DOE/S-0035

Report of the Technical Panel on Magnetic Fusion of the Energy Research Advisory Board

November 1986

A Report of the
Energy Research Advisory Board
to the
United States Department of Energy
Washington, DC 20585

Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
(202) 586-5444

February 12, 1987

Honorable John S. Herrington
Secretary of Energy
Washington, DC 20585

Dear Mr. Secretary:

I am pleased to submit the final report of the Technical Panel on Magnetic Fusion Energy of the Energy Research Advisory Board (ERAB). Unlike other ERAB Panels, this Panel was established as a statutory requirement of the Magnetic Fusion Energy Engineering Act of 1980 and is separately chartered to prepare a report at least triennially. The Board is required to submit the Panel's report to you with our comments. The ERAB generally agrees with the report but with the following comments:

The Board notes that the world fusion effort has been making impressive progress toward demonstrating energy breakeven. Consequently, the Board fully endorses the Panel's recommendation to proceed with an ignited plasma experiment, such as the Compact Ignition Tokamak (CIT). This experiment would address one of the central scientific issues of fusion development, which is the behavior of an ignited plasma core. Furthermore, the Board agrees that the funding to support the vital base program over the next five years should remain approximately constant, and that funding for fusion should be supplemented with incremental funds for design, construction, and operation of the CIT. Since the Board did not discuss priorities or budget levels for fusion or any of the near or long term energy options, this endorsement does not imply that incremental funds for the CIT should be obtained by reducing funds for any other DOE programs.

The Board also endorses the Program's commitment to use international collaboration to advance all areas of fusion development. However, there was a concern expressed that an international agreement to build an Engineering Test Reactor (ETR) based on the tokamak concept could, in effect, cause a premature focusing on the conventional tokamak as the eventual commercial reactor concept. Such premature focusing might delay the development of an attractive commercial reactor concept if the conventional tokamak does not prove to be the optimal reactor choice. Consequently, prior to formal commitment to construction of an ETR, the Board recommends establishing a panel of industry-based engineers in the relatively near future to review the desirability and practicality of the various fusion reactor configurations and the extent to which the ETR would address the relevant engineering issues.

The Board also notes that the Department's program plan does not explicitly extend to include a prototype demonstration. Such a project will probably be needed prior to commercialization, probably funded jointly by government and private industry.

It must be kept in mind that magnetic fusion is still at an early stage of technological development with the possibility of major technological advances as the program proceeds. Consequently it is not realistic to make economic comparisons now with the energy sources with which fusion might compete decades from now. Rather, the focus should be on developing the technology to the stage at which the fusion option can be realistically evaluated in comparison to other future energy sources.

Sincerely,

John H. Schoettler

John H. Schoettler

Attachment

Grumman Corporation
Bethpage, New York 11714-3580

Joseph G. Gavin, Jr
Senior Management Consultant

December 2, 1986

Mr. John H. Schoettler
Chairman
Energy Research Advisory Board
Department of Energy
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Washington, D.C. 20585

Dear Mr. Schoettler:

I am pleased to forward to you the report of the Technical Panel on Magnetic Fusion. This panel, sponsored by the Energy Research Advisory Board, was charged with the triennial review of the magnetic fusion research program in accordance with the Magnetic Fusion Engineering Act of 1980 (Public Law 96-386).

The panel, in public meetings, heard from senior persons within the Dept. of Energy and from several independent individuals including a spectrum of supportive, critical, and concerned views.

I have been pleased with the cooperation provided by the Dept. of Energy; I have the greatest respect and gratitude for the efforts of the panel members.

Very truly yours,

Joseph G. Gavin, Jr.
Chairman, Technical Panel

JGG:jo

ENERGY RESEARCH ADVISORY BOARD NOVEMBER 1986

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TECHNICAL PANEL ON MAGNETIC FUSION OF THE ENERGY RESEARCH ADVISORY BOARD

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ABSTRACT

This report on the Department of Energy's Magnetic Fusion Energy program was requested by Secretary of Energy John S. Herrington, in compliance with the Magnetic Fusion Energy Act of 1980 (Appendix H). The Panel finds that fusion energy continues to be an attractive energy source of great potential for the future, and that the Magnetic Fusion Energy program continues to make substantial progress toward the development of fusion energy. In addition, fusion R&D continues to make valuable contributions to the national science and technology base. These factors fully justify the substantial DOE expenditures in fusion R&D. The Panel endorses the MFE program's direction, strategy, and plan, and recognizes the importance and timeliness of proceeding with a burning plasma experiment, such as the proposed Compact Ignition Tokamak (CIT) experiment. Because the program has been narrowed substantially due to budget reductions, the Panel recommends that incremental funds be provided for the proposed CIT in order to maintain the overall structure of the program. The program has made a good start toward obtaining international collaboration on a major device, an Engineering Test Reactor. The Panel views this as an opportunity for the United States and its partners to save billions of dollars, in the long run, on the development of fusion energy and recommends that DOE proceed with the negotiations needed to reach this goal.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Energy Research Advisory Board Panel on Magnetic Fusion, charged by Secretary of Energy John Herrington (Appendix A) to conduct the required triennial review of the Magnetic Fusion Energy (MFE) program, met six days between May 1986 and October 1986, and received information from 23 speakers. The principal findings, conclusions, and recommendations are outlined below, with a more detailed exposition presented in the main body of this report.

FINDINGS

1. Magnetic fusion energy continues to be a uniquely attractive potential power source for the future.

2. Throughout the program, considerable progress has been achieved since 1983. This has culminated in the recent advances on the TFTR tokamak at Princeton. Important progress has also been made in Europe with JET and in Japan with JT-60. In addition, significant progress has been made in several alternate confinement concepts under active investigation in the U.S. program as well as abroad.

3. The Office of Fusion Energy has dealt effectively with budget reductions, making difficult decisions. Three successive years of budget reductions have curtailed and eliminated some program elements and postponed others. Deferring MFTF-B (the large tandem mirror facility at Livermore) was a difficult, though necessary decision.

4. The disaster at Chernobyl and the domestic controversy concerning fission waste storage have resulted in renewed concern about the environment. There are also long term concerns about the use of fossil fuels due to the buildup of carbon dioxide in the atmosphere.

5. International collaboration in fusion research is being addressed at many levels of government and plays an important role in both the technical and financial aspects of the program.

CONCLUSIONS

1. Because of the uncertainty of energy supply early in the next century, there is an advantage in testing the scientific feasibility of fusion sooner rather than later. This requires studying the physics of an ignited plasma.

2. An ignited plasma experiment, such as the Compact Ignition Tokamak (CIT), is an essential and timely project. In addition, it will enhance the credibility and the likelihood of success of a future Engineering Test Reactor (ETR) whether or not the ETR is a multi-lateral or domestic project. This report does not attempt to define the ETR. The CIT is a useful experiment whether the ETR is a tokamak or an alternative confinement configuration. An ignited plasma experiment will require incremental funding above the FY 87 level.

3. Further budget reductions, beyond the three years cited above, will jeopardize the overall technical integrity of the program, and will make the U.S. fusion program a substantially less desirable partner for international collaboration.

4. A good start has been made toward international collaboration, but collaboration on a large device, such as an ETR is a complicated process that will take time and substantial negotiating effort. The potential savings due to collaboration are considerable and will occur later.

5. Today's environmental concerns about fission and fossil energy cannot yet be extrapolated into the future, but these trends could be of significant importance to the role of fusion. Furthermore, environmental impact and public safety questions must be addressed during early stages of the development of fusion energy.

6. Fusion R&D advances plasma physics, a sophisticated and useful branch of applied science, as well as technologies important to industry and defense. This contribution to a strong national science and technology base warrants a substantial level of investment in its own right.

RECOMMENDATIONS

1. Proceed expeditiously with an ignited plasma experiment, such as the CIT, using existing facilities to the greatest extent possible to minimize the additional funding that will be necessary. Early completion of this project will help to determine whether there are unanticipated phenomena associated with a burning plasma that would alter the prospects for proceeding with fusion development. Incremental funds will be needed in order to proceed with the CIT in a timely fashion and to maintain the strength of the base program.

2. While the tokamak configuration is the mainline of present national and international experimental efforts, exploration of selected non-tokamak concepts as well as tokamak improvements should be pursued. The budget reductions have already resulted in a substantial narrowing of effort. Further reductions would endanger key areas of the program.

3. Continue to study urgently the question of possible atmospheric changes from continued massive use of fossil fuels. The Panel notes that DOE is the lead agency in a multi-agency effort to determine the consequences of the buildup of CO_2. Fusion, second generation fission, and solar technologies are the primary energy options for the future if the atmospheric CO_2 trend is determined to be harmful to the environment. This is a global problem with very significant economic and political consequences.

4. Proceed with the required negotiations to establish major international collaboration in fusion R&D. This should be done recognizing that it will take time and that considerations external to the U.S. program may make it necessary to proceed independently. Reviews of the NRC report of 1984, "Cooperation and Competition on the Path to Fusion Energy", and the ERAB report of 1985, "International Collaboration in the U.S. Department of

Energy's Research and Development Programs" indicate that the conclusions of those reports appear to be valid today.

5. The Panel believes that fusion R&D deserves a priority greater than that provided at present by the U.S. Government. We recommend that the Secretary of Energy press vigorously for a higher national priority within the Administration.

REPORT OF THE TECHNICAL PANEL ON MAGNETIC FUSION OF THE ENERGY RESEARCH ADVISORY BOARD

I. INTRODUCTION

The last review of the magnetic fusion program by a Panel of the Energy Research Advisory Board was completed in February, 1984. Since that time, a number of changes have occurred inside the Department of Energy's program, in the foreign programs, and in the external world. The recent achievements at Princeton in TFTR, the Tokamak Fusion Test Reactor, have shown continued progress to near breakeven levels of operating conditions. At the same time, the Federal budget deficit pressures have resulted in three years of declining funding for the magnetic fusion program. This has resulted in several difficult program adjustments.

The European program has progressed well, both in the European Community's joint tokamak facility, JET, and in the strong, coordinated national programs. The Japanese program has brought a major tokamak facility into operation, the JT-60. The European and Japanese programs have shown both planning and funding stability and now each program matches or exceeds the United States' level of effort. They also appear to be at a comparable level with the U.S. in both science and technology. The European and Japanese programs each include current planning and exploratory analysis leading to a new generation of advanced experiments.

In the world energy situation, three significant changes have recently occurred. Public acceptance of fission generated power, especially in the United States and Europe, has been dramatically weakened by the accident at Chernobyl. The collapse of the world price for crude oil has brought exploration for oil and gas to a minimal pace, has discouraged conservation, and has started a trend for the United States to increase again its dependence on Mid-East oil. The third factor has been exploration of jointly undertaking through major international collaboration the next major fusion facility, known as the Engineering Test Reactor (ETR). This is being explored with the European Community and Japan through the Versailles Summit process and with the U.S.S.R. through the Geneva Summit. In the light of these changes, this Panel reaffirms the importance of continuing a vigorous U.S. program in magnetic fusion energy.

The advantages of international collaboration have been acknowledged earlier and are reaffirmed here. A number of useful bilateral and multilateral agreements have been made involving the United States and Japan, Europe or the Soviet Union. Past examples of successful collaboration such as CERN and JET suggest possible patterns.

The Panel heard from proponents for new fusion undertakings as well as from program critics. On balance, the Panel believes that the direction of the program is correct and that its plan is sound. The Panel also believes that timely initiation of an ignited plasma experiment and assignment of a higher national priority to fusion are vital to the health of the United States magnetic fusion energy program; vital if we are to negotiate mutually advantageous international agreements for long-term collaboration, and vital if circumstances force the U.S. to "go-it-alone" and face international competition.

The body of this report develops these themes and leads to a set of conclusions and resulting recommendations.

II. IMPORTANCE OF ENERGY

Energy supply is a vital and, over the long term, an uncertain issue as well. No factor is more intimately involved in future economic health--domestically and globally--than an adequate, acceptable supply of energy. Furthermore, growth in the demand for energy has a greater potential for producing long term effects on the climate than any other trend. At present, the U.S. has achieved its energy goal of "an adequate supply of energy available at a reasonable cost," as stated in the National Energy Policy Plan (NEPP). Furthermore, the U.S. will continue over the mid-term to enjoy energy stability, energy security and energy strength through its reliance on a balanced mixture of resources, especially the triad of coal, nuclear, and conservation.

Nevertheless, early in the next century, the future of energy supply is unclear. It is generally agreed that in time there will be a pronounced shift in oil production towards the Middle East, which has over half of all proven reserves and an estimated one-fourth of the undiscovered resources. This could again make the United States vulnerable to foreign supply options. As for coal, the most abundant U.S. energy resource, it has been speculated that there may be a limit to its usage on a global basis due to atmospheric pollution. Also, the wide ranging impact of the incident at Chernobyl and the domestic controversy concerning fission waste storage have renewed concern about nuclear energy's effects on the environment.

To resolve these uncertainties and achieve energy strength over the long term, the NEPP calls for a strong emphasis on research and development to provide a diversity of supply options based on domestic resources. This theme is echoed by the ERAB study on "Guidelines for Long Term Civilian R&D" that addresses the critical issues in all the major energy technologies. Both the NEPP and the ERAB study identify fusion as one of the promising energy options for the future.

III. THE FUSION OPTION

The Magnetic Fusion Energy Program has existed for over thirty years and in that time much has changed in the national view of energy. Today's energy technologies must not only provide energy at a reasonable price, they also must do so in an environmentally acceptable manner and not endanger public health and safety. Furthermore, the assurance of an adequate and secure source of fuel supply is a necessary prerequisite for the introduction of a new energy technology.

During these three decades one thing that has not changed has been the potential attractiveness of fusion energy. Fusion is considered to be more benign than fission energy. In addition, the fusion fuel is inexpensive and essentially inexhaustible. Fusion energy would also avoid the building up of CO_2, whatever those consequences are, and save oil for use in transportation and in the petrochemical industry.

