134.41	134.41	125.09
1969	29.10	28.50	28.50	28.55	132.74	130.00	130.00	130.23
1970	29.37	29.37	29.37	29.28	126.38	126.38	126.38	125.99
1971	31.55	30.44	30.55	30.26	127.77	123.28	123.72	122.55
1972	32.04	32.04	32.04	33.16	121.73	121.73	121.73	125.98
1973	40.57	40.57	40.57	39.72	146.66	146.66	146.66	143.58
1974	47.50	53.00	56.80	56.80	158.73	177.11	189.80	189.80
1975	101.80	110.80	101.80	104.80	307.71	334.92	307.71	316.78
1976	166.50	178.00	156.00	157.00	470.06	502.52	440.41	443.24
TQ	44.10	51.60	44.10	47.00	120.37	140.84	120.37	128.29
1977	289.70	324.40	311.50	312.40	756.07	846.63	812.96	815.31
1978	309.50	339.50	309.50	325.35	755.17	828.37	755.17	793.84
1979	334.00	357.70	351.90	348.90	751.48	804.81	791.76	785.01
1980	363.80	357.40	352.40	355.40	740.86	727.83	717.64	723.75
1981	396.02	394.12	394.12	394.12	730.61	727.11	727.11	727.11
1982	460.00	465.53	452.00	456.00	793.53	803.07	779.73	786.63
1983	444.10	460.10	462.80	466.10	730.87	757.20	761.65	767.08
1984	467.00	473.00	471.50	470.75	733.21	742.63	740.28	739.10
1985	483.14	419.14	470.14	440.14	730.85	634.04	711.18	665.80
1986	390.00	385.00	383.00	383.00	573.83	566.48	563.53	563.53
1987	333.00	358.00	333.00	345.50	476.82	512.62	476.82	494.72
1988	345.60	361.60	345.60	335.00	479.11	501.29	479.11	464.41
1989	360.00	343.00	356.00	351.50	479.11	456.49	473.79	467.80
1990	349.25	280.45	330.45	330.75	446.88	358.85	422.82	423.21

1991	325.30	325.30	325.30	275.30	397.47	397.47	397.47	336.38
1992	337.10	337.10	337.10	337.10	399.33	399.33	399.33	399.33
1993	359.71	339.71	335.00	339.71	415.64	392.53	387.09	392.53
1994	347.60	347.60	342.60	347.60	392.35	392.35	386.70	392.35
1995	372.56	372.56	362.56	372.56	410.62	410.62	399.60	410.62
1996	366.05	229.14	225.14	244.14	394.49	246.94	242.63	263.11
1997	255.60	225.00	240.00	232.50	270.22	237.87	253.73	245.80
1998	225.00	225.00	240.00	232.00	233.93	233.93	249.52	241.20
1999	228.16	232.00	232.00	229.75	233.16	237.08	237.08	234.78
2000	222.61	250.00	220.61	250.00	222.61	250.00	220.61	250.00
Total	9,226.1			9,010.2	16,175.8			15,848.5
Total	9,012.8	8,875.4	8,825.6	8,822.0	14,904.5	14,877.0	14,718.2	14,725.0