In addition to the long term energy objective of fusion research, there are also nearer term benefits. Meeting the technological requirements of fusion has led to advances in fields ranging from microwave technology to materials science to applied superconductivity. In addition, plasma physics, the major academic discipline of fusion, has developed over the last twenty-five years into a sophisticated and useful branch of applied science. The major areas of application of plasma physics have been, besides fusion, the understanding of the earth's magnetosphere, interstellar space, and astrophysical plasmas; and the advancement of various high technologies, such as x-ray and ultraviolet light sources, free electron lasers, intense charged particle beams, gyrotrons, and so forth. Also, plasma processing, which is used in semiconductor manufacturing, machine tool hardening and other industrial areas is a promising application of plasma physics. Furthermore, the fusion program has consistently trained large numbers of high-caliber scientists and engineers. Many enter other areas of research and make major contributions to defense applications, space and astrophysical plasma physics, materials science, applied mathematics, computer science, and other fields. Benefits such as these are an important contribution to the national science and technology base. Maintaining the strength of this base has been identified in the ERAB "Guidelines on Long Term Civilian R&D" as a key objective for DOE and merits substantial support in its own right.

In summary, despite all the changes in the national view of energy, fusion continues to be inherently attractive. Moreover, the future promise of safe and inexhaustible energy continues to be the primary motivation for the program and justifies its continuation at present or increased levels of support. The near term benefits of fusion R&D are significant and in their own right warrant substantial support in accord with the ERAB guidelines on R&D.

IV. STATUS OF THE PROGRAM

Since the 1983 ERAB review, there have been significant technical advances and programmatic changes in fusion research. Technically, the U.S. program has made important progress in many areas. The culmination and most visible sign of this progress are the recent results on TFTR. However, the United States is beginning to lose its competitive edge over the European and Japanese programs.

Progress in the U.S. Program

In the TFTR tokamak, well-confined plasmas at ion temperatures of 20 keV (or over 200 million ^{o}C), and electron temperatures of 7 keV (almost 100 million ^{o}C) have been achieved, approaching the temperatures needed for fusion. In addition, energy confinement has been demonstrated for a dense plasma (at a lower, but significant temperature) approaching the quality of confinement needed in a full-scale fusion reactor. Overall, TFTR has achieved about one quarter of the equivalent of energy breakeven conditions. The continued progress of the fusion program over the last twenty years toward energy breakeven is shown in Figure 1.

Since 1983 there have been important advances in many other areas as well. In the Appendix B, more than two dozen are summarized. At this point ten specific accomplishments are identified:

1. Beta values (ratio of plasma pressure to magnetic pressure) of 5% have been achieved in the Doublet III and PBX tokamaks. These values are within a factor of two needed for an economic fusion reactor based on the tokamak concept.

2. Empirical energy confinement scalings for the tokamak concept have been identified which imply favorable reactor sizing. System studies in the last several years have indicated a progressive reduction in the required size of practical and economic fusion reactors.

3. In Alcator C and PLT, plasma currents have been driven by radio frequency waves, demonstrating the potential for steady-state tokamak operation, a desirable reactor characteristic.

4. The TMX-U tandem mirror demonstrated the thermal barrier end plugging at reduced densities. Construction of the TARA tandem mirror was completed, and experiments with thermal barrier end plugging have begun.

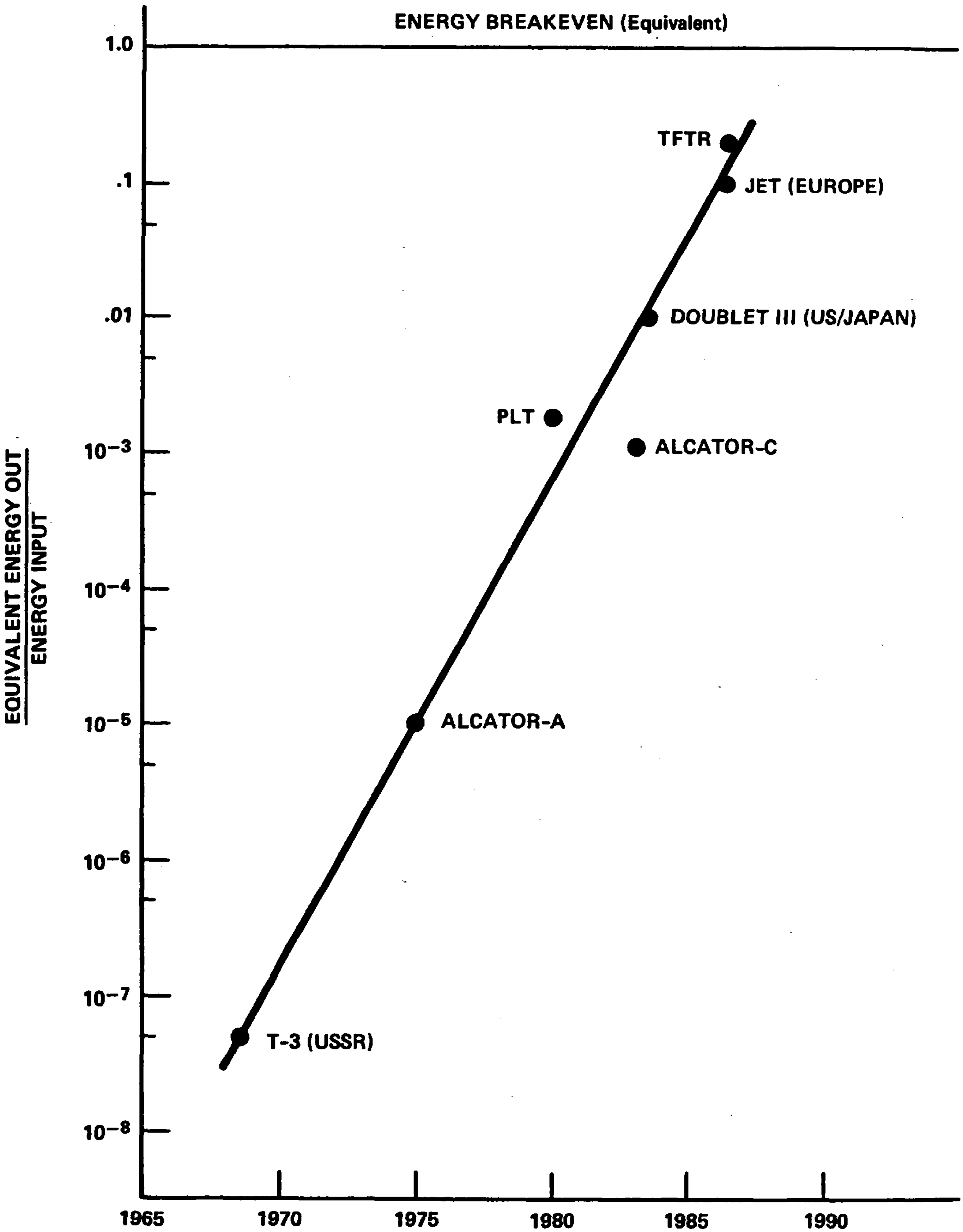
5. The MFTF-B (Mirror Fusion Test Facility) PACE project was completed and all systems performed at design specifications. After completion of the tests, the facility was placed on a standby basis because of budget reductions.

6. Construction of the ATF stellarator project was initiated and will be completed at the end of 1986. This concept offers the potential of high beta, steady state operation.

7. Experiments on ZT-40 and OHTE have advanced significantly the data base for reversed field pinches. Scaling studies include increases in temperature, beta and the quality of confinement.

8. The Large Coil Test Facility has been completed, and the six superconducting coils have been installed, cooled and tested individually. Multiple-coil tests are in progress.

9. The technology for single-and multiple-pellet injectors for plasma fueling has made rapid technical progress. Pellet injection experiments on the TFTR and Alcator C tokamaks have produced significant increases in central plasma density and improved energy confinement.



ENERGY BREAKEVEN (Equivalent)
1.0
.1
.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
EQUIVALENT ENERGY OUT / ENERGY INPUT
TFTR
JET (EUROPE)
DOUBLET III (US/JAPAN)
PLT
ALCATOR-C
ALCATOR-A
T-3 (USSR)
1965
1970
1975
1980
1985
1990

10. The Tritium Systems Test Assembly (TSTA) has operated successfully with 30 grams of tritium.

Progress in Foreign Programs

In addition to TFTR, there are two other major tokamaks in operation in the world. The first device is the European Community's JET (Joint European Torus) located at Culham, England. JET is the largest tokamak in the world; it has a D-shaped plasma and is capable of D-T operations. The goal of JET is to obtain substantial plasma self-heating with D-T at greater than energy breakeven conditions. JET began operating in June 1983 and has achieved (not simultaneously) five megamperes of current, energy confinement times of 0.8 seconds, and ion temperatures of 14 KeV or about 150 million ^{0}C. The other major device in the world is Japan's JT-60. The Japanese device has a divertor, a component which improves performance, but unlike TFTR and JET, it does not have a D-T capability. JT-60 began operation in April 1985 and in July 1986 first operated with neutral beam heating. Thus it is still at an early stage of operation. The device has a current capability of 2.7 megamperes, approximately the same as TFTR. Plasma temperatures up to 4 KeV have been obtained. In addition, the Soviets have a superconducting device, T-15, which is under construction.

Programmatic Changes

Programmatically, the fusion budget has experienced significant cuts for three years in a row. The budget has been reduced from an amount of $468 million in 1984 to $346 million in 1987, corresponding to a 38% reduction in terms of constant dollars. While the program has coped effectively with the reductions, the Panel believes that further reductions will jeopardize the overall technical integrity of the program.

The program has adjusted to the budget reductions in several ways. First, and most important, the program has identified the CIT (Compact Ignition Tokamak) as a cost-effective, next step. The CIT is discussed in more detail in the next section. Second, the program has embarked aggressively on international collaboration, which is discussed in Section VI. The third measure taken by the program was to formulate and implement a new plan, named the Magnetic Fusion Program Plan (MFPP). Fourth, the program has reduced significantly many areas of research.

As a result of the budget reductions, the program was significantly narrowed and all parts of the program were affected. In the confinement systems area, the mirror program was reduced from a mainline to a supporting concept. Operation of MFTF-B, the large tandem mirror facility at Livermore, was deferred, and the program's major tandem mirror experiment (TMX-U) was closed down. Also, the highly productive PLT, at Princeton, was closed down. In addition, tritium preparation on TFTR was delayed and a number of tokamak improvement experiments were not funded such as the current driven tokamak at MIT. In the supporting concept area, the Elmo Bumpy Torus program was discontinued, the next step in the Reverse Field Pinch concept was delayed and the spheromak program was reduced. In technology areas, the overall technology program was halved. Technologies such as neutral beams, gyrotrons and large superconducting magnets are either being significantly reduced or have been canceled. Likewise, university experiments both large and small, were canceled or deferred, such as the superconducting tandem mirror, AXIM, a TRW-UCLA collaboration. As a final point, major participation by the United States industry has been reduced dramatically. McDonnell-Douglas had been heavily involved in the Elmo Bumpy Torus concept, and TRW had been identified for major involvement in the operation of MFTF-B. GA Technologies, however, continues to be a major participant with the Doublet-III facility.

The Program Strategy

As stated in the new program plan, the goal of the program is to provide on roughly a twenty-year time scale the scientific and technological base for an assessment of magnetic fusion. The program plan defines four key issues which must be resolved to meet the program's goal. These are:

1. Magnetic Confinement Systems. Develop an understanding of the plasma science underlying attractive magnetic confinement configurations.

2. Properties of Burning Plasmas. Understand the effects introduced when the plasma is internally heated by fusion reactions.

3. Fusion Nuclear Technologies. Develop the nuclear technologies unique to fusion for the commercial application of fusion energy.

4. Fusion Materials. Develop materials which will enhance fusion's economic and environmental potential.

The present program strategy has two parts. First, it relies primarily on the U.S. program to provide facilities that address the key technical issues on an individual basis. Second, it relies on international collaboration to provide the large facilities needed for integrated tests, such as the Engineering Test Reactor (ETR).

In addition, the program is carrying out a detailed planning effort, known as the Technical Planning Activity (TPA), involving broad participation by the fusion community. The TPA has made significant progress. Its accomplishments include detailed definitions of the technical issues; definitions of the program areas and elements; statements of research and development objectives; identification of key decision points and milestones; and descriptions of the facility requirements. This work could provide the basis for international collaboration and could be a lasting contribution to planning the world fusion effort.

The Panel believes that the program is doing a commendable job in the planning area. It has developed a workable strategy that is compatible with the stringent budget situation. It is earnestly pursuing its strategy of international collaboration, and it has defined the detailed technical planning elements that are the basis for a thorough plan.

V. THE ROLE OF THE CIT

Of the four key technical issues mentioned earlier, the burning plasma issue deals with the basic science of the fusion process itself, namely, how to ignite a magnetically confined plasma and how to sustain it by internal fusion reactions. Although some important details of the operation of magnetic confinement systems are not yet fully understood, the current generation of large tokamaks, led by TFTR, are demonstrating the confinement parameters requisite to producing substantial fusion burning. Thus, the behavior of an ignited plasma core, heated and sustained by internal fusion reactions, is now the central technical issue in fusion development, and the last step in establishing the scientific fundamentals of the fusion process itself.

The 1983 ERAB Fusion Panel endorsed the concept of a Burning Experiment (BCX) that would address ignition, burn control, and long pulse effects. Because of budget reductions, work on the BCX (which had an estimated capital cost of $1.4 billion) was discontinued. Subsequent design efforts have focused on developing concepts for a compact, copper-magnet tokamak at substantially lower cost; this tokamak would examine ignition physics and burn control, but not long pulse issues.

The result of this community-wide design effort is the Compact Ignition Tokamak device or CIT. The proposed CIT has an estimated capital cost of $300 million plus about $60 million for diagnostics and R&D) assuming it is located at the Princeton Plasma Physics Laboratory (where existing site credits would save in excess of $200 million). The impact of the operation of the CIT on the overall program could be alleviated by phasing down the TFTR effort. A technical description of the CIT, along with the viewpoint of the Magnetic Fusion Advisory Committee (MFAC), is given in Appendix C.

The Panel believes that the fusion program should proceed now to construction of the CIT. The CIT is worth the investment because it directly addresses the next major problem, the final fundamental physics problem, in fusion development. Furthermore, it would provide important technical information and experience for operating and optimizing the performance of the multibillion dollar Engineering Test Reactor (ETR) facility. Thus, the CIT would enhance the credibility of the ETR.

The Panel believes that the CIT should be undertaken now even though this is a time of restricted budgets. International fusion research is proceeding toward an ETR project sometime in the next decade. Construction of the CIT here would put the United States in a strong position as a desirable partner in international collaboration in general, and in collaboration on the ETR machine in particular. Conversely, failure to capitalize on the success of the TFTR in this fashion could make it difficult for the United States to reap the benefits of future research successes in fusion.

The Panel strongly recommends that a budget increase be sought to assist in funding the CIT. Fusion funding has been cut three years in a row, and the program has been narrowed substantially. Further cuts to the base program, especially those resulting from a diversion of funds within the current budget level, could endanger the strength and breadth of the supporting science and technology, and thus of the entire endeavor. While this requires a bold initiative in the current budget climate, the Panel recommends that additional funds be provided so that a burning plasma experiment can proceed in a timely fashion consistent with maintaining a strong base program.

VI. ROLE OF INTERNATIONAL COLLABORATION

Since the 1983 ERAB review, the MFE program has significantly expanded its use of international collaboration, and the Panel believes that the program should further expand it, aiming toward an international ETR. The current role of international collaboration spans a broad range of activities covering all of the key technical issues identified in Section IV, namely, properties of burning plasmas, magnetic confinement systems, fusion materials and fusion nuclear technology. These activities are described in Appendix D in a memo prepared by the International Programs Division of the Office of Fusion Energy. Furthermore, it appears that the Technical Planning Activity will play an international role in forming the basis for joint planning in the world fusion community.

The Panel believes that international cooperation in the fusion field should be expanded by continuing to pursue a deliberate policy to achieve this objective. Major international collaboration on fusion development will mean that development can occur in a timely fashion. If each of the world's four principal centers of fusion expertise work separately, development may not even occur with some and certainly will take longer for all. In addition, other benefits should be obtainable. These include sharing the cost as well as the risk of large projects and even helping to build scientific and technical bridges of cooperation in the world. A major objective of international collaboration would be the joint designing, building and operation of an ETR.

There are several secondary advantages to international collaboration as demonstrated at CERN and JET. In the case of CERN, teams of scientists have come from many places to run experiments in a common facility. The resulting interactions and exchange of ideas have been positive. In the case of JET, the problems of assembling and managing an international team were solved successfully. JET is a cost effective, technical success. Without this demonstrated success, the potential for collaboration for an ETR would be much more speculative. A successful pattern now exists for accomplishing something jointly, where no one partner currently has sufficient resources.

The ERAB has recommended four general criteria for use in assessing international collaboration ventures in its recent report entitled, "International Collaboration in the U.S. Department of Energy's Research and Development Programs," February, 1986. The criteria are as follows:

1. Consonance of goals and objectives among the interacting parties.
2. Mutual benefits that are acceptable to all partners.
3. Sustainability of the technical quality and funding base of the program over the period of collaboration.
4. Contribution to U.S. energy security.

In addition, this Panel would include adherence to international safety standards. All these criteria seem to be achievable in the present fusion program, however, the question of the nation's energy security and security in general is more complicated in a project involving the USSR. Issues concerning the transfer of potentially sensitive technology could be a problem, perhaps more because of the present controversial nature of technology transfer controls than because of anything specific to fusion technology.

The National Research Council, in its report entitled "Cooperation and Competition on the Path to Fusion Energy," 1984, reached the following conclusions concerning international fusion relations.

1. On balance, there are substantial potential benefits in large-scale international collaboration on fusion development.

2. A window in time for large-scale international collaboration is now open.

3. Large-scale international collaboration can be achieved but not quickly.

4. International collaboration will require stable international commitments.

5. There are a host of considerations that must be resolved in the implementation, but these appear workable.

6. Past cooperation provides a sound basis for future efforts.

The Panel believes that these conclusions are still appropriate today. For instance, the political will as evidenced by the Economic Summits and by the Reagan-Gorbachev meetings show a strong political desire for international collaboration. Unfortunately, such political will is fluid, and for completely external reasons unrelated to fusion, could change quickly. On the other hand, as more cooperative programs are launched, it provides the impetus for the continuity of good relations. In this regard, an international project involving the European Community, Japan and the United States could be expected to have greater stablity than one including the USSR.

There are two important aspects of international collaboration that are often underestimated. The first is the length of time necessary to achieve an international agreement. Because of the large cost and technical complexity of the ETR, it is likely that there will be delays in reaching an international agreement. The second is that international collaboration is not under the control of the United States; it requires the agreement and continued support of other nations, each of which has its own pressing domestic problems to solve. Thus, there is increased risk in international collaboration. Consequently, each partner must reconcile the impact of interdependence with its own view of energy security.

Becoming a partner in a major facility such as an Engineering Test Reactor can best be achieved by the United States when it has a strong national program. In fact, all potential partners in joint activities must have strong national programs that enable them to make technical inputs as well as to use the knowledge developed through the cooperation. The Panel believes that this is the most important factor in successfully attaining collaboration.

In conclusion, the Panel believes that is is timely for the United States to exercise world leadership that will benefit nations pursuing fusion at this time. For this purpose it is recommended that the Secretary of Energy make every effort to assure that the United States is as reliable a partner as possible through government-wide agreement on fusion issues. The United States should consider reaching out to other Nations to establish a multinational structure for fusion relationships. Such a structure would be an implementation of the expressed political desires to cooperate and through the decades could bring together the political will and the technical skills needed for the science and engineering advancements.

VII. ROLE OF UNIVERSITIES AND INDUSTRY

UNIVERSITIES

Most of magnetic fusion research is carried out at DOE national laboratories (Livermore, Los Alamos, and Oak Ridge), at the Plasma Physics Laboratory at Princeton University, and at the GA Technologies industrial laboratory. Although representing only about 10% of the effort, the universities continue to play a very significant role in magnetic fusion research. Prominent among the universities involved in fusion are Columbia University, the Massachusetts Institute of Technology, New York University, the University of California at Los Angeles, the University of Maryland, the University of Texas at Austin, and the University of Wisconsin. Historically, the universities have contributed to the national fusion program in several unique and important ways. These include (a) the education and training of professional researchers; (b) providing the fusion program with a breadth of talent and intellect in the sciences and engineering; and (c) a major source of innovative ideas and scientific and technological advances. Despite the decrease in the fusion budget, for university activities the total budget has remained approximately the same since 1983; however, the number of universities involved in fusion research has decreased from 39 to 32.

As indicated by the report of the Physics Survey Committee of the National Research Council, fusion R&D advances plasma physics which has valuable applications outside of fusion. The fusion program, through the unversities, has been the major supplier of plasma physicists for the nation. In fact, national programs such as fusion link universities, industry and national laboratories in a way that facilitates the transfer of ideas, knowledge and technology. With the reductions in the fusion program, the development of new advances based on plasma physics will be adversely affected and the supply of highly trained personnel reduced. It is the Panel's assessment that a continued strong component of university involvement is essential to a vigorous fusion research and development program for the foreseeable future.

INDUSTRY

The Magnetic Fusion Program is now, and will be for some time to come, a research program designed to determine the feasibility of fusion. The step from feasibility to demonstration of a practical power generating system is a very large one and its date of accomplishment can only be roughly estimated. However, the practical application of fusion has the potential for new industrial ventures and international competition for that business.

As it stands today, the Japanese fusion program is providing the most significant industrial involvement. The European program ranks second, with the United States program being the least successful in engaging industry and keeping it involved. With greater industrial involvement in the years ahead, United States' industry eventually would be in a better competitive postion and would be more likely to spend discretionary research funds to support DOE efforts. It would also be more likely to invest in university research in general or in specific support of the fusion program. Furthermore, if industry is visibly active in fusion R&D, more students will be attracted to the appropriate university programs.

It may seem premature to be concerned now about our competitive position in the international markets of the future. However, the current trend in the globalization of industry and markets suggests that the real competition may already have started and that the penalty for failing to grasp the opportunity to be a competitor is to become in the future the buyer or license holder of foreign high technology. A decision to proceed with the CIT would stimulate renewed interest on the part of U.S. industry. At the very least, U.S. industry, including the electric utilities, should be involved in the Technical Planning Activity and MFAC.

VIII. CONCLUSIONS

Fusion is an Attractive and Promising Future Energy Source

The Panel reaffirms the unique attractiveness of the fusion process as a future means of generating power. Fusion has a virtually inexhaustible fuel supply. It appears to avoid the long term storage of high-level, long-lived radioactive wastes characteristic of the fission process. Fusion has the potential of reducing the dependence on fossil fuels that may present a major threat of atmospheric pollution. This is particularly important if the industrialization and continued urbanization of the third world is realized. Using the fusion process for power generation would also permit reserving oil for transportation and industrial uses. With the nature of the fusion process and the experience already acquired in fission power generation, it should be possible to design and construct generating stations that are safe, benign, and acceptable to the general public.

The above points are not new. However, they deserve additional emphasis in view of the convincing technical progress within the fusion program and in view of the events at Chernobyl. The Panel reaffirms the potential merit of fusion power recognizing that the actual deployment would be in the long term future.

An Ignited Plasma Experiment is Timely, and Promises to be a Vital Step in MFE Research

The last three years of budget reductions have caused the fusion program to focus on developing concepts for a compact, copper-magnet tokamak which would examine ignition physics and burn control. The Compact Ignition Tokamak (CIT) has emerged as the most cost-effective means for resolving the technical issues of an ignited tokamak plasma. If successful, the proposed device, which is actually smaller than TFTR but has a higher magnetic field, would achieve a major goal sought by the fusion program since its inception.

There are several very practical advantages associated with the early initiation of an ignited plasma experiment and study of burning plasmas. If successful, and today's accomplishments suggest that it should be, the fundamental feasibility of magnetic fusion would be established to a significant degree. Successful control and understanding of burning plasmas would give further confidence in the development of fusion as a practical energy source. Of more direct scientific and technical interest is that such an experiment would enhance the credibility of and contribute to the successful operation of an Engineering Test Reactor--a step now planned by the Europeans and Japanese and the potential subject of an international collaborative effort. A vigorous ignited plasma experiment would make the United States a more attractive partner in an international effort, would improve the United States's position in negotiating that partnership, and finally would place the United States in a superior position if international collaboration fails to materialize or is aborted.

The Panel believes that an investment in the CIT of $360 M (including diagnostics and R&D), obtained by making maximum use of substantial existing facilities, is an exceedingly attractive and effective step that should be initiated as soon as possible.

The Pace And Content of the MFE-Program has been Severely Constrained and Focused by Three Years of Successive Budget Reductions

Much credit must be given to DOE for making difficult decisions--delaying or terminating certain activities--and continuing to make progress within budget directives. The Panel is very concerned that the program--if there are further budget reductions--will lose both momentum and vitality. Therefore the conclusion above regarding the CIT is doubly important. There is also a strong concern that upgrading existing devices and exploring promising supporting confinement concepts should not be further constrained at this time. International collaboration will be discussed later. However, having a strong United States program will increase the likelihood of a mutually acceptable international collaboration. It is noted that the European and Japanese programs show greater funding stability and have made real technical progress.

The Growing Concern with Atmospheric and Environmental Pollution Requires Determination of Real Trends as soon as Possible

The Panel reviewed the existing facts in this area, including the long term increase of carbon dioxide in the atmosphere, and the exploration of models. It appears that extrapolation into the future is presently open to valid questions, and that additional information gathered over a decade may be required before this situation is clearly understood. This is properly a global undertaking. The potential implications with respect to burning fossil fuels are immense and could change dramatically the priorities for fusion energy research and development as well as for second generation fission power plants.

The Several Collaborative Agreements Achieved to Date are Valuable: Further International Collaboration is Encouraged

Review of the 1984 NRC report on international collaboration in fusion indicates that the conclusions in that report appear valid today. There are many factors working against international collaboration: national pride; institutional factors; perception of the reliability of partners; transfer of vital technologies; cultural differences--the list is long. Nevertheless, the Panel urges patience and persistence in working toward acceptable working relationships. We believe there may be some undue optimism concerning how long negotiations will take and how much money will be saved. The larger the commitment, such as an ETR, or other major program elements, the longer the negotiations will take. In any event the savings, although substantial, will be largely avoided future expenditures. Management of a multi-lateral program will require a more stable, enduring commitment than is customary in domestic experience. The reward could be earlier accomplishment of the goal of fusion generated power. The experience at CERN and JET suggest that international collaboration produces far more secondary advantages than can be seen in advance. Finally, some realistic consideration must be given to the possibility that international collaboration on a large scale may not come about.

The Science and Technology of Fusion are at the Cutting Edge of Applied Research

While scientists and engineers have somewhat different views of the fusion program, it is quite clear that its science is sophisticated and challenging and several important technologies have been advanced. Plasma physics is relevant to many high technology endeavors in civilian as well as defense programs. The university involvement in the fusion program is both desirable and beneficial to the nation. Advancing scientific knowledge and education has been identified by ERAB as a proper objective of DOE civilian R&D programs. In this regard, the fusion program has contributed much to the strength and utility of plasma physics today. Consequently, this aspect of the fusion program warrants substantial support by the Federal Government in its own right.

RECOMMENDATIONS

1. Proceed expeditiously with an ignited plasma experiment, such as the CIT, using existing facilities to the greatest extent possible to minimize the additional funding that will be necessary. Early completion of this project will help to determine whether there are unanticipated phenomena associated with a burning plasma that would alter the prospects for proceeding with fusion development. Incremental funds will be needed in order to proceed with the CIT in a timely fashion and to maintain the strength of the base program.

2. While the tokamak configuration is the mainline of present national and international experimental efforts, exploration of selected non-tokamak concepts as well as tokamak improvements should be pursued. Budget reductions have already resulted in a substantial narrowing of effort. Further reductions will endanger key areas of the program.

3. Continue to study urgently the question of possible atmospheric changes from continued massive use of fossil fuels. The Panel notes that DOE is the lead agency in a multi-agency effort to determine the consequences of the buildup of CO_2. Fusion, second generation fission, and solar technologies are the primary energy options for the future if the atmospheric CO_2 trend is determined to be harmful to the environment. This is a global problem.

4. Proceed with the required negotiations to establish major international collaboration in fusion R&D. This should be done recognizing that it will take time and that considerations external to the U.S. program may make it necessary to proceed independently. Reviews of the NRC report of 1984, "Cooperation and Competition on the Path to Fusion Energy", and the ERAB report of 1985, "International Collaboration in the U.S. Department of Energy's Research and Development Programs" indicate that the conclusions of those reports appear to be valid today.

5. The Panel believes that fusion R&D deserves a priority greater than that provided at present by the U.S. Government. We recommend that the Secretary of Energy press vigorously for a higher national priority within the Administration.

APPENDIX A

CHARGE LETTER

THE SECRETARY OF ENERGY
WASHINGTON, D.C. 20585

May 30, 1986

Mr. John H. Schoettler
11855 East Daley Circle
Parker, Colorado 80134

Dear Mr. Schoettler:

Research on magnetic fusion energy is a major component of the Nation's long range energy R&D program. The successful development of magnetic fusion could lead to an energy source that has essentially unlimited fuel reserves and acceptable environmental and safety features. Potential fusion applications include electricity generation, the production of synthetic fuels, nuclear fuels, and high grade heat for industry.

The Magnetic Fusion Energy Engineering Act of 1980 (Pub. Law No. 96-386) established a broad basis for the future development of magnetic fusion energy. The Act provides for a five-year comprehensive program management plan and a series of steps to lead to determining the engineering basis for fusion development.

The Act also requires that an overall review of the conduct of the magnetic fusion program be undertaken by a technical panel of the Energy Research Advisory Board (ERAB) on at least a triennial basis. In particular, the Act specifies that the review shall consider, among others, the following topics:

- the five-year program management plan,
- future facilities needed to meet the goals of the Act,
- the adequacy of participation by universities and industry,
- the adequacy of international cooperation and any problems associated therewith, and
- institutional, environmental and economic factors limiting, or prospectively limiting, efforts to achieve commercial application of magnetic fusion energy systems.

The Panel's most recent review was carried out in 1983. Because the Technical Panel must meet on at least a triennial basis, it is now appropriate to activate the Panel.

Since the last review, several events have taken place that have significantly changed the context within which the magnetic fusion energy program functions. For example, markets for primary energy have changed substantially; the magnetic fusion budget has declined significantly, leading to the virtual elimination of the mirror program; coordinated planning among Economic Summit countries has resulted in the identification of major opportunities for international collaboration.

Consequently, there have been significant changes in the Magnetic Fusion Energy Program, including the goal, the approach, the pace, the budget, and more recently, the role of international collaboration. Therefore, in addition to the specific topics addressed in the Act, it would be helpful if the Panel's review assessed the potential contributions of fusion to future energy needs and whether the goal, approach, pace, budget and role of international collaboration now fit together to form a coherent program. Further, I would like the Panel to consider whether the expenditures for this program are justified in light of the stringent present and anticipated DOE budgets, and whether the technical direction of the program is appropriate.

I realize that the scope of this request is substantial and that the time available for response is short. However, I would like the Panel's written report to be completed in time for it to be considered at the ERAB's November 1986 meeting, and submitted to me shortly thereafter.

By copy of this letter, I am requesting that the Director of the Office of Energy Research provide full cooperation and support, including the resources necessary to complete this study.

Yours truly,

John S. Herrington

John S. Herrington

cc: A.W. Trivelpiece, ER-1

APPENDIX B

TECHNICAL ACCOMPLISHMENTS SINCE THE 1983 REVIEW

Prepared by

1986 ERAB Fusion Panel

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TECHNICAL ACCOMPLISHMENTS SINCE THE 1983 REVIEW

Prepared by

1986 ERAB Fusion Panel

Three years ago, world fusion research still fell short of the minimum reactor goals by roughly a factor of 2 in temperature and a factor of 3 in the quality of energy confinement (as measured by the Lawson parameter $n_0\tau_E$). Present-day toroidal confinement experiments have very nearly succeeded in reaching these goals--and other key reactor requirements as well.

The U.S. tokamak program has led these advances in several important scientific and technological areas, including the achievement of high plasma temperatures ($T_i \sim 20$ keV), confinement quality ($n_0\tau_E \sim 10^{14}cm^{-3}$-sec), and plasma beta ($\sim$ 5%). In 1987, the Tokamak Fusion Test Reactor (TFTR) is expected to achieve breakeven-equivalent conditions in deuterium plasmas. That is, the fusion power which would be produced with a deuterium-tritium fuel mixture will approximate the power required to maintain the plasma temperature.

Alongside these significant advances in experimental fusion parameters, there has been an impressive development of innovative ideas and techniques. The conventional toroidal reactor concept is being extended towards smaller size and higher power density. Encouraging results have been achieved on alternate approaches such as the reversed field pinch, and compact toroids. Also, the tandem mirror approach has provided a promising alternative to toroidal reactor geometry, by sealing up the ends of the "magnetic bottle" with a system of electrostatic potentials.

We summarize here selected significant accomplishments in the U.S. fusion program since the 1983 review.

a. Tokamak Systems

In the TFTR tokamak, well-confined plasmas at ion temperatures $T_i \sim 20$ keV and electron temperatures $T_e \sim 7$ keV have been achieved, approaching the temperatures needed for fusion. These temperatures were achieved during neutral beam heating at values of the Lawson parameter $n_0\tau_E \sim 10^{13}cm^{-3}$-sec, corresponding to entry into the breakeven regime.

In the TFTR tokamak, energy confinement has been demonstrated for a dense plasma (at a lower, but significant temperature) for values of the Lawson parameter in the range $n_0\tau_E \sim 1.5 \times 10^{14}cm^{-3}$-sec. This value is a factor of two larger than that achieved in Alcator C in 1983, and approaches the quality of confinement needed in a full-scale fusion reactor.

Beta values (ratio of plasma pressure to magnetic pressure) of 5% have been achieved in the Doublet III and PBX tokamaks, which are within a factor of two of the requirements for an economic fusion reactor.

Also in the tokamak, empirical energy confinement scalings have been identified which are favorable for reactor sizing. According to one empirical scaling (known as "neo-Alcator" scaling), which fits the data from ohmically heated tokamaks over a wide range of parameters, the confinement time varies with the cube of the plasma linear dimension, as would be expected for a diffusive process in which the transport coefficient depends on gradient-induced "anomalous" processes.

In accordance with theoretical prescriptions, radio frequency waves have been used to drive plasma currents in the Alcator C and PLT tokamaks, thereby permitting confining magnetic fields to be steady-state, a property of importance to the practicality of tokamak reactors. Experiments on radio frequency current drive have exhibited a hot-electron population of current carriers in agreement with theory, and have verified the predicted dependence of current-drive efficiency on plasma density. Using lower hybrid waves, toroidal currents of 500 kA have been sustained on PLT at densities of $1.5 \times 10^{13}cm^{-3}$, and currents of 230 kA have been sustained on Alcator C at densities of $5 \times 10^{13}cm^{-3}$.

High-power neutral beam and rf sources have been developed that can heat plasmas to fusion temperatures. Neutral-beam heating experiments have verified that the beam ions deposit their energy in the plasma by means of well-understood classical processes. Effective plasma heating by radio frequency waves in the ion cyclotron range of frequencies (ICRF) has been demonstrated on the PLT tokamak at densities of $4 \times 10^{13}cm^{-3}$, resulting in ion temperature increases of 5 keV with 4.5 MW of injected power. Lower hybrid heating experiments on Alcator C with 1 MW of injected power have resulted in electron and ion temperature increases of 1.2 keV and 0.8 keV, respectively, at densities of $1.4 \times 10^{14}cm^{-3}$.

The prospects for an attractive tokamak power reactor have improved markedly since the ERAB review in 1983. Major improvements include: the possibility of stable operation at higher beta (through a variety of approaches, such as access to the second stability regime, increased elongation, low-aspect-ratio configurations, and operation at on-axis safety factors of less than one); very-long plasma burns with rf current ramp-up, or full steady-state operation with non-inductive current drive; and simplified impurity control schemes (through improved poloidal divertor configurations, and new, helium-pumping materials for the divertor/limiter and/or first wall). Additional improvements have been made in identifying advanced materials (e.g., vanadium alloys) which greatly reduce long-term radioactivity, and result in longer lifetimes and higher temperature capability. New concepts such as replacing the blanket, shield and heat extraction system with a pool of molten salt exhibit excellent inherent and passive safety characteristics. Recent reactor designs, which explore a range of reactor outputs (300 MWe and larger), have shown that tokamaks can achieve mass power densities exceeding 100 kWe/tonne. Thus, a number of important ideas for improving the tokamak as a power reactor have been developed, and many of these concepts are being explored in experimental programs.

b. Alternate Fusion Concepts

Although at an earlier state of development and demonstrated plasma performance, the alternate fusion concepts are making impressive technical progress in their own right, and they also contribute to the fusion program through advances in the basic understanding of plasma confinement properties, and through the development of advanced technologies. Two examples are the stellarator and the reversed field pinch. As presently designed, the ATF stellarator experiment at Oak Ridge National Laboratory will provide a significant complement to foreign stellarator experiments, and make strong contributions to toroidal concept development. Progress in research on the reversed field pinch has been outstanding, and this concept is technically ready to proceed with a device that has toroidal current capability in the 2 megampere range or beyond.

The Advanced Toroidal Facility (ATF) will be the world's largest stellarator facility when its construction is completed at the end of 1986. The main technical emphasis will include: (a) high-beta operation, in which beta values up to 8% may be attained by direct access to the second-stability regime, and (b) experimental studies of transport properties, particularly at low collisionality. Theoretical models, consistent with existing stellarator data, indicate that plasma temperatures of several keV at densities of $2 \times 10^{13} cm^{-3}$ may be attained with the available heating power. Initial operation will be in the pulsed mode, but the longer-term goal is to implement the inherent steady-state capability of the device.

Since the 1983 review, experiments on ZT-40 and OHTE have advanced significantly the data base for reversed field pinches. Scaling studies on ZT-40 have yielded temperatures up to 600 eV, beta values in the range 20-30%, and values of the Lawson confinement parameter up to $n_0\tau_E \sim 6 \times 10^{10} cm^{-3}$-sec. These scaling studies, which have been carried out for toroidal currents up to 500 kA, suggest that the reversed field pinch has the potential to achieve ignition parameters with ohmic heating alone.

Continuous sustainment of the reversed field pinch configuration by means of self-relaxation has been experimentally demonstrated on ZT-40, with discharge durations at least ten times greater than resistive relaxation times. An improved theoretical understanding of the associated continuous regeneration of the toroidal flux has been obtained. These observations have led to the development of a new steady-state current-drive concept, applicable to the tokamak and the reversed field pinch, which requires relatively simple technology involving low-amplitude 60 Hz modulation of the plasma current.

The TMX-U tandem mirror has demonstrated thermal barrier end plugging up to central cell densities of $3 \times 10^{12} cm^{-3}$, a factor of three below the original design value. Newly developed diagnostics, designed to measure potential internal to the plasma, have provided a large body of data that is consistent with the thermal barrier model. The TMX-U experiment has demonstrated central-cell nonambipolar ion transport consistent with theory. In addition, there is radial ion transport in the plugs of comparable magnitude. The total radial ion transport has been reduced to a low level through the use of segmented end-wall plates, which permit adjustment of the radial potential profile.

Construction of the TARA tandem mirror has been completed, and experiments with thermal barrier end plugging have begun. The startup configuration using weak anchor plugging has established central-cell densities of $3.5 \times 10^{12} cm^{-3}$, perpendicular ion temperatures of 500 eV, and parallel ion temperatures of 150 eV. Initial thermal barrier plugging has been measured for central cell densities of $10^{12}cm^{-3}$. This versatile facility investigates magnetically symmetric geometries that may lead to a significantly improved reactor configuration.

The MFTF-B PACE project was completed in February, 1986, with successful performance tests of the vacuum, magnet, cryogenic, and computer and control systems, with all systems performing at design specifications. Budget constraints have forced a mothballing of this major new tandem mirror facility.

The production of spheromak plasmas has been demonstrated experimentally by several techniques, and non-radiation-dominated plasmas with electron temperatures exceeding 100 eV have been produced, allowing initial studies of the relevant transport properties. Magnetic helicity, the linkage of flux with flux, has been identified as an important concept for spheromaks, and the conservation of helicity for times shorter than the resistive diffusion time has been demonstrated. Systems studies have shown the spheromak to have potentially the highest value of mass power density in a fusion reactor, with considerable simplification of the technology, and a significant lowering of the reactor costs compared with other concepts.

Experimental studies of field-reversed configurations (FRCs) have shown that translating the plasma from the region of formation into another chamber does not adversely affect the confinement properties of the configuration. This enhances the prospects for reactor design simplification stemming from the freedom to separate the region of plasma formation from the region of neutron production. Field-reversed configurations have operated at beta values up to 80%, temperatures up to 200 eV, and the values of the Lawson parameter up to $n_0\tau_E \sim 4 \times 10^{11}cm^{-3}$-sec.

c. Fusion Theory and Computations

Significant advances have been made in plasma theory and computations, which are now able to describe in detail most large-scale phenomena of confined plasmas, and which are beginning to provide valid understanding of microscopic phenomena. Accomplishments of particular note include: (i) the successful description of the nonlinear regime of resistive instabilities and the circumstances leading to disruptions in tokamaks, (ii) the detailed delineation of stability limits on beta in a tokamak for a wide variety of plasma profiles and cross-sections, (iii) the accurate identification and characterization of microinstabilities and mechanisms for their stabilization in mirror configurations, and (iv) the identification of magnetic helicity (the linkage of flux with flux) as an important concept for compact toroids, leading to the invention of novel formation techniques and current-drive methods based on helicity injection.

d. Development and Technology

The technology for single-and multiple-pellet injectors for plasma fueling has made rapid technical progress. Pellet diameters up to 4 mm and injection velocities up to 1.9 km/sec have been achieved. Pellet injection experiments on TFTR and Alcator C have produced significant increases in central plasma density, peaking of the density profiles, and improved energy confinement.

In the area of rf source development for electron cyclotron heating (ECH), the program on cw gyrotrons at 60 GHz and 200 kW has been completed successfully. The research and development effort is now focused on gyrotron sources at higher frequency (140 GHz), for both pulsed (1-2 MW) and steady-state (200 kW) operation.

The Tritium Systems Test Assembly (TSTA) has operated successfully with 30 grams of tritium, and preparations are underway for 130 gram operation. There is strong participation by Japan in testing on TSTA.

Research on structural materials for fusion reactors has shown that austanitic stainless steel performs satisfactorily in a fusion neutron environment up to fluences of 10 MW - years/m^2. In the area of plasma-interactive materials, experimental studies of sputtering and surface materials redeposited on the first wall have been initiated.

Despite project delays, the Large Coil Test Facility (LCTF) has been completed, and the six superconducting coils (three U.S. coils and three coils from Europe, Japan and Switzerland) have been installed, cooled and tested individually. Preparations for multiple-coil tests are in progress.

The fusion systems studies program has proved very cost effective in carrying out its purposes. At approximately 3% of the magnetic fusion budget, it has provided "eyes to the future" for guidance of the larger program. Its impact has been frequent, widespread and significant. The systems studies program carries out conceptual design studies in three general areas: (a) In the area of commerical reactor studies, the systems studies program has evaluated several reactor concepts for tokamaks and the alternate approaches, given guidance to the respective research programs, and generated innovative solutions to perceived reactor shortcomings; (b) In the area of next-generation devices, the systems studies program has evaluated several next-step options covering a wide spectrum of performance and costs, ranging from the compact ignition tokamak (CIT), to the engineering test reactor (ETR), to the international tokamak reactor studies (INTOR) project; (c) For both commercial reactors and next-generation devices, the systems studies program has also investigated several critical technical areas that involve the interaction of physics and technology, e.g., blanket comparisons and impurity control.

APPENDIX C

CIT TECHNICAL DESCRIPTION

APPENDIX C

CIT TECHNICAL DESCRIPTION

In the beginning of FY 1985, the United States fusion program began a new study to find a cost effective device which would yield most of the physics information about burning plasmas in tokamak. The result of the studies was the Compact Ignition Tokamak (CIT). The CIT is a short pulse (as compared to the previous concepts), compact, high field, and high density tokamak that is designed to ignite. It will be used to study burning plasmas. The parameters of the design for this device are listed in Table I, and a schematic of it is shown in Figure 1. The diameter of the CIT is less than three and one-half meters, and its plasma volume is only 25% that of TFTR.

The CIT has been proposed to be sited at the Princeton Plasma Physics Laboratory (PPPL) and would have an incremental capital cost of about $300M. Siting the device at PPPL reduces the total cost significantly because the CIT would make use of about $300M in site credits.

Although the high field and compact size of the CIT reduce the cost, these factors also limit some of the burning plasma physics that can be addressed. These include issues associated with long time evolution of plasmas (times typically greater than 100 sec) and with particle control. It is expected that these issues will be addressed in a large Engineering Test Reactor (ETR).

The strong endorsement of the CIT by the Magnetic Fusion Advisory Committee is given in the next section.

Appropriate coordination with the phasing down of the TFTR effort should minimize the impact of CIT operating costs.

SELECTED PARAMETERS OF CIT

Major Radius	1.22	m
Minor Plasma Radius	0.45	m
Plasma Elongation	1.8	
Plasma Current	9	MA
Toroidal Field (TF)	10.4	T
Plasma Burn Time	3.1	s
Neutron Wall Loading at 300 MW Fusion Power	6.8	MW/m^2
Peak Divertor Plate Heat Flux	9.5	MW/m^2
Toroidal Field Energy Requirement	1.73	GJ
Poloidal Field (PF) Energy	2.2	GJ
Combined Peak Power for TF and PF coils	1100	MVA
Radio Frequency Heating Initial Complement	10	MW
Radio Frequency Full Complement	20	MW
Number of Full Field Pulses	3000	
Number of 70% Field Pulses	50000	

CIT COSTS (1986 $)

Capital Cost	$285 M
R&D	32
Diagnostics Cost	46
TOTAL	$363 M

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

College of Engineering
Department of Nuclear Engineering

February 24, 1986

Dr. Alvin W. Trivelpiece
Director, Office of Energy Research
Department of Energy
Washington, DC 20545

Dear Dr. Trivelpiece:

The Magnetic Fusion Advisory Committee met at Lawrence Livermore National Laboratory on February 19 and 20, 1986, to review the technical assessment by Panel XIV of burning-plasma phenomena that would be investigated in the class of compact, tokamak ignition devices, herein referred to as the Compact Ignition Tokamak (CIT).

The Panel was aided in its deliberations by presentations from the Ignitor, LITE, and ISP conceptual design groups and by information about the physics base and other ongoing project-related work provided by the Ignition Physics Study Group (IPSG) and the Ignition Technical Oversight Committee (ITOC).

We believe that Panel XIV has done an excellent job of identifying the key scientific issues to be addressed in an ignition experiment. It is our strong view that such an experiment would result in significant advances in the scientific understanding of the burning plasma state, the next major frontier in magnetic fusion research.

> The principal recommendation of MFAC is that the magnetic fusion program should continue with high priority to develop a CIT experiment as a cost-effective means for resolving the technical issues of ignited tokamak plasmas.

During the past year, the U.S. fusion program has investigated the CIT as a minimum-size and minimum-cost ignition experiment with the capability to explore the essential physics issues in a burning tokamak plasma. To summarize briefly, the Compact Ignition Tokamak has the primary objectives:

(a) To perform a D-T ignition test including detailed studies of confinement and control of a burning tokamak plasma.

(b) To support the planning for operation of a high-duty-cycle, long-pulse tokamak Engineering Test Reactor (ETR).

A secondary objective is to stimulate the development of diagnostics and remote handling for D-T fusion systems.

Benson Hall, BF-10 / Telephone: (206) 543-2754

We agree with Panel XIV (see attached report) that the CIT will address most of the critical technical issues associated with energetic alpha particles and will begin to address the important issues relating to the control of a burning plasma. In addition, we offer the following specific findings:

1. Plasma behavior under ignited conditions represents a new frontier of physics that must be explored and understood as part of an assessment of magnetic fusion.

2. The burning-plasma issues that are most important for the development of fusion are those relating to the confinement of the energetic-alpha particles produced by the fusion reaction and the confinement of reactor-relevant plasmas that are heated mainly by these alpha particles. Other very important issues relate to controlling the profiles, thermal excursions and composition of a burning plasma.

3. The existing tokamak data base is adequate, with credible extrapolation, to proceed with the design of the CIT. By FY88 we should have acquired sufficient information from present large machines to support proceeding with the construction of the CIT.

4. The proposed schedule of CIT activities fits naturally into the timing of scientific advance in the tokamak area. Early initiation of the CIT project would serve to maintain the U.S. fusion program at the frontier of international research and would be of essential value to the world fusion effort. The CIT results would be available in time to help ensure the successful operation of an Engineering Test Reactor.

5. The CIT would also benefit both the advanced tokamak program and the non-tokamak programs. Certain aspects of alpha particle physics would be expected to be similar in different confinement devices of comparable properties and parameters. However, important aspects would be expected to differ, just as the basic confinement physics varies. The data from the CIT would provide a valuable experience base for developing understanding of ignition in different devices, and it would facilitate the planning and reduce the risk of future burning plasma studies that may be necessary in other concepts.

6. It is important that the CIT be designed to have high probability of achieving ignition. Beyond this, it should have sufficient flexibility to permit investigation of ignition physics over a range of plasma parameters. MFAC is encouraged that preconceptual designs suggest that these aims can be reached at a cost of approximately $300 M plus site credits.

7. Good diagnostics are essential to understanding the ignition experiment and must be addressed from the outset, both through adaptation of existing techniques and development of new techniques and instruments. While we feel that adequate diagnostics can be developed, the effort is of sufficient magnitude to warrant special consideration.

In summary, the CIT is a very cost-effective approach to the rapid attainment of an ignited plasma with reactor-relevant parameters. It will address most of the critical tokamak issues associated with the confinement of the fusion energy released in the form of energetic alpha particles.

Finally, the Magnetic Fusion Advisory Committee strongly reaffirms its belief that experimental investigations of the burning plasma state should be part of a balanced overall fusion program whose other essential elements are concept improvement and optimization, fusion nuclear technology, and materials development as described in the DOE Magnetic Fusion Program Plan.

I look forward to discussing these important findings and recommendations with you at your earliest convenience.

Sincerely yours,

Fred

Fred L. Ribe
Chairman
Magnetic Fusion Advisory Committee

FLR:lk

Encl: MFAC Panel XIV report: "Assessment of Burning-Plasma Phenomena in a Compact Ignition Tokamak", with charge letter: A.W. Trivelpiece to R.C. Davidson, August 8, 1985.

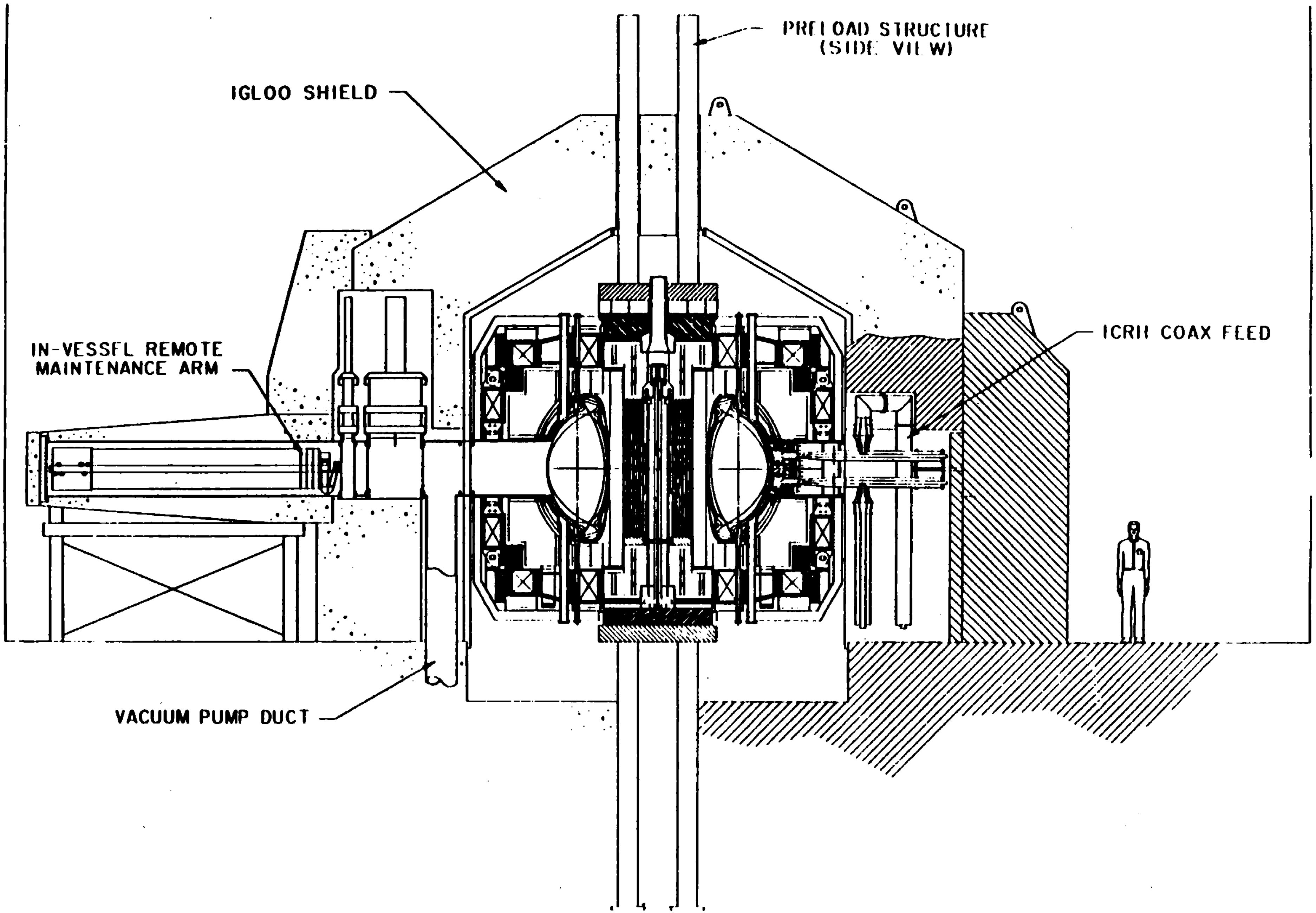

Figure 4.1-2

CIT SIDE ELEVATION VIEW

APPENDIX D

Minimizing Cost in the Fusion Program through International Collaboration

APPENDIX D

Minimizing Cost in the Fusion Program through International Collaboration

Prepared by International Programs Division
Office of Fusion Energy

The US fusion program has tried to maximize its technical productivity while minimizing its overall program costs by using international collaboration as much as feasible. However, as pointed out by the National Academy of Sciences study, "Cooperation and Competition on the Path to Fusion Energy," at least in the short run there "is little possibility that cooperation will produce large annual savings." The study also indicated international collaboration is important for maintaining needed program breath at stable, but not dramatically reduced costs.

OFE has tried vigorously to engage in international collaboration in all key aspects of the program, to maintain the necessary breath as well as to minimize costs. We have been particularly concerned with minimizing the costs of major new facilities. In this case, effective international collaboration would represent real savings to the US because of the likelihood that the incremental US costs for these facilities would be reduced. For example, the proposed Engineering Test Reactor (ETR) could cost $2 billion to construct and $300 million to operate. Building this facility with international partners would mean the US share would represent a significant cost saving.

To support the broad objective of minimizing costs, the four issues in the magnetic fusion program plan were used as a basis to identify and confirm the need for specific key facilities. After developing our view of needed major facilities, the US has pursued international collaboration by seeking and successfully stimulating agreement by The (Economic) Summit Working Group on Controlled Thermonuclear Fusion (FWG) on the remaining technical issues and facility requirements. One focus of the US efforts has been to determine how we might develop the appropriate arrangements to permit among others cost sharing for the ETR. In parallel, OFE has been trying to reduce current costs through collaboration on specific technical activities. These efforts are discussed in greater detail below under each of the four major issue areas.

While, the US has been actively pursuing joint planning with the Economic Summit partners on major facilities such as the ETR, the reality is that it will take time to develop the level of mutual confidence in the stability of financial and programmatic commitments to allow these efforts to come to fruition. The NAS study pointed out the major fusion programs around the world are at different stages in their willingness to take a collaborative approach on keystone facilities. Agreement by the FWG indicates these differences may not be as significant as before. Nevertheless, the EC and

Japan do not at present appear as prepared as the US to commit to internationalizing major facilities. Unfortunately, cost savings cannot be realized unilaterally, since all parties must be willing to share specific research and facility responsibilities.

On a broader scale, the world fusion community has only recently begun to accept the idea of pursuing joint planning that leads to highly coordinated and interdependent programs has been slowly evolving toward broader international acceptance. As experience with successful joint planning and research is translated into mutual confidence and a willingness to share and mutually depend on other partners for research and development activities addressing the most central questions of fusion science and technology, costs will be minimized in the long run. But this will take time.

Nevertheless, the US has pursued a variety of initiatives to build the foundation for accepting this approach. It has encouraged, at all levels, detailed discussions on specific topical areas for future joint international programs. The most general level has been through the (Economic) Summit Members' Fusion Working Group process, its Subpanels 1 through 3, and its Technical Working Party. In addition, the US was instrumental in initiating through the Fusion Power Coordinating Committee (FPCC) of the IEA an international Senior Advisory Panel on materials and joint planning for Nuclear Technology activities to promote international collaboration. On a detailed level, efforts to minimize costs have resulted in specific agreements with Japan and the EC under both bilateral and IEA agreements. They are identified below under the four major issue areas in fusion.

Issue 1: Magnetic Confinement Systems

In the area of advanced concepts we have signed an IEA Stellarator Agreement which should maximize the potential for coordination of the major facilities in the US, EC, and Japan and minimize international duplication. Exchange activities with the USSR allowed testing of techniques for determining magnetic field errors to help align magnets in the Advanced Toroidal Facility (in ORNL) that saved time and money. A Reversed Field Pinch (RFP) IEA Agreement, which is presently being developed between the US, Japan, and EC, should help in coordinated planning and thereby minimize international program costs in the future.

Issue 2: Properties of Burning Plasmas

The US technical community has worked vigorously to produce a low cost burning plasma facility (CIT). The concept of a burning plasma device preceding an ETR and its suitability for collaboration has been endorsed by the Technical Working Party as part of a common international fusion program. Currently, the US is seeking to attract foreign participation in the CIT. Foreign participation in the CIT would also provide valuable leverage for US participation in a foreign based ETR.

The supporting basic science for a burning plasma device was strengthened in several areas while minimizing costs. The IEA Large Tokamak Operation Agreement should lead to a coordinated and cost effective use of the world's three largest tokamaks for studying fusion physics. An additional international initiative reducing US fusion program costs involves the Princeton Plasma Physics Laboratory and the Kernforschungszentrum Karlsruhe (KfK), Germany. A remote maintenance manipulator is being developed by KfK for use in TFTR with cost sharing of about $1.5 million each.

In the area of impurity control the US has made the decision to conduct a substantial portion of its basic reserch on foreign fusion devices. The program has encompased studies of pumped limiters in Textor since 1977, divertors in ASDEX and ASDEX-Upgrade under a recently signed IEA Agreement and pumped limiters and other hardware in TORE SUPRA under an almost completed bilateral with EC/France. The US thus avoided a substantial portion of the cost of building or modifying facilities existing US facilities; the combined total cost of the three foreign machines are on the order of the hundreds of millions of dollars while the US total contribution for design, engineering and hardware would be on the order of 12 million dollars. Participation in TORE SUPRA will also eliminate the need to construct a long pulse and superconducting tokamak in the US, and permit the US to participate in the study of important science issues such as current drive in a steady state facility.

Another prime example of minimizing costs with foreign support has been the financial support of Japan for Doublet III/D-III-D. Japan has contributed approximately $70 million which included hardware for upgrading and machine modifications and operations. The funds doubled operation time on Doublet III with increased scientific productivity as a result of competition and cooperation among scientists from the US and Japan; the result was record level plasma parameters. The Japanese contribution to D-III-D was important support for a device that has the future potential for producing important scientific results.

In the area of needed plasma technology development Europe and Japan provided 3 out of the 6 LCT magnets, each of which was valued at $10 million. Subsequent use of the LCT as a facility for advanced coil development was suggested by the US as a possibility, including the users paying the operating costs. Using the LCT as an example, the US vigorously presented its view in a statement to the JPCC of the IEA in July 1986, that the international community should minimize costs by fully utilizing existing facilities.

Issue 3: Fusion Materials

The U.S. had already reduced its domestic materials program activities to minimize program costs because of budget constraints. Materials activities have traditionally been international cooperative efforts. OFE has sought the maximum use of these international resources. In this regard, a prime example is the next major critical element, a 14MeV neutron materials testing facility of high fluence. A consensus exists among the U.S., EC and Japan that the facility should be pursued as an international collaboration.

This position has been strongly supported by the Senior Advisory Panel to FPCC on Materials for Fusion Energy and the previous Blue Ribbon panel report on Fusion Materials Research and testing of 1983. It has also received recent support in the September 1986 Meeting on Fusion Materials of the TWP, which called for initiating selection and conceptual design of an international High Energy High Fluence 14MeV neutron facility.

In addition to agreement on an international testing facility, the U.S. has pursued expanded international activities in the fusion materials area. The Panel reports mentioned above were initiated at the request of the U.S., our objective being to assure a common international program that maximizes international collaboration and minimizes costs. This would be a shift from the previous general cooperation to a more coordinated program of international collaboration. The TWP at its September 1986 meeting recommended joint planning of a common material database and a common program of structural materials development.

The U.S. also expects to continue financial support from Japan for materials activities in HFIR, in addition to approximately $1.3 million in the future for material testing activities including using a Materials Open Test Assembly (MOTA) in FFTF. Previously, Japan provided funds that permitted the operation of two instead of one cell of the Rotating Neutron Source (RTNS-II), increasing its productivity. Their contribution was approximately $2M per year for five years.

Issue 4: Fusion Nuclear Technology

The U.S. investment toward fusion nuclear technology, which has been very small compared with the other technical issues, amounts annually to about 2% of the total U.S. fusion program budget. Internationally, the investment has also been relatively small but has increased in recent years as the technology needs to support next-step fusion engineering devices such as NET or ETR have become more widely recognized. Given the circumstances that fusion nuclear technology is at early stages of development and that each of the world's fusion programs must proceed through similar or complementary steps, opportunities for international cooperation in fusion nuclear technology development have long been recognized and pursued. Currently, modest bilateral collaborative programs exist in several areas of fusion nuclear technology discussed below. Building on these existing collaborative efforts, the U.S., with support of the TWP, has taken an initiative to establish a multi-national effort under the IEA for joint planning. The objective of the U.S. is to develop an implementing agreement to begin joint planning steps that would provide a foundation for international cooperation in fusion nuclear technology development. The U.S. intent is to create, from its inception, an international program that incorporates the desired approach to reducing costs based on minimizing redundant efforts and maximizing the shared construction and use of major test facilities. As a result of a September 1986 meeting of an IEA group reviewing steps to develop collaborations in fusion nuclear technology, there was agreement on the need to begin joint planning in the near-term on common blanket technology development programs while pursuing a full IEA agreement in the general area of fusion nuclear technology.

Existing bilateral collaborative programs in fusion nuclear technology are between Japan and the U.S. in the areas of neutronics and tritium processing. The U.S. has been able to take advantage of the Japanese investment in the Fusion Neutron Source to study the critical issue of tritium breeding performance in fusion blankets. In tritium processing, the U.S. has stimulated Japanese interests in the Tritium System Test Assembly (TSTA) to the point that Japan has indicated willingness to provide $2 million per year over five year period starting in Japan FY87 to jointly support full operation of the facility. The U.S. and Japan have already begun a modest collaboration at TSTA, with Japan providing prototypes of two components of their own design to be used in a tritium processing system for testing.

APPENDIX E

MAGNETIC FUSION ENERGY PANEL BIOGRAPHIES

BIOGRAPHIES

JOSEPH G. GAVIN, JR., Chairman
Mr. Gavin is currently a Senior Management Consultant. He was former President and Chief Operating Officer for Grumman Corporation. He is a member of the National Academy of Engineering, American Institute of Aeronautics and Astronautics, Energy Research Advisory Board, American Astronautics Society, Aerospace Industries Association, President of the MIT Alumni Association, and member of the MIT Corporation.

RONALD C. DAVIDSON
Dr. Davidson is Director of the Plasma Fusion Center at Massachusetts Institute of Technology. He was an Assistant Research Physicist at UC, Berkeley, Assistant Professor of Physics at the University of Maryland, and an Alfred P. Sloan Foundation Fellow. He was formerly Co-Director of the Joint Program for Plasma Physics at the University of Maryland and the Naval Research Laboratory. He also served as Senior Scientific Consultant to the Naval Research Laboratory and to Science Applications, Inc.

RALPH S. GENS
Mr. Gens is a Consulting Engineer at Bonneville Power Administration. Formerly Chief Engineer, he initiated practices to improve reliability, increase efficiency and conserve energy that have been adopted by electric utilities through the world. He is former Chairman and member, Energy Research Advisory Board; Fellow, Institute of Electrical and Electronic Engineers; and member, National Electric Reliability Council. He has served on the Conference International des Grande Resseaux Electriques a Haute Tension, Electrical Research Council, Western Systems Coordinating Council, Electric Power Research Institute, American Public Power Association, National Science Foundation, and the Interagency Research Coordination Conference.

MELVIN B. GOTTLIEB
Dr. Gottlieb is Director Emeritus of the Plasma Physics Laboratory and Professor Emeritus of Princeton University. He is now Chairman of the Nuclear Oversight Committee of Public Service Electric and Gas Company of New Jersey and Chairman of the United States National Committee of the International Union of Pure and Applied Physics. He was Chairman of the International Union of Pure and Applied Physics Commission on Plasma Physics and first Chairman of the Plasma Physics Division of the American Physical Society. After receiving a Ph.D. from the University of Chicago, he was Assistant Professor of Physics at the State University of Iowa and Professor of Astrophysical Sciences at Princeton.

THOMAS H. JOHNSON
Lt. Colonel Johnson is Director of the Science Research Laboratory at the United States Military Academy and serves as a consultant to the Los Alamos National Laboratory and Lawrence Livermore National Laboratory. He has worked on the early phases of the TFTR at Lawrence Livermore National Laboratory and on nulcear weapon design at the United States Air Force Weapons Laboratory and the United States Defense Nuclear Agency. He is a member of the American Physical Society. He has served as Special Assistant to the President's Science Advisor and Executive Director of the White House Science Council. He served as Executive Secretary to the 1980 Fusion Review Panel of the Energy Research Advisory Board. He won the IEEE Donald Fink Prize.

MANNING L. MUNTZING
Mr. Muntzing is currently a member of the law firm Doub and Muntzing in Washington, DC. Former positions include Counsel, Chesapeake and Potomac Telephone Companies and Director of Regulation, United States Atomic Energy Commission. He is a member of the Bar Association of the District of Columbia, State of Maryland, State of West Virginia, Federal Bar Association; Chairman, Atomic Energy Committee from 1975 to 1976; Council on Science Technology and the Law Section from 1976 to 1979. He is also a member of the American Nuclear Society; Chairman, International Committee and International Advisory Committee 1980-81, Vice President 1981-82, and President 1982-83; Executive Committee and Board of Governors, American Association of Engineering Societies; Board of Management, International Nuclear Law Association; Editorial Advisory Board, Progress in Nuclear Energy, International Review Journal. He is editor of International Instruments For Nuclear Technology Transfer.

LAWRENCE T. PAPAY
Dr. Papay is Senior Vice President of the Southern California Edison Company, a public utility primarily engaged in supplying electrical energy in central and southern California, using water, oil, gas, nuclear, coal, geothermal, wind, solar and biomass to generate electricity. He is a member of the Energy Research Advisory Board, American Nuclear Society, Pacific Coast Electrical Association, and the National Science Foundation. He also served on the Industrial Panel on Science and Technology, Renewable Energy Institute Board of Directors, Board of the Atomic Industrial Forum Chairman, and EPRI Research Advisory Committee.

JANICE PHILLIPS
Dr. Phillips is currently Associate Professor of Chemical Engineering and member of the Biotechnology Research Center at Lehigh University. She is a 1984 recipient of the Presidential Young Investigator Award from the National Science Foundation. She is a member of the American Institute of Chemical Engineers, American Chemical Society, American Association for the Advancement of Science, Society of Industrial Microbiology, Society of Applied Spectroscopy, International Organization for Biotechnology and Bioengineering, and the Energy Research Advisory Board.

APPENDIX F

GLOSSARY

APPENDIX F

GLOSSARY

A. Organizations and Activities

DOE	U.S. Department of Energy
EC	European Community
ERAB	Energy Research Advisory Board
FEDC	Fusion Engineering Design Center, Oak Ridge, Tennessee
GA	GA Technologies, Inc., San Diego, California
Grumman	Grumman Corporation, Bethpage, New York
HEDL	Hanford Engineering Development Laboratory, Richland, Washington
LANL	Los Alamos National Laboratory, Los Alamos, New Mexico
LCP	Large Coil Program--Participants: ORNL, Euratom, Japan, and Switzerland
LLNL	Lawrence Livermore National Laboratory
MFAC	Magnetic Fusion Advisory Committee
MIT	Massachusetts Institute of Technology, Cambridge, Massachusetts
NRC	National Research Council
OFE	Office of Fusion Energy, DOE, Washington, D.C.
ORNL	Oak Ridge National Laboratory, Oak Ridge, Tennessee
PPPL	Princeton Plasma Physics Laboratory, Princeton, New Jersey
Sandia	Sandia National Laboratories, Albuquerque, New Mexico
TRW	TRW, Inc., Redondo Beach, California
UCLA	University of California, Los Angeles, California
Westinghouse	Westinghouse Electric Corporation, Pittsburgh, Pennsylvania

B. Facilities (in operation unless stated otherwise)

Alcator-C	tokamak at MIT designed and operated to produce plasmas with relatively high current and particle densities, completed
AMBAL	tandem mirror machine, U.S.S.R.
ASDEX	tokamak, Federal Republic of Germany
ASDEX-U	proposed upgrade of ASDEX
AFT	Advanced Toroidal Facility, stellarator/torsatron device under construction at ORNL
BCX	Burning Core Experiment (concept endorsed by previous ERAB Panel)
CIT	Compact Ignition Tokamak, Proposed Experiment which would demonstrate an ignited plasma
C-MOD	Upgrade of the Alcator-C facility at MIT (under construction)
CPRF	Confinement Physics Research Facility, reversed field pinch facility under construction at Los Alamos
DIII-D	Doublet III-D, a tokamak with a noncircular (D-shaped) cross section, GA Technologies
ETR	Engineering Test Reactor Concept
GAMMA-10	tandem mirror machine, Japan
HFIR	High Flux Isotope Reactor, ORNL
INTOR	International Tokamak Reactor, large tokamak being designed by the U.S., the U.S.S.R., the EC, and Japan
JET	Joint European Torus, a large tokamak commonly owned by the EC and operating in Great Britain
JT-60	large tokamak in Japan
LCTF	Large Coil Test Facility, ORNL
MARS	Mirron Advanced Reactor Study, design for a large tandem mirror, LLNL (with TRW, General Dynamics Corporation, and the University of Wisconsin)
MFTF-B	Mirror Fusion Test Facility, the large tandem mirror machine at LLNL, completed
ORR	Oak Ridge Research Reactor, ORNL
OHTE	reversed field pinch experiment, GA Technologies

B. Facilities (in operation unless stated otherwise)

PBX	Princeton Beta Experiment, tokamak at PPPL built to increase the plasma beta and to investigate the second stability regime
Phaedrus	tandem mirror machine, University of Wisconsin
PLT	Princeton Large Torus, tokamak at PPPL, completed
PMTF	Plasma Materials Test Facility at Sandia
RTNS-II	Rotating Target Neutron Source, used to obtain data on fusion materials subjected to high neutron doses, LLNL, project completed
STM	Symmetric Tandem Mirror, mirror experiment, TRW, project completed
T-15	tokamak, U.S.S.R.
TARA	tandem mirror machine, MIT
TEXTOR	tokamak, Federal Republic of Germany
TFCX	Tokamak Fusion Core Experiment, previously proposed experiment
TFR	Tokamak Fontenay-aux-Roses, tokamak, France
TFTR	Tokamak Fusion Test Reactor, PPPL
TMX-U	Tandem Mirror Experiment, LLNL
TORE-SUPRA	tokamak with superconducting coils, France
TSTA	Tritium Systems Test Assembly, LANL
WVIIA	Wendelstein VIIA, stellarator, Federal Republic of Germany
ZT-40	Reversed field pinch experiment, Los Alamos

C. Technical Terms

activation product	material that has become radioactive as a result of being bombarded with neutrons, protons, or other nuclear particles
alpha particle (α)	nucleus of a helium atom ^{4}He, released in a D-T fusion reaction with an energy of 3.5 million eV, which it gives up to the plasma
beta (β)	the ratio of the outward pressure exerted by the plasma to the inward pressure of the confining magnetic field
blanket	region surrounding a fusion reactor core, within which fusion neutrons are slowed down, heat is transferred to a primary coolant, and tritium is bred from lithium
burning plasma	a plasma in which fusion reactions supply enough energy to sustain the plasma without auxiliary heating; a plasma in which ignition has been achieved
compact toroid (CT)	a toroidal geometry for magnetic plasma containment in which no conductors or vacuum chamber walls pass through the hole in the torus
confinement	see magnetic confinement
confinement time	the time τ for which the plasma holds its energy
current density	the electrical current per unit cross-sectional area of the plasma column
current drive	induction of a current to produce the magnetic field lines of force that contain the plasma
CW	continuous wave
dc	direct current
density	the number of particles n in a unit volume; a typical value for a D-T fusion reactor is $n = 1\text{-}2 \times 10^{14}$ cm^{-3}
deuterium (D)	a heavy isotope of hydrogen, ^{2}H, which with tritium is a component of the first fusion fuel to be used; it occurs naturally in water

disruption	an instability in the plasma that disrupts the magnetic field lines and destroys confinement
divertor	component of a toroidal fusion device that diverts charged particles (particularly impurities) out of the fusion plasma
D-T	deuterium-tritium
EBT	ELMO Bumpy Torus, a magnetic fusion concept in which high-beta rings of hot electrons, produced by microwave heating, stabilize the plasma circulating in a set of toroidally connected simple mirrors
ECRF	electron cyclotron range of frequencies, 10-300 GHz (see rf heating)
end cell	the plasma at either end of a tandem mirror, confined by magnetic fields and electrostatic potential
end plug	the peak of electrostatic potential in the end cell of a tandem mirror that traps ions electrostatically in a central valley of potential between the mirror cells
electron volt (eV)	a unit of energy (the energy acquired by an electron which it passes through a potential difference of one volt) used to express fusion temperatures; 1 eV = 11,600 degrees Kelvin. Temperatures of about 4 keV will be needed to create burning plasmas
fusion reaction	the merging of two light atomic nuclei into a heavier nucleus, generally accompanied by the release of energy
gyrotron	a device for producing microwave energy that uses a strong axial magnetic field in a cavity resonator to produce azimuthal bunching of an electron beam
ICRF	ion cyclotron range of frequencies, 300 kHz-300 MHz (see rf heating)
ICRH	ion cyclotron resonance heating, technique used to heat the ions in a fusion plasma (see rf heating)

ignition	the point at which the energy from fusion reactions equals the energy lost from the plasma (e.g., through radiation processes)
impurity	any atom heavier than the fusion fuel; the presence of impurities in the plasma can remove the energy needed to sustain ignition
impurity control	any scheme (e.g., divertors or limiters) to reduce the level of impurities in a plasma
Lawson parameter	Description of the conditions required for net power production in a fusion reactor; the product of the density n (in particles per cubic centimeter) and the energy confinement time τ_E in seconds) must equal approximately 6×10^{13} $cm^{-3} \cdot s$ in a thermalized D-T plasma at a temperature of about 20 keV.
limiter	a structure placed at the edge of the plasma that defines the shape of the plasma and may also be used for impurity control
LHRF	lower hybrid range of frequencies, 300-3000 MHz (see rf heating)
lower hybrid current drive	use of LHRF energy for current drive in a toroidal device
magnetic confinement or containment	any scheme in which a fusion plasma is isolated from its physical surroundings by the use of magnetic field lines of force to direct the charged particles
magnetic mirror	see mirror machine, tandem mirror
MHD stability	magnetohydrodynamic stability; the property of a plasma that allows it to be stably confined by magnetic field lines against the forces that tend to make it flow as a fluid out of the contained plasma volume
microinstability	interaction of individual particles through electric (and/or magnetic) fields, which may tend to degrade confinement (see microturbulence)

microturbulence	fluctuations in local electric/magnetic fields (and thus in local density of charged particles) arising from the behavior of a plasma as a conglomeration of individual particles; may be responsible for the degradation of confinement
mirror machine	a magnetic confinement device in which the magnetic field lines of force in the plasma do not close on themselves; a mirror machine is topologically linear, although particles may be reflected from the ends of the machine by magnetostatic and/or electrostatic forces (see tandem mirror)
neutral beam heating	heating a contained plasma by injecting a beam of energetic neutral atoms; the neutral atoms can cross the magnetic field lines but are ionized in the plasma and thus contained
neutron (n)	an uncharged atomic particle; neutrons released in a D-T fusion reaction have an energy of 14.1 MeV, which is to be used for power generation and tritium breeding in fusion reactors
ohmic heating	the heating of the plasma resulting from its electrical resistance to the flow of current induced in the plasma (see current drive)
pellet fueling	fueling a fusion plasma by injecting pellets of frozen deuterium or tritium into the plasma
plasma	an electrically neutral gas consisting of charged particles (an electrically equivalent number of positive ions and free electrons)
poloidal	referring to any plane of the torus that contains the central axis
power density	the rate of heat generated per unit volume of a reactor core
R&D	research and development
rf heating	radio-frequency heating, which occurs when electromagnetic rf waves are converted into thermal energy by a resonant action between the waves and the plasma particles. Three frequency regimes are under investigation: ICRF, LHRF, and ECRF

RFP	reversed-field pinch configuration
stability	see MHD stability
stellarator	a toroidal configuration (pioneered in the U.S.A.) in which plasma equilibrium and stability are achieved through externally imposed magnetic fields, without the current in the plasma required for tokamaks
superconducting coil	a magnet that provides the field required for plasma confinement (about 50,000 gauss, or 100,000 times the earth's average magnetic field) by using superconductors
superconductor	a material that has no electrical resistance below a certain temperature; for the alloys used in superconducting coils for fusion research, niobium-tin and niobium-titanium, this temperature is <20 degrees Kelvin
tandem mirror	a magnetic containment device in which a plasma is contained by magnetic and electrostatic barriers produced by two mirror machines at each end of a simple magnetic solenoid
thermal barriers	proposed technique for increasing the containment properties of tandem mirrors with lower-density, hot plasma in the end-cell mirror machines
tokamak	a toroidal magnetic confinement device in which the magnetic field lines of force close on themselves, with a large current flowing through the plasma
torus	a doughnut shape
toroidal	broadly, in the shape of a torus (as in "toroidal configuration"); specifically, referring to the direction of rotation about the central axis of a torus
toroidal field	the major confining field in a tokamak
tritium	a heavy isotope of hydrogen, ^3H, which with deuterium is a component of the first fusion fuel to be used; it is radioactive and must be produced using neutrons

APPENDIX G

GUEST SPEAKERS

APPENDIX G

GUEST SPEAKERS

MAY

J. Clarke, DOE	Overview of Magnetic Fusion Energy Program
J. Willis, DOE	Progress on the Burning Plasma Issue
D. Nelson, DOE	Development of Magnetic Confinement Systems Discussion of University Programs
R. Dowling, DOE	Development and Technology Programs
M. Roberts, DOE	International Collaboration

JUNE

A. Trivelpiece, DOE	Long Term Energy Picture DOE Policy and Strategy for Fusion
H. Furth, PPPL	Progress in Tokamak Research
R. Davidson, MIT	Summary of MFAC Recommendations
K. Fowler, LLNL	The International ETR
D. Baldwin, LLNL	The Mirror Program and the Future of LLNL in the Fusion Program

JULY

M. McCormack Former U.S. Congressman	Comments on the Magnetic Fusion Energy Program
T. Sakata, Embassy of Japan	Prospects for International Collaboration
J. Negroponte, State Department	Prospects for International Collaboration
J. Crocker, Idaho Nat. Engr. Lab.	Environmental Safety Aspects of Fusion Energy
J. Mackenzie, World Resources Inst.	Factors Determining the Public Acceptance of Fusion Energy
C. Baker, ANL	The Technical Planning Activity

S. Dean, Fusion Power Assoc.	Comments from the Fusion Community
D. Cohn, MIT	Comments from the Fusion Community
G. Navratil, Columbia University	Comments from the Fusion Community
J. Sheffield, ORNL	Requirements for an Attractive Fusion Reactor
L. Lidsky, MIT	An Alternate Strategy of the MFE Program I
R. Linford, LLNL	An Alternate Strategy for the MFE Program II

APPENDIX H

MAGNETIC FUSION ENERGY ACT

Public Law 96-386
96th Congress

An Act

To provide for an accelerated program of research and development of magnetic fusion energy technologies leading to the construction and successful operation of a magnetic fusion demonstration plant in the United States before the end of the twentieth century to be carried out by the Department of Energy.

Oct. 7, 1980
[H.R. 6308]

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Magnetic Fusion Energy Engineering Act of 1980".

Magnetic Fusion Energy Engineering Act of 1980.
42 USC 9301 note.

FINDINGS AND POLICY

42 USC 9301.

SEC. 2. (a) The Congress hereby finds that—

(1) the United States must formulate an energy policy designed to meet an impending worldwide shortage of many exhaustible, conventional energy resources in the next few decades;

(2) the energy policy of the United States must be designed to ensure that energy technologies using essentially inexhaustible resources are commercially available at a time prior to serious depletion of conventional resources;

(3) fusion energy is one of the few known energy sources which are essentially inexhaustible, and thus constitutes a long-term energy option;

(4) major progress in all aspects of magnetic fusion energy technology during the past decade instills confidence that power production from fusion energy systems is achievable;

(5) the United States must aggressively pursue research and development programs in magnetic fusion designed to foster advanced concepts and advanced technology and to develop efficient, reliable components and subsystems;

(6) to ensure the timely commercialization of magnetic fusion energy systems, the United States must demonstrate at an early date the engineering feasibility of magnetic fusion energy systems;

(7) progress in magnetic fusion energy systems is currently limited by the funds made available rather than technical barriers;

(8) it is a proper role for the Federal Government to accelerate research, development, and demonstration programs in magnetic fusion energy technologies; and

(9) acceleration of the current magnetic fusion program will require a doubling within seven years of the present funding level without consideration of inflation and a 25 per centum increase in funding each of fiscal years 1982 and 1983.

(b) It is therefore declared to be the policy of the United States and the purpose of this Act to accelerate the national effort in research, development, and demonstration activities related to magnetic fusion energy systems. Further, it is declared to be the policy of the United States and the purpose of this Act that the objectives of such program shall be—

(1) to promote an orderly transition from the current research and development program through commercial development;

(2) to establish a national goal of demonstrating the engineering feasibility of magnetic fusion by the early 1990's;

(3) to achieve at the earliest practicable time, but not later than the year 1990, operation of a magnetic fusion engineering device based on the best available confinement concept;

(4) to establish as a national goal the operation of a magnetic fusion demonstration plant at the turn of the twenty-first century;

(5) to foster cooperation in magnetic fusion research and development among government, universities, industry, and national laboratories;

(6) to promote the broad participation of domestic industry in the national magnetic fusion program;

(7) to continue international cooperation in magnetic fusion research for the benefit of all nations;

(8) to promote greater public understanding of magnetic fusion; and

(9) to maintain the United States as the world leader in magnetic fusion.

DEFINITIONS

42 USC 9302.

SEC. 3. For the purposes of this Act—

(1) "fusion" means a process whereby two light nuclei, such as deuterium and tritium, collide at high velocity, forming a compound nucleus, which subsequently separates into constituents which are different from the original colliding nuclei, and which carry away the accompanying energy release;

(2) "magnetic fusion" means the use of magnetic fields to confine a very hot, fully ionized gas of light nuclei, so that the fusion process can occur;

(3) "energy system" means a facility designed to utilize energy released in the magnetic fusion process for the generation of electricity and the production of hydrogen or other fuels;

(4) "fusion engineering device" means a magnetic fusion facility which achieves at least a burning plasma and serves to test components for engineering purposes;

(5) "demonstration plant" means a prototype energy system which is of sufficient size to provide safety, environmental reliability, availability, and ready engineering extrapolation of all components to commercial size but which system need not be economically competitive with then alternative energy sources; and

(6) "Secretary" means Secretary of Energy.

PROGRAM ACTIVITIES

42 USC 9303.

SEC. 4. (a) The Secretary shall initiate activities or accelerate existing activities in research areas in which the lack of knowledge limits magnetic fusion energy systems in order to ensure the achievement of the purposes of this Act.

Plasma confinement research.

(b)(1) The Secretary shall maintain an aggressive plasma confinement research program on the current lead concept to provide a full measure of support for the design, construction, and operation of the fusion engineering devices.

(2) The Secretary shall maintain a broadly based research program on alternate confinement concepts and on advanced fuels at a sufficient level of funding to achieve optimal design of each successive magnetic fusion facility using the then best available confinement and fuel concept.

(3) The Secretary shall ensure that research on properties of materials likely to be required for the construction of fusion engineering devices is adequate to provide timely information for the design of such devices.

(c)(1) The Secretary shall initiate design activities on a fusion engineering device using the best available confinement concept to ensure operation of such a device at the earliest practicable time, but not later than the year 1990. Fusion engineering device designs.

(2) The Secretary shall develop and test the adequacy of the engineering design of components to be utilized in the fusion engineering device.

(d) The Secretary shall initiate at the earliest practical time each activity which he deems necessary to achieve the national goal for operation of a demonstration plant at the turn of the twenty-first century.

(e) The Secretary shall continue efforts to assess factors which will determine the commercial introduction of magnetic fusion energy systems including, but not limited to— Magnetic fusion energy systems, assessment factors.

(1) projected costs relative to other alternative energy sources;

(2) projected growth rates in energy demand;

(3) safety-related design limitations;

(4) environmental impacts; and

(5) limitations on the availability of strategic elements, such as helium, lithium, and special metals.

COMPREHENSIVE PROGRAM MANAGEMENT PLAN

SEC. 5. (a) The Secretary shall prepare a comprehensive program management plan for the conduct of the research, development, and demonstration activities under this Act. Such plan shall include at a minimum— 42 USC 9304.

(1) a presentation of the program strategy which will be used to achieve the purposes of this Act;

(2) a five-year program implementation schedule, including identification of detailed milestone goals, with associated budget and program resources requirements;

(3) risk assessments;

(4) supporting research and development needed to solve problems which may inhibit or limit development of magnetic fusion energy systems; and

(5) an analysis of institutional, environmental, and economic considerations which are limiting the national magnetic fusion program.

(b) The Secretary shall transmit the comprehensive program management plan to the Committee on Science and Technology of the House of Representatives and the Committee on Energy and Natural Resources of the Senate not later than January 1, 1982. Submittal to congressional committees.

MAGNETIC FUSION ENGINEERING CENTER

SEC. 6. (a) The Secretary shall develop a plan for the creation of a national magnetic fusion engineering center for the purpose of accelerating fusion technology development via the concentration 42 USC 9305.

and coordination of major magnetic fusion engineering devices and associated activities at such a national center.

Plan development, factors.

(b) In developing the plan, the Secretary shall include relevant factors including, but not limited to—

(1) means of saving cost and time through the establishment of the national center relative to the cost and schedule currently projected for the program;

(2) means of providing common facilities to be shared by many magnetic fusion concepts;

(3) assessment of the environmental and safety-related aspects of the national center;

(4) provisions for international cooperation in magnetic fusion activities at the national center;

(5) provision of access to facilities for the broader technical involvement of domestic industry and universities in the magnetic fusion energy program;

(6) siting criteria for the national center including a list of potential sites;

(7) the advisability of establishing such a center considering all factors, including the alternative means and associated costs of pursuing such technology; and

(8) changes in the management structure of the magnetic fusion program to allow more effective direction of activities related to the national center.

Report to congressional committees.

(c) The Secretary shall submit not later than July 1, 1981, a report to the House Committee on Science and Technology and the Senate Committee on Energy and Natural Resources characterizing the plan and setting forth the steps necessary for implementation of the plan, including any steps already implemented.

TECHNICAL PANEL ON MAGNETIC FUSION

42 USC 9306.

SEC. 7. (a) A technical panel on magnetic fusion of the Energy Research Advisory Board shall be established to review the conduct of the national magnetic fusion energy program.

Membership.

(b)(1) The technical panel shall be comprised of such representatives from domestic industry, universities, government laboratories, and other scientific and technical organizations as the Chairman of the Energy Research Advisory Board deems appropriate based on his assessment of the technical qualifications of each such representative.

(2) Members of the technical panel need not be members of the full Energy Research Advisory Board.

(c) The activities of the technical panel shall be in compliance with any laws and regulations guiding the activities of technical and fact-finding groups reporting to the Energy Research Advisory Board.

Review.

(d) The technical panel shall review and may make recommendations on the following items, among others:

Ante, p. 1541.

(1) the preparation of the five-year program plan prepared pursuant to section 5;

(2) the type of future facilities needed to meet the goals of this Act along with their projected completion dates;

(3) the adequacy of participation by universities and industry in the program;

(4) the adequacy of international cooperation in magnetic fusion and any problems associated therewith; and

(5) institutional, environmental, and economic factors limiting, or prospectively limiting, efforts to achieve commercial application of magnetic fusion energy systems.

(e) The technical board shall submit to the Energy Research Advisory Board on at least a triennial basis a written report of its findings and recommendations with regard to the magnetic fusion program. Written report.

(f) After consideration of the technical panel report, the Energy Research Advisory Board shall submit such report, together with any comments such Board deems appropriate, to the Secretary. Report to Secretary.

PROGRAM ADVISORY COMMITTEES

SEC. 8. The Secretary may direct the director of each laboratory or installation at which a major magnetic fusion facility is operated for, or funded primarily by, the Federal Government to establish, for the sole purpose of providing advice to such director, a program advisory committee composed of persons with expertise in magnetic fusion from such domestic industry, universities, government laboratories, and other scientific and technical organizations as such director deems appropriate. 42 USC 9307.

INTERNATIONAL COOPERATION

SEC. 9. (a)(1) The Secretary in consultation with the Secretary of State shall actively seek to enter into or to strengthen existing international cooperative agreements in magnetic fusion research and development activities of mutual benefit to all parties. 42 USC 9308.

(2) The Secretary shall seek to achieve equitable exchange of information, data, scientific personnel, and other considerations in the conduct of cooperative efforts with technologically advanced nations.

(b)(1) The Secretary shall examine the potential impacts on the national magnetic fusion program of United States participation in an international effort to construct fusion engineering devices. Magnetic fusion, examination and exploration.

(2) The Secretary shall explore, to the extent feasible, the prospects for joint financial participation by other nations with the United States in the construction of a fusion engineering device.

(3) Within two years of the enactment of this Act the Secretary shall transmit to the House Committee on Science and Technology and the Senate Committee on Energy and Natural Resources the results of such examinations and explorations with his recommendations for construction of a national or international fusion engineering device: *Provided, however*, That such examinations and explorations shall not have the effect of delaying design activities related to a national fusion engineering device. Results, transmittal to congressional committees.

TECHNICAL MANPOWER REQUIREMENTS

SEC. 10. (a) The Secretary shall assess the adequacy of the projected United States supply of manpower in the engineering and scientific disciplines required to achieve the purposes of this Act taking cognizance of the other demands likely to be placed on such manpower supply. 42 USC 9309.

(b) The Secretary shall within one year of the date of enactment of this Act submit a report to the President and to the Congress setting forth his assessment along with his recommendations regarding the Report to President and Congress.

need for increased support for education in such engineering and scientific disciplines.

INFORMATION DISSEMINATION

42 USC 9310.

SEC. 11. (a) The Secretary shall take all necessary steps to assure that technical information relevant to the status and progress of the national magnetic fusion program is made readily available to interested persons in domestic industry and universities in the United States: *Provided, however,* That upon a showing to the Secretary by any person that any information or portion thereof provided to the Secretary directly or indirectly from such person would, if made public, divulge (1) trade secrets or (2) other proprietary information of such person, the Secretary shall not disclose such information and disclosure thereof shall be punishable under section 1905 of title 18, United States Code.

(b) The Secretary shall maintain an aggressive program in the United States for the provision of public information and educational materials to promote widespread knowledge of magnetic fusion among educational, community, business, environmental, labor, and governmental entities and the public at large.

REPORTS

Submittal to Congress.
42 USC 9311.
42 USC 7321.

SEC. 12. As a separate part of the annual report submitted pursuant to section 801 of the Department of Energy Organization Act (Public Law 95-91), the Secretary shall submit to Congress an annual report of activities pursuant to this Act. Such report shall include—

(a) modifications to the comprehensive program management plan for implementing this Act;

(b) an evaluation of the status of national magnetic fusion energy program in the United States;

(c) a summary of the findings and recommendations of any report of the Energy Research Advisory Board on magnetic fusion;

(d) an analysis of the progress made in commercializing magnetic fusion technology; and

(e) suggestions for improvements in the national magnetic fusion program, including recommendations for legislation.

AUTHORIZATION OF APPROPRIATIONS

42 USC 9312.

SEC. 13. (a) There is hereby authorized to be appropriated to the Secretary, for the fiscal year ending September 30, 1981, such sums as are provided in the annual authorization Act pursuant to section 660 of Public Law 95-91.

42 USC 7270.
Contract.

(b) In carrying out the provisions of this Act, the Secretary is authorized to enter into contracts only to such extent or in such amounts as may be provided in advance in appropriations Acts.

Approved October 7, 1980.

LEGISLATIVE HISTORY:

HOUSE REPORT No. 96-1096 (Comm. on Science and Technology).
SENATE REPORT No. 96-942 accompanying S. 2926 (Comm. on Energy and Natural Resources).
CONGRESSIONAL RECORD, Vol. 126 (1980):
Aug. 25, considered and passed House.
Sept. 22, S. 2926 considered and passed Senate; passage vitiated and H.R. 6308, amended, passed in lieu.
Sept. 24, House concurred in Senate amendments.
WEEKLY COMPILATION OF PRESIDENTIAL DOCUMENTS, Vol. 16, No. 41:
Oct. 7, Presidential statement.